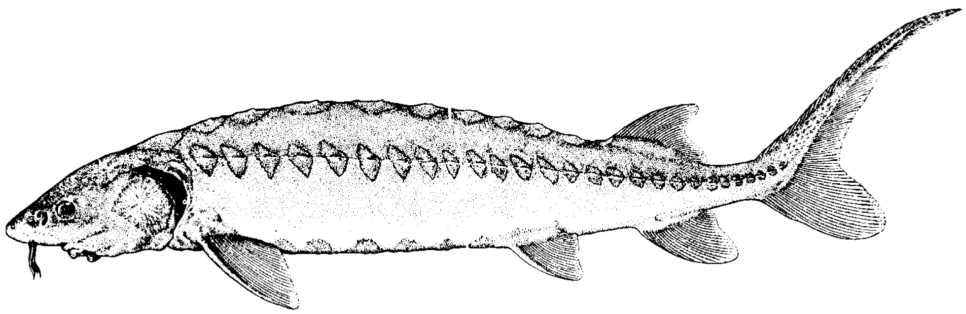
BIOLOGICAL ASSESSMENT OF SHORTNOSE STURGEON
Acipenser brevirostrum



Prepared by the

Shortnose Sturgeon Status Review Team

for the

National Marine Fisheries Service
National Oceanic and Atmospheric Administration

November 1, 2010

Acknowledgements

The biological review of shortnose sturgeon was conducted by a team of scientists from state and Federal natural resource agencies that manage and conduct research on shortnose sturgeon along their range of the United States east coast. This review was dependent on the expertise of this status review team and from information obtained from scientific literature and data provided by various other state and Federal agencies and individuals. In addition to the biologists who contributed to this report (noted below), the Shortnose Stugeon Status Review Team would like to acknowledge the contributions of Mary Colligan, Julie Crocker, Michael Dadswell, Kim Damon-Randall, Michael Erwin, Amanda Frick, Jeff Guyon, Robert Hoffman, Kristen Koyama, Christine Lipsky, Sarah Laporte, Sean McDermott, Steve Mierzykowski, Wesley Patrick, Pat Scida, Tim Sheehan, and Mary Tshikaya. The Status Review Team would also like to thank the peer reviewers, Dr. Mark Bain, Dr. Matthew Litvak, Dr. David Secor, and Dr. John Waldman for their helpful comments and suggestions. Finally, the SRT is indebted to Jessica Pruden who greatly assisted the team in finding the energy to finalize the review – her continued support and encouragement was invaluable.

Due to some of the similarities between shortnose and Atlantic sturgeon life history strategies, this document includes text that was taken directly from the 2007 Atlantic Sturgeon Status Review Report (ASSRT 2007), with consent from the authors, to expedite the writing process. Similarly, where the information had not changed since the publication of the Final Recovery Plan for Shortnose Sturgeon in 1998, we have either referenced the information or included text taken directly from the Recovery Plan.

Contributing Biologists:
Dr. Matthew Litvak
Dr. David Secor
Mark Boriek
Hal Brundage
Dr. Joseph Hightower
Dr. Eric Hilton
John O'Herron
Fritz Rohde
Bob Sadzinski
Tom Savoy
Dr. Wayne Starnes

This document should be cited as:
Shortnose Sturgeon Status Review Team. 2010. A Biological Assessment of shortnose sturgeon (*Acipenser brevirostrum*). Report to National Marine Fisheries Service, Northeast Regional Office. November 1, 2010. 417 pp.

Shortnose Sturgeon Status Review Team Members and their affiliation:

Jeanette Bowers- Altman	New Jersey Division of Fish and Wildlife
Mark Collins, Ph.D.	South Carolina Dept. of Natural Resources
Joel Fleming	Georgia Department of Natural Resources
Kathryn Hattala	New York Department of Environmental Conservation
Micah Kieffer	Conte Anadromous Fish Laboratory (U.S. Geologiocal Survey/Biological Resources Division)
Timothy King, Ph.D.	U.S. Geological Survey Biological Resources Division, Aquatic Ecology Branch
Wilson Laney, Ph.D.	U.S. Fish and Widlife Service – South Atlantic Fisheries Coordination Office, Raleigh, North Carolina
Malcolm Mohead	NOAAs' National Marine Fisheries Service, Office of Protected Resources, Silver Spring, Maryland
Tom Squiers and Gail Wipplehauser	Maine Department of Marine Resources

Liaisons to the team:

Dana Hartley	NOAAs' National Marine Fisheries Service, Northeast Regional Office, Gloucester, Massachusetts[1]
Stephania Bolden, Ph.D.	NOAAs' National Marine Fisheries Service, Southeast Regional Office, St. Petersburg, Florida

[1] Currently at U.S. Fish and Wildlife Service, SFESO, 1339 20th Street, Vero Beach, FL, 32960.

Table of Contents

List of Tables

List of Figures

List of Acronyms and Abbreviations

AAR	alkali-aggregate reaction damage
ACE Basin	Ashepoo, Combahee and Edisto rivers
ACOE	Army Corps of Engineers
AFS	American Fisheries Society
AIWW	Atlantic Intracoastal Water Way
Anon	Anonymous
ARGS	Annapolis Royal Generating Station
ASMFC	Atlantic States Marine Fisheries Commission
BIW	Bath Iron Works
BO	biological opinion
C	centigrade
CAFRC	Conte Anadromous Fish Research Center
C&D Canal	Chesapeake and Delaware Canal
CBP	Chesapeake Bay Program
cfs	cubic feet per second
CHGE	Central Hudson Gas and Electric Corporation
CI	confidence index
CITES	Convention on International Trade in Endangered Species of Wild Flora and Fauna
CLF	Conservation Law Foundation
cm	centimeters
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CPUE	catch-per-unit-of-effort
CSO	combined sewage outflow
CT DEP	Connecticut Department of Environmental Protection
CWA	Clean Water Act
CZMA	Coastal Zone Management Act
dB	decibels
DCA	Deerfield Concentration Area
DDE	dichlorodiphenyl dichloroethylene
DDT	dichlorodiphenyl trichloroethane
DE DFW	Delaware Division of Fish and Wildlife
DEHNR	Department of Environmental and Natural Resources
DFO	Department of Fisheries and Oceans (Canada)
DNR	Department of Natural Resources
DO	Dissolved Oxygen
DPS	Distinct Population Segment
DRBC	Delaware River Basin Commission
DSI	Design Specialties International
E	Endangered
EDC	endocrine disrupting chemical
eds.	editors
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency

ERA	extinction risk analysis
ERC	Environmental Research and Consulting Incorporated
ERM	Environmental Resources Management
ESA	Endangered Species Act
FERC	Federal Energy Regulatory Commission
FL	fork length
FMP	Fishery Management Plan
FPA	Federal Power Act
FR	Federal Register
FSS	Fall Shoals Survey
ft	feet
FWCA	Fish and Wildlife Coordination Act
FWPA	Federal Water Pollution Control Act (Clean Water Act)
g	gram
GA DNR	Georgia Department of Natural Resources
GIS	Geographic Information System
GHG	greenhouse gases
GOM	Gulf of Maine
GPS	Global Positioning Systems
ha	hectare
HNP	Hatch Nuclear Power Plant
HOC	hydrophobic organic compound
hr	hour
I&E	impingement and entrainment
ICPRB	Interstate Commission on the Potomac River Basin
IHNV	infectious hematopoietic necrosis virus
in	inches
IUCN	International Union for the Conservation of Nature and Natural Resources
km	kilometer
lbs	pounds
LNG	Liquefied Natural Gas
m	meters
m/s	meters per second
MA DMF	Massachusetts Division of Marine Fisheries
MAIA	Mid-Atlantic Integrated Assessment
MD DNR	Maryland Department of Natural Resources
ME DMR	Maine Department of Marine Resources
ME DEP	Maine Department of Environmental Protection
mgd	million gallons per day
mg/L	milligrams per liter (parts-per-million)
mm	millimeters
MOU	memorandum of understanding
MPRSA	Marine Protection, Research and Sanctuaries Act
mt	metric ton
mtDNA	mitochondrial DNA
NCCR	National Coastline Condition Report

NC DEM	North Carolina Department of Environmental Management
NC DENR	North Carolina Division of Environmental and Natural Resources
NC DMF	North Carolina Division of Marine Fisheries
NC DWR	North Carolina Division of Water Resources
NCSU	North Carolina State University
NC WRC	North Carolina Wildlife Resources Commission
NEPA	National Environmental Policy Act
NERRS	National Estuarine Research Reserve System
NH FG	New Hampshire Fish and Game
NHP	Natural Heritage Program
NJ DFW	New Jersey Division of Fish and Wildlife
NMFS	National Marine Fisheries Service
NO	Not Operational
NOAA	National Oceanic and Atmospheric Administration
NS	No Sampling
NSBL&D	New Savannah Bluff Lock and Dam
NSW	nutrient sensitive waters
NPDES	National Pollutant Discharge Elimination System
NPS	National Parks Service
NSBL&D	New Savannah Bluff Lock and Dam
NYC DEP	New York City Department of Environmental Protection
NY DEC	New York State Department of Environmental Conservation
NY DOS	New York Department of State
NYHS	New York Historical Society
ORM	organic rich mud
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PCDDs	polychlorinated dibenzo-*p*-dioxins
PCDF	polychlorinated dibenzofurans
pers. comm.	personal communication
pg/g	picograms-per-gram (parts-per-trillion)
PIT	passive integrated transponder
ppm	parts-per-million
ppt	parts-per-thousand
PRRST	Penobscot River Restoration Trust
PSNH	Public Service Company of New Hampshire
PVA	Population Viability Analysis
RA	Risk Analysis
rkm	river kilometer
rm	river mile
SAFCO	South Atlantic Fisheries Coordination Office
SAV	submerged aquatic vegetation
SBFI	Seaboard Fisheries Institute
SC DNR	South Carolina Department of Natural Resources
SE	standard error
SLR	sea level rise

SJRWMD	St. Johns River Water Management District
SNS	shortnose sturgeon
SRT	Status Review Team
SRBC	Susquehanna River Basin Commission
SSC	State special concern
SSIV	Shovelnose Sturgeon Iridovirus
SSRT	Shortnose Sturgeon Recovery Team
T	Threatened
TCDD	tetrachlorodibenzo-*p*-dioxin
TL	total length
TMDL	total maximum daily load
TNC	The Nature Conservancy
µ	micro
UGA	University of Georgia
UMaine	University of Maine
unpubl.	unpublished
UNCW	University of North Carolina at Wilmington
USDOI	U.S. Department of the Interior
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VHS	viral hemorrhagic septicemia
VIMS	Virginia Institute of Marine Science
WAP	Wildlife Action Plan
WSIV	white sturgeon iridovirus
yds	yards
YOY	young-of-year
yr	year

Executive Summary

The National Marine Fisheries Service (NMFS) initiated a status review for the shortnose sturgeon (*Acipenser brevirostrum*) in 2007 (72 FR 67712; November 30). The shortnose sturgeon (SNS) was listed as an "endangered species threatened with extinction" under the Endangered Species Preservation Act on March 11, 1967. Shortnose sturgeon remained on the endangered species list with the enactment of the Endangered Species Act in 1973 (ESA). The status of the shortnose sturgeon was last examined in 1987; however this status review report was never finalized. Subsequently in 1994, the status of the shortnose sturgeon in the Androscoggin and Kennebec Rivers was assessed in response to a petition to de-list the population. NMFS determined that delisting was not warranted based on a number of factors. The Shortnose Sturgeon Recovery Plan was finalized in 1998; it identified 19 populations based on the fish's strong fidelity to natal rivers.

NMFS is charged with conducting a periodic assessment of a species' status: the assessment is called a "5-year review" and it is required by ESA section 4(c)(2). A 5-year review analyzes available information relative to the definitions of endangered and threatened and in the context of the ESA listing factors as outlined in section (4)(a)(1)[2]. Normally, a 5-year review focuses on new information since the last status review. The scope of a 5-year review varies depending on the species, situation, date and scope of the recovery plan, and geographic range of the species. The intent of the National Marine Fisheries Services' (NMFS) Regional Offices in the Northeast (NER) and Southeast (SER) was to conduct a status review for shortnose sturgeon (*Acipenser brevirostrum*) that would fill the requirements of the 5-year reviews that are required by the Endangered Species Act (ESA). The NER and SER anticipated the 5-year review for the shortnose sturgeon would be more complex given the pre-ESA listing coupled with the dated status reports and recovery plan, and with recent advances in genetics that greatly assist in understanding population structure.

To assist NMFS, a team of experts on shortnose sturgeon biology and life history was identified and invited to participate as members of the current Status Review Team (SRT). The SRT was a nine member team comprised of state and federal biologists that provided both data as well as individual expert input to ensure that the status review report (SRR) provides the best available information.

The SRT reviewed information on a river-by-river basis, summarizing published information regarding abundance and distribution (both historic and current), river-specific natural history and habitat information, stressors impacting the riverine system

[2] The five factors given in section 4(a) (1) of the ESA are the following: a) the present or threatened destruction, modification, or curtailment of [a species'] habitat or range; b) overutilization for commercial, recreational, scientific, or educational purposes; c) disease or predation; d) the inadequacy of existing regulatory mechanisms; or e) other natural or manmade factors affecting its continued existence.

(organized relative to the ESA listing factors), and current and recommended research. A summary of existing regulatory authorities relative to sturgeon was complied, as well as a synopsis of ongoing take permitted under ESA section 10 and a current inventory of shortnose sturgeon at research facilities. The SRT also analyzed population structure pursuant to the Distinct Population Segment Policy (DPS policy) and extinction risk analysis (ERA) pursuant to the ESA. Before finalizing the status review, during internal regional review, we identified that the DPS and recommendations regarding the ESA conservation status resulting from the ERA analysis, overreached responsibilities of the SRT. We subsequently removed these two sections. This approach is consistent with the statute which directs the Secretary to make a determination on the conservation status of the species. Without these two sections (DPS and ERA), the document no longer contains the elements required for a five year review.

The SRT examined life history information, migration data, and results of genetic analysis to determine the appropriate population structure of shortnose sturgeon. The SRT determined that there are 5 regional popualtion clusters of shortnose sturgeon: 1) Gulf of Maine (Penobscot, Kennebec, Androscoggin, and Merrimack); 2) Connecticut and Housatonic Rivers; 3) Hudson River; 4) Delaware River/Chesapeake Bay; and 5) Southeast Rivers. Three of these regional population clusters may function as metapopulations: Southeast, Delaware River/Chaeaspeake Bay and the Gulf of Maine. At least one genetically differentriated population exists within Canada; however, the status of this population was not assessed by the SNS SRT.

The ERA was revised, a 3 step risk assessment was developed to assess the general health and status of riverine populations. The three-step risk analysis consists of the following: 1) assess population health; 2) populate a "matrix of stressors" using ranks; 3) validate assessment by comparing population health with the stressors.

It was evident to the SNS SRT that some stressors were likely impacting the species status more than others. To balance this disparity, the SRT weighted the influence of each stressor in their analysis: impacts to habitat and from overutilization were weighted more than competition, effectiveness of regulatory mechanisms, or other factors. The stressors that most depreciate the viability of sturgeon populations were: 1) dams, 2) dredging, 3) poor water quality, and 4) bycatch. In all rivers, impacts to habitat were the greatest threat to the status of shortnose sturgeon.

The SRT compressed the results of the risk analysis to evaluate the population status of each regional population cluster. The SRT realized that some rivers within each regional population cluster were likely of greater biological significance than others as they appeared to function as sources for other rivers. Hence, the SRT concluded these rivers to be biologically integral to the viability of each regional population cluster and the contribution of these rivers were considered when assessing the status of each regional population cluster. Finally, the relationship of population health to stressors was graphed to compare health to stressors at the riverine population and regional population cluster level.

The document includes the most current complete biological assessment of shortnose sturgeon across its range. Given that the document no longer technically constitutes a status review of the species, it is entitled *A Biological Assessment of Shortnose Sturgeon, Acipenser brevirostrum.*

Introduction

Shortnose sturgeon (*Acipenser brevirostrum)* inhabit large coastal rivers of eastern North America. This species is often considered “anadromous” but a more appropriate term is “amphidromous” meaning that they move between fresh and salt water during some part of their life cycle, but not for breeding. Historically, the distribution of shortnose sturgeon extended from the Saint John River, New Brunswick, Canada, to the St. Johns River, FL (Vladykov and Greeley 1963, Gruchy and Parker 1980) and perhaps as far south as the Indian River, FL (Gilbert 1989, Evermann and Bean 1898). Native American fishermen harvested shortnose and Atlantic sturgeons (*Acipenser oxyrinchus oxyrinchus*) for their meat and roe some 4,000 years ago and sturgeon are credited as the primary food sources that saved the Jamestown settlers in 1607 (Saffron 2004). However, it was not until the mid 1800s that Atlantic and shortnose sturgeon began to support a thriving and profitable fishery for caviar, smoked meat, and oil. For the most part, historical landings records failed to differentiate between shortnose sturgeon and the larger Atlantic sturgeon, making historical trends in abundance for populations of either species difficult to determine. The period of greatest exploitation for shortnose and Atlantic sturgeon occurred during the latter half of the 19^{th} century (Secor 2002). Landings in the combined fishery reached a high of 7.3 million pounds for all the states in 1890, but this boon was soon followed by a precipitous decline and by 1920, landings were reported at only 23,000 pounds (Murawski and Pacheco 1977). Bycatch in commercial fisheries and increased industrial uses of the nation’s large coastal rivers during the 20^{th} century (e.g., hydropower, nuclear power, treated sewage disposal) have contributed to the further decline and slow recovery of both shortnose and Atlantic sturgeon.

History of the Endangered Species Act Listing Status

Shortnose sturgeon were originally listed as an endangered species by the USFWS on March 11, 1967 under the Endangered Species Preservation Act (32 FR 4001). Shortnose sturgeon continued to meet the listing criteria as “endangered” under subsequent definitions specified in the 1969 Endangered Species Conservation Act. NMFS assumed jurisdiction for shortnose sturgeon from the USFWS under a 1970 government reorganization plan. The ESA was enacted in 1973 and all species that were listed as endangered species threatened with extinction in the 1969 Endangered Species Conservation Act were deemed endangered species under the ESA (39 FR 41370). Shortnose sturgeon currently remains listed as an endangered species throughout all of its range along the U.S. East Coast.

Although the original listing notice did not cite reasons for listing the species, a 1973 Resource Publication issued by the U.S. Department of Interior (USDOI), stated that shortnose sturgeon were “in peril ... gone in most of the rivers of its former range [but] probably not as yet extinct" (USDOI 1973). Pollution and overfishing, including bycatch in the shad fishery, were listed as principal reasons for the species' decline.

Petition to De-list the Kennebec Complex
In 1994, NMFS received a petition from the Edwards Manufacturing Company to remove the shortnose sturgeon population in the Kennebec River system in Maine (Androscoggin, Kennebec and Sheepscot rivers) from the Endangered Species List. NMFS found that substantial information indicated that the requested action may be warranted and initiated a status review for the shortnose sturgeon population in the Kennebec River system. A Status Review Report was completed in 1996 (NMFS 1996).

In October 1996, NMFS made the finding that de-listing was not warranted. There were two main reasons cited for the not warranted decision. The first was that shortnose sturgeon in the Androscoggin and Kennebec Rivers continued to face substantial threats to their habitat and/or range, and that the existing regulatory mechanisms at the time, other than the ESA, were inadequate to ensure for ongoing appraisal and management of these threats. Secondly, there were questions about the estimates of population size and information was lacking about the population dynamics (e.g., natality, natural mortality, age or size structure) that could be used to assess how well the Androscoggin River and Kennebec River breeding populations are replacing themselves over time (61 FR 53893).

History of Shortnose Sturgeon Status Reviews and Recovery Planning

NMFS first established a shortnose sturgeon recovery team in 1977 to evaluate the species and propose a recovery plan. Although a draft Shortnose Sturgeon Recovery Plan was prepared by this team in 1982, the draft was never forwarded for approval to the Assistant Administrator for Fisheries. Instead, NMFS elected to complete a Status Review for shortnose sturgeon prior to publishing a final recovery plan. A Status Review Team was then established and a Status Review Report was drafted in 1987.

Significant recommendations in the 1987 Report were: 1) to consider each shortnose sturgeon population as a distinct unit under the ESA definition of "species;" 2) to change the status of the Connecticut, Delaware, and Hudson River populations to "threatened;" and 3) to delist the Kennebec River system population. The listing recommendations were met with some disagreement in the scientific community in comments received on the Status Review Report (NMFS 1996) and NMFS never made any changes to the ESA listing based on the recommendations in the 1987 Status Review Report. Although genetic information was not available at the time, the Status Review Team based the DPS recommendations on differences in life history and habitat preferences between different shortnose populations and the species' anadromous life history, which suggested that it was unlikely that populations in adjacent river systems interbred with any regularity. In the 1987 Status Review Report NMFS stated that:

> "the differences reported in longevity, growth rates, and age at sexual maturity between shortnose sturgeon from the northern and southern extremes of its range are expected in any species with a wide latitudinal distribution. The best available information also indicates differences in life history and habitat preferences between the northern and southern river systems (Dadswell et al. 1984) although available genetic and morphometric data do not support any taxonomic splitting of the species. However, given the species' anadromous breeding habits, it is unlikely

> that populations in adjacent river systems interbreed with any regularity. Therefore, until interbreeding is confirmed, we will consider each population within a river system to be a distinct unit under the ESA definition of "species" (NMFS 1987)."

After NMFS received comments on the 1987 Status Review Report, they convened a second Recovery Team in 1988 to critically analyze the recommendations in the 1987 Status Review Report and convey their findings to NMFS. This team disbanded before the completion of their analysis.

NMFS assembled a third Shortnose Sturgeon Recovery Team in 1993, and the "Final Recovery Plan for the Shortnose Sturgeon" was published in 1998. The Recovery Plan includes the following four sections: 1) an updated synopsis of the biology and distribution of shortnose sturgeon; 2) a description of factors affecting species recovery; 3) an outline of actions needed to recover shortnose sturgeon; and 4) an implementation schedule for completing specific recovery tasks.

The 1993 Recovery Team also made recommendations that each of 19 known populations of shortnose sturgeon be managed separately (NMFS 1998). While the term "Distinct Population Segment" (DPS) was used in the Final Recovery Plan, it was used under a different context than is currently accepted (based on the 1996 DPS policy). The Recovery Plan recommended that each population be managed separately until further evidence allowed for the consideration of potential DPS delineations for shortnose sturgeon.

At the same time the Recovery Team established a plan to begin to investigate shortnose sturgeon genetics and recommended that the recovery plan be periodically "revised by NMFS or a NMFS-appointed recovery plan implementation team to reflect new scientific findings, reclassification and recovery of individual populations, and improved understanding of factors affecting population survival" (NMFS 1998). Since then, a number of recommended studies and new population assessments have been completed. As a result, the biological status of shortnose sturgeon is being re-evaluated in this Biological Assessment.

Nomenclature and Taxonomy

The scientific name for the shortnose sturgeon is *Acipenser brevirostrum*. *Acipenser* is Latin for sturgeon and *brevirostrum* means short snout. LeSueur originally described the species from a specimen taken from the Delaware River (Dadswell et al. 1984).

Class: Actinopterygii
- Order: Acipenseriformes
  - Family: Acipenseridae
    - Genus: *Acipenser*
      - Species: *brevirostrum* (LeSueur 1818)
        - Common Name: shortnose sturgeon

Gilbert (1989) provided the following vernacular names for shortnose sturgeon by region: shortnosed sturgeon, little sturgeon (Saint John River, NB), pinkster and roundnoser (Hudson River, NY), bottlenose and mammose (Delaware River), salmon sturgeon (Carolinas), soft-shell or lake sturgeon (Altamaha River).

Species Description and Natural History

Sturgeon have been called "living fossils" due to their ancient lineage and the retention of many primitive physical characteristics. The fossil record suggests that sturgeons had a holarctic distribution (Bemis et al. 1994, Bemis et al. 1997, Choudhury and Dick 1998) and the earliest reported remains of North American sturgeon are from the late Cretaceous, more than 70 million years ago (Hilton and Grande 2006).

All sturgeon possess a distinctive external morphology. Their general shape is similar to sharks with a cylindrical body that tapers at the head and caudal peduncle, and a heterocercal tail (upper lobe of tail is longer than lower lobe). Unlike sharks, sturgeons have a protective armor of bony plates called "scutes" extending longitudinally from the base of the skull to the caudal peduncle. There are five rows of scutes on the body: a single dorsal row and two lateral and ventral rows (Vecsei and Peterson 2004). Sturgeon lack scales but have minute denticles which are tiny tooth-like projections present in the skin of cartilaginous fishes. The dorsal, pelvic, and anal fins are located far back on the body; the pectoral fins are positioned low and the pelvic fins are in the abdominal position (Musick et al. 1994). Other distinctive features include a head covered in bony plates, a subterminal, protractile tube-like mouth, and chemosensory barbels.

Sturgeon are long lived, slow maturing, and spawn infrequently (Bemis and Kynard 1997, Billard and LeCointre 2001). These conservative life history characteristics have served sturgeon well through evolutionary time but sturgeon have responded poorly to anthropogenic impacts in the last centuries (Secor et al. 2002). Anthropogenic impacts include harvest (Boreman 1997) and habitat loss and degradation (Secor et al. 2002, Gross et al. 2002). Many sturgeon, especially the anadromous forms, are in danger of extirpation or extinction throughout most of their ranges (Birstein 1993, Bemis and Findeis 1994, Waldman 1995).

Morphology

Dadswell et al. (1984) prepared a detailed summary of the biology of shortnose sturgeon and much of their work is referenced below. The shortnose sturgeon is the smallest of the three sturgeon species that occur in eastern North America. It has an elongate, cylindrical body and its head and snout are fairly small relative to Atlantic sturgeon. Snout length is variable among specimens and changes through time; smaller, younger individuals generally have longer snouts (Vladykov and Greeley 1963, COSEWIC 2005). The mouth is wide, and generally measures more than half the distance between the eyes (Dadswell 1984). Adult shortnose sturgeon have no teeth, but do possess bony plates in the esophagus that are used to crush hard prey items (Gilbert 1989, Vladykov and Greeley 1963).

Internally, the skeleton is cartilaginous with bones only present in the skull, jaw and pectoral girdle. Shortnose sturgeon are a physostome fish, meaning that the swim bladder is connected to the intestinal tract by a special duct, which allows for regulation of gas pressure via swallowing air or releasing air through the gut. The intestine is dark (Gilbert 1989, Musick et al. 1994, Scott and Crossman 1973) and has a spiral valve, similar to that found in sharks, rays and skates, which is important for nutrient absorption.

Shortnose sturgeon vary in color but are generally dark brown to olive/black on the dorsal surface. Their color is lighter along the row of lateral scutes and is even lighter, nearly white, on the ventral surface. The coloring of the scutes is paler than the surrounding body, making the scute pattern apparent (Gilbert 1989). All fins are pigmented and the leading edges of the paired fins are light colored and often white.

Distinguishing Between Shortnose and Atlantic Sturgeon

Shortnose and Atlantic sturgeon co-occur in many rivers along the East coast of North America. Although the maximum length of shortnose sturgeon of approximately four feet is much shorter than for Atlantic sturgeon, which can grow to lengths upwards of 15 feet, small juvenile Atlantic sturgeon (<150 cm FL) may be confused with adult shortnose sturgeon due to superficial similarities in their appearance and size. Indeed, several misidentifications in recent collections have been confirmed by genetic analyses of archived tissues (T. King, USGS, pers. comm. 2008). It is not surprising then that historic records of shortnose sturgeon collected in the open ocean and in rivers where they had not previously been noted are often suspected to be misidentifications of sub-adult Atlantic sturgeon. Morphological differences between shortnose and Atlantic sturgeon have been described (Vladykov and Greeley 1963, Gorham and McAllister 1974, Bath et al. 1981, Snyder 1988, Gilbert 1989, Kynard and Horgan 2002, Vecsei and Peterson 2004) and recently summarized (Damon-Randall et al. 2010). However, it is important to emphasize that many of the characteristics described in the literature vary with life history stage and there has yet to be a rigorous, range-wide analysis of morphological variation for either species (E. J. Hilton, VIMS, pers. comm. 2008). Although there is evidence that misidentifications have occurred, the SRT believed that this type of error is infrequent and is most often attributed to inexperienced field staff.

Distribution

Shortnose sturgeon occur along the East Coast of North America in rivers, estuaries and the sea (Fig. 1). They were once present in most major rivers systems along the Atlantic coast (Kynard 1997). Their current distribution extends north to the Saint John River, New Brunswick, Canada, which has the only known population in Canada (Scott and Scott 1988). Historically shortnose sturgeon were found as far south into Indian River, FL (Evermann and Bean 1898) but the southern limit of their range is currently believed to be in the St. Johns River, FL (NMFS 1998). They are sympatric with the Atlantic sturgeon throughout much of their range. However, the Atlantic sturgeon spends more of its life cycle in the open ocean. In rivers, shortnose sturgeon and Atlantic sturgeon may

share foraging habitat and resources but shortnose sturgeon generally spawn farther upriver and earlier than Atlantic sturgeon (Kynard 1997, Bain 1997).
Currently, the distribution of shortnose sturgeon across their range is disjunct, with northern populations separated from southern populations by a distance of about 400 km near their geographic center in Virginia. Because the geographic separation distance is great between the shortnose sturgeon inhabiting rivers to the north and south of Virginia, there may be no interchange of adults (Kynard 1997).

Shortnose sturgeon migrate seasonally between upstream freshwater spawning habitat and downstream foraging mesohaline areas within the river based on water temperature, flow and salinity cues. Shortnose sturgeon have been described as anadromous but for some shortnose sturgeon populations that rarely leave their natal river, freshwater amphidromous may be a better description (Kieffer and Kynard 1993). A freshwater amphidromous species is defined as a species that spawns and remains in freshwater for most of its life cycle but spends some time in saline water.

Since the 1998 shortnose sturgeon recovery plan listed 19 distinct shortnose sturgeon population segments, significantly more field data on straying rates to adjacent rivers indicating coastal migrations, and several genetic studies (nDNA and mtDNA) have determined effective movement (i.e., movement with spawning) is occurring between adjacent rivers in some areas, particularly in the Gulf of Maine and the southeast. Mixing of shortnose sturgeon from different rivers is futher investigated in Chapter 4 wherein both field (tagging) and laboratory studies (indirect gene flow estimates from mtDNA (i.e., < 2 individuals per generation)) are utilized to investigate the population structure of shortnose sturgeon.

Until recently there has been little evidence in the literature noting shortnose sturgeon occurrence at sea (Vladykov and Greeley 1963, Schaefer 1967, Fried and McCleave 1973, Wilk and Silverman 1976, Dadswell 1979, Smith et al. 2002a). Most researchers previously believed that coastal movements were rare (Dadswell 1984, NMFS 1998) and that shortnose sturgeon seldom ventured beyond their natal rivers. Magnin (1963) theorized that the species was primarily found in freshwater on the basis of growth (i.e., if shortnose sturgeon spent more time in the ocean they would grow to larger sizes). However, there is conclusive evidence that shortnose sturgeon make coastal movements to adjacent rivers from both tagging data and genetic analysis. Telemetry data and genetic analyses have demonstrated that inter-riverine movements of shortnose sturgeon may be relatively common in some areas (e.g., Maine Rivers based on Fernandes 2008 and 2010; Southeast Rivers based on J. Fleming, GADNR, pers. comm. 2008; and T. King et al. 2013).

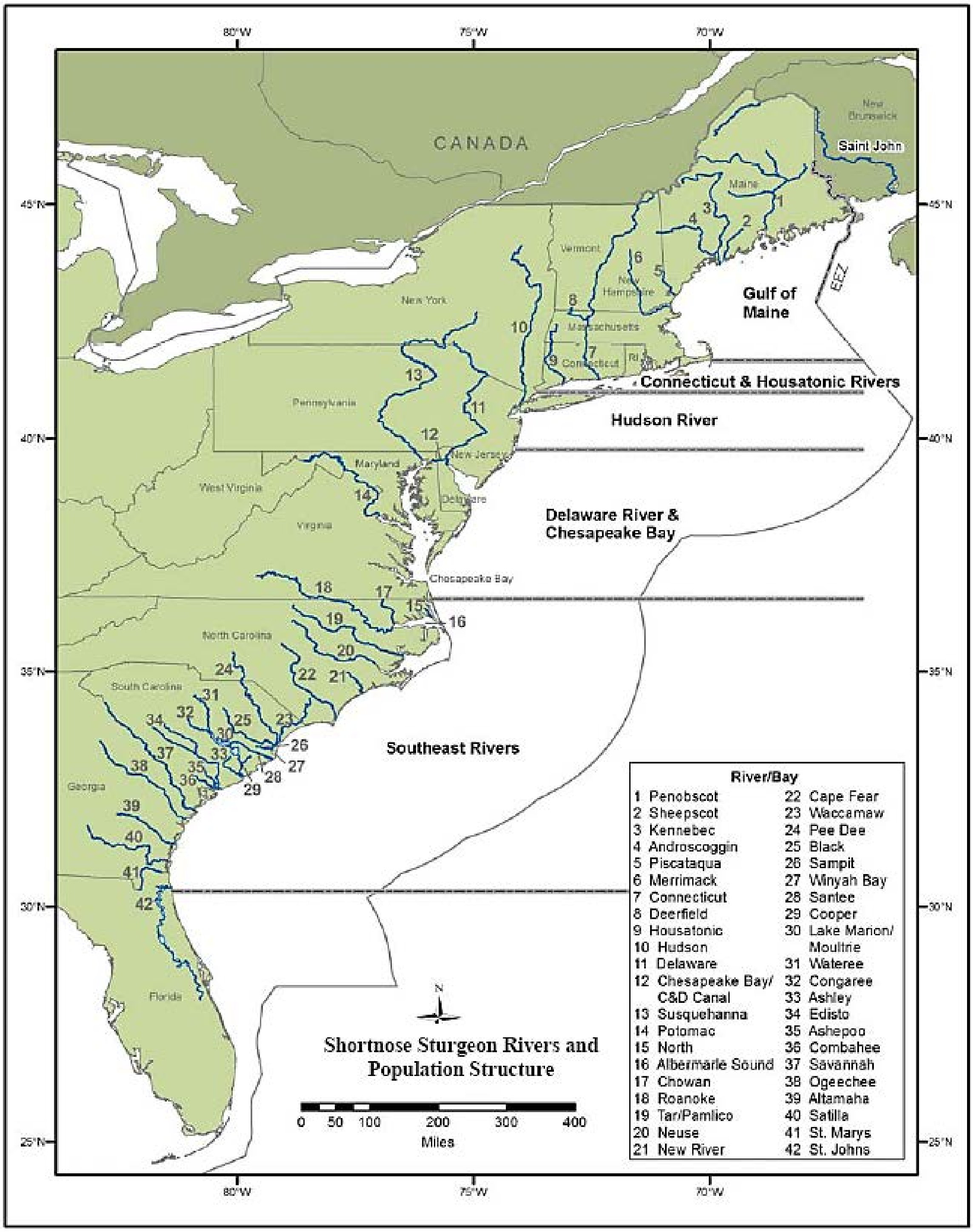


Figure 1. Shortnose sturgeon rivers and population structure.

Life History

Age and Growth

Brennan & Cailliet (1989) examined hard structures in white sturgeon and determined that the "bony" first pectoral fin ray (spine) was the best structure for ageing. Consequently, most sturgeons are aged by taking a cross-section through the first pectoral fin ray (spine) and then counting the alternating translucent (winter) and opaque (summer) annuli (Cuerrier 1951). Accurate age information is critical to the biological understanding and management of shortnose sturgeon. Estimates of growth, mortality, year class structure, reproductive schedules, longevity, and recruitment all rely on accurate ageing. However, ageing sturgeon using fin rays can be problematic, especially when attempting to age older individuals (Rien and Beamesderfer 1994, Rossiter et al. 1995, Paragamian and Beamesderfer 2003, Hurley et al. 2004, Whiteman et al. 2004, Woodland 2005). A recent study of shortnose sturgeon in the Hudson River used marginal increment analysis (Campana 2001) to determine that annuli in shortnose sturgeon were formed sometime between late fall and early spring (Woodland 2005, Woodland and Secor 2007). Ages determined in this study were relatively precise (40% of spines assigned the same age and CV equaled 4.0 % for the sample) but ageing was less precise for individuals aged 17 and older (Woodland 2005, Woodland and Secor 2007). To date, the annuli in fin rays that are used to infer age have been difficult to verify (Woodland 2005, Woodland and Secor 2007), thus, ageing techniques and age validation of shortnose sturgeon merit additional research.

Age

Maximum age of shortnose sturgeon in the northern portion of the species' range is greater than the southern portion of the species' range (Dadswell et al. 1984, Gilbert 1989). Although age determination for older individuals can be problematic, as discussed above, the oldest documented female at 67 years old and the oldest male at 32 were both taken from the Saint John River, Canada (Dadswell et al. 1984). The maximum age reported for a shortnose sturgeon taken from the Kennebec River is 40 years, 37 years from the Hudson River, 34 years from the Connecticut River, 20 years from the Pee Dee River, and 10 years from the Altamaha River (Gilbert 1989 using data presented in Dadswell et al. 1984).

The maximum size of shortnose sturgeon reported was collected from the Saint John River, Canada at 143cm TL (122cm FL) weighing 23kg (Dadswell 1984). More recent collections (1998-2002) report maximum size in the Saint John River as 140.5cm TL (M. Litvak, University of New Brunswick, pers. comm. 2009). Shortnose sturgeon also exhibit sexually dimorphic growth patterns across latitude: males mature at 2-3 years in Georgia, 3-5 years in South Carolina, and 10-11 years in the Saint John River, Canada; females mature at 4-5 years in Georgia, 7-10 years in the Hudson River, and 12-18 years in the St. John River, Canada. Males begin to spawn 1-2 years after reaching sexual maturity and spawn every other year and perhaps annually in some rivers (Dadswell 1979, Kieffer and Kynard 1996, NMFS 1998). Age at first spawning for females is about approximately 5 years post-maturation (Dadswell 1979) with spawning occurring about every three years although spawning intervals may be as infrequent as every 5 years for some females (Dadswell 1979). Female shortnose sturgeon apparently grow larger than and outlive males (Dadswell et al. 1984, Gilbert 1989, COSEWIC 2005).

Growth

Like other sturgeon, the shortnose sturgeon is relatively slow growing, late maturing and long-lived. Dadswell et al. (1984) reviewed growth throughout the latitudinal range. Growth of juvenile shortnose sturgeon in all populations is rapid, attaining lengths of 14-30 cm during the first year. Length at maturity (45-55 cm FL) is comparable throughout the range, but growth rate, maximum age, and maximum size vary with latitude. Shortnose sturgeon in the southern areas grow more rapidly and mature at younger ages but attain smaller maximum sizes than those in the north (Dadswell et al. 1984). Shortnose sturgeon in the north attain the largest sizes and continue to grow throughout life. The land-locked shortnose sturgeon population located upstream of Holyoke Dam at river km 140 of the Connecticut River has the slowest growth rate of any surveyed (Taubert 1980a). This suggests growth advantages associated with foraging in the lower-river or fresh/saltwater interface.

Reproduction

Fecundity

In a review by Gilbert (1989), fecundity of shortnose sturgeon was reported to range between approximately 30,000-200,000 eggs per female. Dadswell gave a range of 27,000-208,000 eggs for the Saint John River, Canada (Dadswell et al. 1984) and a mean of 11,568 eggs/kg body weight (Dadswell 1979).

Eggs

Ripe eggs are typically dark brown, black or olive-gray in color (Meehan 1910, Dadswell 1979, Kynard 1997,). Dadswell (1979) reported egg size from 3.00-3.20 mm in diameter. Kynard (1997) reported a slightly larger egg size of approximately 3.5 mm in diameter and increasing to about 4 mm in diameter after attachment to the substrate. Eggs are negatively buoyant and become adhesive once they are immersed in water (Meehan 1910, Dadswell et al. 1984). Special protuberances on the egg membrane develop within a few minutes after water exposure and maximize surface area available for adhesion to substrate (Meehan 1910, Dadswell et al. 1984). Development of fertilized eggs is correlated with water temperature (Wang et al. 1985, Hardy and Litvak 2004). Meehan (1910) observed an incubation period of 13 days in water temperatures ranging from 8-12°C. Shortnose sturgeon hatched after just 8 days in water temperatures of 17°C (Buckley and Kynard 1981).

Sperm

Dilauro et al. (1999, 2000) used electron microscopy to describe the fine ultrastructure of shortnose sturgeon sperm and suggested that shortnose sturgeon is more closely related to white sturgeon (*A. transmontanus*), lake sturgeon (*A. fulvescens*), and stellate sturgeon (*A. stellatus*) than to the Atlantic sturgeon. Browne (2004) compared the swimming behavior and performance of shortnose and Atlantic sturgeon spermatozoa and found shortnose sturgeon sperm were faster and maintained motility for a longer period of time than did the Atlantic sturgeon. Both shortnose and Atlantic sturgeon spermatozoa were active for longer than five minutes; this is greater than the typical sperm longevity for most freshwater fishes of one minute or less (Jamieson 1991, Lahnsteiner et al. 1997, Turner and Montgomerie 2002), but was less than reported for some marine spawners (Elofsson et al. 2003). Spermatozoa that are fast and long lived have competitive advantages within species for egg fertilization, and for dealing with environmental conditions on the spawning grounds (Browne 2004).

Life Stages

Yolk-sac Larvae (Free-swimming Embryos)

At hatching and until about day 8, shortnose sturgeon have a large yolk-sac, are dark gray or blackish-colored, 7-11 mm long, and resemble tadpoles (Buckley and Kynard 1981, Dadswell et al. 1984). Hatchlings have poorly developed eyes, mouth, and fins (Richmond and Kynard 1995).

Yolk-sac larvae are capable of only "swim-up and drift" swimming behavior and are ill-equipped to survive as free-swimming individuals in the open river (Richmond and Kynard 1995). In the laboratory, one to eight day old shortnose sturgeon were photonegative, actively sought cover under any available material, and swam along the bottom until cover was found (Richmond and Kynard 1995, Parker and Kynard 1995). Yolk-sac larvae are known to form aggregations with other larvae in concealment (Buckley 1982). Litvak observed that from a few days after hatching, they exhibit shoaling behavior forming tight, well-spaced schools and swim against the current; this shoaling behavior only exists when there is a flow (COSEWIC 2005). Sheltering in dark substrate (i.e. in the crevasse of rocks/cobble at the spawning site) may enhance survival at this vulnerable life stage by allowing for some protection from predators (Richmond and Kynard 1995). Eggs and yolk-sac larvae may be concentrated near the spawning area for up to 4 weeks post-spawning. For example, if an individual shortnose sturgeon took 13 days to hatch and 12 days to absorb the yolk sac, it would likely remain near the spawning site for 25 days.

Post Yolk-sac Larvae (Fry)

In 8-12 days after hatching, shortnose sturgeon absorb the yolk-sac when they reach a size of about 15mm TL (Buckley and Kynard 1981). Larvae at this stage have well-developed eyes and fins. They also have a mouth with teeth which may aid in specialized larval feeding (Taubert and Dadswell 1980); the teeth are later absorbed during the juvenile phase. At about 15mm TL, larval coloration begins to resemble that of an adult with darker dorsal pigmentation and lighter lateral and ventral coloration (Taubert and Dadswell 1980). In the lab, larvae could become lighter or darker, corresponding with changes in light intensity (Buckley and Kynard 1981, Richmond and Kynard 1995, Kynard and Horgan 2002).

Once larval shortnose sturgeon absorb their yolk-sac, they experience a rapid change in sensory, feeding and locomotor systems (Bemis and Grande 1992). Fins begin to develop allowing for swimming behavior that is more typical of juvenile and adult sturgeon, and larvae begin to feed exogenously. In the wild, these larvae are often found in the deepest water, usually within the channel (Taubert and Dadswell 1980, Bath et al. 1981, Kieffer and Kynard 1993). Lab experiments of post-yolk-sac-larvae to determine preferred habitat have produced somewhat different results. Richmond and Kynard (1995) found that larvae of this size are active nocturnally, prefer deep water, and silt substrate that is light in color while Parker (2007) reported they emerge from the protection of the rocks, swim in the water column, and prefer open bright habitat.

These behavioral changes disperse shortnose sturgeon downstream of the spawning/rearing areas. Larval dispersal patterns were studied by Parker (2007) that compared behavior of larvae collected from Connecticut River to those spawned from Savannah River stock. All post-yolk-sac larvae made some downstream movement as yolk-sac larvae (observed more often in the Savannah River stock), dispersal downstream was more closely associated with the post yolk-sac larval stage (Parker 2007). Dispersal rates differed as fish from the Connecticut River peaked on days 7–12 after hatching while Savannah River individuals had a longer dispersal with multiple, prolonged peaks, and a low level of downstream movement that continued for the entire larval and early juvenile period.

Juveniles

Based on a morphological study by Snyder (1988), Parker (2007) considered individuals to be juveniles when they reached 57mm TL. At this length, shortnose sturgeon have the full adult complement of fin rays and ossification of bony parts. Juvenile shortnose sturgeon have absorbed their teeth and their mouth becomes fully protrusible (Richmond and Kynard 1995; Disler 1960). Larvae taken from the Connecticut River made the transformation to juveniles on day 40 in the laboratory; the transformation was made on day 41 or 42 for individuals spawned from Savannah River stock (Parker 2007). Growth of juveniles in the first year is rapid with shortnose sturgeon in northern rivers achieving an average of 14cm TL; those in southern rivers grow even larger with an average of 30cm TL (Pekovitch 1979, Dadswell 1984). Young-of-year shortnose sturgeon habitat use differs markedly from that of yearlings and older juveniles; this is believed to be a function of salinity tolerances.

Young-of-Year (YOY)

Little is known about YOY behavior and movements in the wild but shortnose sturgeon at this age are believed to remain in channel areas within freshwater habitats upstream of the salt wedge for about one year (Dadswell et al. 1984, Kynard 1997). Pottle and Dadswell (1979) reported that YOY in the Saint John River, Canada, use intermediate and deep water habitats. Residence of YOY in freshwater is supported by several studies on cultured shortnose sturgeon. Jenkins et al. (1993) found that salinity tolerances of young shortnose sturgeon improve with age; individuals 76 days old suffered 100% mortality in a 96-hour test at salinities ≥15 ppt while those 330 days old tolerated salinities as high as 20 ppt for 18 hours but experienced 100% mortality at 30 ppt. Jarvis et al. (2001) demonstrated that 16-month old juveniles grew best at 0% salinity and poorest at 20% salinity. Lastly, Ziegeweid et al. (2008) demonstrated that salinity and temperature interact, affecting survival of YOY shortnose sturgeon. As salinity and temperature increased, survival decreased; however as body size increased, individuals were better able to tolerate higher temperatures and salinities (Ziegeweid et al. 2008). Carlson and Simpson (1987) examined stomach contents of YOY shortnose sturgeon from the Hudson River and concluded that they consumed organisms found in the channel (amphipods), and dipteran larvae found in the drift and mud substrate, but not in sand substrate.

Immature/Sub-adult

Juveniles in the Saint John, Hudson, and Savannah rivers use deep channels over sand and mud substrate (Pottle and Dadswell 1979, Hall et al. 1991, Dovel et al. 1992). In most rivers, juveniles age one and older join adults and show similar spatio-temporal patterns of habitat use (Kynard 1997). In the upper segment of the Connecticut River, where some juveniles and adults are always in freshwater, there was no macrohabitat segregation by age as both adults and juveniles used the same river reaches (Savoy 1991b, Seibel and Kynard 1992). In the southeast, juveniles age one and older make seasonal migrations like adults, moving upriver during warmer months where they shelter in deep holes, before returning to the fresh/salt water interface when temperatures cool (Flournoy et al. 1992, Collins et al. 2002). Conversely, juveniles of this age in the Saint John River, Canada, preferred different habitat than adults. Dadswell (1979) reported these juveniles prefer freshwater habitats until they reach about 45cm TL or age eight. Recently, preliminary tracking data on juveniles in the Delaware River (n=3) suggest that juveniles use different overwintering areas than adults and do not form dense aggregations like adults (ERC Inc. 2007b).

Immature individuals apparently feed indiscriminately, often ingesting large amounts of mud, stones, and plant material along with prey items (Dadswell 1979, Carlson and Simpson 1987). Prey items commonly include aquatic insects, isopods, and amphipods (Dadswell 1979, Carlson and Simpson 1987, Bain 1997). Kynard (1997) noted that young sturgeon have a size dependent dominance hierarchy that determines use of foraging habitat (C. Cauthron and B. Kynard, USGS, pers. comm.). This behavior may help to regulate density and emigration in each river as a function of resource abundance.

Adults

A morphological description of adult shortnose sturgeon was presented above. Juveniles are considered adults when they begin to develop mature gonads; adults can be immature or mature. Dadswell et al. (1984) reported that shortnose sturgeon in the southern part of their range reach maturity sooner than those in the north. A fairly wide range in the reported sizes at maturity/spawning is apparent and consequently the SNS SRT recognized the need for more research in this area.

Age at first spawning reportedly occurs 1-2 years after maturity for males but may be delayed up to 5 years for females (Dadswell et al. 1984). There is no apparent external sexual dimorphism in shortnose sturgeon with the exception of pre-spawning adults; gravid females can be identified by the dark eggs that can be seen through the female’s swollen abdomen (Dadswell 1979), and milt can be expressed from males (Dadswell et al. 1984). Additionally, Litvak determined that adult males weighed significantly less than females of the same length demonstrating some sexual dimorphism (COSEWIC 2005). A biometric method using head measurements successfully determined sex in the Russian sturgeon (*Acipenser gueldenstaedtii*) with 90% accuracy and the authors suggest this method may be applied to other Acipensarids (Mal'tsev and Merkulov 2006).

Interestingly, researchers have noted that some shortnose sturgeon appear to aggregate with the same individuals within season and from year to year. Dadswell (1979) first observed these groupings in gillnet capture data on the Saint John River, Canada. Individuals that were recaptured were caught with the same group as in the original capture effort and often in the same order. The probability that pairs of fish would be recaptured together and removed from the gillnet in the same order by chance is extremely low (Dadswell, 1979). Decades later, students from Litvak's lab working on the Saint John River observed the same phenomenon (COSEWIC 2005). Similarly, groupings of the same individuals from year to year in overwintering locations have been noted in shortnose sturgeon tracking data from the Connecticut River (Kynard et al. 2012).

Migration and Habitat

Research shows that shortnose sturgeon likely move through all areas of a river system but often remain in important resting and feeding aggregations for extended time periods (Hastings et al. 1987, Kieffer and Kynard 1993). Adult shortnose sturgeon appear to have complex migratory patterns that vary by river system. For some river systems, coastal migrations of adult shortnose sturgeon to neighboring rivers have been documented. Reasons for adult migrations include: 1) abandonment of the overwintering site for spawning upriver in the spring; 2) general downstream movements to feeding areas lower in the river during late spring; and 3) directed movement to distinct overwintering sites in the fall. These movements and the habitats associated with them are described in greater detail below.

Spawning

Spawning Migration and Cues

Shortnose sturgeon migrate from overwintering locations upstream to spawning grounds during the spring in northern rivers and in late winter/early spring in southern rivers (Dadswell 1979, Kynard 1997). Studies of shortnose sturgeon in Massachusetts rivers suggested three patterns for spawning migration: 1) a "short one-step" migration made in the spring just a few weeks prior to spawning (Kieffer and Kynard 1993); 2) a "long one-step" migration made in the late winter/early spring before spawning; and, 3) a "short two-step migration" beginning with a long fall migration that positions the individuals closer to the spawning habitat for overwintering followed by a short migration as described in pattern 1 above (Buckley and Kynard 1985a).

A recent analysis of 15 years (1993–2007) of data regarding shortnose sturgeon spawning behavior on the Connecticut River examined cues that were important to pre-spawning migration. The researchers concluded that day length (13.37–13.77 h) combined with water temperatures of 7.0–9.7°C, and not river discharge, triggered initiation of the pre-spawning migration from overwintering areas with males leaving before females (Kynard et al. 2012).

Shortnose sturgeon throughout their range have been documented to spawn when water temperatures range from 9–15°C (Dadswell 1979, Taubert 1980a and b, Kynard 1997). The spawning period is estimated to last from a few days up to 30 days (K. Hattala, NYDEC, pers. comm. 2008). Kynard et al. (2012) described "spawning suitability windows" which must all be "open" for spawning to occur on the Connecticut River. These include day length (13.9–14.9 h = 26 d; 27 April–22 May), water temperature (6.5–14.9°C), and river discharge (<1,000 m^3/s by 2 May at Cabot Station and < 600 m^3/s by 30 April at Rock Dam).

Behavior

Spawning females deposit their eggs at or near the substrate (, Kynard et al. 2012), and males express milt over the eggs fertilizing them. Kynard et al. (2012) reviewed the available information on sturgeon spawning behavior and suggested that sturgeon have at least two spawning styles: 1) long duration; and 2) short duration. Short-duration spawning is represented by sturgeon that spawn all their eggs in ≤ 12 h, which includes Chinese (Wei 2003) and lake sturgeon (Bruch and Binkowski 2002). Shortnose sturgeon are long-duration spawners where a female spawns eggs in discrete batches during multiple spawning sessions over many hours (24–36 for shortnose sturgeon, Kynard et al. 2012). Kynard demonstrated that females in the Connecticut River spawned small batches of eggs slowly during the day and night. He speculated that this spawning style had the advantage of dispersing eggs over a long time period, allowing females to precisely place eggs in selected habitat (Kynard et al. 2012). Long duration style spawning appears to work well for shortnose sturgeon in this river because there were few documented predators of shortnose sturgeon eggs at the Montague spawning area in 1995 (Kynard and Horgan 2002), one of the most abundant spawns recorded in 16 years of observation (Kynard et al. 2012).

Habitat

In populations that have free access to the total length of a river (e.g., undammed within the species' range in a river) spawning areas are often located at the farthest accessible upstream reach of the river (Kynard 1997). For rivers that are dammed, spawning frequently occurs near the base of the dam or in the tailrace (Kynard 1997, Cooke et al. 2004). Spawning usually occurs over gravel, rubble, and/or cobble or large rocks (Dadswell 1979, Taubert 1980a and b, Buckley and Kynard 1985b, Kynard 1997), or timber, scoured clay and gravel (Hall et al. 1991). Spawning sites are characterized by moderate river flows with average bottom velocities between 0.4 and 0.8 m/s (Hall et al. 1991, Kieffer and Kynard 1996, NMFS 1998). Water depth at the spawning site appears to be a less important habitat feature than substrate type and flow (Kynard et al. 2012). A recent study by Kynard et al. (2012) demonstrated that females in an artificial stream will readily accept a shallow water depth of 0.6 m, with a rubble bottom, and 0.3–1.2 m/s bottom velocity.

Shortnose sturgeon are believed to spawn at discrete sites within a river (Kieffer and Kynard 1993). In the Merrimack River, males returned to only one reach during a four year telemetry study (Kieffer and Kynard 1993). Squiers et al. (1982) found that during the three years of the study in the Androscoggin River, adults returned to a 1-km reach below the Brunswick Dam; Kieffer and Kynard (1993) found that adults spawned within a 2-km reach in the Connecticut River for three consecutive years. More recently, shortnose sturgeon returned to the same gravel bar on the Pee Dee River over two consecutive years (Collins et al. 2003). Spawning location (rkm) is important when considered together with information from laboratory studies regarding larval drift and salinity tolerances. A spawning location low in the river coupled with larval drift behavior that carries larvae downstream would transport them to areas of harmful or fatal salinity regimes.

Spawning Periodicity and Sex Ratio at the Spawning Ground

Age at first spawning appears to differ among males and females and by latitude. Males spawn 1 to 2 years after reaching maturity and females in the northernmost population may first spawn 5 years after maturing (Dadswell 1979). Spawning periodicity (reproductive schedule) data are limited and more reliable information is needed to better understand and predict shifts in population abundance and potential for recovery based on reproductive success. Males are thought to spawn every other year, and perhaps annually, in some rivers (Kieffer and Kynard 1996, NMFS 1998) while females are believed to spawn less frequently, approximately every three years with spawning intervals occurring as infrequently as every 5 years in northern populations (Dadswell 1979). One female in captivity (of Savannah River stock) spawned two consecutive years (M. Mohead, NMFS, pers. comm. 2009).

Sex ratio on the spawning ground may favor males although spawning females are less mobile making them less susceptible to gillnet gear which may skew estimates (Kieffer and Kynard in review-B). Males were most abundant in the available estimates for the Hudson River at 2.5:1 (Pekovitch 1979), the Connecticut River at 3.5:1 (Taubert 1980a and b) and 3 to 7:1 (Buckley and Kynard 1985b), and 3.5:1 in the Savannah River (Collins and Smith 1997).

Hermaphroditisim

Hermaphroditisim has been documented in a shortnose sturgeon raised in captivity (Henne et al. 2006) and in the wild (Atz and Smith 1977). In each case, the authors documented ovotestes. The captive individual was successfully fertilized (self-fertilized and cross-fertilized) resulting in viable fry (Henne et al. 2006). Although hermaphroditism is believed to be an anomaly that occurs in low frequencies, it may have some implications for gender identification in the field and reproductive success. The presence of estrogenic compounds in many of the rivers in which shortnose occur coupled with the potential for hermaphroditism is worthy of additional study.

Survival and Recruitment

Gross et al. (2002) used an age-structured model of shortnose, Atlantic, and white sturgeon to evaluate the degree to which increases in survival and fecundity would contribute to recovery. They noted that for all species studied, that elasticity profiles for population growth were most sensitive (i.e. had the highest potential gains in recovery) for YOY and juvenile ages as compared with mature individuals (Gross et al. 2002). Further, when comparing all three species for a fixed percentage increase in survival of any age-class before maturity, the shortnose sturgeon should show the largest response (Gross et al. 2002). Compared with survival, fecundity had relatively low elasticity (i.e., lower rate of return); this was attributed to the model's shared effects of fecundity across all adult age classes coupled with the high rate of mortality in the YOY age class that diminishes the contribution of egg number to population growth (Gross et al. 2002). These findings underscore the need to protect early life stages, YOY, and juvenile shortnose sturgeon and have implications for management actions such as habitat protection and restoration, and the potential contribution of hatcheries to aid in recovery.

Foraging

Adult shortnose sturgeon typically leave the spawning grounds soon after spawning and move rapidly to downstream feeding areas in the spring (Dadswell et al. 1984, Buckley and Kynard 1985a, Kieffer and Kynard 1993, O'Herron et al. 1993. Kieffer and Kynard (1993) reported that post-spawning migrations were correlated with increasing spring water temperature and river discharge. Shortnose sturgeon in the Saint John River, Canada, appear to be an exception to this rapid downstream movement exhibited in other rivers as a portion of the Saint John River adults remain upriver until a 2-3°C decline in temperature initiates downstream movement in the fall (Litvak in COSEWIC 2005).

Foraging Behavior

Shortnose sturgeon have barbels (fleshy projections) ventral to their mouths that are tactile receptors used to locate prey on the benthos. Sturgeon possess a highly protrusible mouth that extends downward to vacuum up sediments containing their prey (i.e., infaunal macroinvertebrates). This suction feeding requires an expandable mouth cavity and a relatively narrow mouth through which to funnel water and food items. Shortnose sturgeon are benthic invertivores and feed throughout their lifecycle on benthic insects, crustaceans, mollusks, and polychaetes (Dadswell et al. 1984). Studies of gut contents show that the diet of adult shortnose sturgeon typically consists of small bivalves, gastropods, polychaetes, and small benthic fishes (McCleave et al. 1977, Dadswell 1979, Marchette and Smiley 1982, Dadswell et al. 1984, Moser and Ross 1995, Kynard et al. 2000, Collins et al. 2002) and may take fish bait (Collins et al. 2002). Some reports indicate that female adult shortnose sturgeon have been found to feed throughout the year; however, Dadswell (1979) found that pre-spawning females (stage III-V) from the Saint John River rarely had food in their stomachs and likely stopped feeding about eight months prior to spawning; in contrast, ripening males generally had full stomachs. Kynard et al. (2012) documented that spent females in the Connecticut River had lost between 20–40% of pre-spawning weight from egg deposition; males lost between 5–7% of pre-spawning weight. Dadswell (1979) documented both males and females actively feeding immediately after spawning.

Foraging Habitat

Because substrate type strongly affects composition of benthic prey, both juvenile and adult shortnose sturgeon primarily forage over sandy-mud bottoms, which support benthic invertebrates (Carlson and Simpson 1987, Kynard 1997). Shortnose sturgeon have also been observed feeding off plant surfaces (Dadswell et al. 1984).

Foraging Seasonality

Northern Rivers

Foraging in the colder rivers in the northern part of their range appears to cease (or nearly cease) during winter months when shortnose sturgeon become inactive. In mid-Atlantic areas, including the Chesapeake Bay, and the Delaware River, foraging is believed to occur year-round, though shortnose sturgeon are believed to feed less in the winter (J. O'Herron, Amitrone O'Herron, Inc., pers. comm. 2008).

Southern Rivers

In the southern part of their range, shortnose sturgeon are known to forage widely throughout the estuary during the winter, fall, and spring (Collins and Smith 1993, Weber et al. 1998). During the hotter months of summer, foraging may taper off or cease as shortnose sturgeon take refuge from high water temperatures by congregating in cool, deep areas of rivers (Flournoy et al. 1992, Rogers and Weber 1994a, Rogers and Weber 1995, Weber 1996).

Overwintering

There are differences in both the overwintering habitat and behavior of shortnose sturgeon across their range. A key difference is winter activity periods: fish in northern rivers form tight aggregations in specific areas with little movment or foraging; fish in the south are more active and move through the river (Kynard et al. 2012). Habitats also vary from north to south: fish in more northern rivers will inhabit either freshwater or saline reaches of the river while fish in the south are found predominantly near the fresh/saltwater interface during the coldest months.

Northern Rivers

In northern populations, both juveniles and adults form dense aggregations in relatively deep river segments (3–10m; Kynard et al. 2012, Dadswell 1979, Li et al. 2007) during winter months. Seeking winter refuge is likely an adaptive trait driven by cold temperatures that cause a decline in metabolism. Kynard et al. (2012) examined habitat data and discovered that quality of wintering areas differ. Wintering sites appear to be entirely in freshwater in the Merrimack River (Kieffer and Kynard 1993), Connecticut River (Buckley and Kynard 1985a, T. Savoy CT DEP, pers. comm., Kynard et al. 2012), and Hudson River (Dovel et al. 1992, Bain et al. 1998a & b), while only a portion of the wintering sites occur in the freshwater/saltwater zone of the estuary in the Saint John River (Dadswell 1979). The number of wintering sites in any river was unrelated to population size and may be indicative of life history adaptations to each river system (Kynard et al. 2012).

Shortnose sturgeon overwintering sites primarily occur over sand bottom; however in the Hudson River they were reported as comprised of sand, mud, and gravel (Hattala et al., NY DEC, pers. comm. 2009). Flow velocity in the Saint John River was 0.6 to 1.0 m/s, and 0.02–0.31 m/s in the Connecticut River (Li et al. 2007, Kynard et al. 2012). Salinity ranged between 0% to 20%; and dissolved oxygen values ranged from 11.61–12.84 mg/L at sites in the Connecticut River (Kynardet al. 2012), and averaged 10.51 ± 0.26 mg/L on the Kennebecasis River, a tributary to the Saint John River (Li et al. 2007).

The most comprehensive study of shortnose sturtgeon overwintering behavior in northern rivers was done by Kynard et al. (2012). Wintering adults on the Connecticut River above the Holyoke Dam were tracked and video-taped over ten years and four wintering sites were identified. The majority of adults used only one site during each wintering period, and most individuals (78.2%) subsequently returned to the same site the following year (Kynard et al. 2012). Movements to and from wintering areas during spring and fall in the upper portion of the Connecticut River were more strongly correlated with day length (9.82–9.60 h in fall and 13.37–13.77 h in spring) than discharge (Kynard et al. 2012)

Southern Rivers
During winter months, adults in southern rivers spend much of their time in the slower moving waters downstream near the salt-wedge and forage widely throughout the estuary (Collins and Smith 1993, Weber et al. 1998). Older juveniles likely inhabit the same areas as adults, but younger juveniles primarily remain in freshwater habitats perhaps due to low salinity tolerances (Jenkins et al. 1993, Jarvis et al. 2001). Weber et al. (1998) tracked the movements of 20 adults and 1 juvenile shortnose sturgeon in the Ogeechee River: in the fall when water temperature was >16.0°C, shortnose sturgeon moved into mesohaline areas (rkm 26.2-36.6); during winter when water temperatures dropped below 16.0°C**,** sturgeon moved farther downriver to polyhaline regions (rkm 19.2-30.5).

A portion of adults in the Altamaha River may make a fall "pre-spawn" migration similar to fishes residing in northern rivers (Rogers and Weber 1995). Tagged adults in the Altamaha River migrated into an area in the upper tidal portion of the river in the fall and appeared to complete their migration in the spring (Rogers and Weber 1995).

Species Diversity and Evolutionary Significance

Chondrosteans were thought to be the dominant fishes of the Permian period some 200 million years ago (Schultz 1980). Sturgeon (Acipenseridae) are one of two living representatives of the chondrosteans; the other group of fish being the paddlefishes (Polydontidae). The continued existence of these "fossil" fishes is in jeopardy throughout North America, Europe, and Asia, and they require research efforts to identify and sustain ecological and evolutionary processes (Bemis and Findeis 1994, Birstein et al. 1998). While much effort has been directed at understanding ecological factors associated with sturgeon biology (Ludwig 2006), investigations into the evolutionary processes shaping extant species is complicated by the fact that the fundamental evolutionary relationships (i.e., classifications) within the Acipenseriformes are inadequately understood (Krieger et al. 2008).

Recent molecular studies have called into question portions of the Acipenseriform classification which has been historically based on morphological characters (Birstein and DeSalle 1998, Zhang et al. 2000, Birstein et al. 2002, Krieger et al. 2008). Different gene regions, even those physically linked within the mitochondrial molecule, whether viewed individually or in various combinations, have yielded different phylogenetic interpretations (see Krieger et al. 2008 for review). Some of these inconsistencies result from the fact that individual gene trees often inaccurately depict species boundaries (Knowles and Carstens 2007, Krieger et al. 2008).

Taxonomically, shortnose sturgeon (*Acipenser brevirostrum)* has long been thought to be a sister species with lake sturgeon (*A. fulvescens*) and distantly related to the sympatric and morphologically similar Atlantic sturgeon (*A. oxyrinchus oxyrinchus*) (Hocutt and Wiley 1986). Birstein and DeSalle (1998) surveyed three mitochondrial DNA (mtDNA) regions, which are maternally inherited and concluded the three species were distantly related. A survey of four mtDNA genes in all North American sturgeons (Krieger et al. 2000) again found shortnose and lake sturgeon to be sister species. The most recent molecular evidence obtained from eight mtDNA regions in North American and Eurasian species suggests shortnose and lake sturgeon are not sister species, but are evolutionarily similar enough to be placed in the same phylogenetic clade and affirmed the position of Atlantic sturgeon as basal to all Acipenseridae (Krieger et al. 2008).

Efforts to resolve the molecular systematics of the Acipenseridae using nuclear DNA (nDNA) sequences (from a single gene region: 18S rRNA; Krieger and Fuerst 2002) was complicated by the polyploid genome (the nucleus has 4 to 6n the haploid number of chromosome sets) and provided no additional phylogenetic resolution. Given the variable results obtained from the survey of mtDNA genome and the lack of genes currently available from the polyploid nuclear genome, some revision of Acipenseriform classification may be needed to accurately inform conservation efforts.

Future phylogenetic studies of shortnose and other sturgeon should focus on the analysis of multiple genes from the polyploid nuclear genome; the lack of such genomic resources for sturgeon hinders mechanistic study. Contemporary molecular technology allows *de novo* transcriptome assembly and a fast, cost-effective, and reliable method for development of taxonomically informative gene regions, as well as a host of functional genomic tools (Vera et al. 2008); this narrows the gap between genomic approaches based on model organisms with rich genetic resources and less tractable species in need of ecological and evolutionary study. These tools offer the promise of determining how variation in gene sequences and gene expression are associated with key ecological features of shortnose sturgeon including dispersal, natal fidelity, fecundity, and the impact of metapopulation parameters on these traits.

An integrative, systems biology approach that identifies and sustains ecological processes and evolutionary lineages is needed to manage and conserve the biodiversity present in shortnose sturgeon. Inherent in such an approach is the identification and characterization of associated migration, colonization, and extinction processes among populations of this species (Avise 2004). The geographic ranges of most species are much larger than the typical dispersal distances of individuals (or gametes). This creates an opportunity for the generation and maintenance of extensive genetic differences among geographic populations in spite of migration. The degree to which local populations are physically separated from one another partly determines rates of gene flow and/or recolonization among populations. The history of populations may also influence the maintenance and distribution of genetic diversity in addition to ongoing demographic and ecological factors. Long periods of geographic isolation or recent colonization have lasting effects on the pattern of the spatial apportionment of genetic variation and must be considered as primary factors determining genetic patterns. Separating the effects of history and current demographic factors that determine patterns of genetic diversity remains challenging, but central to the identification and study of intraspecific differentiation.

Population Structure of Shortnose Sturgeon

The 1998 Final Recovery Plan for Shortnose Sturgeon recommended that 19 separate river populations of shortnose sturgeon be managed as DPSs (NMFS 1998). This recommendation was based on the available life history information for shortnose sturgeon at that time: populations were believed to be substantially reproductively isolated. Tagging results and telemetry studies indicated few recaptures of tagged shortnose surgeon in adjacent rivers (NMFS 1998). Notably, empirical data on the genetic discreteness (i.e., reproductive isolation) of populations was lacking (NMFS 1998).

Biogeographers have long suggested the existence of two distinct groupings of shortnose sturgeon based on the significant geographic gap in their distribution. No reproducing populations of shortnose sturgeon are known to occur between Chesapeake Bay and the North Carolina/South Carolina state boundary, a distance of about 400 km.

Genetic tools can now provide data for the SNS SRT to characterize genetic differentiation and estimates of gene flow; a quantitative measure by which to determine the number of populations into which shortnose sturgeon can be discerned along with the reproductive independence of each unit. Both haplotype and genotype frequencies and genetic distance estimates between populations indicate population structure for shortnose sturgeon within their geographic range (Grunwald et al. 2002 and 2007; Wirgin et al. 2002; Waldman et al. 2002; Walsh et al. 2001; Wirgin et al. 2009, King et al. 2013). Regional population clusters some of which may also function as metapopulations have been identified.

The following sections describe the population structure of shortnose sturgeon as informed by conemporary genetic analyses (Wirgin et al. 2009, King et al. 2013) as well as straying and behavioral information. Genetics and straying data indicate that some groups of riverine populations of shortnose sturgeon function as metapopulations and others function as independent populations.

Behavioral Information

Parker (2007) demonstrated differences in the innate dispersal patterns in early life stages of shortnose sturgeon from the Connecticut River versus those of Savannah River origin. This research suggested that shortnose sturgeon are likely behaviorally adapted to unique features of their watershed. Similar differences have been noted for other sturgeon species including lake sturgeon (Wolf and Menominee rivers), green sturgeon (Sacramento and Kootenai rivers), and Atlantic/Gulf sturgeon populations (Hudson and Suwannee rivers).

Other differences in shortnose sturgeon life history have been confirmed on at least a regional basis. For example, growth occurs more rapidly in southern rivers: however; sturgeon in the northern rivers attain a larger maximum size and live longer. Differences in growth, larval dispersal patterns, and maturation do not describe the population structure; however, this information does indicate that there are regional differences in life history traits.

Coastal Movements

As described earlier, shortnose sturgeon range from the Saint John River, New Brunswick, Canada, to the St. Johns River, FL (see Fig 1.). Many of the river systems within the range are separated by considerable distances; others are geographically close and sometimes share a river mouth or estuary. As mentioned earlier, tagging data indicates shortnose sturgeon make coastal migrations to adjacent rivers and beyond. However, there appears to be a limit to the distance that individuals will travel.

No tagging and tracking data are available from the St. John River in Canada. Comparitively, Atlantic sturgeon do migrate between the Saint John River, New Brunswick and rivers in Maine. As shortnose sturgeon are known to move to the Merrrimack River and rivers in Maine, the SNS SRT believe it is possible that shortnose sturgeon do move between the Saint John and rivers in Maine.

Mixing among Maine rivers does occur as indicated by the University of Maine (UMaine) tagging and tracking data. UMaine researchers noted ten adult shortnose sturgeon originally tagged in the Penobscot River in 2007 moved more than 150 km to the Kennebec River complex. Some individuals did return to the Penobscot River; these individuals represented approximately 40% of actively moving acoustically tagged shortnose sturgeon (Fernandes 2008 and 2010). Two shortnose sturgeon were PIT tagged in the Kennebec River (1998 and 1999) were later recaptured in the Penobscot in 2008 (Fernandes 2008 and 2010). UMaine researchers have since detected acoustically tagged fish in the smaller rivers between the Kennebec River complex and the Penobscot (Zydlewski et al. 2011). A shortnose sturgeon of unknown origin was caught in the mouth of the Saco River in June 2009 (J. Sulikowski, U. of New England, pers. comm.

2009) and another sturgeon (reported as a shortnose) was counted in an electrofishing survey in the Presumpscot River in 2006 (MBI 2009). Most recently a shortnose sturgeon was captured in the Merrimack River in fall 2009 that was originally tagged in the Penobscot, River, ME, and in the spring of 2010 shortnose tagged in the Merrimack were detected in the Kennbec River (M. Kieffer, USGS, pers. comm. 2010). No coastal migrations have been documented between the Merrrimack River and rivers further south, and the rivers in Maine and rivers south of the Merrimack. Within Conneticut, shortnose sturgeon have been tagged in the Connecticut have been later recaptured in the Housatonic River (Savoy 2004). Genetic analysis of this individual showed that it was more similar to the Hudson River population than to the Connecticut River population, indicating that it was likely spawned in the Hudson River, migrated to the Connecticut River where it was first captured and PIT-tagged, then moved to the Housatonic where it was recaptured. Three adults originally tagged in the Hudson River, NY have also been later encountered in the Conneticut River (Savoy 2004).

Movement of fish tagged in the Delaware River to the Chesapeake Bay via the C and D Canal has not been documented (H. Brundage, ERC, pers. comm. 2008). However, individuals tagged in the Chesapeake Bay have been later found in both the C&D Canal and in the Delaware River. Welsh et al (2002) captured and tagged 13 shortnose sturgeon in the Chesapeake Bay and 26 in the Delaware River: a Chesapeake Bay individual was subsequently detected in both the C&D Canal and the Delaware River, and 2 other individuals were detected in the C&D Canal. Lastly, one individual tagged in Chesapeake Bay was later detected in the Delaware River, but never in the C&D Canal perhaps due to equipment failure (Welsh et al. 2002). The origin of these fish is not known and it is uncertain if a reproducing population exists in Chesapeake Bay (T. King et al. 2013).

Hatchery-reared shortnose sturgeon were stocked into the Savannah River between 1985-1992; details are provided in this section as well as the River Summaries section that discusess the Savananah River. Few of the shortnose sturgeon released were tagged and fewer retained their tags. Tagged shortnose sturgeon stocked and released into the Savannah River have been captured in rivers adjacent to the Savannah in both SC and GA. Beginning in 1995, shortnose stocked in the Savannah River were found in the Ogeechee River, GA and were found to comprise 7.4% of the entire adult population between 1997 and 2000 (Smith et al. 2002a). Likewise 10.6% of the adults captured in the Edisto River, SC between 1995 and 2000 were identifiable as fish stocked into the Savannah River (Smith et al. 2002a). Given that only about 19% of the shortnose sturgeon stocked into the Savannah River were tagged coupled with low tag retention, it is likely that the stocked fish comprised a much larger part of these riverine populations. Shortnose sturgeon bearing tags indicating they were stocked into the Savannah River have also been detected in the Cooper River, SC (M. Collins, SCDNR, pers. comm. 2008) and the Winyah Bay System (about 300 km to the north).

Inter-riverine movement of wild tagged shortnose sturgeon between Santee River, SC and nearby Winyah Bay has occurred (M. Collins, SC DNR, pers. comm. 2008); the mouths of these rivers are geographically proximal (Table 1). Movement of shortnose sturgeon between the Altamaha and Ogeechee Rivers, located about 97 km apart, has been attributed to fish stocked in the Savannah River in the mid 1990's. Recent captures of young shortnose sturgeon indicates that movement between these rivers may be a natural phenomenon (J. Fleming, GADNR, pers. comm. 2008), or the result of progeny from individuals stocked into the Savannah River.

Table 1. Tag recapture information indicating river where shortnose sturgeon were tagged (left column) and then later recaptured (columns across). Yellow highlighting indicates known movement of wild fish; a number within indicates total number of recaptures to date, lack of number indicates movement but unknown total number. Hatched boxes indicate recapture of shortnose sturgeon stocked into the Savannah River 1985-1992 (n= 97,483) and later recaptured. The approximate distance between the rivers (mouth to mouth) of mark and recapture is provided in kilometers.

River where originally tagged	River where capture occured	Penobscot	Kennebec Complex	Piscataqua	Merrimack	Connecticut	Housatonic	Hudson	Delaware	Chesapeake	NC Rivers	Winyah Bay Complex	Santee - Cooper	ACE Basin	Savannah	Ogeechee	Altamaha	Satilla	Approximate distance between river mouths (km)
Penobscot			10		1														150
Kennebec Complex	—	2																	150
Piscataqua																			
Merrimack																			
Connecticut	—						1												50
Housatonic	—																		
Hudson	—					3													140
Delaware	—																		
Chesapeake									4										via C&D canal
NC Rivers																			
Winyah Bay Compl.													(yellow)	(yellow)					13 (S); 98 (C)
Santee - Cooper												(yellow)							
ACE Basin	—																		
Savannah								(yellow)				(hatched)	(yellow, hatched)	(yellow, hatched)	(hatched)	(hatched)			225 (S-C); 105 (ACE)
Ogeechee																			
Altamaha																~5			97
Satilla																			

These tagging data provide information on the physical movements of shortnose sturgeon. Generally this movement seems to be limited by geographic distance between river mouths; there is greater movement between geographically proximate rivers; movement between these larger groups of rivers at greater geographic distance rarely occurs or has yet to be documented. For example, data indicate there is considerable movement among the rivers in Maine. Movement between the Connecticut, Housatonic, and Hudson rivers has been documented as well as movement between the Chesapeake Bay and Delaware River. Fish stocked in the Savannah River have been located in adjacent rivers and movment of wild fish has occurred between the Santee River and Winyah Bay among others.

The general pattern of the physical movements of shortnose sturgeon as indicated by tag and recapture data seems to indicate movement between groups of rivers proximal to each other; this pattern is repeated across the geographic range of the shortnose sturgeon. However, these physical movements do not provide any information if the movement is effective (i.e., if gene exchange is occurring). The SNS SRT then utilized information gained by genetic analysis in order to determine whether this physical movement has led to gene exchange between riverine populations.

Genetic Analyses

Mitochondrial DNA Analyses

All published information on the genetic population structure of shortnose sturgeon has been restricted to the analysis of DNA sequence variation detected in the maternally inherited mitochondrial (mt) genome presumably due to the difficult nature of interpreting allelic data from the hexaploid nuclear genome (Waldman et al. 2008). This research has focused on a moderately polymorphic 440 base pair segment of the mtDNA control region (Fig. 2). These findings are well documented in the peer-reviewed literature (Walsh et al. 2001, Grunwald et al. 2002, Quattro et al. 2002, Waldman et al. 2002, and Wirgin et al. 2005), and are highly consistent both among studies and between researchers. Results from the most thorough survey to date have only recently become available but are consistent with previous findings (Wirgin et al. unpubl. manuscript).

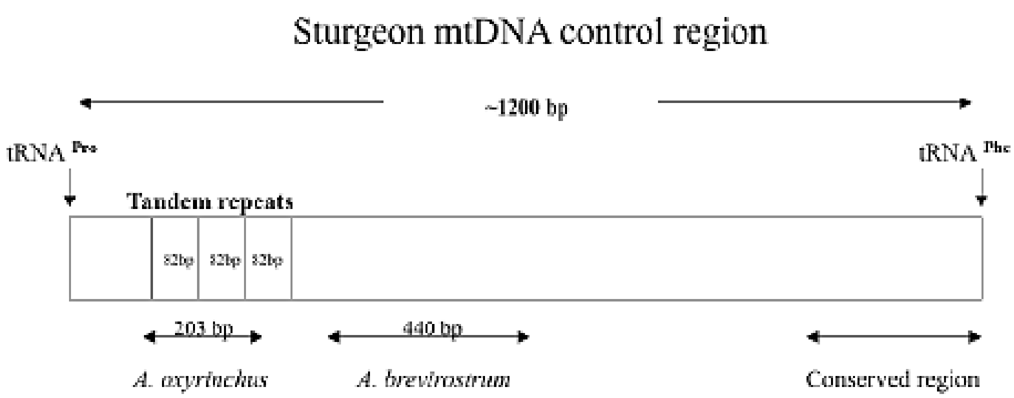


Figure 2. Diagram depicting the polymorphic segment of the mitochondrial DNA control region sequenced for identification of population and phylogeographic structure in shortnose sturgeon. Image taken from Waldman et al. 2002.

Inspection of the available haplotypic data from the mtDNA control region sequences revealed several consistent patterns:

1. relatively modest to high degree of haplotype diversity (Table 2);

2. distinct clustering of haplotypes into three regional groupings (northeast, mid-Atlantic, southeast (Table 3);

3. statistically significant population structuring as measured by haplotype frequency differences (Table 4) and pair-wise estimates of genetic differentiation (F_{ST}) and female mediated gene flow estimates (Table 5);

4. populations inhabiting rivers and embayments that are geographically proximal appear to be closely related (e.g., northeast - Penobscot, Kennebec, Androscoggin rivers; mid-Atlantic – Delaware, Chesapeake Bay; and southeastern rivers) (Figs. 3 and 5);

5. geographically isolated river systems possess populations that tend to exhibit greater levels of differentiation both within and between regions (Figs. 3 and 5);

6. statistically significant isolation-by-distance pattern of genetic variation (Fig. 6); and

7. a shallow gene genealogy (gene tree) for the mtDNA control region (Figs. 4 and 5).

Wirgin et al. (2009) clearly demonstrated the moderate to high levels of genetic diversity and differentiation observed across the species range. The regional partitioning of the matrilineal genome documented represents an impressive amount of differentiation as no haplotype was shared between shortnose sturgeon inhabiting the northeast (Kennebec, Androscoggin, and Penobscot rivers) and southeast (all rivers south of the VA/NC border) river systems and 62% (24 of 59) of the observed haplotypes were unique to one of these regions (see Table 1). Wirgin et al. (2009) also demonstrated differentiation within the mid-Atlantic region (Connecticut, Hudson, and Delaware rivers and the Chesapeake Bay proper). Four haplotypes were found to only occur in Hudson River sturgeon and two were unique to the Delaware River/Chesapeake Bay. Of the nine remaining haplotypes, three were unique to the mid-Atlantic region, and the remainders were distributed between the northeast and mid-Atlantic regions or the mid-Atlantic and the southeast regions. The limited sharing of haplotypes and the high number of private haplotypes is indicative of a regional pattern of high female homing fidelity, and no or limited gene flow among the regional groupings of populations. Wirgin et al. reported that female-mediated gene flow was greater among southeastern rivers than among northeastern and mid-Atlantic regions. This female-mediated gene flow analysis is based on genetic differentiation (Fst values) and coalescent-based approach where one looks backward in time to trace gene copies (alleles) back from offspring to parents, to grandparents, and eventually to single most recent ancestor (Allendorf and Luikart 2007). These authors report a high degree of gene flow among the rivers in Maine and between the Delaware River and Chesapeake Bay proper. Wirgin et al. (2009) also reports appreciable genetic differentiation between the fish in the Saint John River, New Brunswick, Canada, and the rivers in Maine; however the degree of genetic differentiation is shallow. The SNS SRT felt that the reason for this low level of differentiation is that the northeastern populations are relatively young in a geologic sense due to recent glaciations compared to more southerly distributed populations.

Wirgin et al. (2009) and Quattro et al. 2002 either explicitly or implicitly indicate that glaciation and deglaciation in the Pleistocene Era was likely the most significant factor in shaping the phylogeographic pattern (assessment of correspondence between phylogeny and geography) (Avise 2000) of mtDNA diversity and population structure of shortnose sturgeon. The glaciated region of the current shortnose sturgeon range extended south to the Hudson River. There is a high prevalence of haplotypes restricted to portions north and south of this region and relatively few are shared; this represents a historical subdivision that is tied to an important geological phenomenon that reflects historical isolation.

Analyses of haplotype frequencies at the level of individual rivers showed significant differences among nearly all systems in which reproduction is known to occur. Wirgin et al. (2009) concluded that although higher level genetic relationships exist (e.g., northeast vs. mid-Atlantic; northeast vs. southeast; mid-Atlantic vs. southeast; and other mid-Atlantic regional subdivisions), shortnose sturgeon appear to function as independent riverine populations to a certain extent, and that relatively low female-mediated gene flow exists between the majority of populations. Effective dispersal between drainages within region has apparently been sufficient to prevent deep divergence within this species over evolutionary time scales.

Table 2. Locations where samples were collected, number of specimens analyzed, number of mtDNA haplotypes detected, haplotype diversity index, and mean number of pairwise differences within collections of shortnose sturgeon (*Acipenser brevirostrum*).

River	#Specimens	#Haplotypes	Haplotype diversity	Mean # pairwise differences
Saint John	24	7	0.7500	1.8478
Penobscot	44	8	0.8531	4.6395
Kennebec	54	8	0.7806	4.5472
Androscoggin	48	8	0.8121	4.5816
Connecticut	46	4	0.6599	3.1092
Hudson	56	10	0.7779	4.5909
Delaware	57	8	0.6717	2.7832
Chesapeake	39	6	0.7193	3.1012
Cape Fear	5	5	1.0000	3.8000
Winyah	46	13	0.8531	3.0329
Santee	4	2	0.5000	3.0000
Marion	41	5	0.6720	2.5317
Cooper	62	6	0.7832	3.0994
Savannah	25	7	0.8000	2.1100
Ogeechee	53	11	0.8570	3.1858
Altamaha	69	10	0.8615	3.2796

Table 3. Frequencies of mtDNA control region haplotypes in shortnose sturgeon (*Acipenser brevirostrum*) collections analyzed in the most extensive survey of sequence variation to date (Wirgin et al. 2009).

Haplotype	Saint John	Penobscot	Kennebec	Androscoc	Connect	Hudson	Delaware	Chesapea	CapeFear	Winyah	Santee	Marion	Cooper	Savan	Ogeechee	Altamaha	Total
A						1	30	19									50
B					19	1	11	7									38
C							8	4	1	15	1	3	13	3	14	8	70
D							1										1
E							1	4									5
F						22	1	2									25
G									1					6	2	2	11
H										1		5	4		1	15	26
I		3	2	3													8
J						1											1
K	1																1
L	1	7	5	6		12	4	3									38
M						8	1		1	4				1	5	14	34
N										1				1	5	2	9
O										4		12	10	4	9	6	45
P		12	21	15	18												66
Q									1	3	3	20	20		3	11	61
R										7			14	9	10	8	48
S	10	3	1	2													16
T	1	6	8														15
U	1				8	6											15
V						2											2
W															1	2	3
X	3	5	11	7													26
Y						2											2
Z	7	7	5	12	1												32
AA												1	1				2
BB									1							1	2
CC		1		1													2
DD				2													2
EE										5					1		6
FF										1							1
GG										1							1
HH										1							1
II										2							2
JJ			1														1
M/R														1			1
KK										1					2		3
LL						1											1
N	24	44	54	48	46	56	57	39	5	46	4	41	62	25	53	69	673

Table 4. Chi-square tests for statistical significance of heterogeneity of haplotype frequencies of mtDNA control region haplotypes among shortnose sturgeon (*Acipenser brevirostrum*) collections (uncorrected p values within parentheses) surveyed by Wirgin et al. (2009).

	Penob	Kenn	Andro	Conn	Hud	Delaw	Chesap	Winyah	Marion	Cooper	Savan	Ogee	Altama
St John	26.77 (0.0004)	40.89 (0.0000)	31.30 (0.0000)	62.17 (0.0000)	71.52 (0.0000)	77.16 (0.0000)	59.82 (0.0000)	70.00 (0.0000)	65.00 (0.0000)	86.00 (0.0000)	49.00 (0.0000)	77.00 (0.0000)	93.00 (0.0000)
Penob		7.92 (0.4524)	10.10 (0.2571)	90.00 (0.0000)	82.06 (0.0000)	90.65 (0.0000)	35.60 (0.0000)	90.00 (0.0000)	85.00 (0.0000)	106.00 (0.0000)	32.96 (0.0000)	97.00 (0.0000)	113.00 (0.0000)
Kenn			17.10 (0.0240)	57.63 (0.0000)	95.88 (0.0000)	102.10 (0.0000)	85.30 (0.0000)	100.00 (0.0000)	95.00 (0.0000)	116.00 (0.0000)	79.00 (0.0000)	107.00 (0.0000)	123.00 (0.0000)
Andro				57.56 (0.0000)	87.90 (0.0000)	95.33 (0.0000)	78.91 (0.0000)	94.00 (0.0000)	85.28 (0.0000)	110.00 (0.0000)	73.00 (0.0000)	101.00 (0.0000)	117.00 (0.0000)
Conn					84.32 (0.0000)	74.81 (0.0000)	64.40 (0.0000)	92.00 (0.0000)	87.00 (0.0000)	108.00 (0.0000)	71.00 (0.0000)	99.00 (0.0000)	115.00 (0.0000)
Hud						86.08 (0.0000)	69.96 (0.0000)	91.64 (0.0000)	97.00 (0.0000)	118.00 (0.0000)	76.83 (0.0000)	95.69 (0.0000)	104.41 (0.0000)
Delaw							5.80 (0.6039)	78.65 (0.0000)	89.03 (0.0000)	99.16 (0.0000)	69.35 (0.0000)	86.27 (0.0000)	106.09 (0.0000)
Chesap								72.28 (0.0000)	73.14 (0.0000)	88.10 (0.0000)	56.80 (0.0000)	79.26 (0.0000)	96.44 (0.0000)
Winyah									51.11 (0.0000)	34.81 (0.0001)	28.32 (0.0024)	15.85 (0.2992)	38.24 (0.0000)
Marion										16.97 (0.0023)	46.88 (0.0000)	49.05 (0.0000)	37.17 (0.0000)
Cooper											34.39 (0.0001)	31.61 (0.0000)	34.53 (0.0000)
Savan												17.65 (0.0575)	32.96 (0.0000)
Ogee													27.54 (0.0008)

Table 5. Pairwise *F*st values are illustrated above the diagonal. Female mediated gene flow estimates, Nemf = ((1/*F*st-1)/2) are illustrated below the diagonal. Number signs indicate values of infinity. Table taken from Wirgin et al. (2009).

Locale	St John	Penob	Kenn	Andro	Conn	Hudson	Delaw	Chesap	Winyah	Marion	Cooper	Savan	Ogee	Altama
St John		0.171	.250	.206	.331	.190	.424	.389	.256	.534	.389	.489	.318	.302
Penob	2.431		-.0002	-.0007	.062	.190	.249	.217	.332	.500	.429	.435	.369	.373
Kenn	1.502	####		.003	.061	.242	.274	.246	.385	.533	.471	.476	.418	.423
Andro	1.926	####	####		.062	.211	.257	.226	.362	.517	.451	.458	.396	.400
Conn	1.012	7.537	7.699	7.587		.252	.271	.236	.417	.587	.502	.535	.450	.449
Hud	2.138	2.130	1.569	1.870	1.482		.315	.259	.209	.325	.259	.311	.236	.233
Delaw	.680	1.509	1.323	1.442	1.345	1.089		-.011	.438	.614	.535	.585	.489	.480
Chesap	0.784	1.808	1.529	1.711	1.616	1.431	####		.410	.586	.506	.564	.463	.453
Winyah	1.450	1.007	.798	.882	.700	1.895	.642	.718		.239	.089	.156	.029	.029
Marion	.436	.499	.438	.468	.351	1.040	.314	.353	1.591		.054	.292	.197	.148
Cooper	.787	.667	.561	.609	.497	1.429	.435	.489	5.150	8.703		.116	.052	.029
Savan	.523	.649	.551	.591	.435	1.106	.355	.387	2.697	1.210	3.826		.038	.086
Ogee	1.072	.855	.696	.762	.610	1.623	.523	.580	16.489	2.034	9.099	12.801		.014
Altama	1.157	.841	.683	.751	.614	1.647	.542	.604	17.044	2.875	16.765	5.329	35.837	

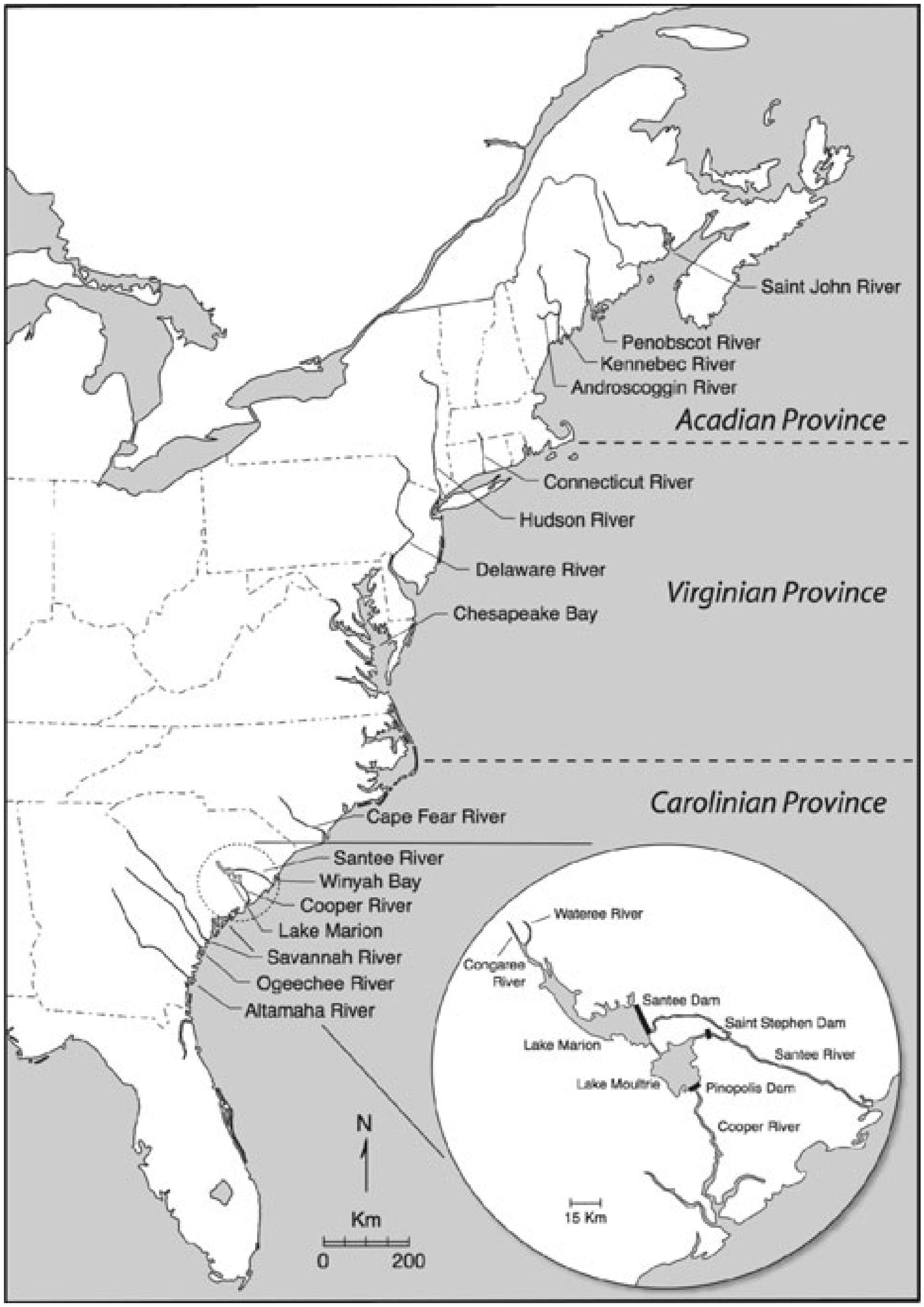


Figure 3. Map of the Atlantic Coast of North America depicting the 14 rivers and estuaries where shortnose sturgeon (*Acipenser brevirostrum*) samples were collected for the most recent and most extensive survey of mtDNA genetic variation (Wirgin et al. 2009).

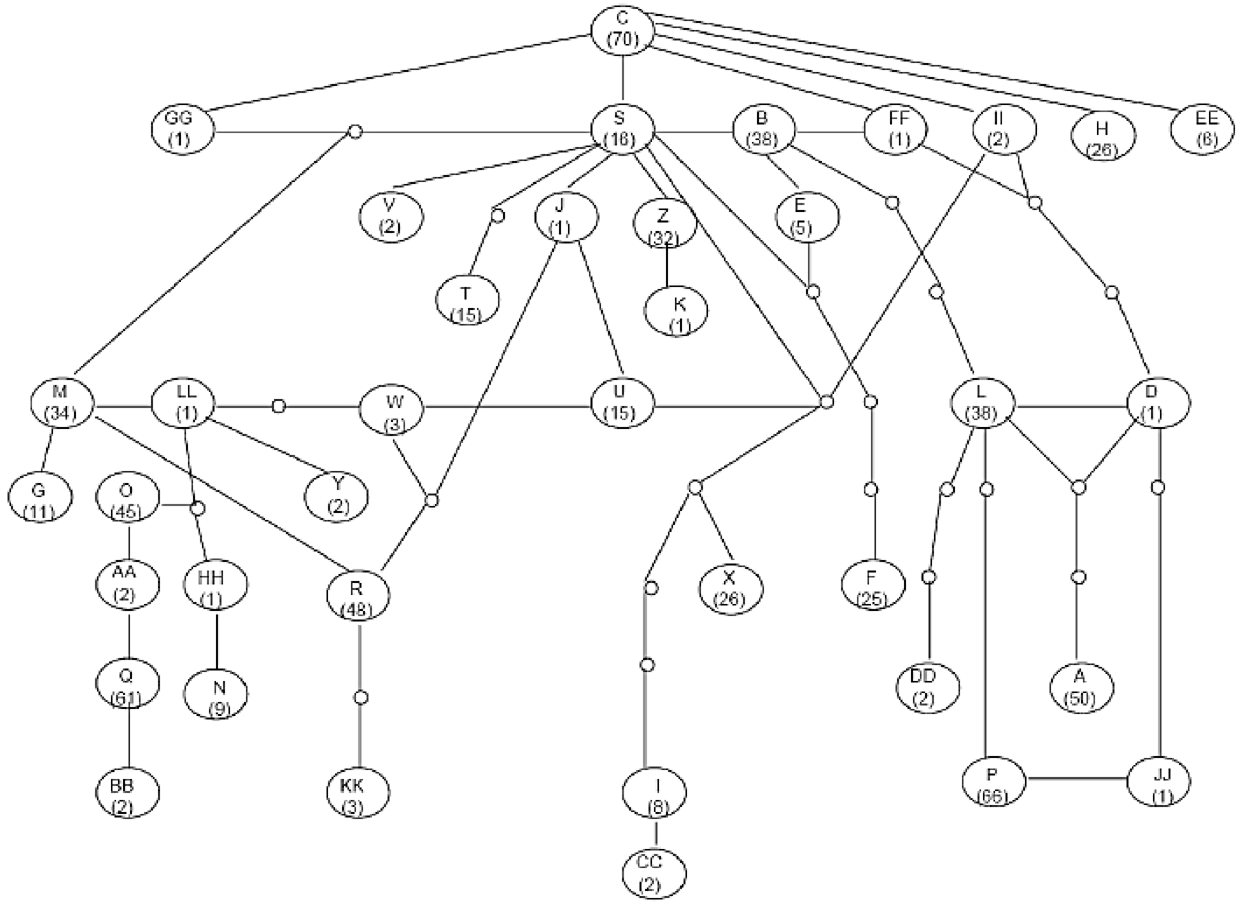


Figure 4. Network of mtDNA control region sequence haplotypes of shortnose sturgeon (*Acipenser brevirostrum*) developed using statistical parsimony as implemented in TCS Version 1.3.1 (Clement et al. 2000). Numbers in parentheses indicate the number of individuals with that haplotype. Unmarked circles represent unobserved haplotypes and haplotypes connected by a single line differ by one nucleotide. This image taken from Wirgin et al. (2009).

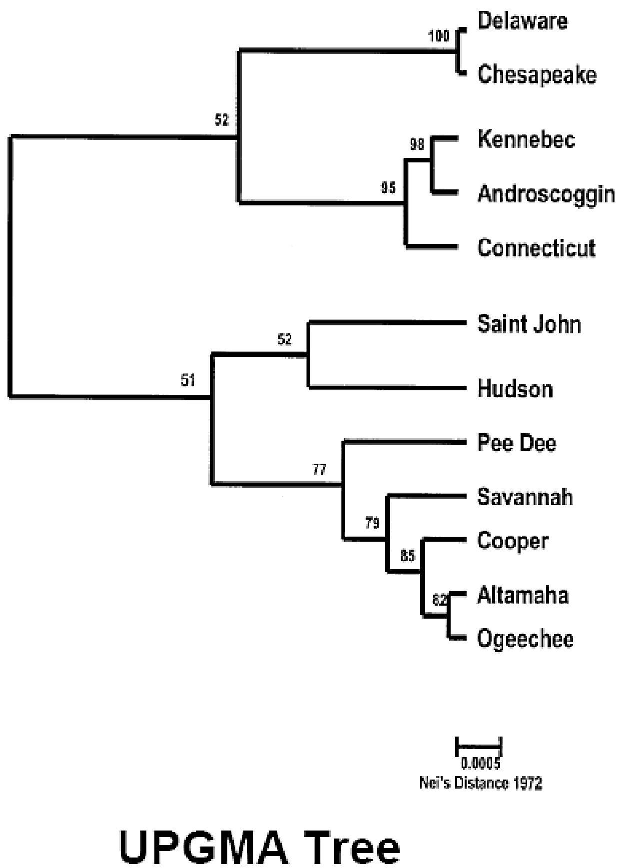


Figure 5. An UPGMA tree of the population genetic distances for the mtDNA control region sequence data from shortnose sturgeon (*Acipenser brevirostrum*) of 12 Atlantic Coast Rivers and estuaries. Bootstrap values are indicated at each node. Taken directly from Wirgin et al. 2005.

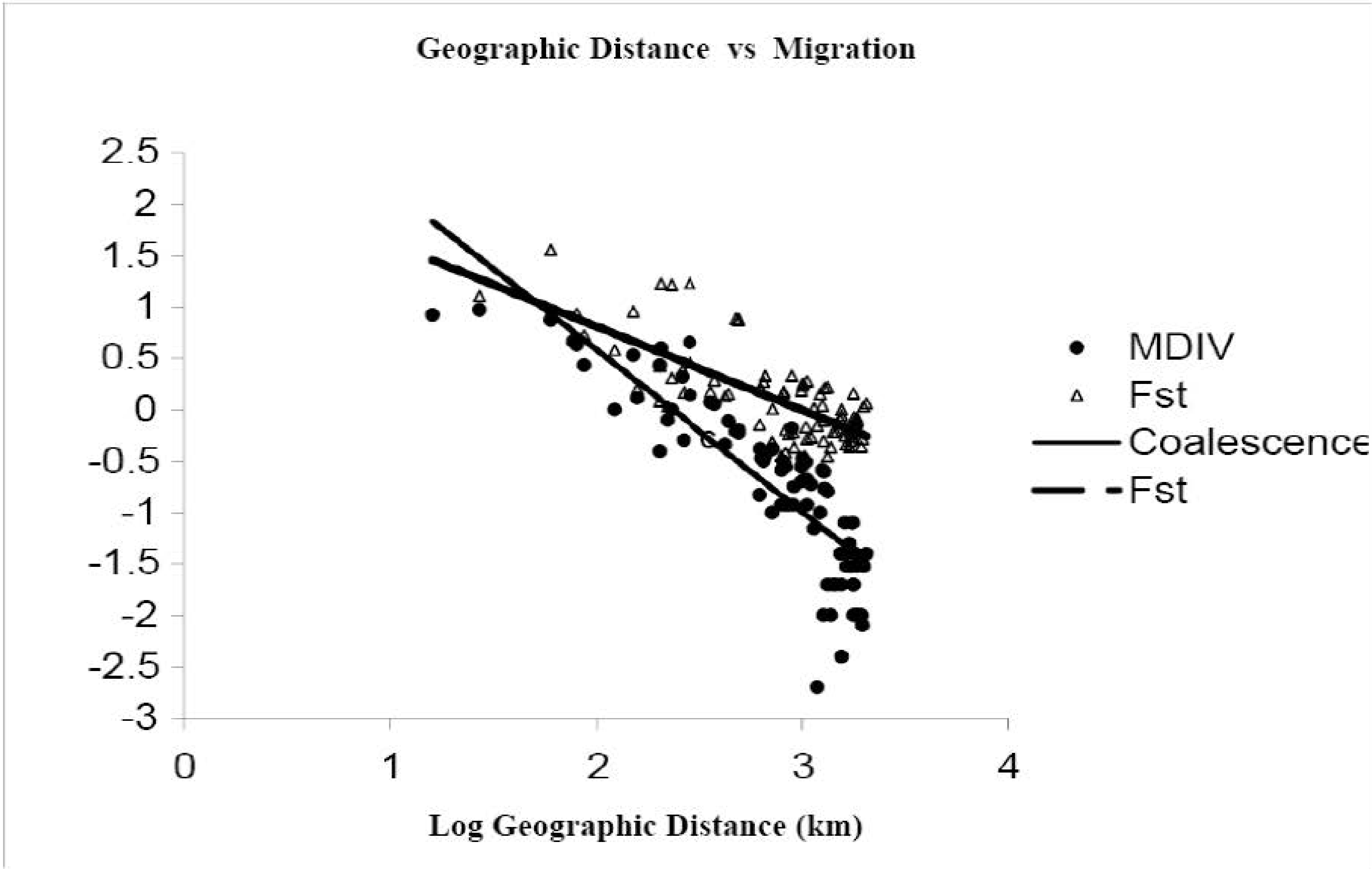


Figure 6. Linear regression of log normalized migration versus geographic distance for both FST and coalescence-based female mediated migration estimates. The open triangles and broken line represent the FST-based estimate. The circles and solid line represent the coalescence-based estimate. For the FST-based estimate b = -.812, t = -10.6, r = .756 and $P < 0.0001$. For the coalescence-based estimate b = -1.57, t = -15.18, r = .731 and $P < 0.0001$.

Summary of Mitochondrial DNA Analyses

Wirgin et al. (2009) indicated that the limited sharing of haplotypes and the high number of private haplotypes is indicative of a regional pattern of high female homing fidelity, and no or limited gene flow among the regional groupings of populations. Based upon higher level associations of mtDNA (less fine scale) and limited by the rivers sampled, 3 regional groupings were identified: 1) Penobscot, Kennebec, and Androscoggin rivers noted as the Gulf of Maine group; 2) Conneticut, Hudson, and Delaware rivers along with Chesapeake Bay noted as the mid-Atlantic group; and 3) Winyah Bay, Santee-Cooper River Complex, Savannah, Ogeechee, and Altamaha rivers noted as the southeast group. Wirgin et al. (2005) identified both 9- and 10-population groupings of shortnose sturgeon differentiated from their nearest neighbors based on mtDNA haplotype frequencies and genetic differences; the 10-group model considered Kennebec and Androscoggin rivers as distinct segments.

Nuclear DNA Analyses

Because sturgeon exhibit polyploidy ranging in a series from 4n-6n times the diploid number, they present significant challenges for investigating the evolutionary processes shaping the nuclear genomes of extant species (Birstein et al. 1997, King et al. 2001, Kim et al. 2005, Fontana et al. 2008). Although it is assumed the extant sturgeon species have been functionally diploid (Blacklidge and Bidwell 1993) for millions of generations, the degree to which the nuclear genome exhibits disomic inheritance is unknown. Shortnose sturgeon has been shown to posses the highest number of chromosomes (sample size ranged between 362 and 372) among all the Acipenseriformes tested (Kim et al. 2005). However, it is still not known whether the species is hexaploid or dodecaploid. Contemporary cytogenetic techniques (including signals from fluorescent *in situ* hybridization) suggest shortnose sturgeon is a hexaploid species (Fontana et al. 2008). While immensely complex, nuclear DNA-based approaches to shortnose sturgeon conservation could identify significant levels of informative genetic variation because certain duplicated loci and repetitive DNA may lack functional constraints, thus allowing rapid accumulation of differentiation in DNA sequences (Wirgin et al. 1997). No phylogeographic or population informative nuclear markers have been identified for shortnose sturgeon (Hett and Ludwig 2005).

To address this research need King et al. (2013) recently developed 96 microsatellite DNA markers for shortnose sturgeon. The inheritance of all 96 markers was first tested among the parents and offspring of three captive families and verified to be polysomic with predictable phenotypic patterns. Next, to identify population and phylogeographic structuring in shortnose sturgeon, King et al. (2013) surveyed 11 microsatellite DNA loci in 561 shortnose sturgeon from 17 geographic collections (Fig. 7). Because of the complex modes of inheritance underlying the putatively hexaploid genome, King et al. (2013) followed the methods of Rodzen and May (2002) and scored each allele (fragment) as its own dominant marker as either present (1) or absent (0) to produce a binary character matrix. Rodzen and May (2002) showed that the utility of this method was validated by: 1) individual alleles within a microsatellite system generally fit the expectation for independent transmission and, 2) a fit with the expected transmission frequency for single copy nuclear markers. A detailed description of the findings in King et al. (2013) is provided below.

King et al. (2013) generated a binary character matrix of 181 alleles (columns) by 561 individuals (rows) (summarized in Table 6). The numbers of alleles with frequencies ≥ 1% observed at the 11 loci ranged from 55 (Cape Fear n=3) to 152 (Hudson n=45). Estimated heterozygosity assuming Hardy-Weinberg equilibrium (wherein allele and genotype frequencies will reach equilibrium, defined by the binomial distribution, in one generation and remain constant in large random mating populations that experience no migration, selection, mutation, or non-random mating) ranged from 10.4% (Cape Fear) to 19.3% (Hudson). A lower estimate of heterozygosity was observed among southeastern populations compared to mid-Atlantic and northeastern populations.

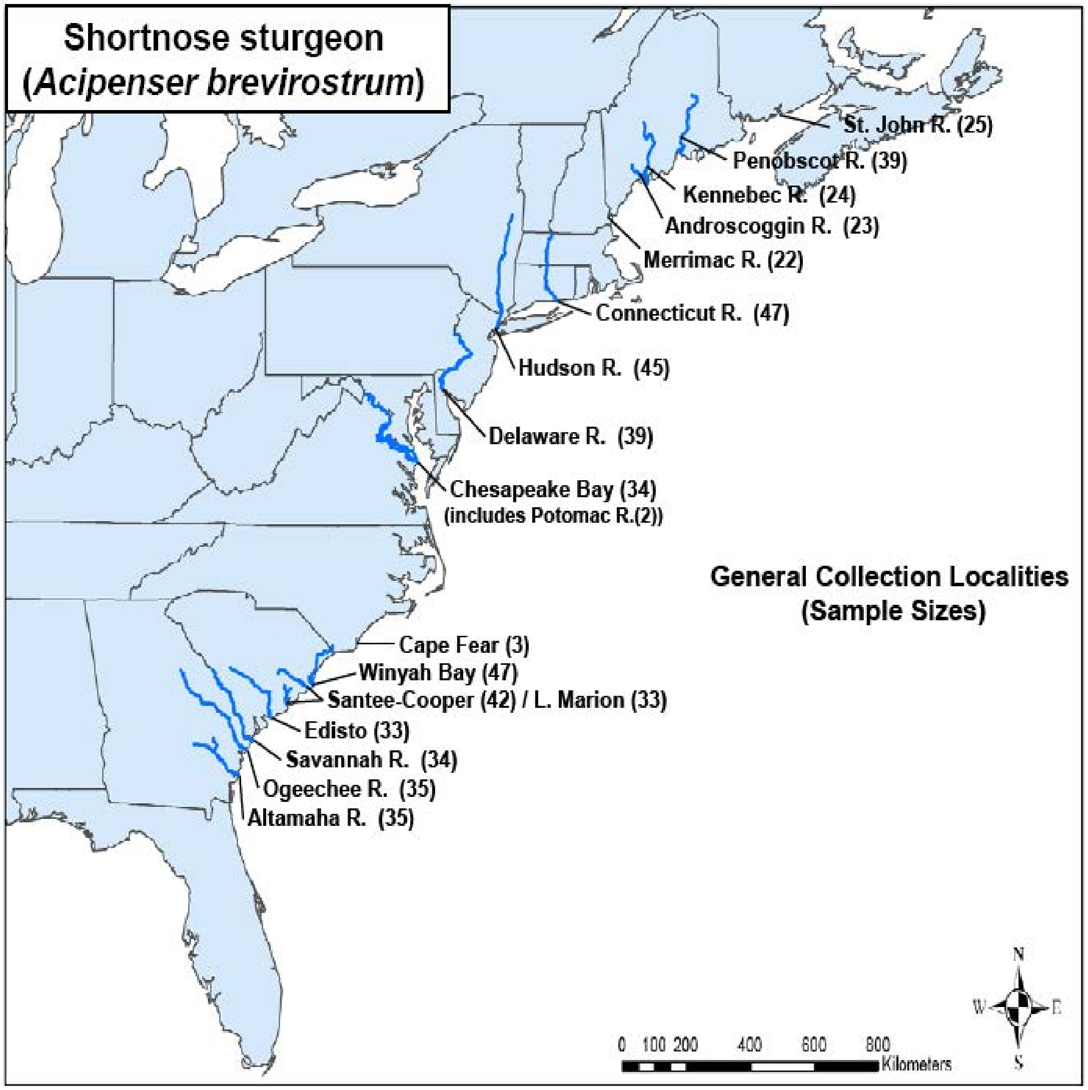


Figure 7. Map of the Atlantic Coast of North America depicting the general location and sample size of 17 river and estuary collections of shortnose sturgeon (*Acipenser brevirostrum*) surveyed at 11 polysomic microsatellite DNA loci (King et al. 2013).

King et al. (2013) then analyzed the binary character matrix for patterns of genetic structure at both the individual and at the population level. At the individual level, a correspondence analysis (CA) was used to ordinate the relationship of each individual to all other individuals (Fig. 8). Three regional groups were indicated among the 17 surveyed river/bay systems: 1) Northeast - including Saint John River, Canada; Penobscot, Kennebec, Androscoggin and Merrimack rivers; 2) Mid-Atlantic including the Connecticut, Hudson, and Delaware rivers, and samples from the Chesapeake Bay proper; and 3) Southeast including the Cape Fear, Winyah Bay, Santee-Cooper Rivers system, Lake Marion, Edisto, Savannah, Ogeechee, and Altamaha rivers. Each of these groupings were further examined.

- The northeastern regional grouping of collections suggested that the Saint John and Merrimack Rivers were differentiated from each other and from the Penobscot, Androscoggin, and Kennebec River collections which exhibited completely overlapping confidence ellipses (Fig. 10). The level of differentiation of the Saint John and Merrimack Rivers from the other collections from the rivers in Maine was not as great as that seen among the mid-Atlantic collections or between the southeastern rivers and all other collections. While the northeast regional grouping does show within grouping differentiation, the differentiation is shallow and should not be subdivided any further.
- The mid-Atlantic collections were then further examined (without the influence of other riverine populations) (Fig. 9) and found that the Delaware River and Chesapeake Bay collections are genetically similar as a large percentage of the two ellipses overlap. This examination also revealed minimal overlap existing among the Connecticut River, Hudson River, and the Delaware River/Chesapeake Bay collections. Based upon this observed differentiation among populations within the regional grouping, the mid-Atlantic can be further subdivided into 3 subclusters: 1) Connecticut River; 2) Hudson River; and 3) Delaware River and Chesapeake Bay.
- The 95% confidence intervals for the southeastern collections are nearly uniformly overlapping suggesting a genetically similar group of riverine populations.

Future analyses may show greater variance among the populations similar to that observed in the mid-Atlantic, which at that time may warrant review of the northeast regional population grouping. King et al. (2013) performed CA at the population level of relatedness that revealed a congruous pattern with that observed with the individual-based analyses (Fig. 11).

A second individual-based analysis designed to identify genetic discontinuity in the binary character matrix using the program STRUCTURE was then conducted by King et al. (2013). These results were consistent with the patterns suggested by the CA and discussed above. The number of inferred clusters (*k*) in the initial (uppermost hierarchical level) analysis was three (clusters [A-C]). These three clusters corresponded to the northern [A], mid-Atlantic [B], and southeastern [C] regional groupings (Fig. 12). Each initial population cluster was subsequently analyzed for within-cluster structure.

- The sequential analysis of the northeastern cluster suggested panmixia among the Penobscot, Androscoggin, and Kennebec Rivers with some degree of differentiation between these collections and the Saint John River to the north and the Merrimack River to the south. Similar to the results of the CA, the observed differentiation between the Maine rivers and the St John and Merrimack rivers was shallow. As with the mtDNA variation, the SRT felt the reason for the "shallowness" of the differentiation is that all of the northeastern populations are relatively young in a geologic sense (due to recent deglaciation) compared to more southerly distributed populations.
- The sequential STRUCTURE analysis of the mid-Atlantic confirmed the results of the CA and also further subdivided the mid-Atlantic cluster into three subclusters identified as the Connecticut River, Hudson River, and the Delaware River/Chesapeake Bay population clusters.

Based upon the CA, and sequential STRUCTURE analysis showing significant genetic differentiation, five relatively well differentiated regional population clusters of shortnose sturgeon occur within the U.S. and the St John in New Brunswick, Canada. The Saint John and Merrimack Rivers, while less differentiated than the mid-Atlantic collections, nonetheless show some signal of genetic structuring. Additional sampling and analysis of the mitochondrial genome is needed for the Merrimack River population. The Merrimack collection consisted of 22 males collected at the same location and sampling event. Thus, additional sampling and future analysis for mtDNA variation is necessary to verify that the northeast population cluster is the appropriate grouping for the Merrimack collection.

To confirm the genetic differentiation revealed by the CA and STRUCTURE, King et al. (2013) then performed a non-parametric analysis of similarity (ANOSIM; Clarke 1993) and to further test the statistical significance of the relationship between populations. Pair-wise Φ_{PT} values (Table 7, below diagonal) and probability values (H_0 = no genetic difference among populations; $\Phi_{PT} = 0$) based on 1000 permutations (above diagonal) revealed that most pair-wise comparisons among collections were statistically significant. Riverine populations in Maine (e.g., Penobscot, Androscoggin, and Kennebec rivers) and selected collections from the southeastern U.S. were found to have similar allelic patterns. Other interesting observations included:

- The greatest Φ_{PT} distances were observed between the northeastern and southeastern collections; the lowest genetic distances were observed between collections from the same cluster (as defined by the correspondence and STRUCTURE analyses). The underlying genetic structure of the Φ_{PT} matrix was illustrated with an unrooted neighbor-joining (N-J) tree (Fig. 14). N-J is a widely used algorithim used to construct dendograms from a distance matrix. The branches of the N-J tree can be different lengths to show relationships between different populations. The patterns observed illustrated high levels of differentiation among and within the five US regional population clusters identified by both the CA and STRUCTURE analyses.
- The genetic differentiation of these 5 regional population clusters was confirmed by high bootstrap support (nonparametric statistical analysis for computing

> confidence intervals); particularly for separation of the three large regional groupings. The genetic similarity observed among the collections from the Penboscot, Androscoggin and Kennebec Rivers and between the Delaware River and Chesapeake Bay collections was also confirmed by the high bootstrap support for these pairings. The latter forming a clade that suggested the closest genetic relationship among the collections surveyed.

Analysis of molecular variance (AMOVA) was then utilized by King et al. (2013) to determine constituencies of evolutionarily significant population groupings as it allows the maximization of genetic differences among groupings and minimization of variation among populations within groupings. Quantitative estimates of hierarchical gene diversity among collections was statistically significant as 16% (P<0.001) of the genetic variation occurred among collections (river/bay populations) and 84% ($P < 0.001$) was due to differentiation within collections. King et al. (2013) also performed a comparison to determine the most appropriate number of and arrangement of populations within population clusters to clarify the population structure among their 17 collections of shortnose sturgeon (Table 9). The best delineation of genetic differentiation resulted in 17% (P<0.001) of the genetic variation occurring among putative population clusters, 3% (P<0.001) occurring among populations within population clusters, and 80% of the genetic variation was due to variation within collections. The best models were based on the five clusters identified by the CA and STRUCTURE analyses with the Saint John and Merrimack Rivers either omitted from the analysis or classified as genetically unique population clusters. All attempts to manipulate the putative southeastern population cluster resulted in a decrease in variation among population cluster components and an increase in the amount of within population variation.

The significant genetic structure observed with other individual- and population-based analyses was confirmed by results of assignment tests performed by King et al. (2013). The average correct assignment to collection of origin (riverine population) was 58.6% and ranged from 0% (Cape Fear River) to 97.8% (Connecticut River) (Table 10). With the exception of the Cape Fear River collection (n=3), assignment to each collection was statistically greater than would be expected by chance (P < 0.05). Assignment tests confirmed the phylogeographic and population genetic structure present within shortnose sturgeon as the three major regions identified by all previous analyses (e.g., northeastern, mid-Atlantic, and southeastern) resulted in greater than 99% correct assignment to regional grouping (Table 11). The differentiation observed among the five northeastern rivers was also observed in the assignment testing as correct assignment rate among pooled Penobscot, Kennebec, and Androscoggin Rivers collections was better than 98% while the Saint John and Merrimack Rivers shortnose sturgeon were correctly assigned to their collection of origin in nearly 77% of comparisons (Table 12). When grouped into two northeast population clusters (i.e., Saint John and GOM (Merrimack, Kennebec, Androscoggin, Penobscot), the assignment to the GOM population cluster was 100%. The five population cluster model identified by the AMOVA analyses, including the GOM population cluster (without the Saint John River), Connecticut River, Hudson River, Delaware River, and the southeastern rivers, resulted in correct assignment to population cluster of 99.1% of comparisons (Table 13).

Population Structure: mtDNA and nDNA

In an assessment of the most complete sets of genetics data, fourteen collections of shortnose sturgeon have been surveyed for patterns in both mtDNA (Wirgin et al. 2009) and nDNA (King et al. 2013) variation. This comparison excludes samples from the Merrimack, Cape Fear, and Edisto Rivers because mtDNA analysis was not completed on samples from those rivers. The mtDNA patterns differ from the nDNA because of the differences in the genomes (one female mediated the other bi-parentally inherited). The other difference can be related to their use of the UPGMA algorithm and the NJ algorithm. All indications are that the variation detected in the mtDNA control region and at 11 polysomic microsatellite DNA markers is highly phylogeographically congruent. Examination of the phenograms used to depict the structure contained within the respective pair-wise distance matrices suggests the presence of the same three major clades representing the northern (Saint John, Penobscot, Kennebec, and Androscoggin Rivers), mid-Atlantic (Connecticut, Hudson, Delaware Rivers and Chesapeake Bay), and southeastern (Winyah Bay, Santee-Cooper, Ogeechee, Altamaha, and Savannah River and Lake Marion) regional groupings (Figures 15a & 15b). Moreover, similar patterns of differentiation were observed in the genomes among the mid-Atlantic populations as the Connecticut River, Hudson River, and Delaware River/Chesapeake Bay populations appear differentiated. Both genomes suggest the presence of at least three regional metapopulations; northeast (i.e., Penobscot, Kennebec, and Androscoggin Rivers), Delaware River and Chesapeake Bay proper, and southeast (Cape Fear, Winyah Bay, Santee-Cooper, Lake Marion, Edisto, Savannah, Ogeechee, and Altamaha Rivers). The identification of existing metapopulation structure in these regions is encouraging as this may help stave off localized extinctions. The degree of congruence between the genetic variation detectable is not only qualitatively similar, but a Mantel analysis comparing the mtDNA F_{ST} values and nDNA $\mathbf{\Phi}_{PT}$ pair-wise distances for 14 Atlantic coast collections of shortnose sturgeon illustrates the strong quantitative relationship (correlation coefficient $r = 0.83$, $P < 0.0001$; Fig. 16) that exists between the genomes. This finding strongly suggests that these marker systems possess similar levels of phylogeographic signal. The geographic structure of these genetic signals seems to indicate that population demography is particularly important to the structure of populations. The loss of a population could be particularly problematic if the likelihood of recolonization is low due to geographic isolation of the cluster.

Table 6. Microsatellite allele (loci) counts and unbiased expected heterozygosity of each locus for 181 alleles surveyed in 561 shortnose sturgeon (*Acipenser brevirostrum*). The analyses were conducted on the binary character matrix.

Population	**Saint John**	**Penboscot**	**Androscoggin**	**Kennebec**	**Merrimack**	**Connecticut**	**Hudson**	**Delaware**	**Chesapeake Bay**	**Cape Fear**	**Winyah Bay**	**Santee-Cooper**	**Lake Marion**	**Edisto**	**Savannah**	**Ogeechee**	**Altamaha**
Sample size (n)	25	39	23	24	22	47	45	39	34	3	47	42	33	33	34	35	35
No. Alleles (loci)	118	131	126	130	105	121	152	134	127	55	119	111	95	112	113	112	107
No. Private Alleles	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0
No. Bands (<=25%)	11	16	13	16	6	12	24	12	11	0	7	3	4	4	5	6	2
Mean UHe	0.179	0.182	0.173	0.173	0.163	0.165	0.193	0.186	0.175	0.104	0.151	0.151	0.137	0.157	0.158	0.152	0.152
SE of Mean UHe	0.014	0.013	0.013	0.013	0.014	0.013	0.013	0.014	0.013	0.015	0.013	0.013	0.013	0.013	0.013	0.013	0.014

No. Alleles = No. of different fragments

No. Private Bands = No. of bands unique to a single population

No. common alleles with frequency <=25%

UHe = Unbiased expected heterozygosity = (2N / (2N-1)) * He

Where for binary data and assuming Hardy-Weinberg Equilibrium, q = (1 - Band Freq.)^0.5 and p = 1 - q.

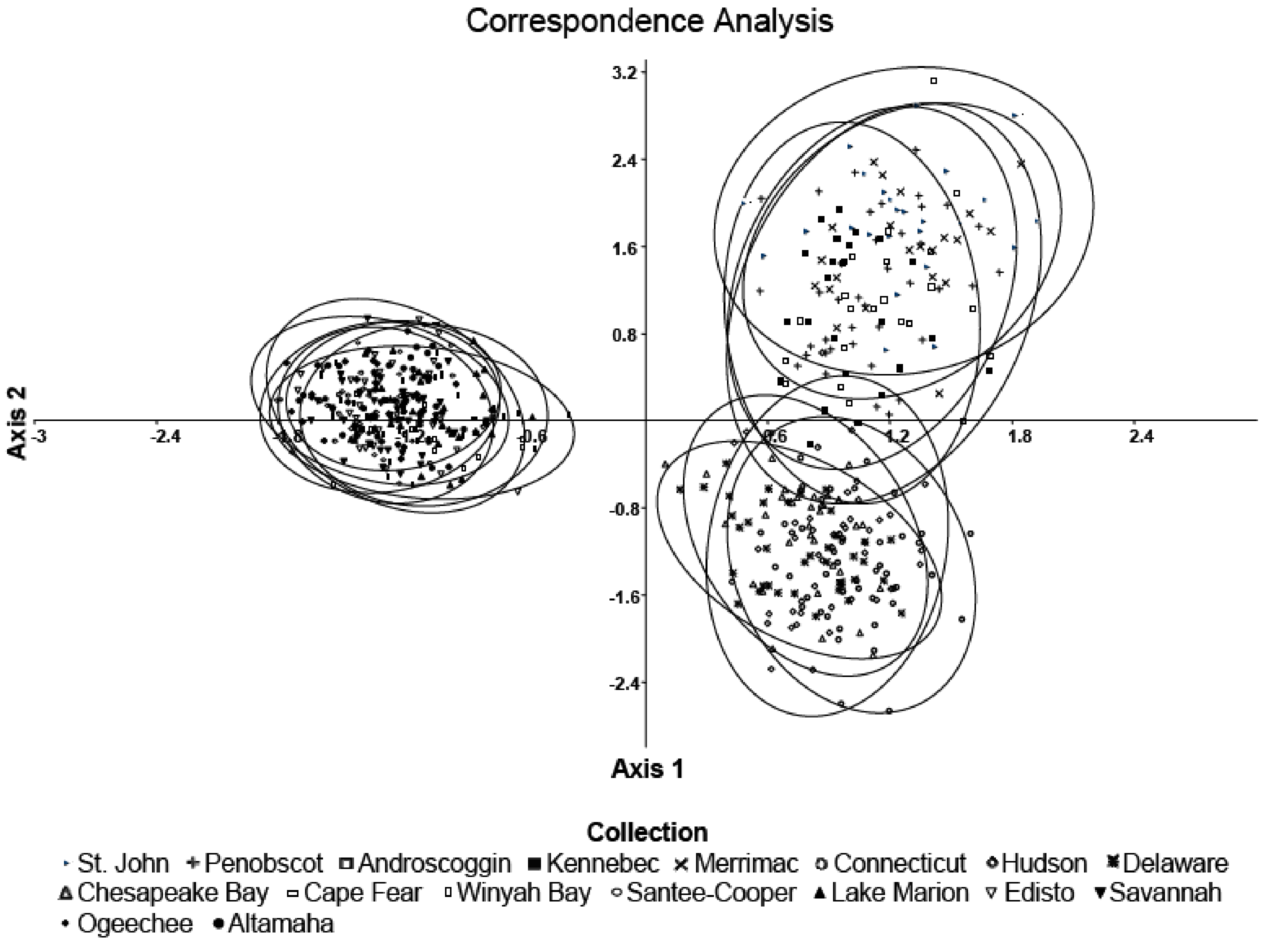


Figure 8. Graphical representation of a correspondence analysis of 561 *Acipenser brevirostrum* collected from 17 rivers and bays along the US Atlantic coast and surveyed at 11 polysomic microsatellite DNA loci. Ellipses are 95% confidence intervals for each collection.

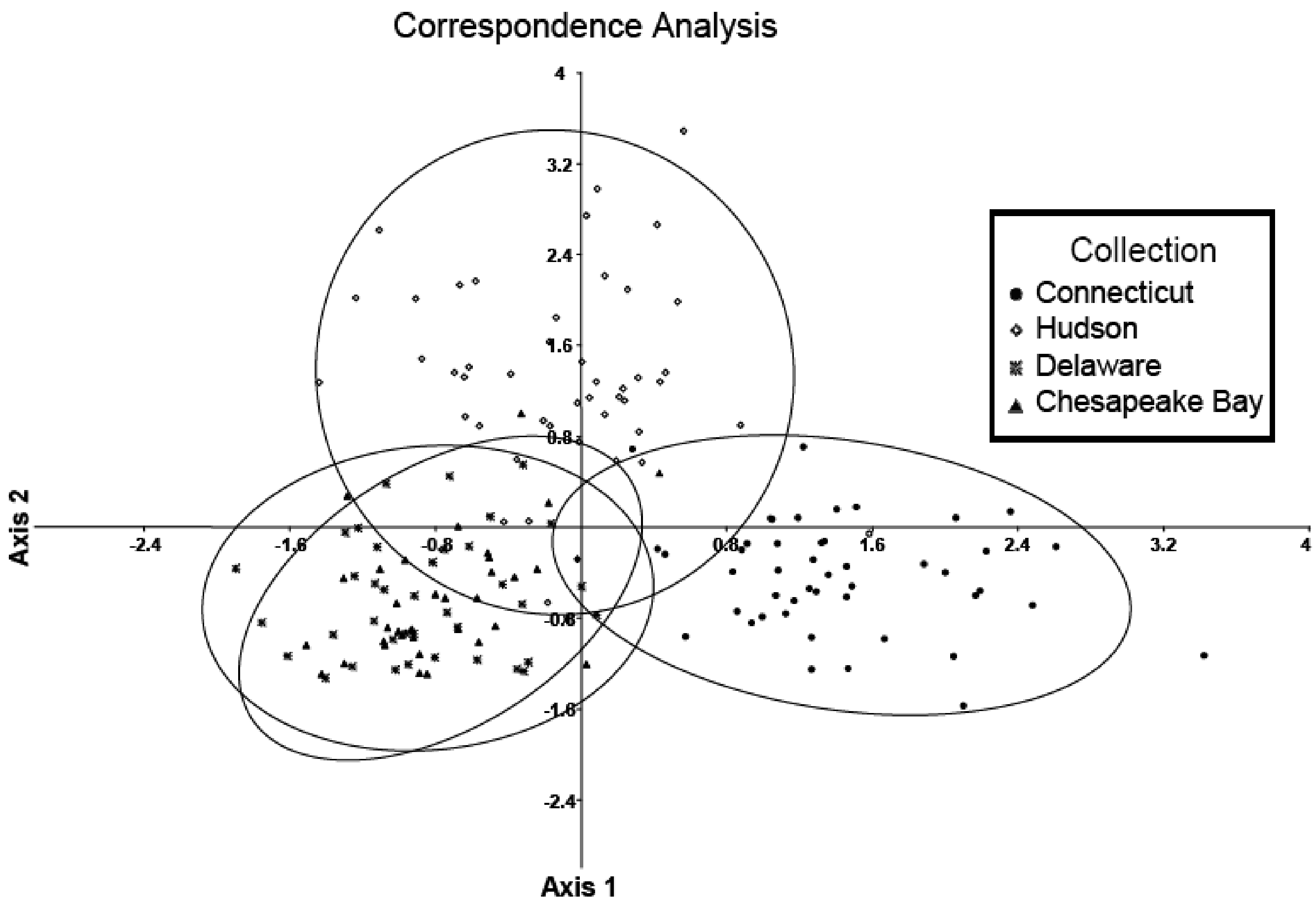


Figure 9. Graphical representation of a correspondence analysis of *Acipenser brevirostrum* collected from four rivers and bays along the US mid-Atlantic coast and surveyed at 11 polysomic microsatellite DNA loci. Ellipses are 95% confidence intervals for each collection.

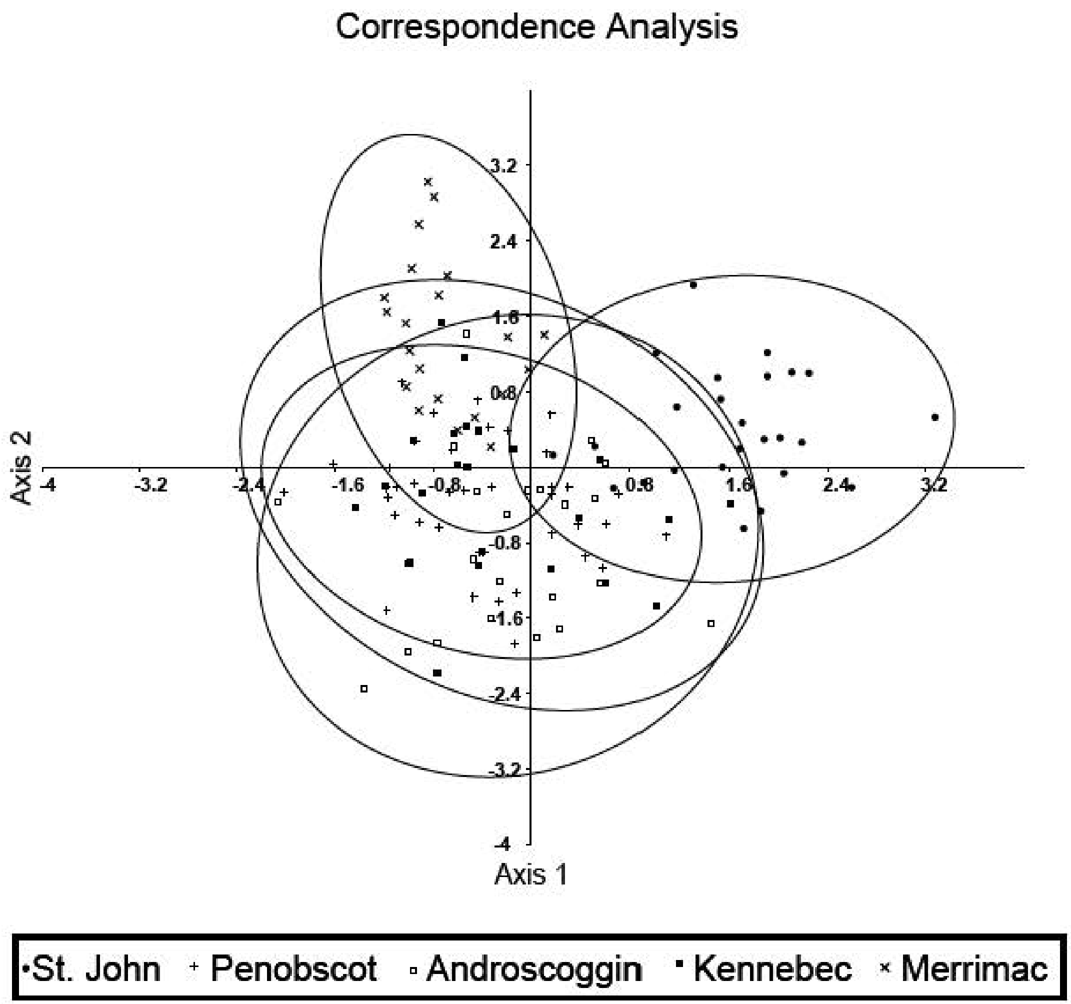


Figure 10. Graphical representation of a correspondence analysis of *Acipenser brevirostrum* collected from five northeastern rivers along the US mid-Atlantic coast and surveyed at 11 polysomic microsatellite DNA loci. Ellipses are 95% confidence intervals for each collection.

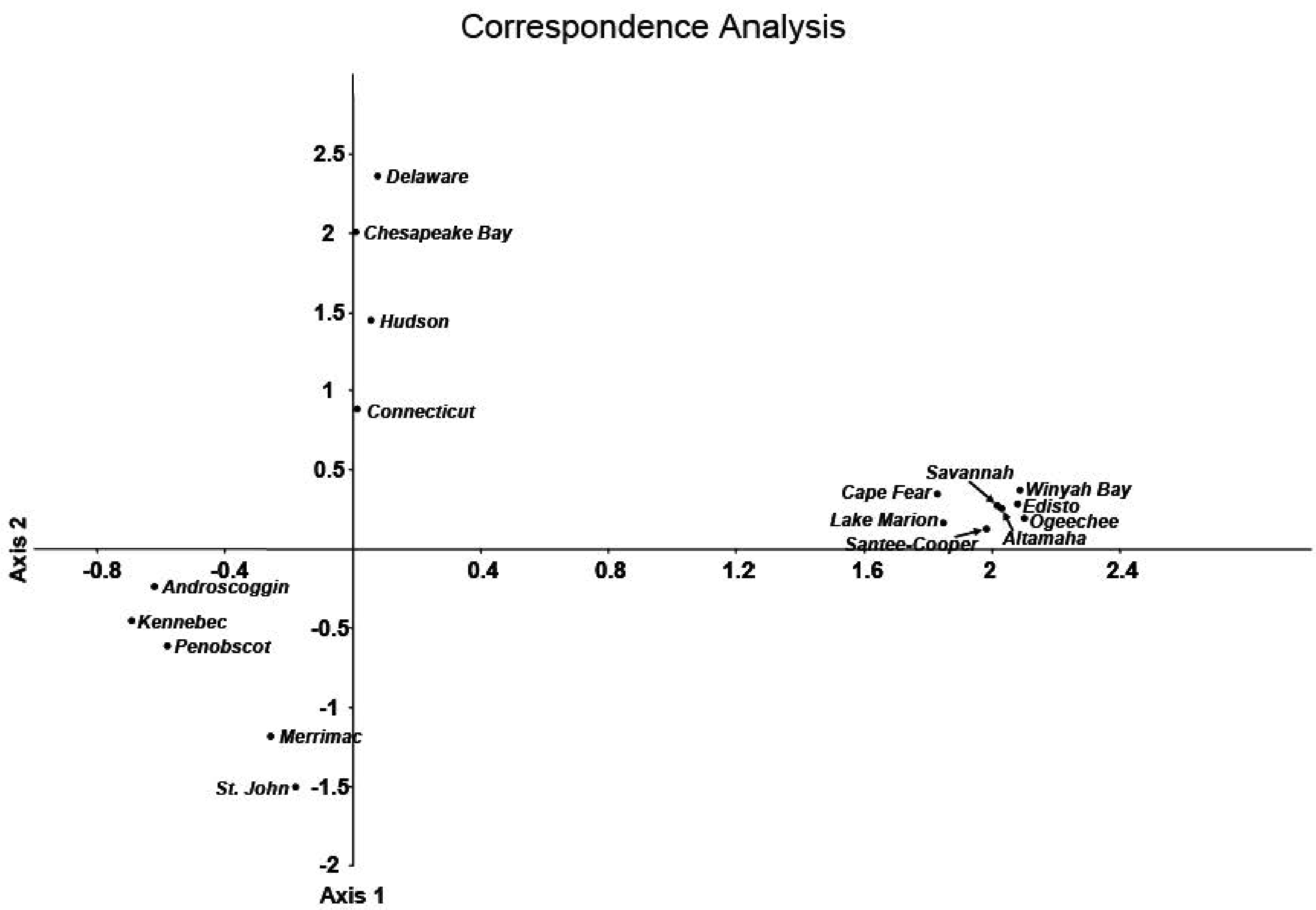


Figure 11. Population-level correspondence analysis of 17 collections of *Acipenser brevirostrum* surveyed at 11 polysomic microsatellite DNA loci.

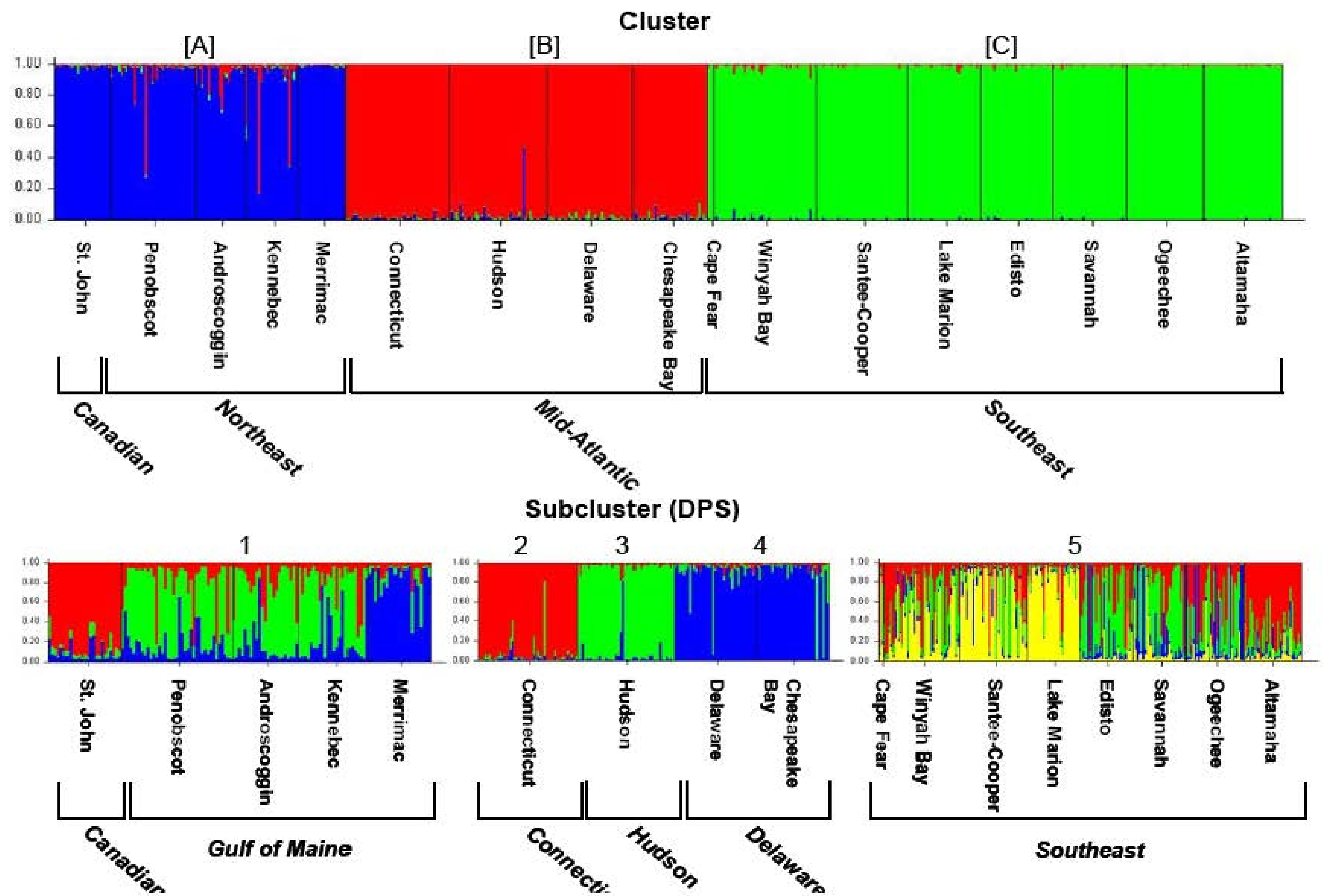


Figure 12. (see text below for explanation)

Figure 12. (see previous page for figure) Summary plots of q estimates generated by the sequential cluster analysis of the program STRUCTURE performed on the multilocus genotypes of 17 collections of Acipenser brevirostrum. The number of inferred clusters (k) in the initial (uppermost hierarchical level) analysis was three (clusters [A-C]). Each initial cluster was subsequently analyzed for within-cluster structure. The sequential analysis further subdivided the mid-Atlantic cluster into three subclusters for a total of five clusters (1-5). Each individual is represented by a single vertical line, broken into k colored segments, the length of which is proportional to the membership fraction in each of the k clusters. Individuals are grouped by populations as indicated by brackets.

Table 7. Pairwise Φ_{PT} values (below diagonal) and probability values (H_0 = No genetic difference among populations; $\Phi_{PT} = 0$) based on 1000 permutations (above diagonal) measured for 17 collections of shortnose sturgeon (*Acipenser brevirostrum*) surveyed at 11 polysomic microsatellite loci. Φ_{PT} is a Euclidean distance metric used to measure population genetic differentiation for binary data that is analogous to F_{ST} (Peakall and Smouse 2007).

	Saint John	Penobscot	Androscoggin	Kennebec	Merrimack	Connecticut	Hudson	Delaware	Chesapeake Bay	Cape Fear	Winyah Bay	Santee-Cooper	Lake Marion	Edisto	Savannah	Ogeechee	Altamaha
Saint John	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Penobscot	0.068	0.000	0.003	0.254	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Androscoggin	0.077	0.015	0.000	0.019	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Kennebec	0.068	0.003	0.013	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Merrimack	0.100	0.065	0.087	0.058	0.000	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Connecticut	0.191	0.116	0.113	0.114	0.201	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Hudson	0.162	0.094	0.091	0.073	0.153	0.086	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Delaware	0.175	0.107	0.099	0.096	0.184	0.100	0.067	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Chesapeake Bay	0.155	0.095	0.093	0.088	0.167	0.118	0.075	0.018	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Cape Fear	0.198	0.144	0.139	0.138	0.249	0.226	0.142	0.165	0.154	0.000	0.458	0.005	0.061	0.027	0.005	0.038	0.070
Winyah Bay	0.253	0.189	0.200	0.186	0.268	0.239	0.179	0.188	0.183	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001
Santee-Cooper	0.289	0.219	0.248	0.222	0.307	0.272	0.217	0.228	0.234	0.090	0.049	0.000	0.001	0.001	0.001	0.001	0.001
Lake Marion	0.269	0.207	0.226	0.205	0.297	0.263	0.208	0.217	0.210	0.052	0.034	0.044	0.000	0.001	0.001	0.001	0.001
Edisto	0.269	0.189	0.209	0.188	0.279	0.256	0.188	0.200	0.200	0.055	0.037	0.043	0.089	0.000	0.165	0.053	0.001
Savannah	0.278	0.201	0.210	0.201	0.295	0.261	0.196	0.206	0.213	0.084	0.046	0.043	0.095	0.005	0.000	0.083	0.001
Ogeechee	0.280	0.205	0.227	0.207	0.293	0.273	0.210	0.216	0.216	0.054	0.031	0.046	0.091	0.008	0.007	0.000	0.001
Altamaha	0.277	0.203	0.226	0.204	0.296	0.273	0.201	0.212	0.206	0.040	0.032	0.069	0.085	0.020	0.052	0.020	0.000

Table 8. Pairwise R values (below diagonal) and probability values (above diagonal) from the non-parametric Analysis of Similarity (ANOSIM) (Clarke 1993) on Jaccard's (Jaccard 1901) distance metric (1-Jaccard similarity) measured for 17 collections of shortnose sturgeon (*Acipenser brevirostrum*) surveyed at 11 polysomic microsatellite loci. The test statistic R results from the distance values being converted to rank values. The significance is computed by permutation of group membership, with 1,000 replicates. R values are proportional to genetic distance.

	Saint John	**Penobscot**	**Androscoggin**	**Kennebec**	**Merrimack**	**Connecticut**	**Hudson**	**Delaware**	**Chesapeake Bay**	**Cape Fear**	**Winyah Bay**	**Santee-Cooper**	**Lake Marion**	**Edisto**	**Savannah**	**Ogeechee**	**Altamaha**
Saint John	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Penobscot	0.241	0.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Androscoggin	0.345	0.099	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.626	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kennebec	0.285	0.014	0.058	0.000	0.000	0.000	0.000	0.000	0.000	0.313	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Merrimack	0.395	0.089	0.306	0.189	0.000	0.000	0.000	0.000	0.000	0.095	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Connecticut	0.793	0.513	0.617	0.573	0.770	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hudson	0.698	0.465	0.491	0.376	0.548	0.373	0.000	0.000	0.000	0.068	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delaware	0.735	0.501	0.510	0.466	0.685	0.452	0.296	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chesapeake Bay	0.659	0.467	0.488	0.426	0.619	0.557	0.352	0.089	0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cape Fear	0.780	0.644	0.473	0.466	0.933	0.860	0.610	0.678	0.629	0.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Winyah Bay	0.926	0.797	0.856	0.811	0.924	0.873	0.742	0.768	0.792	0.000	0.000	0.000	1.000	0.000	0.000	0.082	0.014
Santee-Cooper	0.948	0.775	0.888	0.833	0.972	0.898	0.763	0.795	0.841	0.461	0.153	0.000	0.000	0.000	0.000	0.000	0.000
Lake Marion	0.902	0.714	0.817	0.746	0.946	0.882	0.727	0.737	0.752	0.267	0.058	0.159	0.000	0.000	0.000	0.000	0.000
Edisto	0.945	0.734	0.834	0.774	0.952	0.910	0.733	0.762	0.798	0.265	0.140	0.208	0.342	0.000	1.000	1.000	0.000
Savannah	0.955	0.760	0.832	0.800	0.970	0.918	0.745	0.775	0.822	0.397	0.163	0.194	0.361	0.022	0.000	1.000	0.000
Ogeechee	0.949	0.749	0.854	0.799	0.967	0.923	0.762	0.783	0.810	0.320	0.080	0.192	0.345	0.037	0.027	0.000	0.041
Altamaha	0.945	0.753	0.857	0.803	0.966	0.923	0.749	0.782	0.803	0.238	0.092	0.293	0.321	0.100	0.232	0.073	0.000

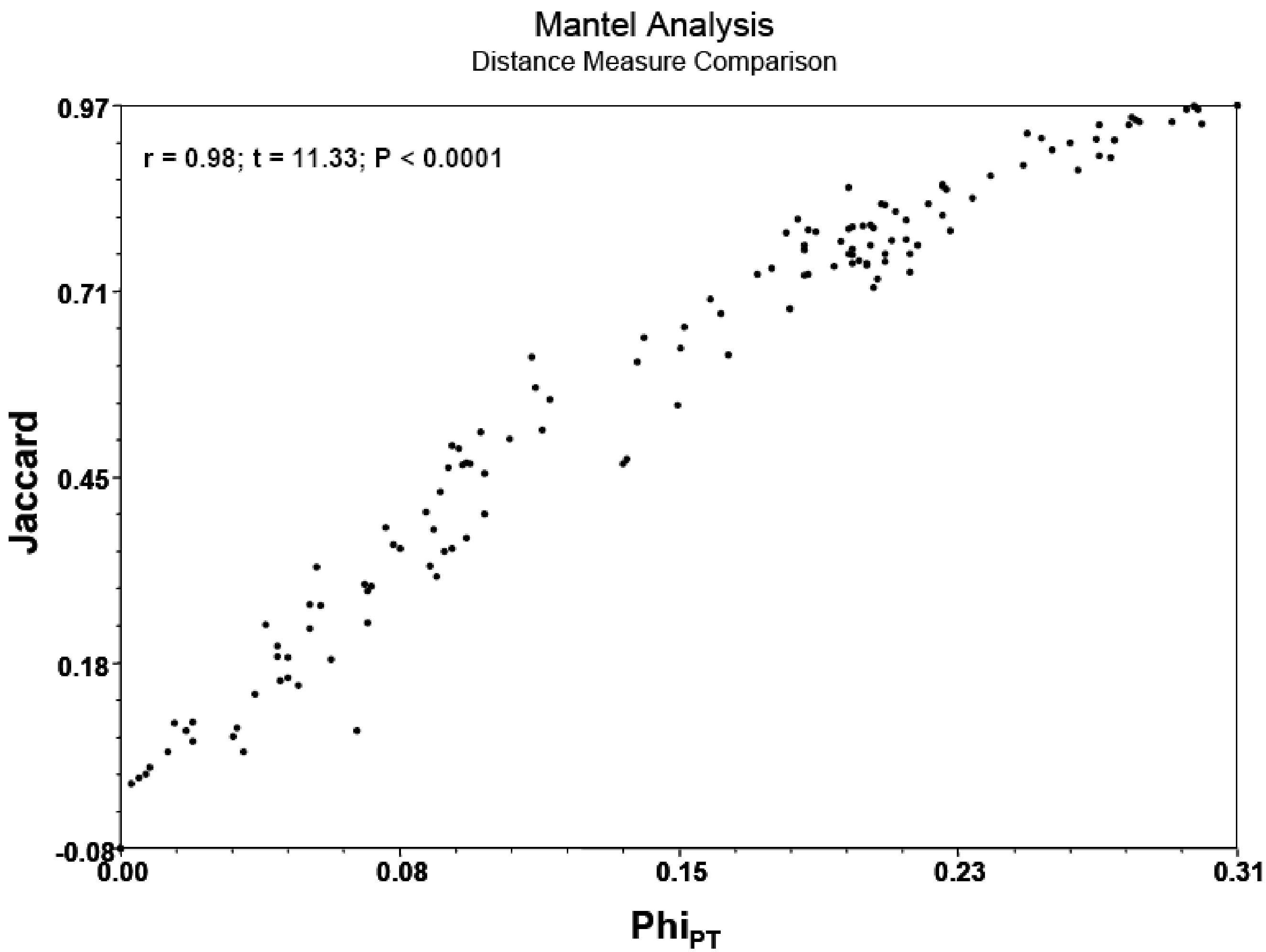


Figure 13. Scatterplot illustrating the significant correlation (Mantel analysis) between Jaccard and ΦPT pairwise distances values for 17 collections of shortnose sturgeon (*Acipenser brevirostrum*) surveyed at 11 microsatellite DNA loci.

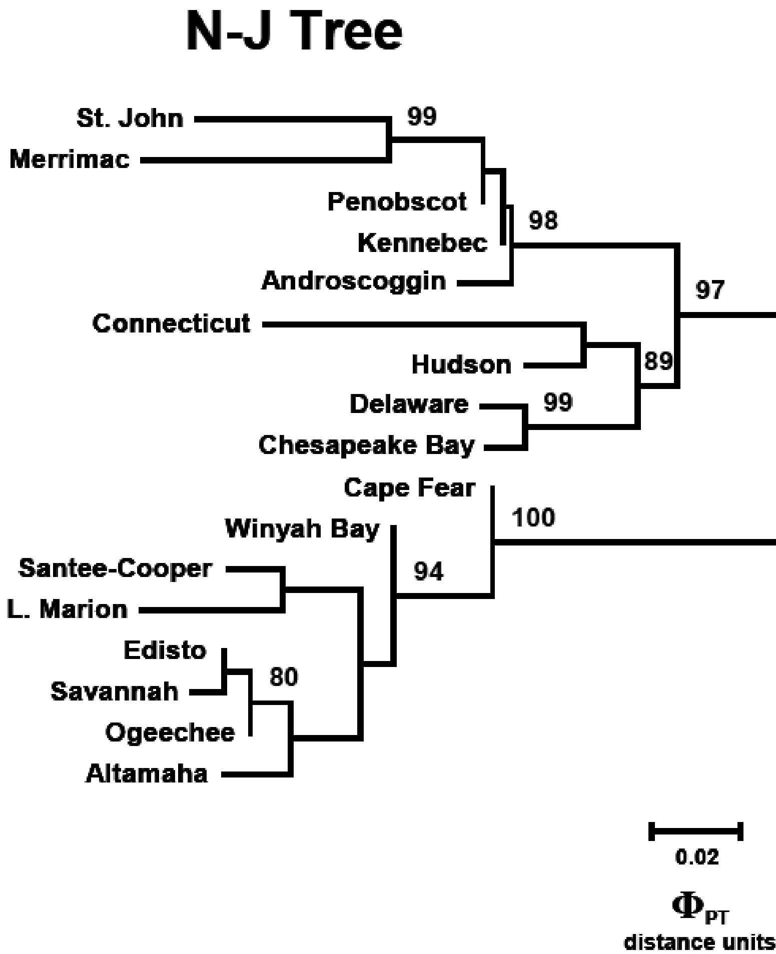


Figure 14. The evolutionary history among 17 collections of shortnose sturgeon (*Acipenser brevirostrum*) surveyed at 11 polysomic microsatellite DNA loci is inferred using the Neighbor-Joining method (Saitou and Nei 1987). The tree is drawn to scale, with branch lengths in the same units as those of the evolutionary distances used to infer the phylogenetic tree. Phylogenetic analyses were conducted in MEGA4 (Tamura et al. 2007). The associated pairwise PhiPT distance matrix was subjected to Neighbor-Joining clustering with 5000 bootstrap replicates using the program PAST (Hammer et al. 2007).

Table 9. Hierarchical structuring of genetic variation was measured for numerous combinations of shortnose sturgeon collections using analysis of molecular variance (AMOVA). Significance levels of the variance components were based on 1000 permutations.

Model	Source of Variance	Percentage of Variance	Test Statistic	Value	Probability
16 populations as 5 clusters	Among clusters	17%	Phi_{RT}	0.166	0.001
(with SJ omitted)	Among Pops within clusters	3%	Phi_{PR}	0.037	0.001
	Within Pops	80%	Phi_{PT}	0.196	0.001
17 populations as 6 clusters	Among clusters	17%	Phi_{RT}	0.167	0.001
(with SJ as a cluster)	Among Pops within clusters	3%	Phi_{PR}	0.036	0.001
	Within Pops	80%	Phi_{PT}	0.197	0.001

Table 10. Assignment to collection of origin for 17 collections of *Acipenser brevirostrum* surveyed at 11 polysomic microsatellite DNA markers.

	Saint John	Penobscot	Androscoggin	Kennebec	Merrimack	Connecticut	Hudson	Delaware	Chesapeake Bay	Cape Fear	Winyah Bay	Santee-Cooper	Lake Marion	Edisto	Savannah	Ogeechee	Altamaha
Saint John	20	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Penobscot	2	27	9	10	3	0	0	0	0	0	0	0	0	0	0	0	0
Androscoggin	1	5	10	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Kennebec	2	6	4	11	2	0	0	0	0	0	0	0	0	0	0	0	0
Merrimack	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0
Connecticut	0	0	0	0	0	46	0	0	0	0	0	0	0	0	0	0	0
Hudson	0	0	0	0	0	1	44	2	3	0	0	0	0	0	0	0	0
Delaware	0	0	0	0	0	0	1	29	8	0	0	0	0	0	0	0	0
Chesapeake Bay	0	0	0	1	0	0	0	8	23	0	0	0	0	0	0	0	0
Cape Fear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Winyah Bay	0	0	0	0	0	0	0	0	0	3	29	3	5	2	0	2	2
Santee-Cooper	0	0	0	0	0	0	0	0	0	0	3	24	4	1	2	2	2
Lake Marion	0	0	0	0	0	0	0	0	0	0	4	3	22	1	1	0	0
Edisto	0	0	0	0	0	0	0	0	0	0	3	4	0	13	8	6	4
Savannah	0	0	0	0	0	0	0	0	0	0	3	4	0	3	12	7	0
Ogeechee	0	0	0	0	0	0	0	0	0	0	1	3	0	7	9	10	9
Altamaha	0	0	0	0	0	0	0	0	0	0	4	1	2	6	2	8	19
Assignment %	80.0	69.2	43.5	45.8	77.3	97.9	97.8	74.4	67.6	0.0	61.7	58.5	66.7	39.4	35.3	28.6	52.8
Overall assignment to collection 58.6%																	

Table 11. Assignment to population cluster of origin for a proposed three population cluster model consisting of 17 collections of *Acipenser brevirostrum* surveyed at 11 polysomic microsatellite DNA markers.

allocated to	Northeast	Mid-Atlantic	Southeast
Northeast	132	0	0
Mid-Atlantic	1	165	0
Southeast	0	0	254
Assignment %	99.1	100	100

Table 12. Assignment to collection and population cluster of origin for five northeastern collections of *Acipenser brevirostrum* surveyed at 11 microsatellite DNA markers.

allocated to	Saint John	Penobscot	Kennebec	Androscoggin	Merrimack
Saint John	19	1	0	0	0
Penobscot	4	27	10	9	3
Kennebec	2	6	11	4	2
Androscoggin	0	5	3	10	0
Merrimack	0	0	0	0	17
Assignment to collection %	76.0%	69.2%	45.8%	43.5%	77.3%
Assignment to 3 NE DPSs%	76.0%	97.4%	100%	100%	100%

Table 13. Assignment to population cluster of origin for a proposed five population cluster model in *Acipenser brevirostrum* surveyed at 11 polysomic microsatellite DNA markers. The overall correct assignment rate to population cluster was 99.1% (522/527).

allocated to	Gulf of Maine	Connecticut	Hudson	Delaware	Southeast
Gulf of Maine	107	0	0	0	0
Connecticut	0	46	0	0	0
Hudson	0	1	44	2	0
Delaware	1	0	1	71	0
Southeast	0	0	0	0	254
Assignment %	99.1	97.9	97.8	97.3	100.0

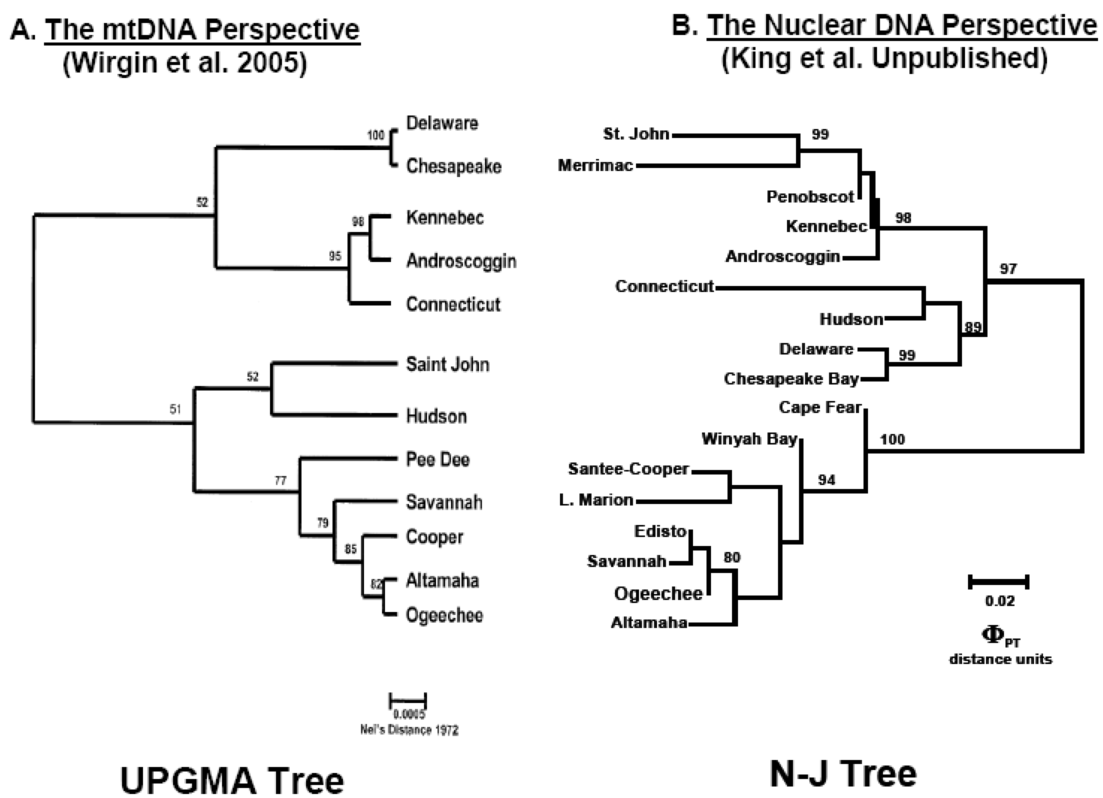


Figure 15a. An UPGMA tree of the population genetic distances for the mtDNA control region sequence data from shortnose sturgeon (*Acipenser brevirostrum*) of 12 Atlantic Coast Rivers and estuaries. Bootstrap values are given at each node. Taken from Wirgin et al. 2005.

Figure 15b. The evolutionary history among 17 collections of shortnose sturgeon (*Acipenser brevirostrum*) surveyed at 11 polysomic microsatellite DNA loci is inferred using the Neighbor-Joining method (Saitou and Nei 1987). The tree is drawn to scale, with branch lengths in the same units as those of the evolutionary distances used to infer the phylogenetic tree. Phylogeographic analyses were conducted in MEGA4 (Tamura et al. 2007). The associated pair-wise PhiPT distance matrix was subjected to Neighbor-Joining clustering with 5000 bootstrap replicates using the program PAST (Hammer et al. 2007).

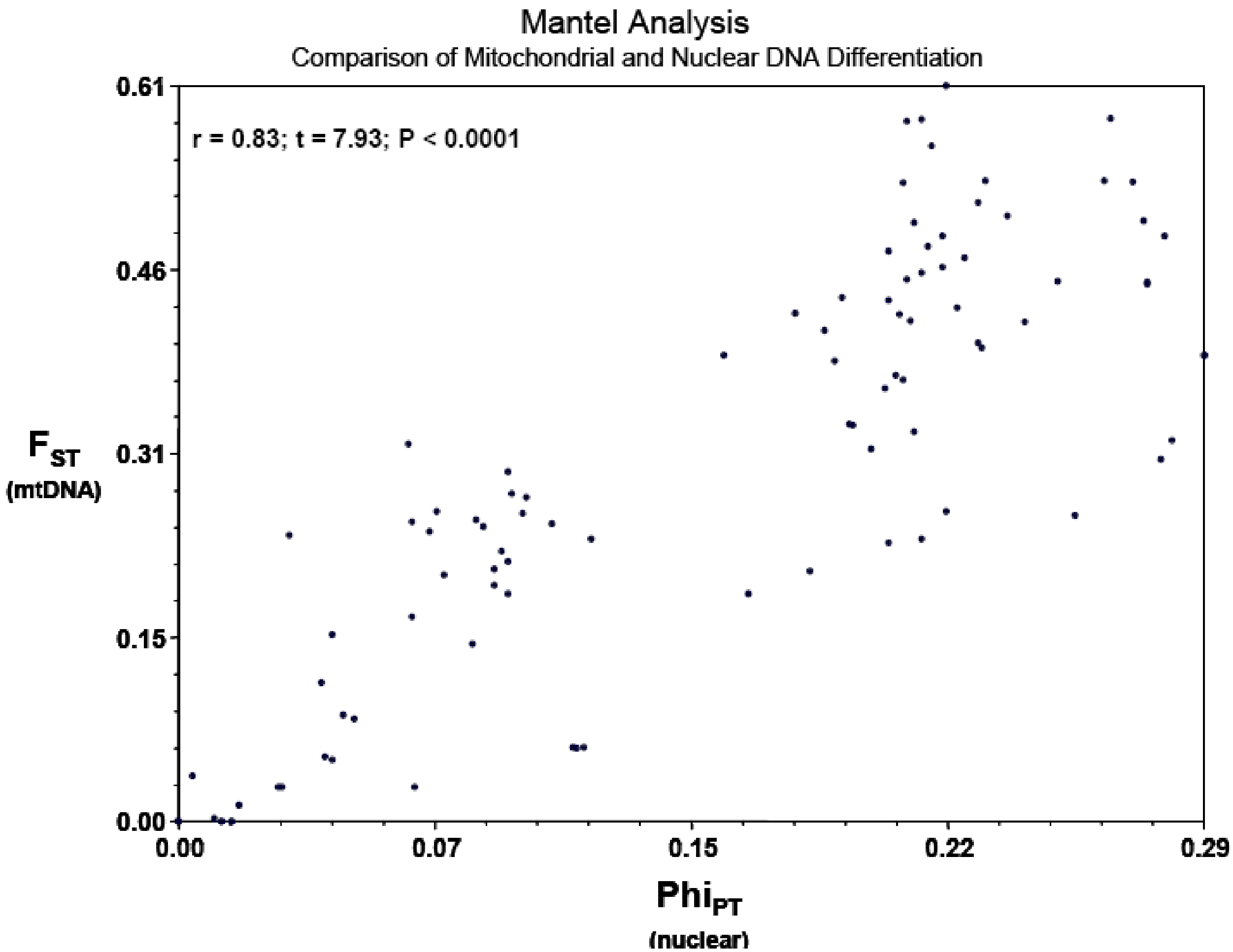


Figure 16. Scatterplot depicting the Mantel analysis comparing the mtDNA FST values for 14 Atlantic coast collection and the microsatellite DNA ΦPT pair-wise distances values for the same 14 collections of *Acipenser brevirostrum* surveyed at 11 microsatellite DNA loci. The correlation coefficient for this analysis was r = 0.83; suggesting a strong positive relationship between the two measures of genetic differentiation.

Summary of Genetic Diversity and Evolutionary Significance

The SRT worked under the supposition that genetic diversity is the most fundamental form of biodiversity providing the raw material for evolutionary processes to act and affording populations the opportunity to adapt to their surroundings. The SRT was presented with ample evidence that significant levels of genetic diversity are present in the shortnose sturgeon mitochondrial and nuclear genomes and that a high degree of similarity exists between genomes in the patterns of this genetic variation. While both mtDNA and nDNA analysis detected statistically significant differences in haplotype and allelic frequencies between most collections, regional zones of genetic discontinuity were detected in the patterns of genetic variation across the range of shortnose sturgeon that the SRT interpreted to likely delineate evolutionarily significant differentiation and adaptive potential for this species. The SRT felt that these zones of genetic discontinuity represented deeper levels of genetic differentiation; perhaps a higher degree of reproductive isolation, than that usually attributable to population-level differentiation.

Upon inspection of the patterns of variation in the mtDNA and nDNA data, the SRT recognized zones of genetic discontinuity between the northeastern and mid-Atlantic populations, and between the mid-Atlantic populations and the southeastern populations; zones which delineated three regional population groupings: northeast, mid-Atlantic, and southeast. Moreover, the SRT felt the narrow zones of genetic discontinuity between the Connecticut River and Hudson River, and between the Hudson River and Delaware River/Chesapeake Bay groups further delineated population structure of shortnose sturgeon. This brought to five (5) the number of shortnose sturgeon regional population clusters in the U.S. (Gulf of Maine, Conneticut/Housatonic rivers, Hudson River, Delaware River/Cheseapeake Bay, and southeast) plus the Saint John population cluster in New Brunswick, Canada. Genetics and straying data indicate that 3 of the 5 regional population clusters function as metapopulations (i.e., GOM, Del. River/Ches. Bay, and southeast rivers).

The SRT recognizes that gene flow estimates do not capture the intra-specific variation in individual behavior related to vagility, which is strongly affected by habitat fragmentation and population/metapopulation history. From a biodiversity conservation perspective, future success in shortnose sturgeon management would benefit from both in-depth demographic and genetic analyses. Therefore, the SRT believes that it should be considered a high priority research need to better delineate population structure within the regional genetic structure and once the type of metapopulation has been identified and the structure delineated, to enhance the demographic understanding of the population/metapopulation structure. Equally important will be determining the maximum extent to which shortnose sturgeon of reproductive age can and do migrate within and between metapopulations. For example, few surveys have been conducted in the rivers and bays along the North Carolina coast and it is unknown if a reproducing population(s) of shortnose sturgeon exists. If the distance to North Carolina rivers (or elsewhere) that could support a reproducing population exceeds the migration distance for sturgeon inhabiting the southeast or Delaware River/Chesapeake Bay metapopulations, supplementation may be a plausible restoration strategy. Accordingly, to ensure the long-term survival of populations, conservation actions should be based on available habitat and structural isolation. In this era of rapid environmental change and sea-level rise, this may be especially pertinent for the shortnose sturgeon that requires upstream migration through freshwater or species at their range margins. Genetic analyses (gene flow estimates from mtDNA and nDNA, genetic distance, and assignment results from nDNA) compliment these data as greater gene transfer occurs rivers in close proximity (Wirgin et al. 2000, Waldman et al. 2002, Wirgin et al. 2005, Wirgin et al. 2009, King et al. 2013).

The SRT believe these zones of discontinuity delineate populations or groups of populations exhibiting levels of differentiation that may be consistent with DPSs under the ESA if a DPS analysis were conducted. The SRT felt these regional population clusters represent evolutionarily significant lineages that warrant special conservation and management consideration. However, the SNS SRT appreciated the individual uniqueness of each riverine population and wished to preserve that diversity and therefore recommends that future recovery and management actions consider each riverine population as a management/recovery unit.

Demographics, Movement, and Genetic Diversity

Population biology theory predicts that lower dispersal and associated gene flow leads to decreased genetic diversity in small isolated populations, which generates adverse consequences for fitness, and subsequently for demographic stability. Recent research results appear to bode well for the fitness of some shortnose sturgeon populations. Both physical and effective movement (i.e., gene flow) among adjacent river systems in all three geographic regions has been recently reported increasing our knowledge. Gene diversity estimates for shortnose sturgeon have been shown to be moderately high in both mtDNA (Quattro et al. 2002; Wirgin et al. 2005; Wirgin et al. 2009) and nDNA (King et al. 2013) genomes. The mtDNA and nDNA studies performed to date suggest that dispersal is a very important factor maintaining these high levels of genetic diversity. While moderately-high gene diversity estimates may be indicative of larger effective population sizes than previously assumed leading to larger population sizes that are more resistant to genetic erosion - genetic diversity can be decreased and directly affect the fitness of individuals at a very local spatial scale when a metapopulation comprised of populations with a moderate number of individuals interconnected by considerable dispersal rates is reduced.

While shortnose sturgeon tagged in one river may later be recaptured in another, migration/ straying is not necessarily resulting in effective gene exchange indicated by high degree of genetic differentiation among riverine populations. Adults are known to return to their natal rivers to spawn. Therefore the loss of a riverine population from within a larger metapopulation or population cluster can occur and result in a long-term and significant gap in the geographic range of the species that in turn negatively impacts stability of the population, metapopulation, and species as a whole.

Captive Broodstock and Progeny

Through issuance of ESA Section 10(a)(1)(A) permits, scientific and enhancement studies are conducted by researchers on captive shortnose sturgeon maintained at various quarantined research facilities. Researchers employed by USFWS, USGS, the University of Florida, and one private facility, are currently authorized to study captive shortnose sturgeon. These captive individuals are periodically conditioned and spawned and the resulting gametes and progeny are used for scientific studies, such as cryogenics, disease transmission, nutrition, genetics, toxicology, fish passage, and fish culture techniques. Additionally, cultured shortnose sturgeon are currently displayed at educational facilities such as public aquaria and zoos. A total of 22 shortnose sturgeon are currently displayed at seven regional aquaria and zoos. An estimated 4.4 million visitors attend these educational facilities each year where visitors are introduced to shortnose sturgeon and to learn about its history, threats, and survival in the wild.

First generation (F-1) stocks of sturgeon from wild parents that originated either from the Connecticut or Savannah Rivers are maintained at these facilities and range in age from YOY to 23 years. Additionally, second and third generation stocks (F-2 and F-3) are also produced as progeny. Although these captive shortnose sturgeon are not releasable to the wild, except under prescribed conditions, shortnose sturgeon can be authorized under separate permits to be transferred to other facilities for further scientific research, enforcement forensics or other educational purposes. Upon expiration of these permits, or at the cessation of research, the permit holders can apply for a new permit, transfer individuals to another permitted facility, or euthanize those not required for further study. Commercial culture, sale or transfer of these individuals to a non-permitted facility is prohibited under the ESA.

Permits for educational display facilities require that shortnose sturgeon held at these facilities are not released, displayed with other sturgeon species, or displayed with shortnose sturgeon from other managed watersheds. If the display is closed and shortnose sturgeon survive, they must be sacrificed, transferred to another facility, or be disposed of in another acceptable manner. Although it is highly unlikely that display individuals could become reproductively active in the controlled environment of these facilities, the permits require that any resulting progeny be sacrificed to prevent an accidental release into the environment. Additionally, commercial culture or sale of these display shortnose sturgeon is prohibited.

Current Listing Status of Captive Shortnose Sturgeon

Similar genetic, physical, physiological, ecological, and behavioral characteristics can be shared by shortnose sturgeon produced in a hatchery and the natural populations from which they are derived. As a result, all components of the shortnose sturgeon, including populations of natural individuals and hatchery stocks derived from similar populations, are included in the ESA listing of the species. Given that new genetic analyses, tagging data, and behavioral information indicate that shortnose sturgeon function as 5 unique regional population clusters, Connecticut and Savannah River origin captive stock should be associated with the appropriate population cluster for management, conservation, and/

or listing purposes. Thus, Savannah River origin stock should be included in management, conservation, or listing activities of the southeast population cluster. Similarly, Connecticut River origin stock should be included in management, conservation, or listing activities for the Connecticut/ Housatonic River population cluster.

Under appropriate conditions, it may be possible to use captive bred shortnose sturgeon to restore or supplement a natural population. If sampling indicates that sturgeon have been either extirpated from a river or watershed where they have historically occurred, or if there is evidence that supplementation of an existing population is the only reasonable manipulation that could prevent the loss of a population in imminent danger of extirpation, then captive individuals could be used to restore or supplement the population if the habitat and environment is judged suitable for survival of all of the life stages. However, great care and consideration should be given to both the genetic diversity of the captive reared stock and the river or population being targeted for restoration or recovery.

Identification of Stressors

While the SNS SRT focused on assessing the status of the species, they wished to organize the contents of this report in a manner to best assist resource managers. To increase utility of the biological assessment, the SRT decided to review the status of the shortnose sturgeon by individual river (River Summaries section) and organize hazards impacting their status relative to factors presented in the ESA in setion 4(a)(1). The ESA directs that the following factors be considered to determine if a species is an endangered or threatened species:

(A) Present or threatened destruction, modification or curtailment of its habitat or rangerange;
(B) Overutilization for commercial, recreational, scientific or educational purposes;
(C) Disease or predation;
(D) Inadequacy of existing regulatory mechanisms; or
(E) Other natural or manmade factors affecting its continued existence.

Stressors are specific conditions that may injure, harm or affect the shortnose sturgeon (e.g., dams impeding access to spawning habitat, low concentrations of DO that reduce water quality), while the response can vary (e.g., death, reduced fitness, reduced habitat availability). Thus, stressors can alter habitat (i.e., listing factor A) and therefore affect status of the shortnose sturgeon. The SRT organized stressors relative to the ESA factors and then later determined the impact of each stressor to each riverine population of shortnose sturgeon to ascertain risk (River Summaries and Risk Analysis sections).

The Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range

Shortnose sturgeon, like all diadromous fishes, occupy a host of habitats at various points in their life including: rivers, estuaries, bays, and coastal marine waters. Habitat alterations potentially affecting shortnose sturgeon include loss of access to historical habitat, loss of and alteration of spawning habitat, poor water quality and changes to water flow, substrate alteration, siltation and contamination.

Loss of habitat and poor water quality have contributed to the decline of shortnose sturgeon since the time of European settlement; however, the importance of this threat has varied over time and from river to river. Some important aspects of habitat quality, especially water quality, have improved during the last thirty years.

The following sections review the impact of dams, dredging, and degraded water quality on shortnose sturgeon and their habitats. If information was not available specifically for shortnose sturgeon, information relevant to other sturgeon species is presented. Similarities in sturgeon life history and physiology make these data and analyses applicable, with some exceptions, to shortnose sturgeon. This section reviews the stressors generally for shortnose sturgeon throughout their range in the wild. Information on stressors to shortnose sturgeon habitat in specific rivers is presented in the River Summaries section.

Dams and Diversions

Dams are used to impound water for water resource projects such as hydropower generation, irrigation, navigation, flood control, industrial and municipal water supply, and recreation. Most modern reservoirs are designed for two or more of these purposes (Baxter 1977). Dams can have profound effects on diadromous fishes by fragmenting populations, eliminating or impeding access to historic habitat, modifying free-flowing rivers to reservoirs and altering downstream flows and water temperatures. Direct physical damage and mortality can occur to diadromous fishes that migrate through the turbines of traditional hydropower facilities or as they attempt to move upstream using passage devices.

In addition to dams impeding diadromous (both anadromous and amphidromous) fish migration and associated mortalities, Hill (1996) identified the following potential impacts from hydropower plants: altered DO concentrations; artificial destratification; water withdrawal; changed sediment load and channel morphology; accelerated eutrophication and change in nutrient cycling; and contamination of water and sediment. Furthermore, activities associated with dam maintenance, such as dredging and minor excavations along the shore, can release silt and other fine river sediments that can be deposited in nearby spawning habitat. Dams can also reduce habitat diversity by forming a series of homogeneous reservoirs; these changes generally favor different predators, competitors and prey, than were historically present in the system (Auer 1996a).

The effects of dams on populations of shortnose sturgeon are generally well documented (Kynard 1998, Cooke and Leach 2004). However, there may be some rivers where shortnose sturgeon have been extirpated almost without notice due to the construction of impassable dams. In these rivers historical presence of shortnose sturgeon was likely but unknown; there are historical accounts of sturgeon but it is unclear if both Atlantic and shortnose sturgeon used the river and if the river supported spawning of either species. Consider the Susquehanna River as one possible example. It is the second largest river on the east coast of the U.S. and there are historical and anecdotal accounts of plentiful "sturgeon" upriver. Currently the Susquehanna has four mainstem dams, the lowermost of which is at ~ rkm 16. The dam has a fish lift but it is not used by shortnose sturgeon. If the Susquehanna River once supported a population of shortnose sturgeon, it is no longer available to them.

Perhaps the biggest impact dams have on shortnose sturgeon is the loss of upriver spawning and rearing habitat (Table 14). Migrations of shortnose sturgeon in rivers without barriers are wide-ranging with total distances exceeding 200 km or more depending on the river system (Kynard 1997). The construction of dams has blocked upriver passage for the majority of the shortnose sturgeon populations. Dams have restricted spawning activities to areas below the impoundment, often in close proximity to the dam (Kynard 1997, Cooke and Leach 2004, Duncan et al. 2004).

Flow

The suitability of riverine habitat for shortnose sturgeon spawning and rearing depends on annual fluctuations in flow, which can be greatly altered or reduced by the presence and operation of dams (Jager et al. 2001, Cooke et al. 2004). Effects on spawning and rearing may be most dramatic in hydropower facilities that operate in peaking mode (Auer 1996b, Secor et al. 2002). Daily peaking operations store water above the dam when demand is low and release water for electricity generation when demand is high, creating substantial, daily fluctuations in flow and temperature regimes. Kynard et al. (2012), have documented that flow fluctuations for hydroelectric power generation affected access to spawning habitat and possibly deterred spawning of shortnose sturgeon on the Connecticut River. Similar results were reported in studies conducted for lake sturgeon *A. fulvescens* in the Sturgeon River, Michigan (Auer 1996b) and white sturgeon *A. transmontanus* in the Columbia River, Oregon and Washington (Parsley and Beckman 1994). Kynard et al. (2012), have also observed flow regimes from an upstream hydroelectric facility that were either so forceful that they completely scoured the rearing shoals used by shortnose sturgeon or so low that the shoals were dry and exposed. Auer (1996b) demonstrated that there is greater spawning success of lake sturgeon on the Sturgeon River, when facilities operated in the more natural "run-of-the-river" mode.

Table 14. Summary of dam location, year completed, and historical and present spawning locations (where known) for river that were considered by the SRT.

	Name of First Dam	rkm; Year completed	Historical Presence of "sturgeons"	Historic Spawning Location of shortnose sturgeon	Current Presence of SNS	Current Spawning of SNS	Current Spawning Location of shortnose sturgeon
Saint John, NB.	Mactaquac Dam	145; 1967	Yes	Unknown, perhaps at Grand Falls, ~rkm 337	Yes	Yes	Below the Mactaquac Dam ~rkm 145
Penobscot River	Veazie Dam	56; 1833	Yes	Unknown, perhaps the falls at Milford, rkm 71	Yes	Unknown	Unknown, research ongoing
Kennebec Complex: Androscoggin	Brunswick	44; 1948	Yes	Unknown, perhaps the falls at Brunswick, ~rkm 44	Yes	Yes	Below the Brunswick Dam, rkm 44
Kennebec Complex: Kennebec	Lockwood Dam[1]	98; 1919	Yes	Unknown, perhaps Ticonic Falls, ~rkm 98	Yes	Yes	11 km below the former Edwards Dam at rkm 59; perhaps further upriver since Edwards Dam removal in 1999
Piscataqua			Yes	Unknown if spawning occurred in this system	Unknown	Unlikely	If a spawning population existed, it was likely extirpated
Merrimack	Essex Dam	46; 1848	Yes	Unknown, perhaps at Amoskeag Falls, NH, rkm 116	Yes	Yes	Haverhill, MA, rkm 30-32
Connecticut	Holyoke Dam[2]	140; 1849	Yes	Unknown, possibly Rock Dam at rkm 194	Yes	Yes	*Upstream segment:* 2 separate sites in Montague, MA, (both at rkm 194 on different river reaches). *Downstream segment:* below the Holyoke Dam (rkm 140)
Housatonic	Derby Dam	23; 1870	Yes	Unknown, perhaps Great Falls (river km 123)	Yes[3]	Unlikely	If a spawning population existed, it was likely extirpated
Hudson	Troy Dam	245; 1825	Yes	Cohoes Falls, rkm 250	Yes	Yes	Coeyman's, NY to Troy Dam (rkms 212-245)
Delaware			Yes	Unknown	Yes	Yes	Trenton Rapids to Scudder's Falls (rkms 214-233)
Susquehanna	Conowingo Dam	16; 1928	Yes	Unknown	Yes[4]	Unlikely	If a spawning population existed, it was likely extirpated
Potomac	Little Falls Dam	189; 1959	Yes	Little Falls, rkm 189	Yes	Likely	Unknown, perhaps near Fletcher's Marina (rkms 185-187)
Roanoke	Roanoke Rapids Dam	221.4; 1955	Yes	Unknown	Yes[5]	Unknown[6]	Unknown
Chowan River Basin	Emporia Dam, Meherrin River	~203; ~1918	Yes	Unknown	Unknown	Unknown[6]	Unknown
Tar-Pamlico (Tar River)	Rocky Mount Mills Dam	199;1971	Unknown	Unknown, anecdotal reports from commercial fishermen	Unknown	Unknown	Unknown
Neuse	Milburnie Dam[7]	341; 1903	Unknown	Unknown, anecdotal reports from commercial fishermen	Unknown	Unknown	Unknown
New			Unknown	Unknown, anecdotal reports from commercial fishermen	Unknown	Unknown	Unknown
Cape Fear	Lock and Dam # 1	97; 1915	Yes	Unknown	Yes	Unlikely	Cape Fear estuary likely serves as a migration or staging corridor for spawning (perhaps in Brunswick River)

River	Name of First Dam	rkm; Year completed	Historical Presence of "sturgeons"	Historic Spawning Location of shortnose sturgeon	Current Presence of SNS	Current Spawning of SNS	Current Spawning Location of shortnose sturgeon
Winyah Bay System: Pee Dee	Blewett Falls Dam	330;1912	Yes	Unknown	Yes	Yes	Great Pee Dee River at rkm 206.5; other sites may exist
Santee	Santee (Wilson) Dam St Stephens Dam[8]	143; 1940s 92;1985;	Yes	Unknown	Yes	Unknown	Unknown
Cooper	Pinopolis Dam	76.8; 1942	Unknown	Unknown[9]	Yes	Yes	Upstream seg.: Congaree River at Columbia (rkm 70) Downstream seg.: base of Pinopolis Dam (~rkm 76)
ACE Basin			Unknown	Unknown if spawning occurred in this system	Yes	Yes	Unknown
Savannah	New Savannah Bluff Lock & Dam	317; 1937	Yes	Unknown, perhaps the shoals at Augusta, GA (~rkm 328)	Yes	Yes	Probable at rkms 179-190, 208-228, and 275-278
Ogeechee	Jordan Mill Pond Dam	375	Yes	Unknown, probably not upstream of the fall line ~rkm 375	Yes	Yes	Unknown
Altamaha	None[10]		Yes	Unknown	Yes	Yes	From Fort Barrington (~rkm 50) upstream to the confluence Oconee, and Ocmulgee rivers (rkm 212)
Satilla			Yes	Unknown if spawning occurred in this system	Yes	Unknown	Unknown
St. Mary's			Yes	Unknown if spawning occurred in this system	Yes	Unknown	Unknown
St. Johns	Rodman Dam[11], Ocklawaha River	12.9; 1968	Yes	Unknown, perhaps above the Rodman Dam	Yes	Unknown	Unknown

[1]The Edwards Dam was formerly the first dam. It was constructed in 1837 at rkm 59 and was removed in 1999.

[2]The Enfield Dam, built in 1880 at rkm 109, was formerly the first obstruction to sturgeon; it was breached in the 1970s.

[3]In 2005, one shortnose sturgeon was captured just downstream of the Derby Dam in 16 net hours of effort. This individual had been PIT tagged in the CT River in 2004.

[4]Since 1996, eight shortnose sturgeon have been documented in the lower Susquehanna River in the sturgeon reward program and individuals were caught in the Dam's tailrace in 1986.

[5]One individual (730mm TL) was collected on the Roanoke River in 1998 (Armstrong and Hightower, 1999).

[6]The individual was collected on the Roanoke River in 1998 (see above) was likely either spawned in the Roanoke or the Chowan River.

[7]The Quaker Neck Dam, built in 1952 at rkm 225 was removed in 1998

[8]The Santee (or Wilson) Dam is on the Santee River and the St Stephens Dam is on the rediversion canal.

[9]No evidence of shortnose presence or spawning before the dam was built and the river system was changed.

[10]There are no dams on the main stem of the Altamaha River; however, there are dams on both the Oconee (Sinclair Dam at rkm 444) and Ocmulgee (Juliet Dam at rkm 573) Rivers.

[11]The first dam (Rodman) is on Ocklawaha River about 12.9 km upstream of its confluence with the St John River, FL.

Fish Passage

Few fish passage opportunities are currently in place for shortnose sturgeon. Usually shortnose sturgeon are expected to utilize a passage opportunity constructed for other, mostly pelagic, species. A single shortnose sturgeon has been documented to use a Denil fish ladder. There has been limited success in passing shortnose sturgeon using fish lifts. For example, the fish lift located at Holyoke Dam on the Connecticut River passed 81 shortnose sturgeon from 1975 to 1995 (Kynard 1996, Gephard and McMenemy 2004). The Holyoke lift passed an average of three adults per year (range 0-13) during April-October (Kynard 1996). The fish lift at St. Stephen on the Santee River, SC, has passed six shortnose sturgeon since 1985 likely due to location of the entrance 10-12 feet off the bottom. Nature-like fish bypass canals have been used with some success for sturgeon. Migration downstream past a dam via spillways or through turbines (entrainment) may occur at any life stage but not without some risk of injury and mortality especially to larger individials. Downstream movement has been documented in the Connecticut River, and appears to coincide with increased river discharge in the spring (Seibel 1993, Kynard et al. 2012).

Fragmented Populations

Dams have blocked historical migration corridors resulting in fragmented populations of shortnose sturgeon in the Connecticut River (Kynard 1997, 1998) and the Santee-Cooper River System (Collins et al. 2003b, Cooke et al. 2002). Although these are the only known cases of dam-locked populations, other rivers may have (or once had) an undetected upriver population segment (Kynard 1997). For example, an upriver population segment may exist above the Mataquac Dam on the Saint John River, Canada but this has not been thoroughly investigated (COSEWIC 2005).

Fragmentation reduces important ecological and genetic exchange across habitats and contributes to extinction risk (Anders et al. 2001, Jager 2001, Jager et al. 2001, Root 2002). Adults that cannot descend to superior foraging areas in the lower river appear less robust than those with access to these areas (Collins et al. 2002, Kynard et al. 2012). Additionally, individuals upstream may experience extended exposure to contaminants that accumulate in the reservoirs behind dams as has been documented in white sturgeon (Feist et al. 2005). Implications of fragmentation to downstream-segment include poor reproduction and recruitment possibly inhibiting recovery (Kynard 1997, Cooke and Leach 2004, Cooke et al. 2004).

Dam Removal

Dams provide many important benefits but some have aged or degraded to a point where they no longer work well, or may even cause public safety concerns. In these cases, dam removal may be a good option. Dam removal may help to achieve conservation goals such as river and fisheries restoration, public safety goals such as elimination of unsafe dams, and other community-revitalization goals through increased recreation and green space (Bowman 2002). A few dams within the historic range of shortnose sturgeon have been removed or have been naturally breached: Treat Falls Dam on the Penobscot River, ME; Edwards Dam on the Kennebec River, ME; and Enfield Dam on the Connecticut River, CT. Dam removal is currently planned for the two lowermost dams on the Penobscot River, ME.

Bowman (2002) reviewed regulatory avenues for dam removal and we include part of her discussion of the dam relicensing process below verbatim:

> "All hydropower dams not owned by the federal government must obtain an operating license from FERC, unless the dam has been issued an exemption or is on a nonnavigable river (US Code, title 16, sec. 797[e]). When these 30- to 50-year licenses expire, the dam owner must reapply to FERC to obtain a new license (US Code, title 16, sec. 808). As part of this licensing process, FERC must determine whether issuing a new license is in the public interest, providing equal consideration to power development and nonpower uses of the river (e.g., fish and wildlife habitat, recreation, aesthetics) (US Code, title 16, sec. 797[e]). In 1994, FERC issued a policy statement concluding that it had the authority as part of a relicensing proceeding to deny a relicense application and to order a dam to be removed if it determines such an action is in the public interest (Project Decommissioning at Relicensing: Policy Statement, 60 Federal Register 339, Code of Federal Regulations [CFR], title 18, sec. 2.24; all CFR citations are available online at *www.access.gpo. gov/nara).* FERC expressly exercised this dam removal authority once, in their 1997 order requiring removal of the Edwards Dam on the Kennebec River in Maine (Edwards Mfg. Co., 81 FERC 61,225 [1997])."

As dam removal becomes an increasingly attractive option, it is important that scientists and decision-makers carefully consider and mitigate for potential negative impacts. Short-term negative impacts include the influx of sediments into the stream flow which can damage spawning grounds and negatively impact water, habitat and food quality. If sediments are contaminated, then impacts from dam removal can be even greater. Fortunately, sediment influx following dam removal is usually temporary; several studies have demonstrated that after removal sediments were flushed from river channels and natural sediment transport conditions resumed (American Rivers 2002). While there are some short-term ecological consequences of dam removal, there are greater long-term ecological benefits such as improved water quality and sediment transport, and recovery of native resident and migratory species (American Rivers 2002).

Other Energy Projects

Tidal Turbines

Tidal energy harnesses the potential energy of the different sea levels created by tides or by using energy directly from tidal streams (Buigues et al. 2008). There are currently two main types of tidal power systems: 1) barrages; or 2) tidal stream systems. Barrages involve building dams or weirs across a small arm of a bay or inlet. Barrages operate somewhat like a traditional hydroelectric dam but draw energy from the differences in the height of high and low tides. Barrages fill the impoundment during flood tide and extract power during ebb tide as water flows through the low head turbines built into the stucture. The 18 MW Annapolis Royal Generating Station (ARGS), built in 1982 on the Annapolis River in Nova Scotia, is currently the only example of this type of tidal turbine in North America and one of three in the world (Ehrlich 2007). Barrages have many of the same challenges for fish passage as traditional dams. Dadswell and Rulifson (1994) documented the negative impacts of the ARGS on marine animals including Atlantic sturgeon (150 – 200cm TL). At least three dead and damaged Atlantic sturgeon were observed below the power plant during 1985 and 1986 and the probability of strike for larger animals (bass, salmon, sturgeon, marine mammals) was 50-100% depending upon the species (Dadswell and Rulifson 1994). The barrage-type tidal turbines such as ARGS have raised considerable concerns about environmental impacts and developers of tidal power systems have turned to new designs.

Tidal stream systems use marine turbines, similar to windmill technology, in a dam-less system to generate power from the flowing water currents of oceans, tides, rivers and manmade channels or conduits. Tidal stream systems do not require damming but instead are stratgically anchored to the substrate in high velocity areas where natural tidal flows are concentrated such as entrances to the mouths of bays, rivers or straits. Many of the tidal stream technologies are still developing and are unproven or have not been adequately tested. There are only a few underwater turbine projects in operation worldwide and there is only one that has been installed for operation on a commercial scale (Ehrlich 2007). A tidal stream device called "SeaGen" successfully powered a grid at Strangford Lough, in Northern Ireland in a July 2008 trial at 150kW; SeaGen is designed to eventually generate 1,200 kW, enough to power about 1,000 homes (Jha 2008).

Currently, there is just one tidal power project in operation along the range of shortnose sturgeon, though more companies are seeking or have received preliminary permits (FERC 2008a; Table 15). Verdant Power has been conducting a pilot project on the East River in New York since November 2006 (Angelo 2005, CBS News 2006). The project started with the placement of two slow-speed tidal turbines in the East River to evaluate the viability of the technology and potential impacts on marine life. The East River experiences strong currents which makes it an ideal location for energy generation. The swift-moving waters damaged the first two types of turbine blades installed in late 2006 and early 2007; reinforced blades were installed in September 2008 (Galbraith 2008). Verdant is working to improve the turbine design with the intent of installing 30 units in the East River starting in the spring 2010, and to develop more sites in Canada and on the West Coast (Galbraith 2008).

Because so few tidal stream systems are in operation, it is difficult to assess environmental impacts. Potential impacts to the marine environment are currently being considered by the U.S. Department of Energy. Possible impacts to shortnose sturgeon may include: effects from construction (increased shipping, noise, substrate alteration, pile driving); and effects from operation (blade strike, impingement, exposure to cavitation, habitat alteration due to decreases in flow, noise, exposure to chemicals such as oils and antifouling coatings) (U.S. Dept. of Energy 2009). Additionally, Dadswell and Rulifson (1994) suggested that introduction of tidal turbines into open-ocean current systems will cause widespread impacts to marine populations and will result in significant declines in abundance; organisms with small populations such as sturgeon and marine mammals would be particularly vulnerable.

Table 15. Summary of preliminary permits that were issued or are pending for hydrokinetic projects proposed for rivers systems in the United States with known presence of shortnose sturgeon. Data are from FERC 2008a.

Project Number	Project Name	Water Body	State	Applicant	Issued
P-12666	Kennebec	Kennebec River	ME	Oceana	6/24/2008
P-12810	Housatonic Tidal Energy	Housatonic River	CT	Natural Currents Energy Serv., LLC	11/16/2007
P-12668	Penobscot	Penobscot River	ME	Oceana	5/16/2007
P-12722	Piscataqua	Piscataqua River	NH	UEK Corporation	4/16/2007
P-12664	Portsmouth	Piscataqua River	NH	Oceana	4/16/2007
P-12665	Astoria	East River	NY	Oceana	5/31/2007
P-12718	Wards Island	East River	NY	Natural Currents Energy Serv., LLC	4/16/2007
P-12611	Roosevelt Island	East River	NY	Verdant Power	12/13/2005

Pending Hydrokinetic Projects - Preliminary Permits

Project Number	Project Name	Water Body	State	Applicant	Filing Date
P-13329	Wiscasset Tidal Energy Project	Sheepscot River	ME	Town of Wiscasset, ME	11/12/2008
P-13246	Wiscasset Tidal Energy Project	Sheepscot River	ME	Natural Currents Energy Serv., LLC	6/23/2008
P-13079	Wiscasset Tidal Energy Plant	Sheepscot River	MA	Natural Currents Energy Serv., LLC	11/26/2007

LNG Facilities

Demand for liquefied natural gas (LNG) is predicted to increase and there are several proposals to build new or expand existing LNG facilities in or near river systems with populations of shortnose sturgeon (Table 16, FERC 2008b). In order to turn natural gas into liquid form for transportation overseas, it is chilled to approximately minus 260°F (-162.2ºC). The liquid gas is loaded onto specialized tankers and upon arrival in the United States it is converted back into a gas for distribution via pipeline. LNG is re-gasified by circulating water (or some other fluid) through a radiator-like system that warms LNG to vaporization temperatures. LNG facilities use either a closed-loop or open-loop system to convert the liquid into gas. Open-loop systems require a continuous stream of water in order to warm LNG (100-200 million gallons per day), usually withdrawn directly from the river system or ocean in which the terminal is sited. Eggs, larvae, and other organisms in the water column can be impinged or entrained as water is withdrawn from the source to the terminal. Once the LNG is vaporized, the seawater used in cooling is either discharged back into the environment or utilized again through the cooling loop. The discharge can be at temperatures significantly different than ambient. Closed-loop systems require far less water withdrawal and subsequent discharge, and therefore have less impact on the aquatic environment. While closed loop systems are more expensive to operate, they are being proposed more and more frequently in areas where the impact of daily water withdrawal would be too great, or where ambient water conditions are not warm enough to facilitate the regasification process.

Potential threats/impacts to shortnose sturgeon associated with the construction and operation of LNG facilities include increased dredging activities to allow for the passage and berthing of LNG vessels, pile driving for pier and berth construction, increased risk of ship strikes due to vessel traffic, potential YOY losses from ballast water and facility intakes, loss of habitat due to water withdrawal, and temperature of discharged water.

Table 16. Summary of LNG projects that are either existing, proposed, proposed for expansion or may be proposed (potential sites) on rivers with known populations of shortnose sturgeon. Data are from FERC 2008b.

Location	Water Body	Type	Company
Existing LNG Terminals			
Cove Point, MD	Chesapeake Bay	Closed loop	Dominion - Cove Point LNG
Elba Island, GA	Savannah River	Closed loop	El Paso - Southern LNG
Approved LNG Terminals (note that two are expansions of existing facilities)			
Cove Point, MD	Chesapeake Bay	Closed loop	Dominion - Expansion
Elba Island, GA	Savannah River	Closed loop	El Paso - Southern LNG Expansion
Logan Township, NJ	Delaware River	Closed loop	Crown Landing LNG - BP
Proposed LNG Terminals			
Baltimore, MD	Chesapeake Bay	Closed loop	AES Sparrows Point - AES Corp.
Potential U.S. Sites Identified by Project Sponsors			
Philadelphia, PA	Delaware, River	Closed loop	Freedom Energy Center - PGW

Impingement and Entrainment

Shortnose sturgeon are susceptible to impingement on cooling water intake screens at power plants. Electric power and nuclear power generating plants can affect sturgeon by impinging larger individuals on cooling water intake screens and entraining larvae. Entrainment of larval shortnose sturgeon has been documented on the Hudson and Delaware rivers. Prior to 2002, the "old" Albany Steam Electric generating station in Bethlehem, NY, used once-through cooling water intakes during power generation. In 1982, a large year class of shortnose was produced and an estimated total of 163 YOY shortnose were impinged at the plant; numbers impinged were much lower from 1984-85 (see River Summaries section – Hudson River). In the spring of 2006, 26 larval shortnose sturgeon were entrained at a small cogeneration plant in Fairless Hills, PA along the Delaware River and five shortnose sturgeon larvae were collected at another plant (see River Summaries section – Delaware River for more information).

Dredging, Blasting, and Pile Driving

Dredging

Many rivers and estuaries are periodically dredged for flood control or to support commercial shipping and recreational boating. Dredging also aids in construction of infrastructure and in marine mining. Dredging may have significant impacts on aquatic ecosystems including the direct removal/burial of organisms; turbidity/siltation effects; contaminant resuspension; noise/disturbance; alterations to hydrodynamic regime and physical habitat and actual loss of riparian habitat (Chytalo 1996, Winger et al. 2000).

Dredges are generally either mechanical or hydraulic. Mechanical dredges are used to scoop or grab bottom substrate and are capable of removing hard-packed materials and debris. Mechanical dredges may be of the clamshell bucket type, the endless bucket conveyor type, or a single backhoe or scoop bucket type. These dredges often have difficulty retaining fine materials in their buckets and do not dredge continuously. Material excavated from mechanical dredging is often loaded onto barges for transport to a designated placement site (ACOE 2008a).

Hydraulic dredges are used principally to dredge silt, sand, and small gravel. Hydraulic dredges include cutterhead pipeline dredges and self-propelled hopper dredges. Hydraulic dredges remove material from the bottom by suction, producing a slurry of dredged material with water that is either pumped directly to a placement site, or in the case of a hopper dredge, pumped into a hopper and later transported to a dredge spoil site. Cutterhead pipeline dredges can excavate most materials including some rock without blasting and can dredge almost continuously (ACOE 2008a).

The impacts of dredging operations on sturgeon are often difficult to assess. Hydraulic dredges can lethally take sturgeon by entraining sturgeon in dredge drag arms and impeller pumps (NMFS 1998). Mechanical dredges have also been documented to lethally take shortnose sturgeon (Dickerson 2006). In addition to direct effects, indirect effects from either mechanical or hydraulic dredging include destruction of benthic feeding areas, disruption of spawning migrations, and deposition of resuspended fine sediments in spawning habitat (NMFS 1998).

Dickerson (2006) summarized observed takes of sturgeon from dredging activities conducted by the ACOE; overall 24 sturgeon (11 shortnose sturgeon, 11 Atlantic sturgeon and 2 Gulf sturgeon) were observed during the years of 1990-2005 (Table 17). Of the 24 sturgeon observed, 15 (62.5%) were reported as dead. Dickerson (2006) noted that the largest take of sturgeon species was observed in the Delaware (n=6) and Kennebec (n=6) rivers. To reduce the impacts of dredging on shortnose sturgeon, NMFS imposes seasonal restrictions through ESA Section 7 consultations. Additionally, work restrictions are commonly required during sensitive time periods (spawning, migration, feeding) when anadromous fishes are present in the area.

Table 17. Shortnose sturgeon captured in observed dredge operations by dredge type as reported by the U.S. Army Corps of Engineers for the U.S. east coast from 1990 – 2005. Reports include only those trips when an observer was on board to document capture, and numbers do not reflect all sturgeon captures.

	Dredge Type		
Year	**Hopper**	**Clamshell**	**Pipeline**
1990			
1991			
1992			
1993			
1994			
1995			
1996			2
1997			
1998			3
1999			
2000			
2001			
2002			
2003	5	1	
2004			
2005			
Total	5	1	5

Dredging impacts to sturgeons are likely common across species (i.e., shortnose, Atlantic, and Gulf) Additional impacts to sturgeon as a result of dredging include filling of deep holes preferred by sturgeon during the warm summer months and an alteration of rocky substrates (Smith and Clugston 1997). Nellis et al. (2007) documented that dredge spoil drifted 12 km downstream over a 10 year period in the Saint Lawrence River, have significantly less macrobenthic biomass compared to control sites. Using an acoustic trawl survey, researchers found that Atlantic and lake sturgeon were substrate dependent and avoided spoil dumping grounds (McQuinn and Nellis 2007). Similarly, Hatin et al. (2007) tested whether dredging operations affected Atlantic sturgeon behavior by comparing CPUE before and after dredging events in 1999 and 2000. The authors documented a three to seven-fold reduction in Atlantic sturgeon presence after dredging operations began, indicating that sturgeon avoid these areas during operations.

Blasting

Bridge demolition and other projects require blasting with powerful explosives. Fishes are particularly susceptible to the effects of underwater explosions and are killed over a greater range than other organisms (Lewis 1996). Unless appropriate precautions are made to mitigate the potentially harmful effects of shock wave transmission, internal damage and/or death may result (NMFS 1998).

A study testing the effects of underwater blasting on juvenile shortnose sturgeon and striped bass was conducted in Wilmington Harbor, NC (Moser 1999). Seven test runs that included 32-33 blasts (3 rows with 10-11 blast holes per row and each hole ~ 10 ft apart) at about 24-28 kg explosives per hole (NMFS 2001) were conducted; during each blast 50 hatchery reared shortnose sturgeon and striped bass were hung in cages three feet from the bottom at distances of 35, 70, 140, 280 and 560 ft upstream and downstream of the blast area. A control group of 200 individuals was held 0.5 miles from the blast site (Moser 1999). Test blasting was conducted with (n=3) and without (n=4) an air curtain placed 50 ft from the blast area. External assessments of impacts to the caged fish were conducted immediately after the blasts and 24 h later. After the 24 h period, a subsample of the caged individuals, primarily from those cages in closest proximity of the blast (i.e., 35 and 70 ft) were sacrificed for necropsy. All shortnose sturgeon selected for subsequent necropsy appeared to be in good condition externally and behaviorally. Results of the necropsies indicated that individuals who survived the blast and persisted for 24 hr post blast, appeared physically healthly but often had substantial internal injuries. Many of these injuries likely would have resulted in eventual mortality (Moser 1999). Additionally the necropsy results indicated that individuals held in cages at 70 ft were less seriously impacted by the test blasting than those held at 35 ft from the blast. Juvenile shortnose sturgeon suffered fewer and less severe internal injuries than juvenile striped bass. The air curtain appeared to have no reduction of injury in shortnose sturgeon (Moser 1999).

Current conservation measures designed to minimize the transmission of harmful shock waves to the endangered shortnose sturgeon include restricting the work to seasonal “work windows” when sturgeon are not likely to be present, installing double-walled cofferdams around piers that are to be blasted, and dewatering of the outer cofferdams (NMFS 1998).

Pile Driving

Additionally, in-water pile driving for bridge construction has resulted in high underwater sound pressures that have proved lethal to fishes (Reyff 2008). The impacts from pile driving vary with the methods used and the species tested. Reyff (2008) reviewed recent construction activities in the marine environments of northern California and evaluated control measures to protect fishes and marine mammals. These measures included different pile-driving methods, cofferdams (with and without water), confined air bubble curtain systems, and unconfined bubble curtain systems (Reyff 2008). Some of the noise reduction methods achieved more than 30dB of noise reduction greatly reducing the impacts to the species of concern for the projects that were evaluated (Reyff 2008).

Water Quality and Contaminants

The quality of water in river/estuary systems is affected by human activities conducted directly in the riparian zone and those conducted upland. Industrial activities can result in discharges of pollutants, changes in water temperature and levels of DO, and the addition of nutrients. In addition, forestry and agricultural practices can result in erosion, run-off of fertilizers, herbicides, insecticides or other chemicals, nutrient enrichment and alteration of water flow. Coastal and riparian areas are also heavily impacted by real estate development and urbanization that result in storm water discharges, non-point source pollution, and erosion. The water quality over the range of shortnose sturgeon varies by watershed.

The EPA published its second edition of the National Coastal Condition Report (NCCR II) in 2004, which is a "report card" summarizing the status of coastal environments along the coast of the United States (EPA 2004; Table 18). The report analyzes water quality, sediment, coastal habitat, benthos, and fish contaminant indices to determine status. The northeast region and the Chesapeake Bay received grades of F. The Southeast region received an overall grade of B-, which was the best rating in the nation.

Table 18. Summary of the National Coastal Condition Report (NCCR II) for the U.S. east coast published by the U.S. Environmental Protection Agency (2004) that grades coastal environments. The northeast region includes Maine through Virginia; the southeast includes North Carolina through Florida. Chesapeake Bay was graded independently.

	Region		
Status Index	**Northeast**	**Chesapeake Bay**	**Southeast**
Water Quality	D	F	B
Sediment	F	F	B
Coastal Habitat	B	-	C
Benthos	F	F	C
Fish Tissue	F	F	A
Overall	**F**	**F**	**B-**

Areas of concern that had poor index scores were: 1) Hudson River – water quality, sediment, and tissue contaminants, 2) Delaware River – water quality and tissue contaminants, 3) Upper

Chesapeake Bay – water quality and sediment, 4) Potomac River – sediment, 5) Pamlico Sound – water quality, 6) ACE Basin – water quality, and 7) St. Johns River – sediment. There was also a mixture of poor benthic scores scattered along the east coast.

Although the northeast scored poorly, it's interesting to note that the largest shortnose sturgeon populations occur in rivers with both high and persistent levels of contaminants, namely the Hudson and Delaware rivers. While the southeast scored relatively well in terms of water quality (Table 18), it appears that low dissolved oxygen concentrations coupled with elevated water temperatures limit available habitat and impacts survival of shortnose sturgeon, particularly the younger stages. Secor (1995) noted a correlation between low abundances of sturgeon during this century and decreasing water quality caused by increased nutrient loading and the increased spatial and temporal frequency of hypoxic conditions. Both Secor and Gunderson (1998) and Collins et al. (2001) have hypothesized that survival of juvenile sturgeon in estuaries may be compromised due to the combined effects of increased hypoxia and temperature in nursery areas impacted by anthropogenic activities. Hypoxia affects sturgeon species more than other fish species because of their limited ability to oxyregulate at low DO levels (Klyashtorin 1976, Secor and Gunderson 1998, Secor 2002). The first year of life may be particularly susceptible to hypoxia owing to high sensitivities to low DO at early life stages and the limited means to escape from hypoxic waters (Secor and Niklitschek 2001).

Niklitschek (2001) modeled suitable habitat availability for juvenile shortnose and Atlantic sturgeon in the Chesapeake Bay using a multivariable bioenergetics and survival model. Results indicated that the cumulative stresses of hypoxia, high temperatures, and salinity during summer months caused large reductions in potential nursery habitat for both species during 1990-1999 (Niklitschek 2001). Further the modeling demonstrated that during dry years when hypoxia persisted in deeper waters access to thermal refuges was impeded and little suitable habitat was available for juvenile sturgeon (Niklitschek 2001).

In 2003 the EPA adjusted open water minimum DO-criteria for the Chesapeake Bay (increased from ~2 ppm to 3.5 ppm) to provide protection specifically for sturgeon species, which require higher levels of DO than other fish species (EPA 2003). Niklitschek and Secor (2005) modeled the achievement of EPA's DO criteria for Atlantic sturgeon and predicted that available habitat increased by 13% per year; notably an increase of water temperature by just 1°C would reduce available habitat by 65%. Similar results may occur for sturgeon in southern rivers where high water temperatures coupled with low DO are a common occurrence especially during summer months.

Life history characteristics of shortnose sturgeon (i.e., long lifespan, extended residence in estuarine habitats, benthic foraging) predispose the species to long-term and repeated exposure to environmental contamination and potential bioaccumulation of heavy metals and other toxicants (Dadswell 1979, NMFS 1998). However, there has been little work on the effects of contaminants on shortnose sturgeon to date.

Chemicals and metals such as chlordane, dichlorodiphenyl dichloroethylene (DDE), DDT, dieldrin, PCBs, cadmium, mercury, and selenium settle to the river bottom and are later consumed by benthic feeders, such as macroinvertebrates, and then work their way higher into the food web (e.g., to sturgeon). Some of these compounds may affect physiological processes and impede a fish's ability to withstand stress, while simultaneously increasing the stress of the surrounding environment by reducing DO, altering pH, and altering other physical properties of the water body. Shortnose sturgeon collected from the Delaware and Kennebec Rivers had total toxicity equivalent concentrations of polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), PCBs, DDE, aluminum, cadmium, and copper above adverse effect concentration levels reported in the literature (ERC Inc. 2002, 2003). Six individuals collected from the Hudson River have been tested over the past 37 years; most carried very high burden load of PCBs, or one of its derivatives (see River Summaries section – Hudson River; Table 22).

Dioxin and furans were detected in ovarian tissue collected from shortnose sturgeon caught in the Sampit River/Winyah Bay system, SC. Results indicated four out of seven individuals analyzed contained tetrachlorodibenzo-*p*-dioxin (TCDD) concentrations greater than 50 pg/g (parts-per-trillion), a level which can adversely affect the development of sturgeon fry (J. Iliff, NOAA, Silver Spring, MD, pers. comm.).

Heavy metals and organochlorine compounds accumulate in sturgeon tissue, but the long-term effects are not known (Ruelle and Henry 1992, Ruelle and Keenlyne 1993). Elevated levels of contaminants, including chlorinated hydrocarbons, in several other fish species are associated with reproductive impairment (Cameron et al. 1992, Longwell et al. 1992, Hammerschmidt et al. 2002, Giesy et al. 1986, Mac and Edsall 1991, Matta et al. 1997, Billsson et al. 1998), reduced survival of larval fishes (Berlin et al. 1981, Giesy et al. 1986), delayed maturity (Jorgensen et al. 2004) and posterior malformations (Billsson et al. 1998). Pesticide exposure in fishes may affect anti-predator and homing behavior, reproductive function, physiological development, and swimming speed and distance (Beauvais et al. 2000, Scholz et al. 2000, Moore and Waring 2001, Waring and Moore 2004).

Sensitivity to environmental contaminants also varies across life stage. Early life stages of fishes appear to be more susceptible to environmental and pollutant stress than older life stages (Rosenthal and Alderdice 1976). Dwyer et al. (2005) compared relative sensitivities of common surrogate species used in contaminant studies to 17 listed species including shortnose and Atlantic sturgeon during a 96-hour acute water exposure to carbaryl, copper, 4-nonphenol, pentachlorophenal (PCP) and permethrin using early life stages with mortality as the endpoint. Atlantic and shortnose sturgeon were ranked the two most sensitive species of the 17 tested (Dwyer et al. 2005). Additionally, a study examining the effects of coal tar, a byproduct of the process of destructive distillation of bituminous coal, indicated that components of coal tar are toxic to shortnose sturgeon embryos and larvae in whole sediment flow-through and coal tar elutrtraite static renewal (Kocan et al. 1993).

As noted above, there are only a few references regarding contaminants in shortnose sturgeon tissue or species-specific potential biological effects from contaminants. However, information is available regarding contaminants in other sturgeon species and summarized below:

- Dadswell (1975) examined 30 juvenile Atlantic sturgeon collected in the Saint John River estuary, New Brunswick. The mean concentration of mercury was 0.29 ppm of wet weight with a range of 0.06 – 1.38 ppm.

- Rehwoldt et al. (1978) examined a limited number of freshly captured Atlantic sturgeon from the Hudson River in 1976 and 1977 and compared them to reference samples collected between 1924 and 1953 (and stored in preservative). Tissues were analyzed for cadmium, mercury, and lead and found that average values of contaminant levels did not show any chronological relationship. Atlantic sturgeon samples from 1924 and 1976 showed little difference for all three metal residues. The 1976-1977 average concentrations (µg/g; ppm, wet weight) in Atlantic sturgeon tissue were as follows: cadmium 0.02, mercury 0.09, and lead 0.16.
- Gulf sturgeon (*A. o.desotoi*) collected from a number of rivers between 1985 and 1991 were analyzed for pesticides and heavy metals (Bateman and Brim 1994). Concentrations of arsenic, mercury, DDT metabolities, toxaphene, polycyclic aromatic hydrocarbons (PAHS), and aliphatic hydrocarbons were sufficiently high to warrant concern.
- Twenty juvenile Gulf sturgeon from the Suwannee River, FL exhibited an increase in metals burdens with an increase in fish length (Alam et al. 2000).
- White sturgeon larvae had a significantly increased incidence of defects with selenium levels greater than 15µg/g in the laboratory (R. Linville, UC-Davis, pers. comm. 2006).
- Kootenai River white sturgeon exhibited organochlorine levels that could potentially affect reproduction or other physiological functions (Kruse and Scarnecchia 2002a).
- Growth and reproductive impacts were observed in Columbia River white sturgeon, where plasma triglycerides and conditions factors were negatively correlated with total DDT, total pesticides, and PCBs (Feist et al. 2005). In males, plasma androgens and gonad size were also negatively correlated with total DDT, total pesticides, and PCBs.
- Kruse and Scarnecchia (2002b) noted that the mortality of white sturgeon embryos was significantly different between individuals reared in different media (Fuller's earth 12.6% versus river bottom sediment 20.6%), which was related to copper and Aroclor 125 (PCB) concentrations.
- Omoto et al. (2002) found that by varying doses of estradiol-17β or 17α methyltestosterone given to captive hybrid "bester" sturgeon (*Huso huso* female × *Acipenser ruthenus* male) could induce abnormal ovarian development or a lack of masculinization.
- Mercury concentrations of white sturgeon captured from the Columbia River (Webb et al. 2006) was correlated with suppressed circulating sex steroids, decreased condition factor and relative weight, and a lower gonadosomatic index in immature males. A significant positive linear relationship was determined between age and liver mercury concentrations. Mercury concentration in muscle tissue from the mature adult female (1.094 ppm) exceeded state and Federal action limits.

Lastly, the operation of power plants can have unforeseen and detrimental impacts to water quality which can affect shortnose sturgeon. For example, in June 1991 a fish kill occurred in the Santee River after a period of several days of zero discharge from the St. Stephen hydropower facility. Large mats of aquatic plants entered the plant's intake canal and clogged the cooling water intake gates. Decomposing plant material in the tailrace canal coupled with the turbine shut down (allowing no flow of water) triggered a low dissolved oxygen water condition downstream and a subsequent fish kill. Carcasses from a minimum of 20 shortnose sturgeon were later found (White and Lamprecht 1991, Cooke and Leach 1999).

Water withdrawal for municipal and industrial purposes occurs on many of the rivers inhabited by shortnose sturgeon so there is the potential for impingement or entrainment at intakes (see Stressors – Impingement and Entrainment for discussion of intakes at power generating facilities). Other impacts from water withdrawal include decreased flow (and resultant habitat problems associated with low water) and the potential for loss of cool deepwater holes preferred by shortnose sturgeon in summer months, especially in southeastern rivers. The relationship between water withdrawals and impacts to shortnose sturgeon (especially the loss of cool-water refugia) requires further study.

Climate Change

Long-term observations confirm that climate is changing at a rapid rate. Over the 20th century, the average annual U.S. air temperature has risen by almost 0.6^{o}C (1^{o}F) and precipitation has increased nationally by 5%-10%, mostly due to an increase in heavy downpours (NAST 2000). These trends are most apparent over the past few decades.

Climate model projections exhibit a wide range of plausible scenarios for both temperature and precipitation over the next century. Both of the principal climate models used by the National Assessment Synthesis Team (NAST) project warming in the southeast by the 2090s, but at different rates (NAST 2000): the Canadian model scenario shows the southeast U.S. experiencing a high degree of warming, which translates into lower soil moisture as higher temperatures increase evaporation; the Hadley model scenario projects less warming and a significant increase in precipitation (about 20%). The scenarios examined, which assume no major interventions to reduce continued growth of world greenhouse gases (GHG), indicate that temperatures in the U.S. will rise by about 3^{o}-5^{o}C (5^{o}-9^{o}F) on average in the next 100 years which is more than the projected global increase (NAST 2000). A warming of about 0.2^{o}C per decade is projected for the next two decades over a range of emission scenarios (IPCC 2007). This temperature increase will very likely be associated with more extreme precipitation and faster evaporation of water, leading to greater frequency of both very wet and very dry conditions. Climate warming has resulted in increased precipitation, river discharge, and glacial and sea-ice melting (Greene et al. 2008).

The past 3 decades have witnessed major changes in ocean circulation patterns in the Arctic, and these were accompanied by climate associated changes as well (Greene et al. 2008). Shifts in atmospheric conditions have altered Arctic Ocean circulation patterns and the export of freshwater to the North Atlantic (Greene et al. 2008, IPCC 2007). With respect specifically to the North Atlantic Oscillation (NAO), changes in salinity and temperature are thought to be the result of changes in the earth's atmosphere caused by anthropogenic forces (IPCC 2007). The NAO impacts climate variability throughout the northern hemisphere (IPCC 2007). Data from the 1960s through the present show that the NAO index has increased from minimum values in the 1960s to strongly positive index values in the 1990s and somewhat declined since (IPCC 2007). This warming extends over 1000m deep and is deeper than anywhere in the world oceans and is particularly evident under the Gulf Stream/ North Atlantic Current system (IPCC 2007). On a global scale, large discharges of freshwater into the North Atlantic subarctic seas can lead to intense stratification of the upper water column and a disruption of North Atlantic Deepwater

(NADW) formation (Greene et al. 2008, IPCC 2007). There is evidence that the NADW has already freshened significantly (IPCC 2007). This is turn can lead to a slowing down of the global ocean thermohaline (large-scale circulation in the ocean that transforms low-density upper ocean waters to higher density intermediate and deep waters and returns those waters back to the upper ocean), which can have climatic ramifications for the whole earth system (Greene et al. 2008).

Regional Effects of Climate Change

Northeast and Mid-Atlantic

The changes in freshwater export and circulation patterns have resulted in significant salinity changes (IPCC 2007), leading to two main ecological shifts (Pershing et al. 2005, Greene and Pershing 2007, Greene et al. 2008). The first major ecological shift is the biogeographic range expansion by Boreal Plankton, including trans-Arctic exchanges of Pacific species with the Atlantic (Greene et al. 2008). The second ecological shift had mainly affected the Northwest Atlantic where, during the early 1990s, a dramatic shift in shelf ecosystems occurred (Pershing et al. 2005, Greene and Pershing 2007, Greene et al. 2008). The major shifts observed specifically in the Gulf of Maine and Scotian shelf ecosystems in the early 1990s are specifically linked to these changes in salinity and lower trophic level communities (Pershing et al. 2005, Greene and Pershing 2007, Greene et al. 2008). These changes may be related to changes in higher trophic level consumer populations as well (Greene et al. 2008). Shifts in ecological communities in the Northwest Atlantic include commercially harvested fish and crustacean populations, both of which underwent large changes in abundance during the 1990s (Frank et al. 2005, Pershing et al. 2005, Greene et al. 2008). While overfishing was the predominant cause of the collapse of cod in particular, the cold, low-salinity Arctic waters entering the northern portion of the range of cod seem to have hampered subsequent recovery (Rose et al. 2000, Greene et al. 2008). Other species, such as shrimp and snow crab, have increased in abundance in the absence of cod predation (Frank et al. 2005).

Greene et al. (2008) describe that changes in salinity can result in more localized effects on ocean circulation patterns and climate that are confined to the North Atlantic basin and the adjacent landmasses. For example, these changes specifically affect thermal regimes within the Gulf of Maine and possibly mid-Atlantic (Fay et al. 2006). Fay et al. (2006) documents that in the Gulf of Maine ecosystem, the spring runoff occurs earlier; water content in snow pack for March and April has decreased; and the duration of river ice has been reduced (Dudley and Hodgkins 2002). Several studies indicate that small thermal changes may substantially alter reproductive performance, species distribution limits, and community structure of fish populations (Van Der Kraak and Pankhurst 1997, McCormick et al. 1997, Keleher and Rahel 1996, McCarthy and Houlihan 1997, Welch et al. 1998, Schindler 2001). Recent analyses of bottom water temperatures found that negative NAO years are warmer in the north and cooler in the Gulf of Maine (Petrie 2007). Positive NAO years are warmer in Gulf of Maine and colder in the north (north of 45° N) (Petrie 2007). Strength of NAO is related to annual changes in diversity of potential predators: at southern latitudes, there are more species during positive NAO years (IPCC 2007). The effect is system-wide where 133 species showed at least a 20 percent difference in frequency of occurrence in years with opposing NAO states (IPCC 2007).

Southeast

In the Southeast in particular, sea-level rise (SLR) is one of the more certain consequences of climate change; it has already had significant impacts on coastal areas and these impacts are likely to increase. Since 1852 when the first topographic maps of the southeast region were prepared, high tidal flood elevations have increased approximately 12 inches. During the 20th century global sea level has increased between 15 and 20 cm (NAST 2000). Analyses attribute the coastal forest decline in the southeast to salt water intrusion associated with sea level rise. Coastal forest losses will be even more severe if SLR accelerates as is expected as a result of global warming.

Between 1985 and 1995, more than 32,000 acres of coastal salt marsh were lost in the southeastern U.S. due to a combination of human development activities, SLR, natural subsidence, and erosion (NAST 2000). Sea level is predicted to increase by 30-100 cm by 2100 (IPCC 2007). The vulnerability of tidal wetlands to accelerated SLR depends on geologic factors, such as tectonic uplift and glacial isostatic adjustment, which buffer shorelines from SLR, and subsidence, which accelerates it. Tide range also affects marsh vulnerability, as macro- (>4m) and meso-tidal (2-4m) marshes are less susceptible to SLR than micro-tidal (<2m) marshes (Stevenson and Kearney in press). In some coastal areas, rising sea level may result in tidal marsh submergence (Moorhead and Brinson 1995) and habitat migration, as salt marshes transgress landward and replace tidal freshwater and brackish marshes (Park et al. 1991). Flood and erosion damage stemming from SLR rise coupled with storm surges are very likely to increase in coastal communities. Simulation modeling predicts that a 52-cm increase in SLR will lead to a decline in tidal marsh area and delivery of ecosystem services along the Georgia coast during this century (Craft et al. 2009); a 20% reduction in salt marsh, along with a small increase in tidal freshwater marsh (+2%) and a larger increase in brackish marsh (+10%). The decline in salt marsh is attributed to submergence and replacement by tidal flats and estuarine open water (Craft et al. 2009). Regionally, the areas most vulnerable to future sea level change are those with low relief that are already experiencing rapid erosion rates, such as the southeast and gulf coast (NAST 2000).

Many ecosystems are highly vulnerable to the projected rate and magnitude of climate change. While it is possible that some species will adapt to changes in climate by shifting their ranges; human and geographic barriers and the presence of invasive non-native species will likely limit the degree that adaptation can occur. Losses in local biodiversity are likely to accelerate towards the end of the 21st century.

It is difficult to assess the potential effects of climate change over the next few decades on coastal and marine resources, especially as climate variability is a dominant factor in shaping coastal and marine systems. The effects of future change will vary greatly in diverse coastal regions for the United States. Warming is very likely to continue in the U.S. during the next 25 to 50 years regardless of reduction in GHGs, due to emissions that have already occurred (NAST 2000). It is very likely that the magnitude and frequency of ecosystem changes will continue to increase in the next 25 to 50 years, and it is possible that they will accelerate. Climate change can cause or exacerbate direct stress on ecosystems through high temperatures, a reduction in water availability, and altered frequency of extreme events and severe storms. Water temperatures in streams and rivers are likely to increase as the climate warms and are very likely to have both direct and indirect effects on aquatic ecosystems. Changes in temperature will be most evident during low flow periods when they are of greatest concern (NAST 2000). In some marine and freshwater systems, shifts in geographic ranges and changes in algal, plankton, and fish abundance are associated with high confidence with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation (IPCC 2007).

A warmer and drier climate will reduce stream flows and increase water temperatures. Expected consequences would be a decrease in the amount of dissolved oxygen in surface waters and an increase in the concentration of nutrients and toxic chemicals due to reduced flushing rate (Murdoch et al. 2000). Because many rivers are already under a great deal of stress due to excessive water withdrawal or land development, and this stress may be exacerbated by changes in climate, anticipating and planning adaptive strategies may be critical (Hulme 2005). A warmer-wetter climate could ameliorate poor water quality conditions in places where human-caused concentrations of nutrients and pollutants currently degrade water quality (Murdoch et al. 2000). Increases in water temperature and changes in seasonal patterns of runoff will very likely disturb fish habitat and affect recreational uses of lakes, streams, and wetlands. Surface water resources in the southeast are intensively managed with dams and channels and almost all are affected by human activities; in some systems water quality is either below recommended levels or nearly so. A global analysis of the potential effects of climate change on river basins indicates that due to changes in discharge and water stress, the area of large river basins in need of reactive or proactive management interventions in response to climate change will be much higher for basins impacted by dams than for basins with free-flowing rivers (Palmer et al. 2008). Human-induced disturbances also influence coastal and marine systems, often reducing the ability of the systems to adapt so that systems that might ordinarily be capable of responding to variability and change are less able to do so. Because stresses on water quality are associated with many activities, the impacts of the existing stresses are likely to be exacerbated by climate change. Within 50 years, river basins that are impacted by dams or by extensive development, like the SCPSA Project, will experience greater changes in discharge and water stress than unimpacted, free-flowing rivers (Palmer et al. 2008).

Large-scale factors impacting riverine water quality and quantity that likely exacerbate habitat threats to shortnose sturgeon include drought and intra- and inter-state water allocation. Since 2007 the southeast U.S. has been experiencing several years of ongoing drought. During this time, South Carolina experienced drought conditions that ranged from moderate to extreme (South Carolina State Climatology Office 2008). From 2006 until mid-2009, Georgia experienced the worst drought in its history. Between November 2007 and November 2008, 50 to 100 percent of the state of Georgia experienced some level of drought ranging in intensity from “abnormally dry” to “exceptional”, based on the drought intensity categories used by the U.S. Drought Monitor (NIDIS 2008). Likewise, North and South Carolina have been in litigation since 2007 over water withdraws from the Catawaba River. A settlement was reached in 2010 that imposes strict drought protocols for removing water from reservoirs. Both states will be required to restudy the Catawba’s water supply every 10 years “so future planning will be based on up-to-date, scientifically-based knowledge and information,” a summary of the settlement states.

Abnormally low stream flow can restrict access to habitat areas, reduce thermal refugia, and exacerbate water quality issues such as high temperature, low dissolved oxygen, and elevated nutrient and contaminant levels. Further reduction in flow would likely disrupt spawning cues, and upstream migration may occur earlier; a disparity between prey availability and demand by larvae could ensue. NMFS believes that reduced flow down the rivers coupled with rising sea level will push the salt wedge farther upriver and likely result in constricting available shortnose sturgeon foraging habitat. Data from southeast gauging stations indicate that periods when river flows are inadequate to protect the riverine environment from salt water intrusion are becoming more frequent. Human-induced modifications to free-flowing rivers also influence coastal and marine systems, often reducing the ability of the system to adapt to natural variability and change.

In summary, drought and water allocation issues and their associated impacts on water quality will likely work synergistically with climate change impacts along the U.S. east coast. While debated, researchers anticipate: 1) the frequency and intensity of droughts and floods will change across the nation; 2) a warming of about 0.2^{o}C per decade; and 3) a rise in sea level (NAST 2000). A warmer and drier climate will reduce stream flows and increase water temperature resulting in a decrease of DO and an increase in the concentration of nutrients and toxic chemicals due to reduced flushing. Sea level is expected to continue rising: during the 20th century global sea level has increased 15 to 20 cm, and between 1985 and 1995 more than 32,000 acres of coastal salt marsh was lost in the southeastern U.S. due to a combination of human development activities, sea level rise, natural subsidence and erosion. Rising sea level will likely drive the salt wedge farther upstream possibly affecting the survival of drifting larvae and constricting available foraging habitat, below the action area dams.

Anticipated impacts to shortnose sturgeon

Rising sea level may result in the salt wedge moving upstream, possibly affecting the survival of drifting larvae and YOY shortnose sturgeon that are sensitive to elevated salinity. Similarly, for river systems with dams, YOY may experience a habitat squeeze between a shifting (upriver) salt wedge and a dam causing loss of available habitat for this life stage.

The increased rainfall predicted by some models in some areas may increase runoff and scour spawning areas and flooding events could cause temporary water quality issues. Rising temperatures predicted for all of the U.S. will likely exacerbate existing water quality problems with DO and temperature. While this occurs primarily in rivers in the southeast U.S. and the Chesapeake Bay, it may start to occur more commonly in the northern rivers. One might expect range extensions to shift northward (i.e. into the St. Lawrence River, Canada) while truncating the southern distribution.

Increased droughts (and water withdrawal for human use) predicted by some models in some areas may cause loss of habitat including loss of access to spawning habitat. Drought conditions in the spring may also expose eggs and larvae in rearing habitats. If a river becomes too dry all shortnose sturgeon life stages, including adults, may become susceptible to strandings. Low flow and drought conditions are also expected to cause additional water quality issues.

Any of the conditions associated with climate change are likely to disrupt river ecology causing shifts in community structure and the type and abundance of prey. Additionally, cues for spawning migration and spawning could occur earlier in the season causing a mismatch in prey that are currently available to developing shortnose sturgeon in rearing habitat.

Summary and Evaluation

Shortnose sturgeon throughout their range are exposed to a variety of habitat stressors from anthropogenic activities including: obstructed or restricted access to riverine habitat; perturbations of habitat from dredging and construction and degraded habitat and water quality which may result in water quality standards that are below fish health standards and tissue contamination. Without substantial mitigation and management to improve access to historical habitats and water quality of these systems, shortnose sturgeon populations will likely continue to be depressed until suitable habitat and water quality conditions are achieved. This is particularly evident in some southern rivers that are suspected to no longer support reproducing populations of shortnose sturgeon. The potential for recolonization of some rivers throughout the range of shortnose sturgeon may be further compromised by habitat degradation via dams, dredging and water pollution. The recovery of shortnose sturgeon, particularly in areas where habitat and water quality is severely degraded, will require improvements in the following areas: 1) elimination of barriers to spawning habitat either through dam removal, breaching, or installation of successful fish passage options; 2) operation of water control structures to provide flows compatible with shortnose sturgeon use (especially for spawning and rearing); 3) continued controls on dredging, 4) mitigation of water quality parameters that are restricting sturgeon use of a river (i.e., nutrient loading and low DO) and 5) analysis and mitigation (where possible) of emerging threats from new technologies (such as tidal turbines) and the consequences of climate change.

Overutilization for Commercial, Recreational Scientific or Educational Purposes Commercial Fisheries

The majority of commercial harvest and resultant declines in abundance of shortnose sturgeon occurred at the turn of the 20th century with the combined sturgeon fisheries along the U.S. east coast (Murawski and Pacheco 1977). Native American fisherman harvested shortnose sturgeon for their meat and caviar (Hildebrand and Schroeder 1928, Saffron 2004) and early settlers reluctantly turned to east coast sturgeon as a food source for themselves and their animals (Saffron 2004). Commercial exploitation of shortnose sturgeon for meat began in colonial times and peaked in the late 1880s followed by a precipitous decline; and continued periodically into the 1950s. Sturgeon were first processed for caviar in the U.S. beginning in the middle of the 19th century but initial attempts at processing failed, producing a spoiled product (Saffron 2004). Later when the processing and preservation of caviar was perfected in 1870, the demand for caviar export from the U.S. rapidly expanded (Saffron 2004). By 1880, major commercial fisheries for sturgeon were established along much of the U.S. east coast including New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, North Carolina, South Carolina, and Georgia (Smith 1985). Annual harvest reached a high of 7 million pounds in 1890 but the intense demand for caviar quickly devastated sturgeon populations. By the turn of the century stocks began to collapse, and in 1920 only 22,000 pounds were reported landed (Smith 1985).

Bycatch

Directed harvest of both shortnose and Atlantic sturgeon is prohibited. As stated earlier, shortnose sturgeon are listed as endangered under the ESA and therefore prohibited from take.

In 1998, the Atlantic States Marine Fisheries Commission (ASMFC) imposed a coast-wide fishing moratorium on Atlantic sturgeon until 20 year classes of adult females could be established (ASMFC 1998). NMFS followed this action by closing the Exclusive Economic Zone (EEZ) to Atlantic sturgeon take in 1999. Shortnose sturgeon has likely benefited from this closure as any bycatch in the fishery targeting Atlantic sturgeon has been eliminated.

Although directed harvest of shortnose sturgeon has been prohibited since 1967, incidental capture of shortnose sturgeon in fisheries targeting other species has been documented throughout its range (Table 19). While shortnose sturgeon caught incidentally cannot be landed, bycatch can be a threat if fish are injured or killed or if the capture interferes with important behaviors (such as reproduction). For example, if a pre-spawning female is captured and released on a spawning run and subsequently abandons the spawning activity, then the annual potential reproductive output of that individual is lost.

Shortnose sturgeon are considered to be sensitive to fishing mortality as they are a long-lived species, reach maturity at an older age, have lower maximum fecundity values, and 50% lifetime egg production occurs late in life (Boreman 1997).

The Recovery Plan for shortnose sturgeon (NMFS 1998) lists commercial and recreational shad fisheries as a source of bycatch. Although shortnose sturgeon are primarily captured in gillnets, they have also been documented in the following gears: pound nets, fyke/hoop nets, catfish traps, shrimp trawls and hook and line fisheries (recreational angling). Adult shortnose sturgeon are believed to be especially vulnerable to fishing gears for anadromous species (such as shad, striped bass, alewives and herring) during times of extensive migration – particularly their spawning migration (Litwiler 2001). Shortnose sturgeon bycatch in the southern trawl fishery for shrimp (*Penaerrs* spp.) was estimated at 8% (Collins et al. 1996).

Bycatch of shortnose sturgeon from the shad gillnet fisheries can be quite substantial. Catch rates in drift gillnets are believed to be lower than for fixed nets, longer soak times appear to be correlated with higher rates of mortalities, and the cooler water temperatures likely increase release survivability of shortnose sturgeon. Of the 51 shortnose sturgeon captured in the SC American shad gillnet fishery, 16% resulted in bycatch mortality and another 20% were visibly injured (Collins et al. 1996). See River Summaries section for detailed information of shortnose sturgeon bycatch by river. Additional research is needed to observe and quantify bycatch and fishing effort. These data will allow more refined estimates of bycatch and potential impacts on the recovery rate across a range of gear and water temperature.

Table 19. Reported incidental capture of shortnose sturgeon with associated fishing effort by river.

Population Unit	DPS	Incidental Captures of Shortnose Sturgeon	Fishing effort in the river (reported for gear types known to incidentallly capture SNS)
Penobscot	Gulf of ME	None reported or observed	No commercial gillnetting allowed; other commercial fishing activity is limited. Recreational angling.
Kennebec Complex	Gulf of ME	None reported or observed	Limited bait gillnetting is allowed but commercial fishing activity is very limited. Recreational angling.
Piscataqua	Gulf of ME	None reported or observed. Presence of shortnose in this river is unknown	Recreational angling regulations include : limited use of nets and weir; hook and line; and bow and dip netting. Piscataqua River, including Great Bay estuary and tributaries (inland of the Memorial Bridge) – is closed to the use of gill nets with mesh larger than 3 inches.
Merrimack	Gulf of ME	Suspected in the recreational hook and line fisheries, particularly by catfish anglers using baited hooks on the river bottom.	No commercial gillnetting. Recreational Angling
Connecticut	CT/Hous	Beginning in 2000, reports of incidentally captured sturgeons (Atlantic and SNS) in the shad fishery have ranged from 15–74 per year	Commercial gillnet for American shad in lower river. Recreational angling in lower and upper segments.
Housatonic	CT/Hous	None reported or observed (presence of shortnose in this river is rare)	Commercial fishing is not prhibited but there is limited or no commercail fishing effort. Recreational angling.
Hudson	HD	Reported in the commercial gillnet fishery for shad (fixed & drift gillnets) (see table 21) and in the recreational fishery for shad on the spawning grounds in spring.	Commercial gillnet fishing for shad. Recreational hook and line fishery for shad.
Delaware	DE/Ches.	Reported in the commercial gillnet fishery for shad (fixed & drift gillnets) and in the recreational fishery for shad on the spawning grounds in spring.	Commercial gillnet fishing for shad. Recreational hook and line fishery for shad.
"Chesapeake" & C&D	DE/Ches.	SNS reported in reward program for Atlantic sturgeon (1996 to present) were incidentally caught in commercial fisheries: 35% gillnets; 33% pound nets; most of the remainder in fyke/hoop nets	Commercial drift and anchored gillnet fishery. Commercial pound net and fyke and hoop net fisheries. Commercial trap fisheries for cat fish.
Susquehanna	DE/Ches.	Since 1996-present, 8 SNS were incidentally caught in commercial fisheries on/near flats. 6 in catfish traps; 1 in hoop net; 1 in gillnet. Bycactch of SNS by recreational anglers near Conowingo Dam rare (2 reported in 1986)	Same as Chesapeake (above)
Potomac	DE/Ches.	See Chesapeake (above)	Same as Chesapeake (above)

Population Unit	DPS	Incidental Captures of Shortnose Sturgeon	Fishing effort in the river (reported for gear types known to incidentallly capture SNS)
Roanoke	SE Rivers	capture of a SNS in Albemarle Sound/Roanoke in a gillnet in 1998. If pop were restored, bycatch in commercial fisheries would have to be addressed.	
Chowan		no documented shortnose captures	
Tar/Pamlico		no documented shortnose captures	
Neuse		no documented shortnose captures	
New		no documented shortnose captures	
North		no documented shortnose captures	
Cape Fear		Documented incidental capturein a commercial gillnet in 1987.	Multiple com fisheries. Moser and Ross (1995) indicated that "Shortnose sturgeons are very rare in the Cape Fear River drainage and are extremely susceptible to both set and drifting gill nets that target striped bass (Morone saxatilis) and American shad (Alosa sapidissima)
Winyah Bay Complex		A 16 % bycatch mortality has been documented in the American shad gillnet fishery and another 20 % of bycaught fish were visibly injured in this fishery	
Lower Santee		There is shortnose sturgeon bycatch mortality in the commercial American shad fishery in the Santee River, which is heavily fished. Gillnets are not permitted in the Cooper River. Bycatch in commercial catfish traps in the Congaree River has been documented and, unusually, in the commercial catfish trotline (longline) fishery as well as in the recreational hook-and-line fishery in Lake Marion.	Mandatory self-reported effotr and bycatch by the commercial shad fishery in the Santee River began in 2000. Number of liceses vary between 71 and 33; annual trips between 903 and 486. The number of shortnose sturgeon reported as bycatch to ASMFC between 2000 and 2007 varied between 0 and 12 fish.
Cooper		See above	
S-C Reservoir Sys		Shortnose sturgeon captured on baited hooks by recreational fishers were ustilized in a tagging study (Collins et al., 2003). This unusual method of capture may be the result to limited food availbility.	
ACE Basin		Bycatch mortality in the commercial fishery for Am.shad represents some threat, but fishing effort has declined dramatically in recent years, perhaps because abundance of shad has also declined.	
Savannah		Bycatch in the commercial shad fishery has in the past been substantial, with one fisherman catching at least 123 adults by himself in a single shad season (which unfortunately coincides with the SNS spawning migration).	
Ogeechee		Bycatch documented in (relatively sm) Am shad gilllnet fishery (occurs from January 1 - March 3)	
Altamaha		A recent study of the shad fishery on the Altamaha using set gill nets between the head of tide to above the shortnose sturgeon spawing areas indicated a high degree of bycatch of spawning individuals.	Bycatch of sturgeon by the shad fishery in the Altamaha River, Georgia. Finding presented as oral presentaiton at 2009 AFS Annual Meeting. Robert Bahn(1), Douglas Peterson(1), Joel Fleming(2). (1)University of Georgia, Athens, GA, United States; (2)Georgia Department of Natural Resources, Georgia, United States
Satilla		Shad fishing is permitted on the Satilla River. Because researchers have recently captured Atlantic sturgeon in the river, sturgeon bycatch is possible, but unquantified at this time. If the shad stocks were to recover, then it could be a potential to SNS	
St. Mary's		Shad fishing is permitted on the St. Marys River. Sturgeon bycatch is possible, but unquantified at this time. If the shad stocks were to recover, then it could be a potential to S	

Poaching

Shortnose sturgeon are likely targeted by poachers throughout their range, and likely have greater pressure in areas where they are more abundant (such as on the spawning grounds); however the extent at which poaching is occurring is difficult to assess (Dadswell 1979, Dovel et al. 1992, Collins et al. 1996). There have been several documented cases of shortnose sturgeon caught by recreational anglers. One shortnose sturgeon illegally taken on the Delaware River was documented by a NJ DFW conservation officer in Trenton, New Jersey: the officer observed a man wrap a fish in plastic bag and put it in the back of his truck. Upon questioning, the man said he had caught a carp. When the officer asked to see the fish he discovered a live 34" shortnose sturgeon. He took a picture and measured it then returned it to the water (NJCOA 2006). Additionally, citations have been issued for illegal recreational fishing of shortnose sturgeon in the vicinity of Troy, New York (see River Summaries section – Hudson River). Lastly, at least one case of poaching was documented on the Cooper River, South Carolina (see River Summaries section – Cooper River).

Poaching has been documented for other sturgeon species in the United States. Cohen (1997) documented poaching of white sturgeon from the Columbia River that were later sold to buyers on the U.S. east coast. Poaching of Atlantic sturgeon has been documented by law enforcement agencies in Virginia, South Carolina, and New York and is considered a potentially significant threat to the species, but the present extent and magnitude is largely unknown (ASSRT 2007).

Scientific research

ESA Section 9 prohibits the taking of the endangered shortnose sturgeon; however ESA section 10 provides a mechanism to grant exemptions to the section 9 taking prohibitions for scientific research, enhancement, and incidental take permits. Scientific research on shortnose sturgeon is essential to assess the status of the species, obtain critical biological information, and achieve recovery goals. A detailed discussion of current shortnose sturgeon research is provided in Chapter 8. ESA Section 10 research permits provide broad guidance to researchers via permit conditions and established research protocols, which are designed to minimize stress and mortality of shortnose sturgeon.

Summary and evaluation

There is no evidence that the limited mortality associated with scientific research poses a significant threat to the species or to individual river populations. However, shortnose sturgeon are sensitive to overfishing (Boreman 1997) and bycatch (Hightower et al. unpubl. data, see Appendix A). Although the level of bycatch and poaching is mostly unknown, increasing the annual mortality of shortnose sturgeon by only 7% could cause significant population declines in small populations (Hightower et al. unpubl. data, see Appendix A). This suggests that bycatch could have a substantial impact on the status of shortnose sturgeon, especially in populations of small numbers. Efforts should be made to better quantify bycatch across gear types and fishing effort so that fisheries management at the state and Federal level can predict and limit bycatch of shortnose sturgeon.

Competition, Predation and Disease

Competition and Predation

The general scarcity of sturgeon is a major limiting factor in assessing sturgeon species interactions such as competition and predation (Scarnecchia 2000). For example, an entire brood of young sturgeon may be eaten by predators, but researchers may need to sample the stomachs of many predators to find the few sturgeon present (Scarnecchia 2000).

Specific information concerning competition between shortnose sturgeon and other species over habitat and food resources is scarce. There are no known exotic or non-native species that compete directly with shortnose sturgeon. It is likely that species such as suckers or other bottom forage fishes would compete with shortnose sturgeon, but these interactions have not been documented.

Shortnose sturgeon and Atlantic sturgeon occur sympatrically, although their use of fresh, brackish, and marine habitats differs slightly (Niklitschek 2001). Both species spawn in freshwater habitats; shortnose sturgeon spawn earlier and generally farther upriver than Atlantic sturgeon (Bain 1997). Distribution of YOY shortnose and Atlantic sturgeon partially overlap at the freshwater/brackish water interface; shortnose sturgeon primarily occupy freshwater and Atlantic sturgeon primarily occupy brackish regions of estuaries (Dadswell 1979, Dovel and Berggren 1983, Dovel et al. 1992, Bain 1997, Haley 1999, Collins et al. 2000a & b, Niklitschek 2001). Additionally, older juvenile shortnose sturgeon are found predominantly in fresh and oligohaline waters (<15 ppt), while Atlantic sturgeon mainly occupy marine waters after the first 1 to 6 years of life in estuarine waters (Dove1 and Berggren 1983, Dadswell et al. 1984, Smith 1985).

There is some evidence to support that shortnose and Atlantic sturgeon compete for food and space. Analysis of the stomach contents of juvenile shortnose and Atlantic sturgeon captured in the Saint John River system revealed that common food organisms were found in the crop and gizzard of both species (Pottle and Dadswell, 1979). In contrast, Haley et al. (1996) analyzed stomach contents of adult shortnose sturgeon and juvenile Atlantic sturgeon in the Hudson River using gastric lavage, and found clear differences in their diets. Amphipods were the dominant prey obtained from shortnose sturgeon while polychaetes and isopods were primary foods retrieved from Atlantic sturgeon. Haley et al. (1996) also found that while adult shortnose and juvenile Atlantic sturgeon overlap in their use of the lower Hudson River estuary, the overall distribution of the two species differed by river kilometers, providing evidence that shortnose and Atlantic sturgeon may partition space within the Hudson River despite co-occurrence in channel habitats. Further, Kahnle and Hattala (1988) conducted late summer-fall bottom trawl collections in the lower Hudson River Estuary from 1981-1986 and found that most shortnose sturgeon occupied rkm 55-60 in water depths of greater than six meters. Even though their geographic distribution overlapped, the two species were located across different water depth. In Georgia, the distributions of adult shortnose and juvenile Atlantic sturgeon overlap somewhat, but Atlantic sturgeon tend to use more saline habitats than shortnose sturgeon (ASSRT 2007). This finding is consistent with Kieffer and Kynard (1993) who found that adult shortnose sturgeon and subadult Atlantic sturgeon in the Merrimack River, MA were spatially separate except for brief use of the same saline reach in the spring.

M. Litvak (in COSEWIC 2005) suggested that understanding the mechanisms for partitioning resources between Atlantic and shortnose sturgeon is important. Researchers have theorized that partitioning between Atlantic and shortnose sturgeon was influenced by salinity (Appy and Dadswell 1978, Dadswell 1979, NMFS 1998) but it may also be influenced by flow (COSEWIC 2005). Giberson (1999) developed an angular flume to provide individual sturgeon with a choice of different flow rates; in all cases, shortnose sturgeon chose to swim in higher flows than did the Atlantic sturgeon.

Kynard and Horgan (2002) observed larger shortnose sturgeon out-competing smaller individuals for limited forage space in captivity and theorized that dominance hierarchies may exist in the wild. Dominance hierarchies have been noted within and among other fish species and has often affected growth as more aggressive individuals or species may get more of limited food resources (Beacham 1993, Cutts et al. 1998, McCarthy 2001). Giberson (2004) investigated this theory by placing sturgeon in cages and offering them different food regimes. When juvenile shortnose and Atlantic sturgeon are grown together, the presence of Atlantic sturgeon suppresses foraging activity and growth rates of shortnose sturgeon (Giberson 2004). These results suggest that Atlantic sturgeon are an apparently superior competitor and may put pressure on shortnose sturgeon when either food or habitat is limited (COSEWIC 2005). The opposite effect was found in a similar study (Niklitschek 2001) which inferred that a larger relative mouth size made shortnose sturgeon more efficient foragers than Atlantic sturgeon. Future research in resource partitioning between shortnose and Atlantic sturgeon is needed.

The introduction of exotic pecies

There is little information available on introduction of exotic species and their competition with or predation on shortnose sturgeon. Zebra mussels and other invertebrates introduced may impact water quality and indirectly affect spawning areas or food webs critical to sturgeon and paddlefish (Auer 2004).

The introduction of zebra mussels in the Hudson River is discussed in River Summaries section – Hudson River. Zebra mussels caused major declines in the phytoplankton and micro and macro-zooplankton communities (Caraco et al. 1997) and water clarity improved dramatically. Strayer et al. (2004) explored potential effects of zebra mussel impact on YOY fishes. Effects included a decrease in abundance and observed growth rate of YOY open-water fish species (such as American shad) and appeared to benefit littoral species, with population size of several species more than doubling. Distribution of species within the Hudson River also shifted following the zebra mussel invasion: open-water species generally shifted downriver at the same time that populations of littoral species shifted upriver (Daniels et al. 2005). The relationship between shortnose sturgeon and zebra mussels is not clear. Zebra mussels may be out-competing other benthic invertebrates that are prey for shortnose sturgeon but there is also some anecdotal information suggesting that adult shortnose sometimes feed on zebra mussels. McCabe et al. (2006) assessed potential impacts of zebra mussel beds on habitat use and forgaing success of juvenile lake sturgeon (<600mm TL) in the laboratory; juvenile lake sturgeon avoided substrate with zebra mussels preferring all other available habitats, and foraging success was reduced with just 50% mussel cover, particularly for amphipods and isopods (McCabe et al. 2006). The authors theorized that small lake sturgeon were too small to consume zebra mussels and that zebra mussels may render the preferred habitat (sand) unappealing to juvenile lake sturgeon (McCabe et al. 2006).

Water chestnut (*Trapa natans*), is an exotic aquatic plant species that has invaded several river systems occupied by the shortnose sturgeon (e.g., Hudson, Potomac and Connecticut rivers). There have been annual surveys and removal efforts in the Connecticut River and its tributaries at numerous sites between South Hadley, MA and Hartford Windsor, CT. From 2004–2008 over 16 tons of water chestnut were removed by volunteers and Silvio O. Conte National Fish and Wildlife Refuge staff (M. Kieffer, CAFRC, pers. comm. 2008). Water chestnut alters fish habitat by increasing both the amount of vegetative cover and spatial complexity in the littoral zone and affects concentrations of both dissolved oxygen and nutrients (Caraco and Cole 2002). Although the water chestnut typically occupies shallow water (< 2 m depth), adult and juvenile shortnose sturgeon in the Connecticut River have been documented using depths shallower than 2 m (Kynard et al. 2000).

Predation

There is very little documentation of predation on any life stage of shortnose sturgeon though there is a correlation between size and survival (bigger individuals are less susceptible to predation). Accordingly, juvenile and adult shortnose sturgeon have few predators, particularly in freshwater habitats (Gilbert 1989). YOY shortnose sturgeon (approximately 5 cm FL) were found in the stomachs of yellow perch (*Perca flavescens*) in the Androscoggin River, ME, (Dadswell et al. 1984). Adult shortnose sturgeon are less likely targets for predation owing to their larger size, bony scutes and their deep water habits. Predation on an adult shortnose sturgeon was recently documented on the Penobscot River, ME, where a gray seal (*Halichoerus grypus*) caught and partially consumed a shortnose sturgeon while it was being actively tracked (Fernandes et al. 2008). A second anecdotal account of seal predation on a sturgeon was recently reported (2008) by a fisherman on the same river (P. Dione, UME, pers. comm. 2008). Alligators (*Alligator mississippiensis*) may be potential predators in the south, along with sharks, or other large fishes (e.g., gar, catfish). Predation by birds on shortnose sturgeon has not been documented but one SRT member thought that eagles could potentially target shortnose sturgeon in shallow areas and Dadswell et al. (1984) considered that certain marine birds could too.

Other known predators of sturgeon include sea lampreys (*Petromyzon marinus*), gar (*Lepisosteus sp.*), striped bass (*Morone saxatilis*), common carp (*Cyprinus carpio*), northern pikeminnow (*Ptychocheilus oregonensis*), channel catfish (*Ictalurus punctatus*), smallmouth bass (*Micropterus dolomieu*), yellow perch (*Perca flavescens*), walleye (*Sander vitreus*), grey seal (*Halichoerus grypus*), fallfish (*Semotilus corporalis)* and sea lion (*Zalophus californianus*) (Scott and Crossman 1973, Dadswell et al. 1984, Miller and Beckman 1996, Kynard and Horgan 2002, Gadomski and Parsley 2005, Fernandes et al. 2008, Wurfel and Norman 2006, Fernandes 2008).

Predation of sturgeon eggs has also been documented. MacNeill and Busch (1994) reported that mudpuppies, crayfish, carp, and suckers feed on lake sturgeon eggs in the lower Great Lakes. Miller and Beckman (1996), reported that northern squawfish (*Ptychocheilus oregonensis*), large scale sucker (*Catastomus macrocheilus*), prickly sculpin (*Cottus asper*), and common carp fed on white sturgeon eggs in the Columbia River. Additionally, several species of predatory fish intensively forage on eggs of Chinese sturgeon as they are spawned (Wei 2003). Lastly, Dovel (1979) hypothesized that American eels may be predators of both shortnose and Atlantic sturgeon eggs.

Gadomski and Parsely (2005) investigated the size of white sturgeon when they are preyed upon by channel catfish, northern pikeminnow, walleyes, and prickly sculpins (*Cottus asper*): channel catfish (mean TL = 472 mm), northern pikeminnow (mean TL = 464 mm), and prickly sculpin (mean TL = 126 mm) fed on juvenile sturgeon of an average size of 121 mm TL, 134 mm TL, and 50 mm TL, respectively. Oddly, similar size walleye (~470 mm TL) rarely fed on white sturgeon, but juvenile walleye (mean TL = 184 mm) consumed sturgeon with a mean size of 59 mm TL. Gadomski and Parsley (2005) suggest that these findings indicate that predation could play an important role in sturgeon recovery.

Similarly, Brown et al. (2005) concluded that the "…introduction of [flathead catfish] has the potential to adversely affect ongoing anadromous fish restoration programs and native fish conservation efforts in the Delaware and Susquehanna basins." The same concern has been stated by fishery management agencies along the southern U.S. where flathead catfish are firmly established in many river basins and have reached considerable biomass, significantly altering native fish assemblages and biomass in the process. However, it is unknown if flathead catfish compete with or consume shortnose sturgeon in the wild. Moser et al. (2000b) tested whether flathead catfish (*Pylodictus olivaris*) preyed on shortnose sturgeon (30 cm) in a controlled system, and despite sturgeon being the only prey available, none were consumed.

Lastly, the accidental introduction of exotic sturgeon species by aquarium enthusiasts or aquaculturalists could potentially threaten existing populations of shortnose sturgeon (ASSRT 2007). These species include but are not limited to white sturgeon (*Acipenser transmontanus*), lake sturgeon (*A. fulvescens*) and Russian sturgeon (*A. gueldenstaedtii*), Russian sturgeon were recently marketed illegally as "diamond sturgeon" on ebay (M. Kieffer, USGS, pers. comm. 2008).

Disease

There is little information available on the diseases of shortnose sturgeon. There have been very few incidences of disease in wild populations of sturgeon species and most disease related mortality has been documented in captive rearing facilities.

While disease is rarely documented for shortnose sturgeon in the wild, there have been several documented or suspected incidences in aquaculture facilities. An epizootic of *Columnaris* sp., a myxobacterium causing ulcerated lesions, occurred at the USFWS' Orangeburg Hatchery in South Carolina (Amlacher 1970, NMFS 1998). More recently, at the USFWS Bears Bluff Hatchery in South Carolina, shortnose sturgeon exhibited significant signs of stress from an unknown vector. Symptoms included lesions on the body, lethargy in the larger individuals, and the large-scale mortality of offspring. Hatchery officials sent tissue samples of the lesions to several different labs for analysis. Each noted that the health issue was related to a virus, but each lab cited a different virus as the cause. Subsequently all shortnose sturgeon housed at the hatchery were euthanized and the facility cleaned. Hatchery officials do not know what caused the problem but suspect it was related to the environmental conditions at the Bears Bluff facility as fish previously transferred to other hatcheries did not exhibit symptoms.

Viral diseases have been documented in other sturgeon species in aquaculture facilities. The white sturgeon iridovirus (WSIV) was first detected in cultured white sturgeon in California in 1988 (LaPatra et al. 1994). It is known to cause mortality in the early life stages and secondary bacterial and protozoal infections are common. Clinical signs of WSIV include anorexia and skin lesions. WSIV is of concern because it is thought to be carried by wild sturgeon and has been shown to cause significant mortalities in juvenile white sturgeon (Hedrick et al. 1990, 1992, LaPatra et al. 1994).

The shovelnose sturgeon iridovirus (SSIV) a viral pathogen, similar in appearance to WSIV was first detected in cultured progeny of wild adults collected from the Missouri River (MacConnell et al. 2001). The virus, which is thought to be the first documentation of a virus in shovelnose or pallid sturgeon, has the ability to cause debilitating disease and large-scale mortalities (MacConnell et al. 2001).

LaPatra et al. (1995) demonstrated that a rhabdovirus, infectious hemotopoietic necrosis virus (IHNV), can be carried by white sturgeon. IHNV is one of the most lethal diseases of salmonids, but currently the disease is confined to the western U.S. While LaPatra et al. (1995) states no mortality has been reported in sturgeon exposed to IHNV, there is concern among fish health biologists that any movement of sturgeon carrying the IHNV virus to the U.S. east coast could spread the disease to salmonid populations with potentially devastating consequences.

Fin rot, a fungal disease, has been documented in wild shortnose sturgeon. Dovel et al. (1992) reported that more than 75% (447 of 586 individuals) of adult shortnose sturgeon captured in the Hudson River (1975-1980) had severe incidence of fin rot. The fungus is thought to act as either a primary pathogen that overcomes the immune system or as a secondary pathogen that has invaded after disease resistance has been reduced. Some researchers have hypothesized that PCBs may lower the sturgeon's resistance to fin rot (Dovel et al. 1992) but more recent observations of shortnose sturgeon in the Hudson River (see River Summaries section – Hudson River) revealed no incidence of fin rot although PCB concentration remain high.

Fungal disease also appears to affect shortnose sturgeon eggs grown in hatcheries (Litvak in COSEWIC 2005). Hatchery workers have learned to coat eggs with Fuller's earth to prevent clumping and then reared in MacDonald jars with a flow of 3 l/min (COSEWIC 2005). Despite these efforts, a portion of the eggs grown in captivity still succumb to fungal infections. Kynard (1997) observed that 8% of egg mortality at a natural spawning site on the Connecticut River was due to fungal infections.

As mentioned under earlied in the section titled "Competition and Predation,"predation", the introduction of non-native sturgeon species sold as pets in the aquarium trade and subsequently released into the wild could also conceivably cause the spread of infection. White sturgeon have been imported into North Carolina and possibly other U.S. east coast states and sold in the aquarium trade. It is unclear whether a ban imposed by a fishery management agency on importation of a species would apply to the pet industry (ASSRT 2007).

Parasites

Dadswell et al. (1984) provided a list of shortnose sturgeon parasites and related information including the location of the parasite on the individual, capture location, and the information source. Gilbert (1989) summarized this work: 13 taxa were represented including four coelenterates, two nematodes, three hirundinids (leeches), one arthropod, and the sea lamprey. Of these parasites, the coelenterates, nematodes, and acanthocephalans are internal and the remainder were external. The degree of infestation is believed to be quite low with the exception of *Capillospirura* sp. (Dadswell et al. 1984) and shortnose sturgeon do not appear to be harmed by these parasites.

Summary and Evaluation

As benthic foragers, shortnose sturgeon may compete with other bottom-feeding fishes and invertebrates for prey, but there is no evidence of abnormally elevated interspecific competition. Most studies of the potentially competitive relationship between shortnose and Atlantic sturgeon indicate that while shortnose and Atlantic sturgeon may overlap in their use of habitats, their overall differences in distribution by river kilometers, depth, salinity, and perhaps flow indicate resource partitioning. The mechanisms of this partitioning and the theory that shortnose and Atlantic sturgeon may form dominance hierarchies for limited forage space, requires further investigation.

The potential for predation by flathead catfish and other exotic species on juvenile sturgeon needs further investigation (Brown et al. 2005). The extent of seal predation on shortnose sturgeon in northern rivers is also of interest.

There is concern that non-indigenous sturgeon pathogens could be introduced, most likely through aquaculture operations. Additionally, the aquarium industry is another possible source for transfer of non-indigenous pathogens or non-indigenous species from one geographic area to another, primarily through release of aquaria fishes into public waters. With millions of aquaria fishes sold to individuals annually, it is unlikely that such activity could ever be effectively regulated. Definitive evidence that aquaria fishes could be blamed for transmitting a non-indigenous pathogen to wild fish (sturgeon) populations would be very difficult to collect (J. Coll and J. Thoesen, USFWS, pers. comm. 1998 as referenced in ASSRT 2007).

Inadequacy of existing regulatory mechanisms

Numerous Federal, state and inter-jurisdictional laws, regulations and policies govern activities that have the potential to affect the shortnose sturgeon and their habitat. A summary of the regulatory mechanisms that are likely aiding in the recovery of shortnose sturgeon is provided below.

International

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)

CITES was enacted to ensure that commercial demand does not threaten the survival of listed species in the wild. It is an international treaty that regulates international trade in listed species of plants and animals through a permit system. Shortnose sturgeon are listed under Appendix I (endangered), which requires both the importing country to issue an import permit and the exporting country to issue an export permit. The USFWS Office of Management Authority administers CITES in the U.S. and processes any applications for shortnose sturgeon import or export.

International Union for the Conservation of Nature and Natural Resources (IUCN)

The IUCN's (often called the World Conservation Union) mission is to influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable. The IUCN developed the "Red List" to assess the conservation status of species, subspecies, varieties and selected subpopulations on a global scale in order to highlight taxa threatened with extinction. Shortnose sturgeon have had IUCN "Red List" Status as Vulnerable since 1986. The last assessment was conducted in 2004 and shortnose sturgeon remain listed by the IUCN as vulnerable based in part on an estimated range reduction of greater than 30% over the past three generations, irreversible habitat losses, effects of habitat alteration and degradation, degraded water quality and extreme fluctuations in the number of mature individuals between rivers.

Canadian Authorities

In Canada, management of shortnose sturgeon falls under the jurisdiction of the Department of Fisheries and Oceans (DFO). Shortnose sturgeon were listed as a species of Special Concern in Canada in 1980 and maintained that status in a 2005 assessment (COSEWIC 2005).

National

Endangered Species Act (16 USC §1531-1544)

Federal efforts to protect endangered and threatened species began with the passage of the Endangered Species Preservation Act of 1966 and shortnose sturgeon were listed under this Act on March 11, 1967. The Endangered Species Preservation Act was followed by the Endangered Species Conservation Act of 1969, which was in turn followed by the ESA of 1973.
The ESA protects plants and animals identified as endangered or threatened with extinction and also protects the habitat on which they depend. It is administered by both USFWS and NMFS. Species that are in decline are listed as either endangered or threatened based on assessments of the risk of their extinction. Once a species is listed, legal tools become available to aid in its recovery and to protect its habitat.

Atlantic States Marine Fisheries Commission (ASMFC) and Enabling Legislation

Authorized under the terms of the Atlantic States Marine Fisheries Compact, as amended (P.L. 81-721), the purpose of the ASMFC is to promote better use of fisheries (marine, shellfish, and anadromous) of the Atlantic seaboard "by the development of a joint program for the promotion and protection of such fisheries, and by the prevention of the physical waste of the fisheries from any cause."

Given management authority in 1993 under the Atlantic Coastal Fisheries Cooperative Management Act (16 U.S.C. 5101-5108), the ASMFC may issue interstate Fishery Management Plans (FMPs) that must be administered by state agencies. If the Commission believes that a state is not in compliance with a coastal FMP, it must notify the Secretaries of Commerce and Interior. If the Secretaries find the state not in compliance with the management plan, the Secretaries must declare a moratorium on the fishery in question. To date, this has only happened once when a state was not found in compliance with the striped bass coastal FMP.

Some additional protections for shortnose sturgeon may have been afforded in 1998 when the ASMFC amended the 1990 Atlantic Sturgeon Management Plan and issued a moratorium for commercial fishing of Atlantic sturgeon. Shortnose sturgeon resemble Atlantic sturgeon and co-occur in many riverine and bay habitats throughout its range, therefore, this moratorium may have reduced the risk of illegal bycatch of shortnose sturgeon in fisheries for Atlantic sturgeon. The Atlantic sturgeon moratorium is designed to be in effect until 20 year classes of adults are established, effectively closing this fishery for 20–40 years.

American Fisheries Society (AFS)

The AFS listed shortnose sturgeon on their list of imperiled North American fishes as threatened in 1989 (Williams et al. 1989). More recently the shortnose sturgeon was reclassified as "endangered" as their status has declined since 1989 (Jelks et al. 2008). "Endangered" in this report was defined as follows: "a taxon that is in imminent danger of extinction throughout all or extirpation from a significant portion of its range". The 2008 AFS report also outlines their criteria and shortnose sturgeon were listed as endangered based on the following: 1) present or threatened destruction, modification, or reduction of the taxon's habitat or range, and 2) over-exploitation for commercial, recreational, scientific, or educational purposes including intentional eradication or indirect impacts of fishing (Jelks et al. 2008).

The Lacey Act Amendments of 1981 (16 U.S.C. 3371-3378; Pub. L. 97-7)

The Lacey Act is a valuable tool for law enforcement agents in their efforts to control smuggling and trade of illegally taken fish, wildlife, or plants. The Lacey Act makes it a Federal crime to participate in the trade of fish, wildlife, or plants that are taken, possessed, transported, or sold in violation of any Federal, state, tribal, or foreign law. The 1981 amendments strengthened Federal laws and improved Federal assistance to states and foreign governments in enforcement of fish and wildlife laws. The Act allows the Secretary of Commerce to offer rewards for information furthering the intent of this Act. The Act also allows for the seizure of vessels, vehicles, aircraft, and other equipment used to aid in the criminal violation of this Act (Buck 1995).

The Federal Power Act (FPA) (16 U.S.C. 791a-828c

This Act requires hydropower project owners to obtain a license from the Federal Energy Regulatory Commission (FERC). Section 10(j) of the Act provides that licenses issued by FERC contain conditions to protect, mitigate damages to, and enhance fish and wildlife based on recommendations received from state and Federal agencies, including NMFS, during the licensing process. Specifically Section 18 requires a FERC license to construct, maintain, and operate fishways prescribed by the Secretary of the Interior or the Secretary of Commerce. Under the Act, others may review proposed projects and make timely recommendations to FERC to represent additional interests. Interested parties may intervene in the FERC proceeding for any project in order to receive pertinent documentation and to appeal an adverse decision by FERC.

Anadromous Fish Conservation Act (16 U.S.C. 757a-757f)

This law, passed in 1965, authorizes the Secretaries of Interior and Commerce to enter into cooperative agreements and cost sharing with states and other non-Federal interests for the conservation, development, and enhancement of the nation's anadromous fishes. Pursuant to the agreements authorized under the Act, the Secretary may: 1) conduct investigations, engineering and biological surveys, and research; 2) carry out stream clearance activities; 3) undertake actions to facilitate the fishery resources and their free migration; 4) use fish hatcheries to accomplish the purposes of this Act; 5) study and make recommendations regarding the development and management of streams and other bodies of water consistent with the intent of the Act; 6) acquire lands or interest therein; 7) accept donations to be used for acquiring or managing lands or interests therein; and 8) administer such lands or interest therein in a manner consistent with the intent of this Act (Buck 1995).

Studies on the status, distribution, abundance, and movements of shortnose in the Connecticut and Delaware rivers, and rivers in Georgia have been funded by the NMFS under this Act. Additionally, funding from this Act has supported striped bass surveys in the Hudson River which have furnished information on shortnose and Atlantic sturgeon (K. Hattala, NY DEC, pers. comm. 2008).

The Fish and Wildlife Coordination Act (16 U.S.C. 661-666c)

The Fish and Wildlife Coordination Act (FWCA) requires equal consideration of fish and wildlife resources to other project features in proposed Federal water resource development projects. Under this law, whenever a body of water is proposed to be modified in any way and a Federal permit or license is required, the Secretaries of Commerce and Interior may investigate and advise on the effects of the project on fish and wildlife resources. Such reports and recommendations, which require concurrence of the state fish and wildlife agency(ies) involved, must accompany the construction agency's request for congressional authorization, although the construction agency is not bound by the recommendations. Typical FWCA recommendations for maintenance dredging include construction "windows" to avoid times and locations where shortnose sturgeon may be spawning.

The FWCA applies to water-related activities proposed by non-Federal entities for which a Federal permit or license is required. The most significant permits or licenses required are Section 404 and discharge permits under the Clean Water Act, and Section 10 permits under the Rivers and Harbors Act. Both USFWS and NMFS may review the proposed permit action and make recommendations to the permitting agencies to avoid or mitigate any potential adverse effects on fish and wildlife habitat. These recommendations must be given full consideration by the permitting agency, but are not binding.

Federal Water Pollution Control Act, or the "Clean Water Act" (CWA) (33 U.S.C. 1251-1376)

The Federal Water Pollution Control Act (FWPA), also called the "Clean Water Act," is a broad statute with the goal of maintaining and restoring waters of the United States. The Clean Water Act authorizes water quality and pollution research, sets pollution discharge and water quality standards, offers grants for sewage treatment facilities, addresses oil and hazardous substances liability, and establishes permit programs for water quality, point source pollutant discharges, ocean pollution discharges, and dredging or filling of wetlands (Buck 1995). The law provides for assessment of injury, destruction, or loss of natural resources caused by discharge of pollutants. Of major significance to shortnose sturgeon habitat, is Section 404 of the Clean Water Act, which prohibits the discharge of dredged or fill material into navigable waters without a permit. The permit program is administered by the ACOE. The EPA may approve delegation of Section 404 permit authority for certain waters (not including traditional navigable waters) to a state agency; however, the EPA retains the authority to prohibit or deny a proposed discharge under Section 404 of the Clean Water Act.

Section 401 of the Clean Water Act authorizes programs to remove or limit the entry of various types of pollutants into the nation's waters. A point source permit system was established by the EPA and is now being administered at the state level in most states. This system, referred to as the National Pollutant Discharge Elimination System (NPDES), sets specific limits on discharge of various types of pollutants from point source outfalls. In addition, a non-point source control program focuses primarily on the reduction of agricultural siltation and chemical pollution resulting from rain runoff into the nation's streams. This control effort currently relies on the use of land management practices to reduce surface runoff through programs administered primarily by the Department of Agriculture.

Like the Fish and Wildlife Coordination and River and Harbors Acts, Sections 401 and 404 of the Clean Water Act have played a role in reducing discharges of pollutants, restricting the timing and location of dredge and fill operations, and affecting other changes that have improved shortnose sturgeon habitat in many rivers and estuaries over the last several decades. Examples include reductions in sewage discharges into the Hudson River (K. Hattala, NY DEC, pers. comm. 2008) and nutrient reduction strategies implemented in the Chesapeake Bay (Secor 2002).

Rivers and Harbors Act of 1899

Section 10 of the Rivers and Harbors Act requires a permit from the ACOE to place structures in navigable waters of the United States or modify a navigable stream by excavation or filling activities.

National Environmental Policy Act of 1969 (NEPA) (42 U.S.C. 4321-4347)

NEPA applies to Federal agencies and the programs they fund. It requires Federal agencies to consider and analyze the potential effects of a proposed Federal action which would significantly affect historical, cultural, or natural aspects of the environment (Buck 1995). An "environmental impact statement (EIS)" is required for major Federal actions that may affect the quality of the human environment. A less rigorous EIS is prepared and reviewed for most other actions, while some actions are categorically excluded from formal review. These reviews provide an opportunity for the agency and the public to comment on projects that may impact fish and wildlife habitat.

Coastal Zone Management Act (16 U.S.C. 1451-1464) and Estuarine Areas Act

Congress passed the Coastal Zone Management Act (CZMA) in 1972 to encourage states to better manage coastal areas. The Act provides grants to states that develop and implement Federally-approved coastal zone management plans. It also allows states with approved plans to review Federal actions to ensure that they are consistent with state plans. The National Estuarine Research Reserve System (NERRS) is authorized by CZMA. The NERRS is a partnership between coastal states and NOAA that supports long-term research, education, and coastal stewardship. There are currently 27 National Estuarine Research Reserves nationwide.

The Estuary Protection Act (16 USC 1221-1226; PL 90-454)

The Estuary Protection Act is designed to protect, conserve, and restore estuarine resources. Compliance with the Estuary Protection Act requires that projects and studies funded by Congress (e.g., ACOE planning or construction projects) consider the effect of the project on estuaries and their resources. Information from state coastal management programs and local planning agencies can assist in determining what environmental resources exist in the project area and potential impacts of these activities on the coastal zone and estuaries.

Federal Land Management and Other Protective Designations

Protection and good stewardship of lands and waters managed by Federal conservation agencies, such as the Departments of Defense and Energy (as well as state-protected park, wildlife and other natural areas), contributes to the health of nearby aquatic systems that support important shortnose sturgeon spawning and nursery habitats. Relevant examples include the ACE Basin National Wildlife Refuge and the Savannah-Pinckney National Wildlife Refuges.

Marine Protection, Research and Sanctuaries Act of 1972 (MPRSA), Titles I and III and the Shore Protection Act of 1988 (SPA)

The MPRSA protects fish habitat through establishment and maintenance of marine sanctuaries. This Act and the SPA regulate ocean transportation and dumping of dredge materials, sewage sludge, and other materials. Criteria that the ACOE uses for issuing permits includes consideration of the effects dumping has on the marine environment, ecological systems, and fisheries resources.

State

Shortnose sturgeon are currently protected in all the coastal states along their range by the ESA. In addition, many states maintain their own endangered species list that may include shortnose sturgeon; individual states then mandate protections for those listed animals. States listing shortnose sturgeon as protected under state law are listed in the River Summaries section. In addition many state laws and regulations limit benthic habitat destruction and flow alterations, some of which mirror or implement Federal clean water law, that provide protection to the shortnose sturgeon or the habitat upon which they depend.

Section 6 of the ESA encourages cooperation between the federal and state governments to protest ESA-listed species. A state may apply and obtain a cooperative agreement; in turn research dollars are available. Currently eight states (ME, MA, NY, NJ, DE, NC, SC and GA) have an ESA Section 6 agreement to assist in the recovery of the shortnose sturgeon.

Other natural or manmade factors affecting the continued existence of the species

Ship strikes

Ship strikes have been documented for Atlantic sturgeon, particularly on the Delaware, James, and Cape Fear Rivers (ASSRT 2007) and seem to occur most frequently in rivers that support large ports and have relatively narrow waterways. Atlantic sturgeon (usually 120-240 cm in length) that apparently have been struck by ships are reported each spring to the Delaware Division of Fish and Wildlife (DE DFW) (ASSRT 2007). Although most strikes to Atlantic sturgeon on the Delaware River are believed to be from large ocean going vessels at least one strike was reported from a smaller craft (ASSRT 2007).

Fewer boat strikes to shortnose sturgeon are known to occur, perhaps due to their smaller size. In recent years (2006-2008) there have been several reports of boat strikes to shortnose sturgeon: 2 in the Delaware River and one in the Kennebec River. Details of each report follow:

1. November 28, 2007 - one adult female shortnose sturgeon was removed dead from the intake trash racks at the Salem Nuclear Generating Station on the Delaware River. Staff at the generating station reported that the carcass appeared to have been lacerated, with a pattern suggesting propeller injuries but unfortunately the carcass was discarded and no pictures were taken (PSEG Nuclear LLC 2007).

2. July 7, 2008 - a sturgeon was collected dead from the Delaware River near Philadelphia. A necropsy was performed and head trauma was reported as a possible propeller wound. Review of the photos revealed that the wound could also been the result of blunt trauma or a crushing wound to the head and cause of death could not be attributed to ship strike.

3. November 5, 2008 - ME DMR staff observed a small (<20) ft boat transiting the Kennebec River at high speeds over a known shortnose sturgeon wintering aggregation site. When they approached the area in their own vessel they discovered a freshly dead shortnose sturgeon floating at the surface. This individual was collected and necropsied and propeller injury was documented on the right side of the mouth and gills. This may be the first confirmed incidence of ship strike on a shortnose sturgeon.

Although rare, ship strike of just one large female could have detrimental effects on small populations (< 100 adults) of shortnose sturgeon.

Artificial propagation

There are currently two companies producing shortnose sturgeon via artificial propagation in Canada. Both are located on the Saint John River and one is currently operating at a commercial scale (see River Summaries section – Saint John River for more information). In the U.S. USFWS has been culturing shortnose sturgeon for approximately 22 years. Until recently Bears Bluff National Fish Hatchery in SC raised the bulk of the shortnose sturgeon although some were also reared at the USFWS' Warm Springs, GA and Orangeburg, SC hatcheries. While propagation of shortnose sturgeon at Bears Bluff has commenced, some broodstock and their offspring are still maintained at both the USFWS Warm Springs and Orangeburg hatcheries.

The broodstock of shortnose sturgeon at Bears Bluff were collected from the Savannah River and have produced generations of hatchery-bred and raised shortnose sturgeon. Laboratory studies conducted on these captive fish have provided information that would not have otherwise been possible due to the endangered status of shortnose sturgeon.

Captive shortnose sturgeon are also maintained by the USGS at the Conte Anadromous Fish Research Center located on the Connecticut River. These fish are held in quarantine and are primarily used to test fish passage technology; however some progeny are also made available to other research facilities and educational display aquaria when requested. The F-1 progeny are produced periodically using wild native individuals from the Connecticut River in a *living stream* natural spawning environment; however, hatchery protocol is not a research objective at the facility.

Escapement of hatchery/captive fishes

Because aquaculture facilities are currently raising shortnose sturgeon near or on rivers, there is a chance for escapement. Potential threats from aquaculture escapement include the genetic alterations to native populations and potential competition for space and resources between hatchery-reared and wild individuals. Since most sturgeon diseases have been documented in captive-reared individuals, there is also the chance that escapees could spread pathogens and disease (see section 5.3.2). A few circumstances where hatchery-raised fish have entered rivers have been verified:

1. 97,483 shortnose sturgeon raised at Bears Bluff were released into the Savannah River between 1985 and 1992. Straying of these hatchery-raised shortnose sturgeon in to other rivers has long been suspected and was recently confirmed with the capture of a tagged adult in the Ogeechee River (D. Peterson, University of GA, pers. comm.).
2. Six individuals were deliberately released bearing radio tags in the Connecticut River upstream of the Holyoke Dam in 1989 and 1990.
3. Several juvenile shortnose sturgeon were accidentally released in into the Connecticut River in 2006 (see section 6.5 for more details).

Introduction of non-native sturgeon speices via escapement from aquaculture facilities is a concern. White sturgeon escaped from an aquaculture facility in Georgia in the early 1990s; subsequently there have been at least two reports of white sturgeon captured by hook and line 150 miles downstream in the Mobile Basin in Alabama (M. Spencer, GA DNR, pers. comm.

1998 as referenced in ASRT 2007). While this particular incident is unlikely to impact shortnose sturgeon, it illustrates the potential for escapement of non-native sturgeon from aquaculture facilities that could have negative impacts through competition for food and habitat, hybridization, and the spread of fish pathogens as demonstrated in Europe where surveys have revealed a dramatic decline (eight fold decrease) in native European sturgeon (*Acipenser sturio*) but a dramatic increase (two to 33 fold increase) in non-native species such as the Siberian sturgeon (Arndt et al. 2000, Arndt et al. 2002).

Amendment 1 to the ASMFC's Atlantic sturgeon FMP recommends that states may authorize sturgeon aquaculture if conducted in accordance with ASMFC Special Report No. 22. The report states:

> *"If non-native or hybrid sturgeon are permitted within a state, they should be restricted to culture operations where escapement and reproduction can and will be controlled."*

Potential impacts to genetic diversity from stocking or escapement

Hindar et al. (1991) reviewed the genetic effects that have occurred following releases of cultured fishes into natural environments. They reported outcomes ranging between no noticeable effect to complete displacement. Where genetic effects on performance traits have been measured, they are always negative when compared to unaltered populations in the wild (Hindar et al. 1991).

Summary and evaluation

Of these other natural and manmade factors assessed, few were considered to be major stressors to the viability of shortnose sturgeon populations. The vast withdrawal of water from rivers that support shortnose sturgeon was considered to be threat; however, data are lacking to determine the overall impact of this threat on sturgeon as impacts are dependent on a variety of factors (e.g., species, time of year, location of the intake structure, and strength of the intake current). Loss of thermal refugia due to water withdrawal and drought in southern rivers requires further investigation. The impact from boat strikes appears to be minimal but may increase with increases in abundance of shortnose sturgeon and with the boating traffic. Lastly, the use of the artificial propagation of shortnose sturgeon was a concern to some SNS SRT members, as both stock enhancement programs and commercial aquaculture can have negative impacts on a recovery (e.g., fish disease, escapement, out-breeding depression).

River Summaries

Occurrences of shortnose sturgeon over the range of the species were chronicled by Dadswell et al. (1984) and summarized in Kynard (1997). The following section summarizes the most current information regarding the status of and stressors to shortnose sturgeon throughout its range. To increase utility of the document for future conservation efforts, the SRT organized stressors to the status of each riverine population relative to the factors specified in the ESA (4(a)(1)).

New genetic analyses, straying data, and other behavioral information indicate that certain riverine populations are closely associated with one another and represent genetically differentiated regional population clusters. The the SRT examined the available data and information on historical presence and choose to examine the status of and threats to shortnose sturgeon at a riverine scale across the range. Following is a summary of available data and information on historical presence for each riverine population of shortnose sturgeon. The summaries are organized from north to south, and sometimes, based on geography, individual rivers are lumped if they have a common estuary. Notably, the rivers listed in this section include only those where there is evidence of shortnose sturgeon; the exclusion of a river does not necessarily indicate that shortnose sturgeon do not occur.

Saint John River, New Brunswick, Canada

The Saint John River in New Brunswick, Canada supports one of the largest populations of shortnose sturgeon in North America and is the only river in Canada where shortnose sturgeon are known to occur (Scott and Scott 1988). The Saint John River is the northern limit of the species' range and is believed to be the thermal limit for reproductive populations (Dadswell et al. 1984). It is possible that shortnose sturgeon occur in other estuaries in the Bay of Fundy or in the Miramichi Estuary and they have gone undetected because of limited sampling or because of misidentifications of shortnose sturgeon as Atlantic sturgeon (Dadswell 1984).

Historic Distribution and Abundance

There is little information on the historical distribution and abundance of shortnose sturgeon in the Saint John River. As was the case in many other river systems, shortnose sturgeon were not distinguished from Atlantic sturgeon and were classified simply as "sturgeon" in fishery statistics. The first record of the shortnose sturgeon in the Saint John River was in 1957 (Liem and Day 1959).

Although historical habitat use is unknown, Cunjak and Newbury (2005) reported that Grand Falls (approximately rkm 337) was the first natural impediment to diadromous fishes on the Saint John River prior to the construction of dams. Shortnose and Atlantic sturgeon were important to Native Americans in this region for food (COSEWIC 2005). Representatives from the Oromocto First Nation's fisheries technician team (Levi Sabattis, Harold Paul and Brian Paul as referenced in COSEWIC 2005) indicated that Elders of the Oromocto First Nations believe that abundance of shortnose sturgeon has decreased in the past 30 years, which they attribute to the Mactaquac Dam.

Current Distribution and Abundance

Shortnose sturgeon currently occur in the Saint John River from its mouth upstream to the Mactaquac Dam. Construction of the Mactaquac Dam in 1967 likely closed off much of the former spawning grounds and researchers theorize that a dam-locked population may exist above the dam but this has never been investigated (COSEWIC 2005). Shortnose sturgeon are also commonly found in lakes and tributaries of the Saint John River downstream of the dam including Grand Lake, French Lake, Washademoak Lake, Belleisle Bay and the Kennebecasis River (Gorham and McAllister 1974, Dadswell 1979). As recently as the early 1970s, commercial sturgeon fishermen from the Long Reach (~ rkm 35), on Saint John River, reported capturing equal numbers of shortnose and Atlantic sturgeon that were apparently sold to markets in New York City (Scott and Crossman 1973).

There are three population estimates for shortnose sturgeon on the Saint John River. One estimate is for the entire population below the dam and the other two are partial estimates of shortnose sturgeon using the Kennebecasis River, a tributary in the lower reaches of the Saint John River. The entire Saint John population below the dam was calculated by Dadswell (1979) approximately 30 years ago using tag recapture date from 1973-1977. Dadswell (1979) used the Seber-Jolly estimate and concluded that there were 18,000 adults (±30%) in the Saint John River. Two surveys conducted in recent years targeted shortnose sturgeon in the Kennebecasis and are not directly comparable to the Dadswell (1979) estimate. Litvak and Associates using data from 1998 to 2005 (COSEWIC 2005) estimated 2,068 shortnose sturgeon (CI = 801-11,277) in the Kennebecasis River (COSEWIC 2005). Using survival estimates, Litvak and Associates surmised that the population in the Kennebecasis River was highly variable likely due to movements between this tributary and other tributaries in the Saint John (COSEWIC 2005). Next Li et al. (2007) videotaped aggregations of overwintering shortnose sturgeon on the Kennebecasis River at the confluence of the Hammond River (rkm 35) and estimated that 4,836 (± 69) shortnose sturgeon were overwintering in that area. The estimate was derived using the ordinary kriging method to interpolate sturgeon density at unsampled sites (Li et al. 2007).

Natural History and Habitat

Spawning

The location of historical shortnose sturgeon spawning sites on the Saint John River is not known. Prior to the construction of the Mactaquac and Beechwood dams, shortnose sturgeon may have traveled as far upriver as the falls at Grand Falls. A current spawning site was identified at the Mactaquac Dam (rkm 145), which is also the present day upstream limit of their distribution (Litvak in COSEWIC 2005). In recent studies, Litvak and Associates tracked sonic-tagged, adult shortnose sturgeon to just below the Mactaquac Dam in the spring. These individuals had been tagged the previous fall, overwintered in the Kennebecasis River, and traveled rapidly upstream during the spring (COSEWIC 2005).

Temperature and timing

Dadswell (1979) concluded that spawning occurred from mid-May to mid-June in the Saint John River based on capture of ripe and spent shortnose sturgeon. Water temperatures during this period (1973-1977) ranged from 10-15^{o}C. In more recent years, Litvak used data from a laboratory growth study (Hardy and Litvak 2004), to back-calculate date of hatching and timing of reproduction. Litvak found that shortnose sturgeon started spawning in the Saint John River in April, earlier than had previously been recorded (COSEWIC 2005).

Rearing

The Litvak lab collected a total of 14 shortnose sturgeon larvae below the Mactaquac Dam using a towed and weighted bongo net in the spring months of 1998-2002 (Litvak in COSEWIC 2005). In the spring 2003, using a different system, they caught hundreds of eggs and larvae all within 5 km of the dam (Litvak in COSEWIC 2005). Additionally, in an earlier study, Taubert and Dadswell (1980) captured two shortnose sturgeon larvae at the Oromocto shoals (rkm 120).

Spawning and rearing habitat features have not yet been characterized for the Saint John River (M. Litvak, U. of Saint John, pers. comm. 2008).

Foraging

Dadswell (1979) examined shortnose sturgeon from foraging areas in the freshwater upper estuary and in saline reaches of the lower estuary; shortnose sturgeon fed on benthic invertebrates but prey items varied with fish size and locations in the estuary. In the upper estuary, shortnose sturgeon fed only in months when the water was warm (~ 10^{o}C and warmer). At the beginning of June, occurrence of prey and stomach fullness increased considerably, remained high during July, August, and September, and then declined by November (Dadswell 1979). Freshwater foraging grounds in the upper estuary were in shallow (1-5 m) inshore regions that were highly eutrophic and characterized by abundant aquatic macrophytes (Dadswell 1979).

In saline portions of the lower estuary shortnose sturgeon fed heavily in fall, winter, and spring (Dadswell 1979). Ripening males captured in saline water during winter usually had full stomachs, but stomachs of ripening females (stage IV and V) captured in saline and freshwater were always empty (Dadswell 1979). Foraging grounds observed in the saline, lower estuary were over sand-mud bottoms in depths of 5-15 m (Dadswell 1979).

A detailed list of prey items identified from the stomachs of shortnose sturgeon collected from these areas is presented in Dadswell (1979) and can be summarized as: 1) food preferences of shortnose sturgeon in the Saint John River differ by life stage; 2) juveniles primarily feed on crustaceans and insects while adults mainly eat mollusks, predominantly *Mya arenaria* a soft-shelled clam (Dadswell 1979, Pottle and Dadswell 1979, Dadswell et al. 1984) and; 3) juveniles are random feeders whose stomachs often contained up to 90% by volume, nonfood items (mud, stones, and wood chips) while adults were apparently more selective; their stomachs contained little or no nonfood items.

Overwintering/resting

Dadswell (1979) documented seven wintering sites in both fresh and salt water throughout the Saint John River. Freshwater sites were relatively deep (exceeding 10 m) with moderate tidal currents and cold water temperatures (0-3^{o}C). Saline reaches in the lower estuary were warmer (2-13 ^{o}C) and up to 20% saline. An additional wintering site was recently identified by Li et al., (2007) at the confluence of the Kennebecasis and Hammond Rivers (rkm 35) comprised of sand substrate in depths ranging from 3.1-6.9 m. Even though this area is tidal, temperatures were stable at 0^{o}C and salinity was near 0% (Li et al. 2007). Current velocity varied with the tide (ranging from -0.6 to 1 m/s) but did not appear to affect aggregations of fish; the researchers did note that study fish oriented head-first to the current (Li et al., 2007). Dissolved oxygen values were high and averaged 10.51 mg-L-I ± 0.26 (SE). None of the sturgeon tagged by Li et al. (2007) were tracked to the other wintering sites reported by Dadswell in 1979. Sampling at one of the sites previously described by Dadswell (1979) yielded no results (Li et al. 2007).

Migration

Dadswell (1979) described seasonal movement of shortnose sturgeon in the Saint John River as complex due to overlapping behavior patterns of individuals of different ages and spawning conditions.

Juveniles

The youngest shortnose sturgeon captured by Dadswell (1979) was two years old and therefore there is currently no information on young juvenile habitat use and movement on the Saint John River (COSEWIC 2005). Dadswell (1979) did catch older juveniles (>45 cm FL) and found that they appear to remain non-migratory in predominately freshwater riverine habitat until about 45 cm FL and approximately age eight. Juveniles were distributed from Oak Point (rkm 36) to Fredericton (rkm120), but were concentrated between Evandale (rkm 46) and Oromocto (rkm 105); mean size was smaller in the upper reaches than in downriver reaches (Dadswell 1979).

Adults

Adult migrations include directed movement for overwintering, spawning and foraging. These movements are discussed in more detail below.

Overwintering

In the fall, adult shortnose sturgeon in the Saint John River move from foraging areas to overwintering sites in either one of two locations: 1) the more saline reaches of the lower estuary, or 2) the deep freshwater regions of estuarine lakes (Dadswell 1979).

Spawning

Dadswell (1979) suggested that Saint John River females spawn once every 3-5 years and males spawn every other year. Dadswell et al. (1984) suggested that shortnose sturgeon engaged in two-step spawning migration-strategy. Litvak (COSEWIC 2005) has only seen sonic-tagged individual make a long "one-step" migration in the late winter/early spring.

Foraging

Dadswell (1979) suggested that Saint John River adults remain upriver after the spawning season until a 2-3^{o}C decline in the fall triggers migration to overwintering sites. Kynard (1997) reported that adults in other rivers leave the spawning area and move downriver after spawning. Litvak (COSEWIC 2005) recently documented that sonically-tagged individuals used both strategies in the Saint John River.

Stressors to Riverine System

1. Habitat

Dams and diversions

The Saint John River is dammed at three sites along the main stem. The uppermost dam is at Grand Falls (approximately rkm 337); the falls were the natural upstream migration barrier for many diadromous fishes (Cunjak and NewBury 2005). Downstream of the Grand Falls Dam are the Beechwood (rkm 275) and Mactaquac dams.

The lowermost dam, the Mactaquac Dam, impedes access to historical habitat and limits the upstream spawning migration. Although historical spawning locations are not known, one current, validated sight is just below the Mactaquac Dam and a number of eggs and larvae were collected within 5 km (COSEWIC 2005). The dam controls water flow and temperature, both of which may impact spawning habitat and behavior and survival of early life stages. This dam powers the largest hydroelectric generating station in the Maritime Provinces and has a head of up to 35 m. There is a fish collection facility in the base of the dam which includes a migration channel, collection gallery, holding pool, crowder and hopper (Canada DFO 2008a). The hopper lifts upstream migrants into tank trucks for upriver distribution. Unfortunately, since its construction in 1967, the lift has not been used by shortnose sturgeon (R. Price in COSEWIC 2005).

It is interesting to note that Whitehead (2001) reports that the integrity of the Mactaquac Dam is dubious. Apparently the concrete sections of the dam are suffering from alkali-aggregate reaction damage (AAR) and while remedial action is currently underway, if AAR-related decay were to continue at the current rate, the expected lifespan of the dam could be reduced from the original projection of one hundred years to approximately one-third that time (Whitehead 2001).

In addition to the dams on the main stem, the Tobique Narrows Dam, built in 1953 near the confluence with the Saint John River at (approximately rkm 286), blocked access to the Tobique River which is a major tributary to the Saint John.

Other energy projects

Tidal turbines

The Bay of Fundy experiences some of the most dramatic tidal ranges in the world. While there are currently no tidal turbines in close proximity to the Saint John River there is one tidal turbine in the Bay of Fundy and several more are proposed.

The earlier tidal turbine proposals primarily involved building dams or weirs across a smaller arm of the bay to extract power from the water flowing through the low head turbines that are built into them. The 18 MW ARGS, built in 1982 on the Annapolis River in Nova Scotia, is currently the only example of this type of tidal turbine in North America and one of three in the world (Ehrlich 2007). Dadswell and Rulifson (1994) documented the negative impacts of the ARGS on marine animals including Atlantic sturgeon (150 – 200 cm TL). At least three dead and damaged Atlantic sturgeon were observed below the power plant during 1985 and 1986 and the probability of strike for larger animals (striped bass, salmon, sturgeon, marine mammals) was 50-100% depending upon the species (Dadswell and Rulifson 1994).

The barrage-type tidal turbines such as ARGS have raised considerable concern about environmental impacts and developers of tidal turbines have turned to new designs. Aquanators or “tidal stream systems” are the underwater equivalent to wind turbines and do not require any damming. Instead, they are anchored to the sea floor and generate electricity as strong flows power the underwater turbines. There have been several proposals in recent years for installing aqaunator-type tidal turbines in the Bay of Fundy. The technology is still emerging and there are only a handful of marine turbines operating in the world, therefore many impacts to marine organisms and the larger ecosystem have yet to be documented. Impacts from tidal turbines to the Saint John population of shortnose sturgeon will largely depend upon the location of the tidal turbines.

LNG facilities

An LNG facility has been approved and is under construction in Saint John, New Brunswick. This is a closed loop system owned by Canaport – Irving Oil. Potential impacts to shortnose sturgeon associated with the approved facility include increased risk of ship strikes, loss of foraging habitat via dredging and construction, and YOY/sub-adult losses via ballast water uptake and facility intakes, and changes in ambient water temperature (usually cooling) of water withdrawn and then discharged.

Dredging and blasting

Maintenance dredging for shipping is conducted annually in Saint John Harbor which appears to take place primarily in summer months. A comprehensive study of the effects of this dredging on the estuary and its fishes is currently underway by the Canadian Rivers Institute (Gowan 2008).

Water quality and contaminants

The Saint John River system is in a highly developed area with residential and industrial activities, all impacting water quality (COSEWIC 2005). Industrial activities on the Saint John River include forestry, agriculture and five pulp and paper mills. Agricultural industries include four potato-processing plants (COSEWIC 2005). Raw sewage from towns along the river, including the city of Saint John, flows directly into the river (COSEWIC 2005).

Saint John Harbor has been receiving 120 million liters of untreated sewage and storm water run off per day (Parsons and Payne 2002). Industrial and urban sewage discharge into the Harbor can cause contamination of waters and aquatic life forms. Several studies have been initiated in the last decade to examine the impacts of this practice. One study identified various human pathogens of bacterial origin in flounder, crab, and lobster collected from Saint John Harbor, and concluded that human consumption of organisms harvested from contaminated areas poses a public health risk (Parsons and Payne 2002). A second study analyzed endocrine disruptors in sewage, seawater and mussels that provided additional evidence of marine contamination in Saint John Harbor (Saravanabhavan 2003). Lastly, a study of sediment and water column samples collected in Saint John Harbor identified enteric pathogens together with *Listeria* and *Staphylococcus* that were present in sediment and water column samples from Saint John Harbor (Patel and Payne 2004).

There has been little work to date on the effect of contaminants on shortnose sturgeon in the Saint John River population (COSEWIC 2005). However, Dadswell (1975) published information on mercury contamination in Atlantic sturgeon from the Saint John River estuary: mean concentrations of mercury from 30 juvenile Atlantic sturgeon was 0.29 ppm of wet weight with a range of 0.06-1.38 ppm.

Fish kills that included sturgeon and other species were documented in eutrophic areas of the estuary in the past; these were attributed to oxygen depletion caused by eutrophication related to pulp mills, silviculture, agriculture and sewer discharges and the resultant vegetative blooms (COSEWIC 2005).

2. Overutilization

There is no directed commercial harvest of shortnose sturgeon on the Saint John River; however, there is a recreational fishery for sturgeon over 120 cm total length (NB Canada Nat. Res., 2008).

Sturgeon season is open all year except for the month of June; most sturgeon fishing occurs July through August (Dadswell 1984). Litvak examined the size distribution of the shortnose sturgeon caught in the Saint John River during 1998-2002 and lengths of up to 140.5 cm TL were recorded (M. Litvak, U of New Brunswick, Saint John Campus, pers. comm. 2009).

Bycatch

Shortnose sturgeon in the Saint John River are caught incidentally in the alewife/gaspereau (*Alosa pseudoharengus*) and shad (*A. sapidissima*) commercial fisheries (Litvak in COSEWIC 2005). Additionally there have been reports of shortnose sturgeon bycatch in the recreational angling fishery for smallmouth bass (Canada DFO 2008b). Shortnose sturgeon are generally captured alive and released “unharmed” but bycatch of pre-spawning shortnose sturgeon in the spring alewife fishery may interrupt spawning or cause abandonment of spawning migrations (COSEWIC 2005).

Poaching

There are no accounts of poaching of shortnose sturgeon on the Saint John River. Targeted poaching of shortnose sturgeon probably exists throughout its range (Dadswell 1979, Collins et al. 1996, Kynard 1997) and poaching may be more prevalent in river systems with more abundant populations such as the Saint John River where shortnose sturgeon are more accessible.

Scientific research

Saint John River shortnose sturgeon were intensely studied by Dadswell and his co-investigators in the 1970s; Litvak and his students at the University of New Brunswick, Saint John Campus, are currently updating and adding to Dadswell’s work (COSEWIC 2005). Current research includes an age and growth study and a habitat study which involve gillnetting, tagging and tracking but the mortality rate due to these activities in extremely low (M. Litvak, U. of Saint John, pers. comm. 2008). Further research objectives are described under “current research and recommendations” below.

3. Competition, predation and disease

Competition

Pottle and Dadswell (1979) reported that shortnose sturgeon juveniles compete with Atlantic sturgeon juveniles for the same food resources in the upper regions of the Saint John River.

Introduced fish species include the muskellunge (*Esox masquinongy*) which have established a home range of ~25 km in areas downstream of the Mactaquac Dam (Curry et al. 2007). However, the impact of muskellunge on shortnose sturgeon is unknown.

Predation

There is very little documentation of predation on any life stage of shortnose sturgeon. Predators of shortnose sturgeon in other rivers include yellow perch and gray seals, both of which are present in the Saint John River.

Disease

It is possible that disease could occur in sturgeon hatcheries on the river and spread to wild populations. Additionally, infectious disease could conceivably arise from white or other sturgeon species sold as pets in the aquarium trade and subsequently released into the Saint John River.

4. Inadequacy of existing regulatory mechanisms

Fishing regulations provide a minimum size for shortnose sturgeon (120 cm TL). This may allow for capture of very large, and perhaps predominantly female, shortnose sturgeon.

Existing regulatory programs

Shortnose sturgeon are a Federal responsibility under the Canada/New Brunswick Recreational Fisheries Memorandum of Understanding (MOU). Although no specific legislation is in place for protection of the habitat, general protection is available under Habitat sections of the Fisheries Act (COSEWIC 2005). While the river itself is a navigable body of water and therefore falls under public ownership, lands along the river are largely under private control (COSEWIC 2005). A license is required to retain shortnose sturgeon for any purpose, including transferring them to a rearing facility, releasing them into fish habitat or for inter-provincial transport (COSEWIC 2005).

5. Other natural or manmade factors

Ship Strikes

No ship strikes have been reported for shortnose sturgeon on the Saint John River (M. Litvak, U. of St. John, pers. comm. 2008).

Impingement and Entrainment

There are no intakes on the Saint John that are known to impact shortnose sturgeon (M. Litvak, U of St. John, pers. comm. 2008)

Artificial propagation

There are currently two companies propagating shortnose and Atlantic sturgeon in Canada - both are located on the Saint John River. The Supreme Sturgeon and Caviar located near Pennfield New Brunswick (Latitude 45.113639°, Longitdue -66.758723°) near the Letang River which opens to the Bay of Fundy was the first to successfully propagate shortnose sturgeon. This company has been the major player in sturgeon aquaculture in New Brunswick and they have been actively pursuing shortnose aquaculture since the mid 1990's. They use groundwater and recirculation systems in their production of sturgeon and are now selling shortnose sturgeon caviar.

More recently, Acadian Sturgeon and Caviar has begun sturgeon production at Carter's Point, Westfield New Brunswick on the Saint John River (approximately rkm 24). Acadian Sturgeon and Caviar has been marketing meat, caviar, and stocking material since 2005. An expansion, started in 2007, included a grow-out facility on 2.5ha of land that is designed to eventually produce 165 tons of sturgeon meat and 10 tons of caviar (Hatchery International Magazine 2006).

Escapement of hatchery/captive fishes

Because two aquaculture facilities are currently raising shortnose sturgeon on the Saint John River, with one operating on a commercial scale, the chances of escapement exist. Potential threats from aquaculture escapement include the genetic alterations and potential competition for space and resources between hatchery-reared and wild individuals. Because most sturgeon diseases have been documented in captive-reared individuals, there is also the chance that escapees could spread pathogens and disease.

Current and Recommended Research

The following research objectives have been during ongoing sturgeon ecology studies to evaluate shortnose status and develop protection and/or recovery plans (UNB Litvak Lab 2008).

- Determine population size and structure.
- Find spawning and overwintering sites.
- Define spawning and overwintering habitat.
- Determine egg distribution and factors, both physical and biological affecting survival.
- Examine larval and early juvenile behavior and mechanisms of distribution.
- Determine larval and juvenile habitat use.
- Examine juvenile flow rate preference in the lab and field.
- Examine potential competitive interactions between shortnose and Atlantic sturgeon juveniles.
- Build a model to analyze the larval distribution patterns relative to river flow regimes. This model will allow us to determine the potential impact of flow manipulation in the Saint John River system.
- Continue to develop the protocol for mass rearing of shortnose juveniles so that we can enhance the local populations if necessary.
- Dissemination of results through presentation of papers at learned societies, publications and presentations to and involvement with the public.

Penobscot River

Historic Distribution and Abundance

There is no documentation of shortnose sturgeon historically occurring in Maine waters although it is very likely that they occurred in the Kennebec and Penobscot rivers. Atkins (1887) stated that the common sturgeon (*Acipenser sturio*) of the Atlantic rivers was the only species known to visit the rivers of Maine. The common sturgeon, also known as the Baltic sturgeon, has been misidentified in the U.S. primarily with the Atlantic sturgeon.

The first reported shortnose sturgeon in Maine was captured in the Penobscot River estuary (Northport, Maine) on June 30, 1978, during a ME DMR sampling program (Squiers and Smith 1979). Archeological data suggesting that sturgeon from the Penobscot River were used by native peoples (Knight 1985, Petersen and Sanger 1986) supporting the conclusion that shortnose sturgeon likely occurred in this system. Evidence confirming sturgeon presence in the Penobscot River strongly suggests the presence of shortnose sturgeon.

Current Distribution and Abundance

There have been two surveys conducted in the last 15 years to document the presence of shortnose and Atlantic sturgeon in the Penobscot River. ME DMR conducted a limited sampling effort in 1994 and 1995 to assess whether shortnose sturgeon were present in the Penobscot River: 55 sets of 90 meter experimental gillnets were set for a total fishing effort of 409 net hrs (1 net hr = 100 yds fished for 1 hr). The majority of the fishing effort in the Penobscot River was in the upper estuary near head-of-tide and no shortnose or Atlantic sturgeon were captured. In 2006, a similar gillnet survey was implemented by the UMaine in the lower river using both 15 cm and 30 cm stretched mesh sinking gillnets yielding 62 shortnose and seven Atlantic sturgeon captured in 1004.39 net hours, (506.18 net hours using the smaller mesh and 498.21 net hours using the larger mesh) (Fernandes 2008 and 2010). Later 99 shortnose sturgeon were captured in 2007 and 185 were captured in 2008 (Fernandes 2008 and 2010).

Natural History and Habitat Information

Spawning

No shortnose sturgeon spawning sites have been located in the Penobscot River. In 2006 researchers from UMaine implanted ultrasonic tags in 20 shortnose sturgeon four of which were confirmed to be mature adult females with late-stage developing eggs. The four pre-spawning adult shortnose sturgeon overwintered at rkm 37 but all subsequently moved downriver in the spring and none were relocated in the potential upriver spawning areas in the Penobscot River. One of the four pre-spawning adult shortnose sturgeon was subsequently located upriver in the Kennebec River (rkm 61) on June 2, 2007.

In late September 2007, UMaine researchers implanted ultrasonic transmitters in five pre-spawning adult shortnose sturgeon in the Bangor/Brewer overwintering area (rkm 37) (Fernandes 2008 and 2010). The intent was to track these individuals the following spring to locate spawning site(s) in the Penobscot River. ME DMR subsequently detected these five pre-spawning adults with its passive receiver array in the Kennebec River in October and November of 2007. Later these five sturgeon were located in the Kennebec River overwintering area near rkm 38 in February 2008.

Foraging

Preliminary data collected in 2006 indicate that adult shortnose repeatedly moved upstream and downstream from rkm 40 to rkm 20 from early June until the beginning of July. From this time until August, the adults settled into the section of the river around rkm 32 and remained relatively still for the remainder of the summer. The only exception was a shortnose sturgeon that moved out of the river and into Penobscot Bay (Eggemoggin Reach) in early July (Fernandes 2008).

Overwintering/resting

Recent data collected in the Penobscot River indicate that an overwintering site is located at approximately rkm 37 upriver of the majority of the foraging habitat (Fernandes 2008 and 2010). Twelve of twenty ultrasonically tagged shortnose sturgeon were located at this overwintering site between early October and mid-April in 2007. This overwintering area can be characterized as being tidal freshwater.

Migration

Recent data collected by UMaine and ME DMR indicate that migration between river systems is more extensive than was previously reported (Dadswell 1984, NMFS 1998). Sonic transmitters were implanted in a total of 39 shortnose sturgeon from June 14, 2006 through September 27, 2007 in the Penobscot River; however some tags were expelled and some individuals may have suffered mortality (Fernandes 2008 and 2010). Eleven of these sturgeon have been subsequently detected in the Kennebec River by ME DMR via the passive receiver array. The distance between the mouth of the Kennebec River and the mouth of the Penobscot River is about 70 km. One tracked individual traveled 230 km from its tagging site in Bangor on the Penobscot River to upper Kennebec River (Fernandes 2008 and 2010). Movement from the Kennebec to the Penobscot was documented when two shortnose sturgeon PIT tagged by ME DMR in the Kennebec River in 1998 and 1999 were recaptured in the Penobscot River in 2006 by UMaine researchers.

Ultrasonic transmitters were implanted in five pre-spawning adult shortnose sturgeon in late September 2007 in the Bangor/Brewer overwintering area on the Penobscot River (Fernandes, 2008 and 2010). The intent was to track these individuals the following spring to locate the spawning area(s) in the Penobscot River. ME DMR subsequently detected four of these pre-spawning adults with its passive receiver array in the Kennebec River during October and November 2007. Four of the five sturgeon were subsequently located in the Kennebec River overwintering area near rkm 38 in February 2008. These sturgeon were located between rkm 37.25 and 39.25. The fifth shortnose sturgeon implanted with a transmitter during the same time period and area was located in the Kennebec River overwintering area.

ME DMR deployed its passive receiver array in early April 2008. Four of the five Penobscot shortnose sturgeon located in the Kennebec River overwintering grounds in February 2008 were detected. These four were females with late stage eggs. One migrated upriver to the Farmingdale/Hallowell (rkm 61) reach in the Kennebec River which had been previously identified by ME DMR as a spawning area. Another migrated to Waterville (rkm 97) which is the upstream limit of sturgeon habitat and was made accessible with the removal of the Edwards Dam in 1999. A third fish migrated to the known spawning area on the Androscoggin River near Brunswick, ME (rkm 44). Collectively these three fish moved rapidly downriver after a few days and are presumed to have left the Kennebec River system. The fourth sturgeon with late stage eggs migrated to the mouth of the Androscoggin and was last located in Merrymeeting Bay on May 12, 2008. Its signal was not picked up on any of the downriver receivers.

In addition to the Penobscot females with late stage eggs, an additional three Penobscot River shortnose sturgeon outfitted with acoustic transmitters in 2006 were located in the Kennebec River in the spring of 2008. One fish arrived at Townsend Gut on May 10, 2008 and migrated through the Sasanoa River to the Kennebec River and on May 20 arrived in the Farmingdale/Hallowell reach. Another fish was located in the Merrymeeting Bay overwintering area in the Kennebec River on April 16, 2008 and migrated to the Eastern River arriving on April 19, 2008 arriving in the Sasanoa River on April 25, 2008 and moving to the Phippsburg area from April 25 to May 19, 2008. Subsequently the individual migrated upriver to the Farmingdale/Hallowell reach of the Kennebec River on May 21, 2008, remained for two days and was subsequently picked up in Phippsburg on May 24, 2008 and was last recorded on May 28, 2008. The third tagged fish was recorded at Townsend Gut on May 12, 2008 and was never subsequently picked up on any of the Kennebec River receivers.

Stressors to riverine system

1. **Habitat**

Dams and diversions

There are currently two obstructions to sturgeon historical spawning habitat in the Penobscot River, Maine. In 1833, the Veazie Dam was constructed on the Penobscot River at rkm 56, and blocked 29 km of habitat that was historically accessible to sturgeon. Just upstream of the Veazie Dam is the Great Works Dam (rkm 41.3; completed in 1887). Five kilometers downstream of the Veazie Dam was the Treats Falls Bangor Dam (completed in 1875) which also impeded migration during the summer months. The Treats Falls Bangor Dam, however, was breached in 1977 and now allows diadromous fish passage. Thus, there are currently 50 km of tidal and freshwater habitat available for spawning and nursery habitat. Historically, the first natural obstacle to sturgeon migration on the Penobscot River may have been the falls at Milford, rkm 71 (L. Flagg, ME DMR, pers. comm. 1998). If sturgeon were able to ascend the falls at Milford, they could have migrated without obstruction to Mattaseunk (rkm 171).

In June, 2004 the Penobscot Accord was signed which gave the Penobscot River Restoration Trust, a non-profit corporation established in May 2004, the ability to buy Veazie, Great Works and Howland Dams on the Penobscot River over a five year period. Once purchased, the Trust has the right to decommission and remove the Veazie and Great Works Dams, and install fish passage or remove the Howland Dam. However, these options cannot be initiated until 2007-2010. Removal and passage at these facilities would open large portions of historical habitat to sturgeon on the Penobscot.

Other energy projects

Tidal turbines

FERC issued a preliminary permit for the Penobscot Tidal Energy Project to the Maine Tidal Energy Company (Oceana) on May 16, 2007. The project location is in the Penobscot River west of Verona Island, Maine. The submerged project location begins west of Bucksport, Maine and extends south along the western side of Verona Island where it branches into two areas just north of Sandy Point and continues to the southern tip of Verona Island (~ rkm 5). Water depths in the area are variable and range from about 35 to greater than 70 feet. The proposed project would consist of 100 Tidal In-Stream Energy Conversion (TISEC) devices comprised of rotating propeller blades, integrated generators with a capacity of 0.5 to 2.0 MW, anchoring systems, mooring lines, and interconnection transmission lines. The project is estimated to generate 8.76 gigawatt-hours per-unit per-year, which would be sold to a local utility. The proposed TISEC devices are not yet commercially available nor have they been demonstrated in the field to be technically or economically feasible. As a result, the impact of multiple underwater tidal power generating units on public uses, marine end other natural resources has not yet been evaluated.

LNG facilities

No LNG facilities are currently proposed within the Kennebec and Penobscot watersheds or in the coastal waters between the two river systems. Nearby the Canadian border, Downeast LNG Maine has proposed a facility in Passamaquoddy Bay, which opens to the Gulf of Maine, in the St. Croix River estuary that may or may not be an area for occasional or resident use by shortnose sturgeon (Downeast LNG 2009).

Dredging and blasting

An ACOE permit has been issued to dredge approximately 15,000 cubic yards from the Penobscot River in Brewer (~ rkm 48) to increase landing depth for barges at a site being developed for the outdoor modular prefabrication of components to be shipped to construction sites (i.e. Cianbro project). During the pre-application process, NMFS and the ACOE determined that the proposed project could have adverse affects on shortnose sturgeon and that a formal section 7 consultation was necessary. Consultation was completed prior to the commencement of in-water work in 2007. The permit issued by ACOE to Cianbro included several special permit conditions designed to minimize and monitor effects on listed species including: 1) instream work window of August 1 to March 30; 2) monitoring for turbidity; and 3) monitoring by an endangered species observer approved by NMFS during dredging activities. The dredge site is located adjacent to an overwintering area for shortnose sturgeon where 62 shortnose sturgeon were captured in 2006. Through telementry it is known that shortnose sturgeon moved into the area in early October and remained until mid-April 2007. Fish monitored during dredging activites of winter 2008 indicated no effects to shortnose sturgeon resulted from either the dredging or other in-water construction activity.

The Penobscot River federal navigation channel has been maintained since the 1800's. The channel has not been dredged since 1985, which may be attributed to considerable changes in the use of the Penobscot River through the years and the natural deepness of the river (E. O'Donnell, ACOE, pers. comm. 2009). Currently there are no plans to dredge the Penobscot River in the near future (E. O'Donnell, ACOE, pers. comm. 2009).

Water quality and contaminants

DO levels reached zero ppm in the Penobscot River estuary during the summer months in the late 1960s (Hatch 1971). These low DO levels occurred at the freshwater/saltwater interface (salinities 0-10 ppt), which is an important zone for foraging shortnose sturgeon. Dissolved oxygen levels improved significantly in the late 1970s and 1980s to levels sufficient to support aquatic life coincident with improved point source treatment of municipal and industrial waste, although the substrate is still severely degraded (Squiers 1988), which in turn decreased the diversity of benthic fauna (EPA 1994). The predominant substrate types in the Penobscot River from Winterport to Bucksport, ME, consist of wood chips, silt/sawdust, and Mytilus mussel beds (Metcalf and Eddy 1994). Data on the substrate and benthic communities above Winterport (in the tidal freshwater section) are limited, but it is likely that the mid-estuary and freshwater tidal zones are impacted from organic debris deposits (Metcalf and Eddy 1994). A coal tar deposit has been discovered in the tidal section of the Penobscot River in Bangor. Weathered coal tar collected from the Connecticut River near Holyoke, Massachusetts was found to be toxic to shortnose sturgeon embryos and larvae (Kocan et al. 1996). Coal tar deposits in the Connecticut River have been linked to tumors and reduced reproductive success in shortnose sturgeon (Kocan et al. 1996). Plans for remediation of the coal tar site in Bangor are currently ongoing and will likely involve dredging to remove contaminated sediments. The former Holtra-Chem facility in Orrington, ME, on the Penobscot River was known to use large quantities of mercury in the production of chemicals for subsequent sale to paper mills. A portion of the site remediation includes the removal of mercury hot-spots in the river (ME DEP 2006). Dioxin, likely generated from wastewater discharges from pulp and paper mills and municipal wastewater treatment plants, has been found in fish tissue samples collected in the Penobscot River. Dioxin levels in fish collected from the Penobscot River have dropped from a high of 7.6 pg/g (parts-per trillion) in 1984 to < 0.1 pg/g in 2004 (ME DEP 2005).

1. Overutilization

Bycatch

There has not been any reported or observed bycatch of shortnose sturgeon in the Penobscot River. No commercial gillnetting is allowed and other commercial fishing activity is very limited.

Poaching

No cases of poaching of shortnose sturgeon in the Penobscot River have been reported.

Scientific research

There is one ESA Section 10 Research Permit issued for the Penobscot River: Permit #1595 has been issued to M. Hastings at UMaine at Orono for sampling shortnose sturgeon on the Penobscot River, includes lethal take of two adult/juvenile shortnose sturgeon annually, and the location and timing of sampling have been restricted to protect Atlantic salmon. There has been no known take of shortnose sturgeon by other scientific sampling projects on the Penobscot River.

2. Competition, predation and disease

Competition

Both adult shortnose sturgeon and sub-adult Atlantic sturgeon utilize the lower Penobscot River for foraging. Recent capture and tracking data indicates the shortnose are somewhat spatially separated from the sub-adult Atlantic sturgeon spatially; adult shortnose sturgeon were usually located upriver of the sub-adult Atlantic sturgeon especially during the summer (Fernandes 2008). Sub-adult Atlantic sturgeon were generally found in deeper water than adult shortnose sturgeon (Fernandes 2008).

Predation

It is likely that sharks and seals may occasionally prey on shortnose sturgeon based on the occasional specimen lacking a tail (Dadswell et al. 1984). While their large size, heavy armor, and deep water-habits likely limit predation, it appears that some natural predation on shortnose sturgeon does occur. During active tracking of a tagged shortnose sturgeon, researchers observed a gray seal (*Halichoerus grypus*) preying upon a tagged individual in the Penobscot River (Fernandes 2008). The seal tore through the right ventral operculum and body cavity, and removed most of the entrails and organs including the ultrasonic tags (which fell to the bottom of the river). The sturgeon carcass was retrieved and examined.

Disease

There have been no observations of disease in shortnose sturgeon from the Penobscot River.

3. Inadequacy of existing regulatory mechanism

Federal, state, local laws or treaties

Shortnose sturgeon were listed as endangered in 2007 under the List of State Endangered And State Threatened Marine Species of the State of Maine. The listing allows the Commissioner of Marine Resources to enter into agreements with federal agencies, other states, state agencies, political subdivisions of the State of Maine or private persons for the establishment and maintenance of programs for the conservation of state endangered or state threatened marine species and to receive all federal funds allocated for obligations to the State pursuant to these agreements. Federal funds received for the conservation of state endangered or state threatened marine species listed pursuant to this chapter must be allocated directly to the department to ensure compliance with any conditions of the listing. An ESA Section 6 agreement for shortnose sturgeon was subsequently approved between the ME DMR and the NMFS.

4. Other natural or manmade factors

Ship strikes

There have been no ship strikes on shortnose sturgeon reported in the Penobscot River.

Impingement and entrainment

There have been no incidences of impingement or entrainment of shortnose sturgeon reported in the Penobscot River.

Artificial propagation

There is no artificial propagation of shortnose sturgeon occurring in the state of Maine.

Escapement of hatchery/captive fishes

No hatchery or captive sturgeon are known to have escaped into Maine waters.

Current and Recommended Research

Current research

Research is ongoing to assess the distribution, abundance, and movements of adult and subadult shortnose sturgeon in the Penobscot River through a grant awarded to the ME DMR by NOAA through ESA Section 6 funds. Mark-recapture and passive tracking are the primary methods being applied.

Recommended research

- Determine if spawning is occurring in the Penobscot River. Locate spawning site(s).
- Conduct further work to locate and characterize overwintering sites.
- Inverstigate inter-basin movement(s).
- Estimate population size.
- Characterize other important habitats.

Kennebec System

Historic Distribution and Abundance

The Kennebec system includes the Kennebec, Androscoggin, and Sheepscot rivers. The Kennebec River, at its mouth, drains an area of 24,667 square kms encompassing the drainage area of the Androscoggin River and the smaller tributaries of Merrymeeting Bay. The Kennebec River estuary below Chops Point (outlet of Merrymeeting Bay) forms a complex with that of the Sheepscot River estuary. Atkins (1887) confirmed the presence of sturgeon in Maine rivers though he believed that they were common sturgeon (*Acipenser sturio*). There is further evidence for historical presence of sturgeon in the Kennebec System in the name of a tributary: "Passagassawakaeg" River near Belfast, ME, means "place where they spear sturgeon" in a Native American dialect. Fried and McCleave (1973) first noted shortnose sturgeon within Montsweag Bay in the Sheepscot River in 1971, the first reported occurrence in all of Maine.

Shortnose sturgeon were subsequently found in the Kennebec River by ME DMR in 1977 (Squiers and Smith 1979).

Current Distribution and Abundance

ME DMR has conducted studies in the past to determine the distribution and abundance of shortnose sturgeon in the estuarine complex of the Kennebec, Androscoggin and Sheepscot rivers (Squiers and Smith 1979, Squiers et al. 1982). Additional studies were conducted to determine the timing of the spawning run and the location of spawning areas in the tidal section of the Androscoggin River (Squiers 1982, Squiers et al. 1993). The estimated size of the adult population (>50cm TL), based on a tagging and recapture study conducted between 1977-1981, was 7,200 (95% CI = 5,000 - 10,800; Squiers et al. 1982). The average density of adult shortnose sturgeon/hectare of habitat in the estuarine complex of the Kennebec River was the second highest of any population studied through 1983 (Dadswell et al. 1984). Another population study conducted 1998-2000 estimated population size at 9,488 (95% CI = 6,942 - 13,358; Squiers 2003).

Natural History and Habitat Information

Spawning

Suspected spawning areas on both the Androscoggin and Kennebec rivers were identified in gillnet studies conducted from 1977 through 1981 (Squiers et al. 1981, Squiers et al. 1982).

Androscoggin River

Large catches of shortnose sturgeon on the Androscoggin River about 400 m downstream from the Route 201 bridge between Brunswick and Topsham (~rkm 44) between late April and mid-May. This site is approximately 44 km upriver from the mouth of the Kennebec River and water temperatures ranged between 8.5°C and 14.5°C. Many of the males captured were freely expressing milt. During 1983, a few female sturgeon were so ripe that eggs were extruded as they were retrieved from the nets. The substrate at the sampling site graduated from ledge, boulders, cobbles, pebbles, and gravel on the Brunswick shore to sand in the middle to silt on the Topsham shore. The maximum depth at low tide was 6.7m, with an average depth of 3m. Water velocities measured along a transect from the Brunswick shore to the Topsham shore on October 14, 1983, during an outgoing tide ranged from 32cm/sec. to 60cm/sec.

A follow-up study conducted in 1993 using radio telemetry, artificial substrate, and bottom-set plankton nets found ripe shortnose sturgeon concentrated about 500 m below the Brunswick Hydroelectric dam, which is approximately 100 m upriver of the Route 201 bridge (rkm 44). Shortnose sturgeon eggs were collected in this area using artificial substrate and plankton nets. Spawning migration extended from the end of April to the last week in May with spawning occurring from May 7-19 based on eggs collected on artificial substrate. Temperatures ranged between 7°C to 17°C during this time. Gillnet catches and radio telemetry indicated that the peak spawning occurred from May 8 to May 10 at a water temperature of 14°C.

Kennebec River

Spawning site(s) on the Kennebec River are not as well delineated as the site(s) on the Androscoggin River. Squiers et al. (1982) suspected a spawning area occured 11 km below the former Edwards Dam (rkm 59) as males extruding milt were collected in 1980 and 1981. Additional samples were obtained on May 11, 1999 approximately 10 km below the former Edwards Dam (rkm 60) when 135 adults were captured in an overnight set at 14 °C. It is assumed that these sturgeon were on the spawning run.

ME DMR conducted an ichthyoplankton survey from 1997 through 2001 to monitor the recolonization of the habitat above the Edwards Dam which was removed in 1999. Sampling sites located both above and below the dam location were surveyed via surface tows with one-meter plankton nets (800 microns) or stationary sets of one-half meter D-shaped plankton nets (1600 microns). A small number of shortnose sturgeon eggs and/or larvae were collected at sites located in the first nine kilometers below the former Edwards Dam (rkm 61-70) annually. No shortnose sturgeon eggs or larvae were collected above the former Edwards Dam site in 2000 or 2001 (Wippelhauser 2003). It is likely that the primary spawning area for shortnose sturgeon in the Kennebec River is located in the first 11 kms below the former Edwards Dam site (rkms 59-70). While there have not been any directed studies to determine if shortnose sturgeon are utilizing the habitat above the former Edwards Dam, shortnose sturgeon have been captured upstream about 27 km at Waterville.

Ages were determined for 58 shortnose sturgeon collected on the spawning run in the Androscoggin River in 1981 (Fig. 17); sex was not determined. Average age of the shortnose sturgeon collected on the spawning run was 12 with a median of 10 years. Length ranged between 52.5cm FL to 90.0cm FL with the average of 68.9cm FL.

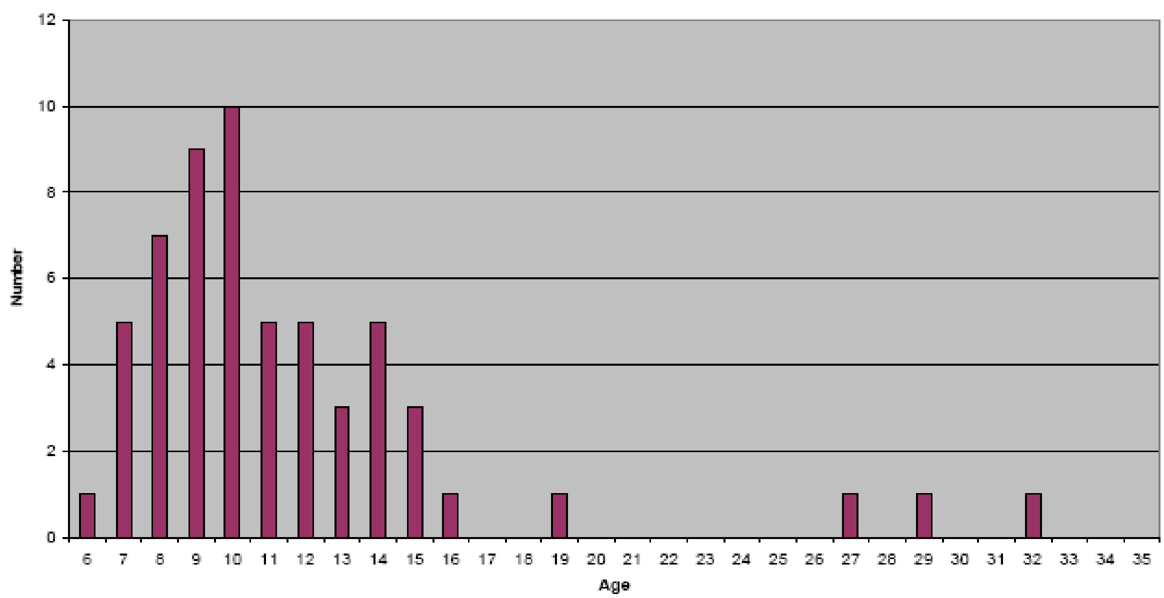


Figure 17. Age of shortnose sturgeon captured in the Androscoggin River during the 1981 spawning run.

Foraging

Tracking data and gillnet studies indicate that the majority of shortnose sturgeon feed in the Bath region of the Kennebec River (rkm 16 to rkm 29) from mid April through late November and early December. Sturgeon then migrate upriver to overwinter in Merrymeeting Bay. Although the major concentration of shortnose sturgeon is found in the Bath region which includes the Sasanoa River, shortnose sturgeon are also found in Monstweag Bay in the lower Sheepscot River and in Merrymeeting Bay (rkm 29 to rkm 42) located upriver of Bath. Based on limited gillnetting data and telemetry data it appears that shortnose sturgeon occasionally make forays upriver to the Augusta/Gardiner (rkm 59-70) area during the summer months.

The salinities in the main foraging area in the Bath Region range from 0 to 21 ppt from May through November. There is very little stratification during most of this time period and the difference in salinities from the surface to the bottom are usually less than 1 ppt. Water temperature ranges from 4°C in April to over 24°C in July, to around 5°C in late November. DO levels are almost always near 100% saturation.

Some shortnose sturgeon also utilize Montsweag Bay, which is part of the Sheepscot River, as a foraging area. The Sheepscot River is interconnected with the Kennebec River through the Sasanoa River and Hockomock Bay. Salinities ranged from 12 to 28 ppt and temperatures ranged from 12 to 22°C in June and July in Montsweag Bay during an ultrasonic telemetry study (McCleave et. al. 1977).

A few shortnose sturgeon stomachs, captured in Montsweag Bay, were examined by McCleave et al. (1977). The most common prey items found were crangon shrimp (*Crangon septemspinosous*); clams (*Mya arenaria*); and small winter flounder (*Pseudopleuronectes americanus*). No food habit studies have been conducted for shortnose sturgeon in the Kennebec River. Tracking studies indicate that shortnose sturgeon make use of two large marshes in the Bath area: Hanson Bay (Pleasant Cove; rkm 21) in the Sasanoa River, and Winnegance Cove (rkm 17) in the Kennebec River. A Wetland Functional Assessment was conducted by Bath Iron Works (BIW) as part of the assessment of impacts of the proposed expansion of the shipyard into wetlands habitat (Normandeau Associates 1998) and included a quantitative assessment of the benthic community in Winnegance Creek. The benthic assemblage in Winnegance Creek (rkm 17) contained no mollusks, the preferred food of adult shortnose sturgeon in the Saint John River, New Brunswick (Dadswell 1979, Dadswell et al. 1984). One of the dominant species in Winnegance Creek was the sabellid polychaete (*Maranzariella viridis*) which was found in stomachs of shortnose sturgeon from the Saint John River but was not identified as a preferred food item.

No sampling for epibenthic invertebrates was done in the BIW Wetland Functional Assessment. On numerous occasions, gammarid amphipods were observed on the nets when sampling for sturgeon in the summer foraging area. In an earlier study on the food habits of smelt in the lower reaches of the Kennebec River, it was found that the dominant food item was gammarids, particularly *Gammarus oceanicus* (Flagg 1974). Shortnose sturgeon consumed gammarid amphipods and polychaete worms in the estuary of the Connecticut River (Savoy and Benway 2004). Shortnose sturgeon also fed heavily on gammarid amphipods in the Hudson River (Haley 1999).

Overwintering/resting
No studies had been done to locate the overwintering sites of adult shortnose sturgeon in the Kennebec River prior to 1996. Based on catch per unit effort from gillnet sets in the lower Kennebec River, it was thought that the most likely overwintering sites were in the deep saline region of the lower river (below Bluff Head at rkm 15) and possibly in the adjacent estuary of the Sheepscot River (Squiers et al. 1982). Some shortnose sturgeon overwinter in the tidal freshwater sections of the Eastern and Cathance Rivers; which are tributaries to Merrymeeting Bay (Squiers et al. 1982).

ME DMR attempted to identify shortnose sturgeon overwintering sites in the Kennebec River in 1996. A total of fifteen shortnose sturgeon were tagged in October and November, 1996 to track them to their overwintering habitat. Initial capture locations of the sturgeon varied within the Kennebec System: 8 were captured, tagged and released in Pleasant Cove (rkm 21) on the Sasanoa River which joins the Kennebec River in Bath just a short distance downriver of the Carlton bridge; 5 were captured, tagged and released in Winnegance Cove (rkm 17) which is located approximately 2700 m below the Carlton Bridge on the Kennebec River; and 2 were captured in Merrymeeting Bay (rkm 38) and released at the Richmond town landing in channel west of Swan Island (rkm 40.5).

The eight shortnose sturgeon captured in Pleasant Cove and the five captured in Winnegance Cove were all later relocated: 11 of these 13 fish were relocated in Merrymeeting Bay. The first two sturgeon tagged in Pleasant Cove (code #338 and 356) were never found in Merrymeeting Bay. Sturgeon #338 did move from Pleasant Cove to Winnegance Cove and back and sturgeon #356 moved to Days Ferry (rkm 24) and back. Both sturgeon #338 and #356 were last found in Pleasant Cove (rkm 21) on November 13, 1996. After November 13, 1996, sturgeon with transmitters were only found in upper Merrymeeting Bay on the east side of Swan Island (rkm 38). Because 11 sturgeon were in the area it became impossible to separate signals as the sturgeon grouped together. Multiple signals were always found at the suspected overwintering site near Swan Island in Merrymeeting Bay. It was difficult to survey large areas of Merrymeeting Bay due to poor ice so it is possible other sturgeon were in the area and other overwintering areas exist.

In 1997, five additional shortnose sturgeon captured in the immediate vicinity of BIW were tagged: two were later captured by Normandeau Associates in an otter trawl, and three were captured by ME DMR in gillnets. These tagged sturgeon remained in the lower Kennebec River in the Bath area until late November. One was later located in the area on December 2, 1997, but no others have been detected since.

In 1998, 17 shortnose sturgeon were captured by Normandeau Associates under contract to BIW and tagged. Fourteen receiver/data loggers were deployed: 9 around BIW and 5 upstream and downstream BIW. The majority of shortnose sturgeon moved out of the Bath area by the end of November although three remained in the Bath area in early December. Ten shortnose and one Atlantic were at the overwintering site upriver in Merrymeeting Bay on December 15, 1998. Additional manual tracking did not occur during this period due to weather conditions.

Five pre-spawning adult shortnose sturgeon originally captured and tagged in the Bangor/Brewer overwintering area of the Penobscot River in late September 2007 were later relocated in

October and November of 2007 (Fernandes 2008 and 2010). Four individuals were subsequently located at the Kennebec River overwintering area (Merrymeeting Bay) near rkm 38 in February 2008 (Fig. 18). These sturgeon were located between rkm 37.25 and 39.25 in a tidally influenced area in depths are approximately 4.5 to 6.0 m in predominantly sandy substrate.

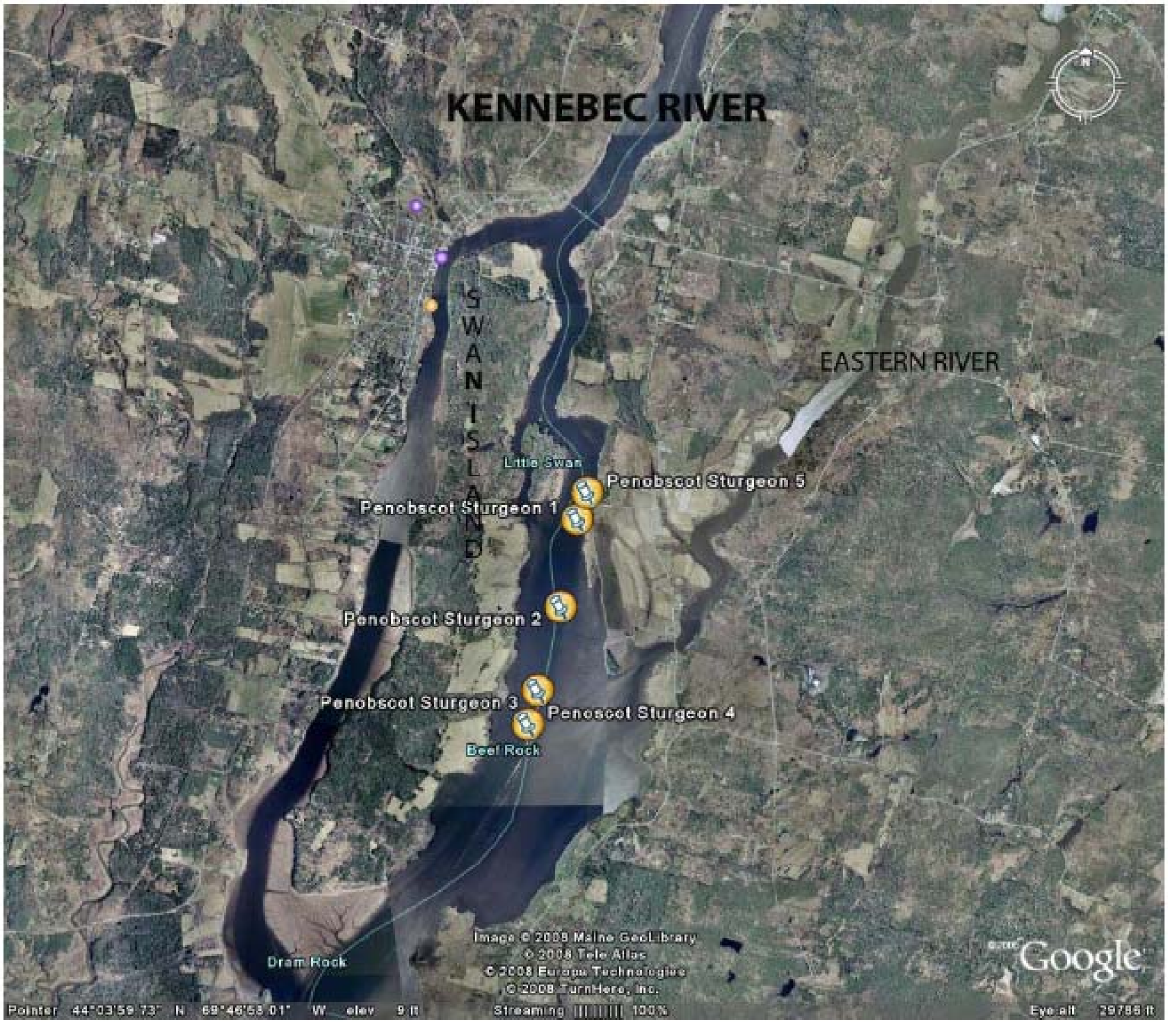


Figure 18. Location of Penobscot Sturgeon in Kennebec River Overwintering Area-February 2008.

Migration
See Penobscot River – Migration section.

Stressors to riverine system

1. **Habitat**

Dams and diversions

Historically, the upstream migration of sturgeon on the Kennebec River was limited to Waterville at Ticonic Falls (rkm 98) (NMFS and USFWS 1998). Ticonic Falls is located 65 rkm downstream of the fall line (based on reference points provided by Oakley 2005). The construction of Edwards Dam at rkm 71 in 1837 denied sturgeon access to historical habitat in the Kennebec River until 1999 when it was removed. Since its removal, almost 100% of historic habitat is now accessible. Since the removal of the Edwards Dam, shortnose sturgeon have been documented at the Lockwood Dam (rkm 98) indicating that this habitat is being utilized to some extent. One shortnose sturgeon was stranded below the Lockwood Dam spillway in 2003 as result of flow manipulation to allow the installation of flashboards. During the re-licensing of the Lockwood Hydroelectric Project, FERC requested ESA Section 7 formal consultation; a Biological Opinion was issued by the NMFS on January 12, 2005, where NMFS concluded the proposed re-licensing was likely to adversely affect but not likely to jeopardize the continued existence of shortnose sturgeon. The Opinion included an Incidental Take Statement (ITS), Reasonable and Prudent Measures, and Terms and Conditions designed to minimize and monitor future effects of the project, including strandings. No additional strandings of shortnose sturgeon have been reported. There is a fish lift at the Lockwood project, but to date, no shortnose sturgeon have been documented in the lift. The FERC license for this project includes a requirement that any shortnose sturgeon observed in the lift be removed and returned downstream of the project. This is consistent with the terms of the Opinion's ITS. Additionally, the project's shortnose sturgeon handling plan is updated annually by the project owner (FPL Energy).

In the Androscoggin River, the Brunswick Hydroelectric Project (rkm 44) is located at the head-of-tide at the site of a natural falls. This facility was licensed by FERC in 1979 and the license is set to expire in 2029. The limited storage capacity of the Brunswick Dam restricts its ability to influence river flows; therefore, during the FERC licensing process, a minimum flow requirement was deemed not necessary. The location of historical spawning grounds on the Androscoggin River is unknown but it is unlikely that sturgeon could navigate the natural falls located at Brunswick Dam (NMFS and USFWS 1998).

Other energy projects

Tidal turbines

A preliminary permit was issued to the Maine Tidal Energy Company by the FERC on June 24, 2008, for a tidal energy project in the Kennebec River. The proposed Kennebec Tidal Energy Hydroelectric Project is to be located in the Kennebec River between Chops Point and West Chops Point in the City of Bath and Town of Woolwich in Sagadahoc County, Maine (~ rkm 28). The proposed project would consist of up to 50 Tidal In-Stream Energy Conversion (TISEC) devices installed in one or more clusters in approximately 25 to 100 feet of water. Each TISEC device has rotating propeller blades approximately 20 to 50 feet in diameter, an integrated generator with an installed capacity of from 0.5 to 2.0 MW, anchoring systems, mooring lines to an anchor on the river bottom, and an interconnection transmission line to shore.

The proposed TISEC devices are not yet commercially available nor have they been demonstrated in the field to be technically or economically feasible. Therefore, the impact of multiple underwater tidal power generating units on public uses, marine and other natural resources has not yet been evaluated. The purpose of the permit is to maintain priority of application for a license during the term of the permit (36 months) while the Permittee conducts investigations and secures data necessary to determine the feasibility of the proposed project and, if said project is found to be feasible, prepares an acceptable license application.

Three additional permits are currently pending for hydrokinetic projects on the Sheepscot River: 1) Natural Currents Energy Serv., LLC., filed for a preliminary permit for projects on the Sheepscot River on November 26, 2007, 2) and on June 23, 2008, and 3) a preliminary permit was filed by the Town of Wiscasset, ME on November 12, 2008 for a hydrokinetic project on the Sheepscot River.

LNG facilities

No LNG facilities are currently proposed within the Kennebec and Penobscot watersheds or in the coastal waters between the two river systems.

Dredging and blasting

There is an authorized Federal Navigation Channel in the Kennebec River extending from the mouth of the river to Augusta. This channel is maintained by the ACOE. Historically, the Kennebec River has been dredged along Swan Island in Merrymeeting Bay (~ rkm 36), at Gardiner (~ rkms 59) and from Hallowell to Augusta (~ rkm 65-69). The upriver dredging projects are all located in tidal freshwater habitat. No channel maintenance dredging above Bath, where spawning habitat used to be located prior to the removal of Edwards Dam, has been conducted since 1963. On average, shoaled areas at Doubling Point and Popham Beach are dredged every three years. Maintenance dredging was last conducted in October 2003. The primary user of the deepwater channel in the lower Kennebec River is the U.S. Navy that routinely moves ship to and from the BIW facility in Bath, ME. ESA Section 7 consultation between the ACOE and NMFS has been completed on the effects of the maintenance dredging of this channel. Interactions with shortnose sturgeon have been recorded during hopper dredging activities in this river including the entrainment of 5 shortnose sturgeon at Doubling Point over three days in October 2003 when three shortnose sturgeon were killed and the other two suffered serious injuries. In April 2003, a shortnose sturgeon was killed in a bucket dredge (NMFS, Biological Opinion 2004) operating in the BIW sinking basin. More recently, a live shortnose sturgeon was recorded in dredging operations in the BIW sinking basin on June 1, 2009 and later released alive (M. Bowen, Normandeau Associates, pers. comm. 2009).

There are no Federal navigation projects in the Androscoggin River or Sheepscot Rivers, however, private dredging activities occur throughout the estuarine complex.

Water quality and contaminants

During the late 1960s and early 1970s, DO levels reached zero ppm in the Kennebec and Androscoggin Rivers from the head-of-tide to the mid-estuary during the summer months. The drop in oxygen levels commonly caused fish kills. DO levels improved significantly in the late 1970s and 1980s, coincident with improved point source treatment of municipal and industrial waste. Although DO was at severely low levels until the late 1970s, a population of shortnose sturgeon managed to persist in the system during this time period. The substrate in the upper freshwater section of both the Kennebec and Androscoggin rivers was severely degraded by wood chips, sawdust, and organic debris until the late 1970s. This accumulation was quickly flushed from the river systems after the cessation of log drives and the construction of water treatment plants.

Dioxin, likely generated from wastewater discharges from pulp and paper mills and municipal wastewater treatment plants, has been found in fish tissue samples collected in the Kennebec and Androscoggin Rivers (ME DEP 2005). The concentrations of dioxins in fishes collected from Maine rivers have decreased significantly over time. Concentrations of dioxins in fishes collected from Maine rivers were in the 2 to 30 ppt range in the mid 1980s while today levels are much more commonly seen in the less than 1 to 2 ppt range. The Androscoggin River has had the highest dioxin levels for fishes in the state of Maine. Levels of tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) were as high as 20 - 30 pg/g (parts-per-trillion) in fishes sampled from the Androscoggin and Kennebec Rivers during 1984-1986, before dropping to 0.1 pg/g in 2004 (ME DEP 2005). ME DEP has conducted limited testing for heavy metals, PCBs, and organochlorine pesticides in the tidal waters of the Kennebec River.

The Maine Center for Disease Control issues fish consumption advisories for segments of the Kennebec and Androscoggin Rivers. As of October, 2008 they advise no consumption of fish between Augusta and Chops Point (~ rkm 69) and 6 to 12 meals a year in the tidal section of the Androscoggin River. The consumption advisory for the Kennebec River from Augusta to the Shawmut Dam in Fairfield is 5 meals of trout a year and 1 to 2 bass meals a month.

Contaminant analysis of muscle, liver, and ovarian tissue has been performed for a shortnose sturgeon killed in May 2003 during dredging operations at BIW on the Kennebec River (see above). Fourteen metals, one semivolatile compound, one PCB Aroclor, PCDDs, and PCDFs were detected in one or more of the tissue samples. Of these chemicals, cadmium and zinc were detected at concentrations above an adverse effect concentration reported for fishes in the literature (Brundage 2003).

Despite water quality degradation in the past, the Kennebec estuarial complex has continued to support sturgeon. Improvements in habitat quality from the 1980s to the present should facilitate recovery of the shortnose sturgeon in this estuary.

2. Overutilization

Bycatch

There has been no reported or observed bycatch of shortnose sturgeon in the Kennebec River. Some bait gillnetting is allowed in the Kennebec system but commercial fishing activity is very limited.

Poaching

No shortnose sturgeon poaching has been reported in the Kennebec River.

Scientific research

There is one ESA Section 10 Research Permit issued for the Kennebec River: the permit exempts the take of 480 live adults/juveniles shortnose sturgeon and 30 eggs and/or larvae annually.

3. Competition, predation, and disease

Competition

Both adult shortnose sturgeon and sub-adult Atlantic sturgeon utilize the lower Kennebec River for foraging. Sub-adult Atlantic sturgeon were generally found in deeper water compared to adult shortnose sturgeon.

Predation

There is very little documentation of predation on any life stage of shortnose sturgeon. YOY shortnose sturgeon (approximately 5cm FL) were found in the stomachs of yellow perch (*Perca flavescens*) in the Androscoggin River, ME (Dadswell et al. 1984). It is likely that sharks and seals may occasionally prey on shortnose sturgeon based on the occasional specimen lacking a tail (Dadswell et al. 1984). While their large size, heavy armor and deep water habits likely limit predation of sdult shortnose sturgeon, it appears that some natural predation does occur.

Disease

There have been no observations of diseased shortnose sturgeon in the Kennebec system.

4. Inadequacy of existing regulatory mechanism

Federal, state, local laws or treaties

Shortnose sturgeon were listed as endangered in 2007 under the List of State Endangered And State Threatened Marine Species of the State of Maine. The listing allows the Commissioner of Marine Resources to enter into agreements with federal agencies, other states, state agencies, political subdivisions of State of Maine or private persons for the establishment and maintenance of programs for the conservation of state endangered or state threatened marine species and to receive all federal funds allocated for obligations to the State pursuant to these agreements. Federal funds received for the conservation of state endangered or state threatened marine species listed pursuant to this chapter must be allocated directly to the department to ensure compliance with any conditions of the listing. An ESA Section 6 agreement for shortnose sturgeon was subsequently approved between the ME DMR and NMFS.

5. **Other natural or manmade factors**

Ship strikes

There is very little commercial ship traffic in the Kennebec system; the majority of boat traffic comes from recreational boaters. There are no documented cases of boat strikes with the exception of a recent mortality found by MDMR personnel when a moribund shortnose sturgeon with lacerations to the head was found in the lower Kennebec River. The lacerations to the head were presumed result of a propeller strike.

Impingement and entrainment

There are no facilities located in the Kennebec system with significant water withdrawals. Several shortnose sturgeon were impinged on the intake racks to the Maine Yankee Atomic Power Plant which was located on Montsweag Bay in the Sheepscot River in Wiscasset while it was in operation from 1972 until permanent shutdown in 1997.

Artificial propagation

There is currently no artificial propagation of shortnose sturgeon occurring in the Kennebec System.

Escapement of hatchery/captive fishes

There are no sturgeon aquaculture facilties located in the Kennebec System and therefore no documented escapement of hatchery/captive sturgeon.

Current and Recommended Research

Current research

ME DMR has been recently been awarded a three year contract from NOAA through Section 6 to assess the distribution, abundance and movements of adult and subadult shortnose sturgeon in the Penobscot River through UMaine at Orono. This project builds on a project initiated by UMaine in 2006 and involves mark-recapture and passive tracking of shortnose sturgeon.

Recommended research

- Delineation of the spawning habitat on the mainstem and tidal tributaries of the Kennebec River.
- Assessment of the use of seventeen miles of recently restored habitat in the Kennebec River.
- Determination of the physical and chemical parameters associated with the wintering area on the Kennebec River, i.e. depths, temperature, salinities, and substrate types.

Piscataqua River

Historic Distribution and Abundance

Historical presence of shortnose sturgeon in the Piscataqua River is largely unknown as there are few records of any sturgeon captured on the river. It is thought that they were once abundant as in similar rivers in the Gulf of Maine because a creek along the river was given the name Sturgeon Creek (~rkm 17).

Current Distribution and Abundance

There are very few records of any sturgeon being captured in the Piscataqua River. Dadswell et al. (1984) reported a single shortnose sturgeon captured in the Piscataqua River since 1818 recorded in 1971. Prior to 1818 landing records did not distinguish between shortnose and Atlantic sturgeon therefore it is difficult to determine the presence or abundance of shortnose sturgeon. The New Hampshire Fish and Game Department (NHFG) conducted surveys of the Great Bay Estuary including the Piscataqua River and sampled 11 locations with gillnets fishing for 146 net days. The 1988 sampling occurred in the spring and summer in suspected spawning and feeding areas; the 1989 sampling occurred only in May and June. No sturgeon were encountered. A sturgeon carcass was found in December 2007 at Kittery, ME, at (rkm 1); the sturgeon was not identified as either an Atlantic or shortnose sturgeon (C. Patterson, pers. comm. 2008).

Natural History and Habitat Information

Spawning
No recorded incidents of shortnose sturgeon spawning in the Piscataqua River.

Rearing
Rearing habitat is unknown.

Foraging
Foraging habitats of shortnose sturgeon in the Piscataqua River have not been documented.

Overwintering/resting
Overwintering and resting habitat for shortnose sturgeon in the Piscataqua River is unknown.

Migration
Shortnose sturgeon migration to, from, and within the Piscataqua River is unknown.

Stressors to Riverine System

1. **Habitat**

Dams and diversions
There are currently no major dams or diversions on the mainstem of the Piscataqua River.

Other energy projects

Tidal turbines
A study on the effects of building a tidal turbine facility underneath the Spaulding Turnpike Bridge, where the Great and Little Bay meets the Piscataqua River, has been proposed (Dornin 2007). Final determinations have not been made, and studies are incomplete. Preliminary permits were issued on April 16, 2007, to Oceana and UEK Corporation for hydrokinetic projects on the Piscataqua River.

LNG facilities
No LNG facilities occur on the Piscataqua River.

Dredging and blasting

In 1966 the ACOE completed the dredging of the Piscataqua River Federal Channel (Pease Development Authority 2006). Dredging projects for maintenance were proposed by the ACOE for portions of a federal navigation channel in the Piscataqua River in 2000. Dredged material from this project was deposited in-river approximately 3,000 feet seaward of the dredging site and upstream of the I-95 bridge (rkm 7) (Anonymous 2000). North of the Public Service Company of New Hampshire/Northeast Utilities' (PSNH) power plant there is a reach of the Piscataqua River that has required dredging every five to six years due to shoaling and was most recently dredged in 2001. Disposal sites for these projects had typically been in-river sites; however NMFS, USFWS, and NH FG have recently requested alternative disposal sites (Pease Development Authority 2006).

Water quality and contaminants

Concerns regarding elevated levels of PAHs in the Piscataqua River arose following an incident in 1996 when approximately 1,000 gallons of fuel oil were spilled. Beyond this event, other sources of contaminants include waste disposal from the Portsmouth Naval Shipyard as well as sewage treatment plants on the river. The naval shipyard has been in operation since before the Revolutionary War and was most heavily used during World War II. Some practices employed at the naval yard between the mid-1940's and the late 1970's resulted in various hazardous wastes being released into the estuary including metals, PCBs, phenols, cyanide and oils. Tidal flats were turned into landfills via dumping of hazardous wastes including solvents, asbestos, incinerator ash, waste oils, and other semivolatile compounds (Johnston et al. 2002). While dumping is no longer occurring, hazardous waste is still present.

Organic contaminants including sewage discharge have also posed problems for the Piscataqua River. The Pierce Island wastewater treatment plant (rkm 4) has been operating under the "Section 301(h) waiver" through the EPA since 1985; the waiver allowed discharge of wastewater after undergoing the minimum primary treatment. The EPA in 2007 denied the waiver and now requires the minimum of "secondary" treatment prior to discharge (CLF 2008).

2. Overutilization

Bycatch, Poaching, and Scientific research

Because occurrence of shortnose sturgeon in the Piscataqua River is either very low or zero, bycatch or poaching is not a concern.

3. Competition, predation, and disease

No information is available regarding shortnose sturgeon diseases in the Piscataqua River and there is currently no evidence of predation on shortnose sturgeon in this river.

4. Inadequacy of existing regulatory mechanisms

Shortnose sturgeon are listed as endangered in the state of New Hampshire and Maine.

5. Other natural or manmade factors

Ship strikes

No evidence of ship strike interactions with shortnose sturgeon on the Piscataqua River is available.

Impingement and entrainment

The Newington Energy Plant, commissioned in 2002, is a facility that utilizes combustion turbines and heat recovery steam generators with a steam turbine for production of electricity. This plant is located at approximately rkm 12 on the Piscataqua River with an intake in the river for cooling of the generators. Through multiple studies, findings show the level of impingement at this facility is significantly lower than is reported for other power plants around New England (Power Engineering 2004).

Artificial propagation

No artificial propagation of shortnose sturgeon is currently occurring on the Piscataqua River. Great Bay Aquafarms, Inc. partnered with PSNH to use their Newington Station on the Piscataqua River for artificial propagation of flounder (Anonymous 1998).

Escapement of hatchery/captive fishes

Because there is no artificial propagation of shortnose sturgeon currently occurring on the Piscataqua River, there have been no incidents of escapement of hatchery reared or captive shortnose sturgeon. Furthermore, there have been no incidents reported of flounder escapement from the Great Bay Aquafarms, Inc. Newington Station (Anonymous 1998).

Current and Recommended Research

Current research

There is currently no research occurring on shortnose sturgeon in the Piscataqua.

Recommended research

- Conduct surveys to assess presence or absence of shortnose sturgeon.
- If shortnose sturgeon are found in the river :
    - Collect non-invasive tissue samples under the appropriate research permit for genetic testing to determine river of origin.
    - Employ tagging and tracking to determine movements to important habitats.
    - Survey for early life stages.

Merrimack River

Historic Distribution and Abundance

Historic anecdotal and commercial records of sturgeon in the Merrimack River made no distinction between the two sturgeon species later known to inhabit the river: the diadromous (freshwater amphidromous) shortnose sturgeon spending its entire life in riverine and estuarine portions of the river, and the anadromous Atlantic sturgeon, entering the river as adults for spawning and rearing in the river plus others entering as sub-adults during summer-fall for foraging. Several historical town ledgers of surrounding communities indicate large runs of Atlantic sturgeon and successful commercial harvests in the mid-1600s (Jerome et al. 1965), but the smaller shortnose sturgeon, likely present in the commercial harvest, remains unrecorded (Kieffer 1991). The farthest upstream observations of any sturgeon were noted at Amoskeag Falls (Manchester, NH, rkm 116) where Native Americans harvested sturgeon during the spring diadromous fish migration (Piotrowski 2002).

Current Distribution and Abundance

The first comprehensive survey of fish species in the Merrimack River (including the estuary and offshore reaches) was conducted by the MA Division of Marine Fisheries (MA DMF) in 1964 (Jerome et al. 1965). Beach seines and small otter-trawls were used to conduct sampling throughout the entire year, however, no sturgeon were captured. Shortly after the survey ended, the fisherman hired to conduct the trawl work gave MA DMF biologists a photograph of two apparent shortnose sturgeon carcasses that were found washed ashore near rkm 5 in Newburyport, MA (W. Jerome, MA DMF, pers. comm. circa 1965).

The first scientific attempt to capture adults was in December 1984 when J. Buckley and B. Kynard set gill nets for 3 days in slow water areas 2 km downstream of Essex Dam at Lawrence, MA, that might hold wintering sturgeon (Buckley and Kynard unpublished report). No sturgeon were captured, and it was concluded that the reach did not contain suitable wintering habitat. They recommended “further efforts in the Merrimack River should be directed downriver”.

The first detailed study of shortnose sturgeon in the Merrimack River was conducted between 1987 and 1991 (MA Cooperative Fish and Wildlife Research Unit, University of MA, Amherst). The project was funded by the MA DMF and NMFS. During four field seasons of intensive gillnetting, tagging and tracking, a small, viable population of shortnose sturgeon was discovered.

A total of 630 overnight gill nets were set between April and November throughout the study (approximately 11,524 sampling hours) and only 24 adults were captured with few recaptures. Tracking data indicated that the majority of the population resided between rkm 7and 32 (Kieffer and Kynard 1993). Only a rare individual was observed outside of this range (one tagged individual made a brief movement upstream to river km 35 in the summer of 1989).

Because telemetry data indicated that shortnose sturgeon remain in the river (no/low emigration) and there was low annual adult mortality, mark-recapture results from three years (1988-1990) were combined in a Schnabel abundance estimate of 32 adults (20–79; 95% CI = 20 – 79; B. Kynard and M. Kieffer, USGS, unpubl. data).

Recent gill-net sampling efforts show a dramatic increase in numbers of adults. During population estimate sampling in the winter of 2009, researchers captured a total of 170 adults (M. Kieffer, pers. comm. 2009). The recapture of too few marked fish resulted in unacceptably high confidence intervals around a Schnabel abundance estimate. A preliminary estimate, however, indicates an adult population close to 2,000 significantly higher than the estimate 20 years ago.

Natural History and Habitat Information

Spawning

Adult spawning behavior was studied for three years (1988 – 1990) at the spawning ground in Haverhill, MA (rkm 30–32; Fig. 19). Spawning success was confirmed by the capture of two live embryos in 1990 at rkm 32 (Kieffer and Kynard 1996). Tagged pre-spawning adults arrived at the spawning grounds no earlier than 12 April and departed no later than 30 April. Between acoustic tracking and gillnet captures, a total of 10 individuals were observed during the three years of study at the spawning grounds in Haverhill. Additionally, a one-day tracking effort in April 1999 showed three tagged males had again moved to the spawning area. Captures at the spawning site indicated males outnumbered females. Of 10 total individuals observed, eight were males (all ran sperm at least once) and the sex of two was unknown. Among the 10 individuals, five were observed at the spawning area multiple years (northern females are not known to spawn annually).

The specific timing and location of spawning was determined by observing mature adults in likely spawning activity and by back-calculating the estimated age of the captured embryos. In 1989, mature males aggregated at rkm 31 between 26–30 April within a site measuring approximately 10.5 ha. In 1990, spawning occurred during 22–29 April within a similarly small site, (13.5 ha), but was located ≤ 1 km upstream (at rkm 32) of the site used in 1989. Spawning in 1990 was confirmed by capturing viable embryos but sampling for early life stages was not done in other years.

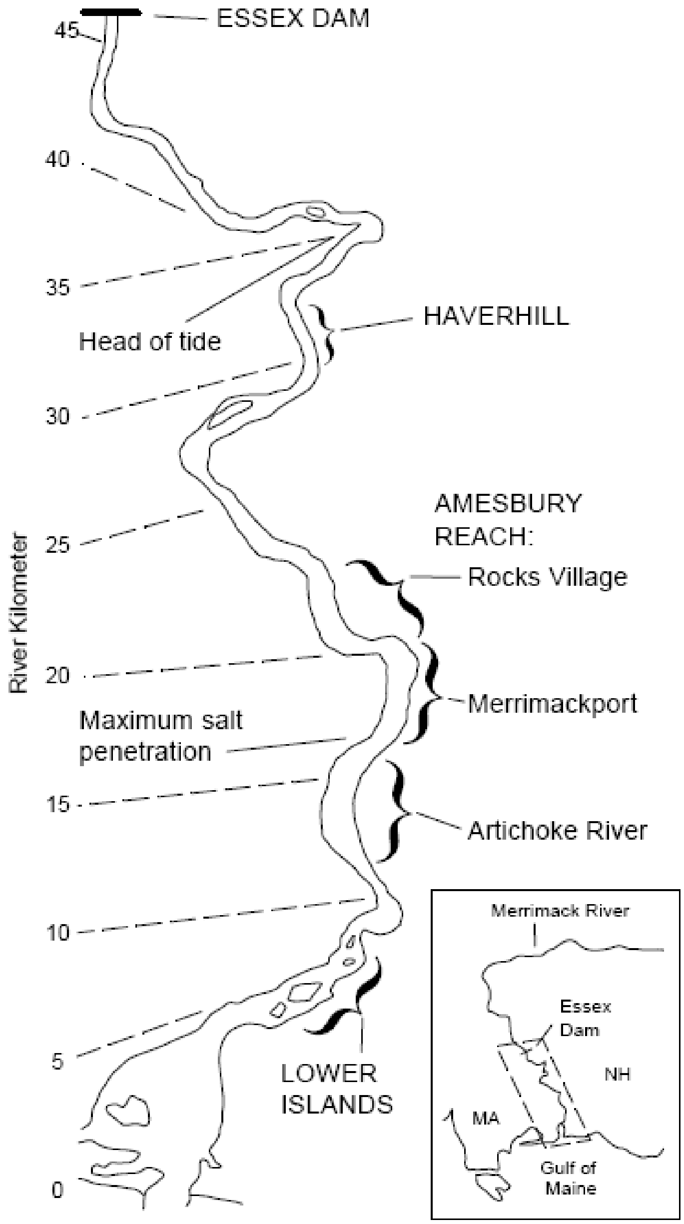


Figure 19. Map of the lower 46 km of the main-stem Merrimack River showing major tidal features where sturgeon were studied (area enclosed by dashed line in inset).

During the estimated spawning periods in 1989 and 1990, decreasing river discharge was between 390–240 m^3/s and increasing temperature was between 9.6–14.0°C. In both years, spawning occurred over boulder-rubble substrate. In 1989, mean depth was 2.3 m (range, 1.8–3.0 m); bottom velocity averaged 0.48 m/s (range, 0.3–0.7 m/s). In 1990 mean depth was 3.8 m (range, 2.7–5.5 m) and bottom velocity averaged 0.33 m/s (range, 0.3–0.4 m/s).

A recent NMFS-funded survey effort (Kieffer and Kynard unpublished data) resulted in the capture of 22 adults (all but one individual a ripe male) in six gill nets set overnight for 1 day in late-April 2008 at the Haverhill, MA spawning site (rkm 32; Kieffer and Kynard 1996). The high catch-per-unit-effort (CPUE) in the spring 2008 (0.305; Kieffer and Kynard unpublished data) were in stark contrast to the CPUE results from previous years 1989 = 0.005 and 1990 = 0.018 (Kieffer and Kynard 1996).

A continuation of this effort in spring of 2009 resulted in the capture of 14 additional ripe males at Haverhill during 124.7h of gill-net effort; none of the males had been previously captured. In addition to the gill-net effort, ELS nets set between 26–28 April 2009 sampled 37,178 m^3 of water at Haverhill, capturing two free embryos and four eggs; back calculation indicated spawning occurred on 18–20 April, 2009.

In the fall of 2009, Kieffer (USGS, pers. comm. 2010) captured the first documented females in the Merrimack River, three late-stage and three early-stage fish. All six were captured during gill-net efforts to capture and tag coastal migrant Atlantic sturgeon in a tidally influenced reach between river km 12–9.

Rearing

Two live shortnose sturgeon embryos were collected at rkm 32 near the spawning site identified in 1990 (Kieffer and Kynard 1996). Thus, successful spawning does occur at Haverhill. However, no information exists on rearing habitat or success for any early life stage.

Foraging

Kieffer and Kynard (1993) found that following spawning, in the first week of May, a portion of post-spawning and non-spawning adults moved downstream to the salt/freshwater interface (rkm 7–12). Adults remained for as long as six weeks (through mid-June) in an area with wide tidal shifts in temperature, salinity, turbidity, and velocity. This was also the time and reach that sub-adult Atlantic sturgeon entered the river, and the only time−space when the range of the two species overlapped.

Although the reason for the downstream movement by adults is unknown, the movement occurs in other North-central shortnose sturgeon populations: Delaware River (O'Herron et al. 1993) and the Connecticut River (Buckley and Kynard 1985a, Savoy 1991a and b). Researchers in the Merrimack River speculated this movement by adults was a foraging movement to obtain an essential mineral or dietary element following energetic depletion (Kieffer and Kynard 1993). As river discharge decreases in late-spring and summer, tidal salinity during high tide travels farther upstream. Maximum upriver penetration of tidal salinity (1–10 ppt) occurs between rkm 14–9 during the tidal extremes. Except for the six-week period following spawning, Merrimack

River sturgeon in the study by Kieffer and Kynard (1993) were mostly separated by tidal salinity with shortnose sturgeon upstream of this reach and Atlantic sturgeon downstream of this reach.

During the remainder of the year, shortnose sturgeon occupied an 11-km reach (river km 13–23 between Haverhill and Amesbury) with reversing currents during flood tides and a maximum salinity penetration to rkm 16. Habitat selections during daily and seasonal cycles were characterized as follows: adults used three geomorphological regions (curve, island, and run) equally during foraging (summer-fall) and used channel and shoal habitats equally during summer, but favored channel in fall. Micro-habitat use follows: adults used a depth range of 2–6m that changed little during the foraging season; substrate use varied among four categories of substrate, but adults were tracked mostly over sand; adults used mostly low levels of illumination (< 2,500 lx), when illumination availability was a maximum of 20,000 lx (Kynard et al. 2000).

Overwintering/resting

Tracking efforts during winter months were infrequent, however, tagged adult shortnose sturgeon tracked between late November–March remained within an 11-km reach (river km 12–23; Kieffer and Kynard 1993). Although no temperature loggers were placed in the river through the winter, temperatures could be expected to follow a typical New England profile, approaching minimums of 0°C, indicating that shortnose sturgeon would likely adopt the energy-conserving behavior of minimal movements and foraging like the minimal movement observed by Kynard et al. (2012) in the Connecticut River.

Recent tracking in this reach showed tagged fish concentrated in three separate sites (rkm 17, 21, and 23), with the rkm 21 site having the greatest percentage (47.6%) of acoustic-tagged wintering fish (M. Kieffer, pers. comm. 2009). This recent data shows the range of wintering sites remained within the same 11-km reach observed 20 years ago.

Migration

Adults

Adults have two seasonal migration periods (Kieffer and Kynard 1993). In mid-April, tagged adults moved the 10 km from wintering areas to the spawning sites at Haverhill. Following spawning, post-spawning adults departed Haverhill by early May. Some moved the 10 km back downstream to the summer-fall foraging area (rkm 13–23), while others moved farther downstream to the lower islands (rkm 7–12). Some non-spawning adults also moved downstream from Amesbury to the lower islands; thus the lower islands reach was used by both post- and non-spawning adults during the period following spawning (April 29–June 22), the period when they were beginning to resume feeding following winter inactivity. After a maximum of 6 weeks, all adults at the lower islands returned upstream to the summer-fall foraging area (river km 13–23).

Inter-basin movements

The relatively short distance between the Merrimack River and the Gulf of Maine complex (Kennebec, Androscoggin, and Penobscot Rivers; ~ 135–270 km) as well as the theory that Merrimack River shortnose sturgeon spawning near head-of-tide (rkm 35) may be a behavior introduced to the Merrimack River by migrants from the Androscggin River where fish also spawn lower in the river (Kynard et al. 2000), suggests the possibility of inter-basin movements. However, recent genetic evaluation of individuals from both areas (T. King et al. 2013) shows small but statistically insignificant amount of genetic exchange likely occurs between the Merrimack River and the rivers in Maine.

During recent efforts, however, four late-stage females tagged in the Merrimack River between October-December 2009 (M. Kieffer, pers. comm. 2010) departed the river between March 3rd and April 4th of 2010 and migrated roughly 130 km to the Kennebec River mouth. Fish were detected on Kennebec River data loggers positioned at known or suspected spawning areas between March 30th and May 7th 2010 (G. Whippelhauser, pers. comm. 2010), then returned to the Merrimack River during May 9-21, 2010. In addition, an adult fish captured in the Kennebec River in October 2000 was recaptured on November 20, 2009 in the Merrimack River near the wintering site at rkm 17.

Stressors to Riverine System

1. Habitat

Dams and diversions

The first mainstem dam (Essex Dam) is located at river km 46 in Lawrence, MA. The stone and plywood dam was built in 1848. A hydroelectric facility is located at the dam and is operated pursuant to a license issued by FERC in 1978 and operates as a run-of-the-river facility. The license is set to expire in 2028. There is a functioning fish lift at the dam. In three years of telemetry and gillnetting, no shortnose sturgeon was detected upstream of river km 35, even though habitat suitable for spawning (at least) appeared abundant in this reach. Although the reason Merrimack River shortnose sturgeon remain downstream of river km 35 is unknown, shortnose sturgeon have rarely been observed to occupy reaches upstream of spawning areas, suggesting the life history of the Merrimack River shortnose sturgeon is an adaptation to complete their life cycle in the lower portion of the river.

Other energy projects

Tidal turbines

There are no tidal turbines in the Merrimack River and none have been proposed. However, in 2004, Verdant Power, a Virginia-based firm tested a series of tidal generators in Amesbury. At the time of testing the firm indicated a feasibility study would be conducted for potential use of tidal turbines in the Merrimack River.

LNG facilities

There are no LNG facilities on the Merrimack River and none have been proposed.

Dredging and blasting

A navigation channel exists in the Merrimack River and is maintained by the ACOE. In the late 1800s, a channel from the Route 1 bridge (rkm 5) to Haverhill (rkm 30) was dredged to a continuous depth of seven feet mainly for recreational and light commercial boating. The channel was re-dredged in the 1940s. Maintenance of the lower river portion of the channel near Newburyport occurs every few years. Recently, the City of Haverhill approached the ACOE regarding dredging shoaled areas in the upper river near Haverhill to restore the authorized depths. The City has indicated that the shallow depths prohibit the use of this section of the river by party and tour boats that the City would like to encourage. No action has been taken to date and discussions between the City, NMFS and the ACOE are ongoing to determine if dredging in this area can be conducted in a way that would avoid harm to shortnose sturgeon and potential spawning habitat.

Water quality and contaminants

Pathogens from combined sewer overflows and urban runoff are the major causes of water quality problems for the river according to a 2001 watershed assessment (Dunn 2001). Additionally, nutrients and ammonia are listed as problems, particularly around urban areas. The city of Haverhill, MA, surrounds the spawning area. During heavy rains, storm drains dump directly onto the spawning area. Although DO has greatly improved following the Clean Water Act, during periods of drought or low flows, DO can decrease below minimum tolerances for shortnose sturgeon. Water quality reports from the late 1990s indicate contaminants from metals have been removed from the river's list of stressors, however various independent groups found periodic violations of metal releases around industrial sites, during dumping, and during high river discharge. Although only limited sediment sampling has recently been done in the Merrimack River, increased sampling of fish tissue indicates an increase in mercury, (largely from incinerators and power plants), resulting in the 1999 Department of Public Health release of fish consumption advisories on several river reaches.

Water quality of the Merrimack River was also assessed by the MA DEP (Meek and Kennedy 2010). Reaches from Lowell to Newburyport were consistently determined impaired for fish consumption due to PCB and mercury contamination and for primary recreational contact (swimming) due to fecal coliform bacteria. In addition, the report cited advisories for shellfishing in the lower river.

Currently, drinking water withdrawals directly from the mainstem river occur in only four communities. The most downstream water withdrawal occurs at Lawrence, MA (rkm 46), the location of the lowermost mainstem dam (Essex Dam). Because of the brackish conditions downstream of Haverhill, drinking water withdrawals are not feasible; however, water is withdrawn from many tributaries entering the lower Merrimack River. In addition, many communities have applied for or received permits to increase water withdrawals and have exceeded permitted withdrawal levels, particularly during low water in summer. Because withdrawals are assessed on an annual, not daily basis, annual maximums are not violated.

2. Overutilization

Bycatch

There is no commercial gillnet fishing on the Merrimack River. In 2008 six Atlantic sturgeon were reported hooked by recreational anglers; shortnose sturgeon are probably accidentally captured in recreational hook and line fisheries as well, particularly by catfish anglers using baited hooks fishing on the river bottom.

Poaching

Poaching of sturgeon in the Merrimack River has not been documented.

Scientific research

There is currently a permitted mark-recapture and tracking study that allows the capture of up to 200 adults and the acoustic tagging of 15 adults per year.

3. Competition, predation and disease

Competition

During the months when most foraging occurs (June–October), shortnose sturgeon share portions of the river with the sympatric Atlantic sturgeon sub-adults. Although both species may compete for feeding resources, numbers of both species are low and are mostly separated by tidal salinity. Nothing is known about competition of juvenile shortnose sturgeon with other benthic foraging fishes, like catfish

Predation

Because numbers of shortnose sturgeon in the Merrimack River are low, even a small amount of predation may be significant. Smaller life stages are undoubtedly preyed upon by the typical host of predators inhabiting New England rivers. Predators capable of taking adults (such as eagles or seals) are rare in the portion of river inhabited by shortnose sturgeon.

Disease

There have been no observations of disease in shortnose sturgeon from the Merrimack River.

4. Inadequacy of existing regulatory mechanisms

Shortnose sturgeon is listed as an endangered by the state of MA, but not by NH. Current regulatory programs protect the shortnose sturgeon population from major assaults on habitat quality (dredging, water quality, wetlands conservation); however, the increasing amount of boating traffic and the infrastructure needed to serve the recreational and commercial boating industry along with total accumulation of non-point pollution sources potentially puts long-term survival of the species at risk. In a population with such small numbers, the loss of one adult female may be deleterious to recruitment.

Water use

Regarding water use regulations, water supply management plans are left up to the discretion of local communities, and are not regulated by the MA DEP. Many communities have not implemented water conservation practices, or provide adequate protection to surface watershed areas.

Enforcement

Limited resources for environment makes illegal harvest difficult to enforce.

5. Other natural or manmade factors

Ship strikes

Although there is a high volume of recreational boating in the lower Merrimack River, particularly closer to the river mouth (rkm 0–20), no strikes have been documented. However, that does not mean none occur. A carcass recovered from the riverbank at rkm 5 in 2005 and one photographed in June 2008 showed no signs of propeller damage.

Impingement and entrainment

There have been no incidences of impingement or entrainment reported for the Merrimack River.

Artificial propagation

There is no current artificial propagation of shortnose sturgeon nearby the Merrimack River; however CAFRC is permitted to do so.

Escapement of hatchery/captive fishes

There are no shortnose sturgeon currently being reared artificially in the Merrimack River drainage.

Current and Recommended Research

Currently, researchers are gillnetting on the Merrimack River to capture, sample tissue, and acoustically-tag pre-spawning and pre-wintering adults. Movements of individuals that were tagged in spring 2008 are being tracked remotely with seven remote acoustic data loggers between rkm 2–35 to determine if residency range of adults has changed since the early-1990s. In the fall, gillnetting will continue in the foraging area to collect additional adults for tissue samples, tagging with acoustic tags, and estimating population size (mark-recapture). When shortnose sturgeon transition to wintering behavior, winter concentrations will be located and surveyed with underwater video cameras (if possible). Duration of winter behaviors will be determined by deploying an additional data logger near wintering sites. During the 2009 foraging period, a small otter trawl will be used to sample for juveniles to gather evidence of successful recruitment, and to potentially, obtain a mark-recapture estimate of juvenile abundance.

Recommended research

- Continue the survey and tracking of adults to gather additional tissue samples and detect changes in population status (abundance, residency ranges, winter ecology, and spawning success).
- Determine status of juveniles (an indication of recruitment) and characterize ecology and habitat use.

Connecticut River

Historic Distribution and Abundance

Shortnose sturgeon in the Connecticut River inhabit a reach downstream of the Turners Falls Dam (Turners Falls, MA; rkm 198) to Long Island Sound (Fig. 20). Construction for the Turners Falls Dam was completed in 1798 and built on a natural falls-rapids. Turners Falls is believed to be the historic upstream boundary of shortnose sturgeon in the Connecticut River and there have been only a few anecdotal sightings of sturgeon upstream of the dam. In 1849, another mainstem dam was completed on the South Hadley Falls (Holyoke, MA; rkm 140), obstructing the movements of both up- and downstream migrant shortnose sturgeon.

Downstream of the Holyoke Dam, historic records show Connecticut River sturgeon were harvested by both Native Americans and settlers. Commercial fishing records from the 1800's show spear, seine, and trap fisheries for Atlantic sturgeon at the South Hadley Falls (the current location of the Holyoke Dam). Eastman (1912) describes the commercial harvest of sturgeon 8–10 feet long using stone weirs at the South Hadley Falls (the current site of the Holyoke Dam) in the early 19th century as fish moved through to Turners Falls, MA. In the early 1900's, a haul-seine fishery captured sturgeon at the Enfield rapids (rkm 110). Lastly, about 10 familes using gill-nets harvested sturgeon over a 25-year period in the early 1900's at Cromwell, CT (~ rkm 50).

Upstream of the Holyoke Dam, commercial sturgeon fishing activity is reported by McCabe (1942). Although the presence of both species was not acknowledged, McCabe reports the observation of only one sturgeon ("*Acipenser sturio oxyrhynchus"*), an average size of over 100 sturgeon (2.7 kg) captured commercially in the early-1940's between Holyoke and Northampton (rkm 140–164), and the observation of sturgeon presence in this reach late in the year (jumping observations in November) strongly suggests the presence of shortnose sturgeon. Like many early sturgeon fisheries in New England, the two sturgeon species were not recognized and separated as individual species in the recorded landings.

Current Distribution and Abundance

Currently the Connecticut River population of shortnose sturgeon is separated into an upstream and downstream segment bisected by the Holyoke Dam: upstream in a 59-km area between the Turners Falls and the Holyoke Dam, and downstrewam in a 140-km segment between the Holyoke Dam and Long Island Sound (Fig. 20). While literature indicates that the shortnose sturgeon were separated following construction of the Holyoke Dam, recent behavioral and genetic information indicates shortnose sturgeon in the Connecticut River are of a single population impeded, but not isolated, by the dam (Kynard 1997, Wirgin et al. 2005, Kynard et al. 2012). Individuals upstream are typically found as far north as rkm 194 (Montague spawning area), but on several occasions, an adult has been reported at the base of the Turners Falls Dam (rkm 198; Fig. 20). There is no scientific evidence that sturgeon ever occupied reaches upstream of Turners Falls.

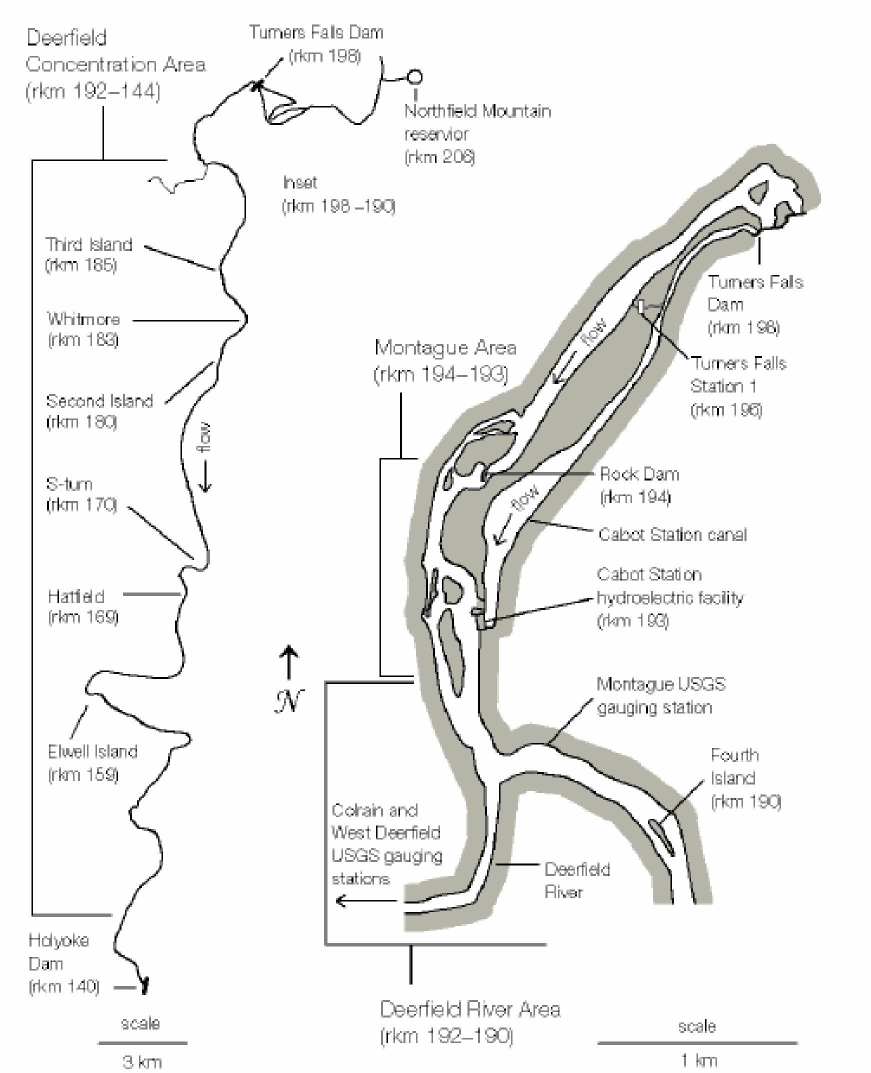


Figure 20. Map of the Connecticut River from Turners Falls Dam to the Holyoke Dam showing the Montague Area with the Rock Dam and the Cabot Station hydroelectric facility, the Deerfield River Area, and the Deerfield Concentration Area (with foraging sites and four wintering sites of shortnose sturgeon). River kilometer = rkm.

Upstream of the Holyoke Dam there is a 2-km shortnose sturgeon spawning area at Montague, MA (rkm 194–193; Kynard et al. 2012). Foraging and wintering areas for the shortnose sturgeon upstream lay in the 49-km Deerfield Concentration Area (DCA) between rkm 192–144. Downstream the Holyoke Dam, a concentration of shortnose sturgeon may be found in a 2-km reach immediately below Holyoke Dam (rkm 140–138) throughout the spring, summer and fall. Most individuals found at Holyoke Dam are likely shortnose sturgeon attempting to migrate upstream are impeded by the Holyoke Dam. There is also evidence of marginal spawning success in this reach (Kynard et al. 2012). Shortnose sturgeon also concentrate in a 9-km reach near Agawam, MA (rkm 120–112) throughout the year, in an area impounded by the breached log-crib Enfield Dam (Buckley and Kynard 1985a, Kynard et al. 2012). Downstream of the Enfield Dam, adults occupy tidally influenced reaches between rkm 100–0 throughout the year (Buckley and Kynard 1985a, Savoy 1991a and b, Savoy 2004).

Shortnose sturgeon have also been observed in Connecticut River tributaries. Pre-spawning adults from the upstream segment have been tracked and captured in the lower 3.5 km of the Deerfield River, near its confluence with the Connecticut River at rkm 192. Kynard et al. (2012), report a total of 30 adults (ripe males and late- and early-stage females) detected in the Deerfield River from 1991–2007 by CAFRC researchers. The confluence of the two rivers occurs just 1–2 km downstream of known spawning sites in the Connecticut River at Montague. Some adults found in the Deerfield River (late-stage males and females) continued upstream to spawn at Montague while others remained in the Deerfield River until November (Kynard et al. 2012).

Sturgeon from the lower river may also use tributaries. In May 2007, an adult shortnose sturgeon from the downstream segment entered a fish trap on the Westfield River at the Design Specialties International (DSI) Dam (USFWS 2007 fish count). The DSI Dam is located ~ 9.5 km upstream of the confluence of the two rivers at rkm 122 on the Conneticut River.

Population estimates have been completed for shortnose sturgeon occurring both upstream and downstream of the dam in the Connecticut River. Taubert (1980a) conducted the earliest population estimate: a Peterson mark-recapture model for sturgeon upstream the dam resulted in an estimate of 370–714 adults. More recently, a Schnabel mark-recapture estimate upstream the dam during the summer-fall foraging period of 1994 indicated an abundance estimate of 328 adults (CI = 188–1,264 adults; B. Kynard, USGS, unpubl. data). Lastly, during studies of spawning ecology upstream the dam at the Montague spawning site, abundance of pre-spawning adults was estimated each spring between 1994–2001 at a mean of 142.5 spawning adults (CI = 14–360 spawning adults; Kynard et al. 2012).

Downstream of the dam (rkm 100–0), researchers conducted annual estimates of foraging and wintering adults using the Schnabel mark-recapture technique during 1989–2002: mean abundance was 1,042 adults, with the average estimates almost doubling between the sampling periods of 1989–1994 at 788 adults and 1996–2002 at 1,297 adults (Savoy 2004).

In addition to the distribution of shortnose sturgeon in the wild, broodstock of Connecticut River origin are currently held at the USGS Conte Research Center and Alden Research Lab, MA. These two facilities conduct a variety of research to improve sturgeon culture, fish passage and tagging technology, and other biological studies. Fish generated from the Connecticut River stock are also currently being held at several educational facilities for public display including Maritime Aquarium, Norwalk, CT; Virginia Museum Newport News, VA; Liberty Science, Jersey City, NJ; and Springfield Museum, Springfield, MA. Although, captive shortnose sturgeon may not typically be released into the wild, NMFS recognizes similar genetic, physical, physiological, ecological, and behavioral characteristics can be shared by shortnose sturgeon produced in a hatchery and the natural populations from which they are derived. As a result, all components of the shortnose sturgeon, including populations of natural individuals and hatchery stocks derived from similar populations, are considered part of the original wild population and therefore these individuals are included in the ESA listing of the species.

Natural History and Habitat Information

Spawning

Upstream

Researchers confirmed spawning success upstream the Holyoke Dam in 1993 by capturing shortnose sturgeon early life stages (ELS = eggs, embryos, or larvae) at two distinct sites in Montague. The sites are both located approximately 4km downstream of the Turners Falls Dam (Kynard et al. 2012). Researchers refer to the main site as "Cabot Station" because it occurs in the tailrace of the Cabot Station Electrical Generation Facility (rkm 193). This site is approximately 2.7 ha in area and receives water from above Turner's Falls Dam that has been diverted through a power canal for the Station. The secondary, smaller site (0.4 ha in area) is located at Rock Dam (rkm 194). Rock Dam is a natural rock barrier located at the end of a natural river reach also flowing from the Turner's Falls Dam (Fig. 20).

Researchers have studied shortnose sturgeon spawning at these sites for more than 16 years (Kynard et al. 2012). A continuous monitoring effort between 1993–2007 revealed spawning succeeded at the Cabot Station site 71% of years and at the Rock Dam site 21% of years. Tagged pre-spawning adults arrived at Montague as early as 13 April and departed by 1 June. In successful spawning years, 1–324 ELSs were captured each year in anchored D-net sampling. Spawning periods, back-calculated from estimated ages of sampled ELS, occurred between April 27 and May 22, and ranged between 3–17 d (mean; 7.8 d). In all years, spawning occurred as river temperature was increasing and river discharge was decreasing. During estimated spawning periods, daily mean temperature ranged from 6.5–15.9 °C and daily mean discharge ranged from 901–121 m^3/s. All spawning occurred during photo-periods of 13.9–14.9 h (corresponds with 27 April–22 May).

From 1993–1995, researchers measured bottom velocity and depth on spawning sites over 24-h sampling periods (Kynard et al. 2012). Mean spawning depths (for both sites) were 1.8m (range; 1.2–5.2m) and mean bottom velocities of 0.7m/s (range 0.3–1.2m/s). Both sites occurred in areas of swift water resulting in rubble substrate continuously swept clean of fine particles and algae.

Analyses of river conditions indicated spawning success was dependant on the timing of habitat suitability windows (Kynard et al. 2012). No spawning occurred outside the day-length window of 13.9–14.9h of daylight. During this photo-period, shortnose sturgeon spawned only during daily mean temperatures of 6.5–15.9°C. Spawning was also dependant on a mean daily discharge of 901–121m^3/s, but water levels had to be within this window by 30 April. If reaching this discharge level was delayed even for a few days at the Cabot Station site, spawning failed, even late-stage females and ripe males were present. Although temperature and discharge appeared to affect spawning, photo period was the dominant factor influencing the timing of spawning.

Spawning at the Rock Dam site was affected by high discharge levels like at the Cabot Station site, but was also affected by low discharge (Kynard et al. 2012). Because the Rock Dam site is located between the Turners Falls Dam, flow is significantly reduced when water is diverted from the natural river by the Turners Falls Dam to a power canal serving the Cabot Station. Flow at the Rock Dam all but stops whenever river discharge drops to below ~400m^3/s (maximum used for power generation at Cabot Station). Complete diversion typically occurs at some point during the spawning season as the spring floods subside (1 April–27 May). Tracking and ELS sampling indicate all spawning activity ceases when water is diverted from the Rock Dam site. Even if water returns to the mainstem for brief periods, pre-spawning adults are rarely attracted to the site. Because complete diversion usually occurs in early May, spawning succeeds infrequently at Rock Dam. There was no year when spawning succeeded at Rock Dam but failed at Cabot Station.

Downstream

Although shortnose sturgeon ELSs have been captured downstream of the Holyoke Dam (Fig. 20), evidence indicates that only minimal spawning occurs. In the mid 1980s, a multi-year study tracked ripe, pre-spawning adults congregating just below the Holyoke Dam (Buckley and Kynard 1985b). At that time, the capture of ripe males and females together in the spring was believed to indicate imminent spawning. The Holyoke Dam area was systematically surveyed to determine depth, velocity, and substrate present under several hydro-power flow regimes during spawning (Buckley and Kynard 1985b). Because no efforts to capture shortnose sturgeon ELS were made, successful egg release and fertilization during these efforts remains inconclusive. Between 1993–1997 systematic ELS sampling occurred at Holyoke Dam (Kynard et al. 2012) along with gill-net sampling and tracking and in 1995, four eggs and four free embryos (also called yolk-sac-larvae; transition period between hatchlings and larvae) were captured along with mature males and females. Habitat measurements showed conditions at Holyoke Dam were similar to that observed upriver at the Montague spawning site during the same year. That same year (1995) proved to be the most productive spawning year observed upstream the Holyoke Dam at Montague where sampling for ELS resulted in the capture of 324 eggs, 16 free embryos, and two larvae (Kynard et al. 2012).

Shortnose sturgeon ELS were captured again at Holyoke Dam in a 1998–1999 (Kynard et al. 2012). Researchers used a similar evaluation as in 1993–1997 including ELS sampling. Eight unfertilized eggs (one in 1998 and seven in 1999) were captured along with mature males and females. Although ELS were captured with similar effort at Holyoke and Montague during the same years, low capture numbers of ELS at Holyoke Dam in 1999 (seven eggs) versus those found at Montague (113 eggs and 14 embryos) and the absence of spawning behavior (localization) by tracked Holyoke adults showed minimal spawning success.

Recently, additional efforts to identify shortnose sturgeon spawning downstream of the Holyoke Dam were conducted. In spring 2005 and 2006, ELS nets were set during known spawning temperatures at several sites between Hartford, CT (~ rkm 85) and Springfield, MA (~ rkm 125) for a total of 62,519 m^3 of water sampled. No shortnose sturgeon ELS were captured as a result of these efforts; however, during unrelated ichthyoplankton sampling during the same years, three shortnose sturgeon larvae were captured (1 in 2005 and 2 in 2006; Kleinschmidt 2006, 2007).

One interpretation of these larval captures is that significant spawning occurs downstream of Holyoke Dam, perhaps at several sites. The few numbers of larvae captured downstream of Holyoke in 2005 and 2006 were consistent with the low numbers of ELS captured at the Montague site during the same years: 0 in 2005 (346,660 m^3 of water sampled) and 4 eggs in 2006 (106,689 m^3 of water sampled; Kynard et al. 2012). Because spawning success at Holyoke appeared to reflect success at Montague during the same years (Kynard et al. 2012), few ELS may have been available downstream of Holyoke Dam during the 2005 and 2006 sampling resulting in the low number of ELS captures. In addition, nets towed at mid-column that captured ELS totaled only 100 m^3 of water sampled, a very small amount of effort to have captured larvae dispersed over a long distance (55 km from Holyoke), suggesting increased sampling may have resulted in higher captures. The effort required to capture 13 larvae 3–15 km downstream of Montague in 1977 and 1978 was large in comparison, totaling 479.2 hours of effort (Taubert 1980b). In addition, Whitworth (1996) states fall-line topography at Windsor Locks, CT (~ rkm 100) as a possible historic spawning area.

An alternative interpretation of the 2005 and 2006 larval captures downstream of Holyoke Dam is that all three larvae were the result of downstream dispersal following rare spawning events at Holyoke. The larvae captured at Springfield could easily have moved downstream 15 km from Holyoke, similar to the 3–15 km distance larvae were captured downstream of the Montague spawning area by Taubert (1980b). Although a larva spawned at Holyoke would have to disperse downstream 55 km to be captured at Hartford, results from laboratory experiments of larval dispersion duration indicate this migration distance is possible. Parker (2007) reported larvae dispersal activity continued up to a maximum of 25d within test groups, although maximum dispersal periods of individuals were unknown. A conservative estimate of dispersal distance using a 10-d dispersal period, assuming movement occurred only during night hours (~ 9hours/day in May), and the slowest velocity conditions measured (mean velocity; 0.1 m/s measured at the Agawam wintering site located in the Enfield Dam impoundment; Kynard et al. 2012) suggests some dispersing larvae could travel over 30km. Movement distances could easily be greater than 30km when considering mean discharge between mid-May and mid-June 2006 was 1,224 m^3/s (range 2,107–606 m^3/s; USGS Holyoke Gauging Station data), over 4 x the discharge when bottom velocities at Agawam were measured at 0.1 m/s in winter (275 m^3/s).

Researchers at the CAFRC conducted annual experiments in semi-natural laboratory spawning of shortnose sturgeon from 2000–2007. During a preceding fall or winter, up to four late-stage females were captured from foraging or wintering areas in both the up- and downstream-segments (Kynard et al. 2012). Females were held indoors under ambient or heated water temperatures and then in early May they were placed in an experimental spawning channel with up to 15 ripe males. The males were captured each spring (2002–2007) from both the upstream segment (Montague) and the downstream segment (below Holyoke Dam). The spawning channel was lined with rocks similar in size to rocks observed on known spawning sites and had a flow-through source of Connecticut River water. Water velocity and depth were both within levels known to be suitable for spawning. The study demonstrated that most shortnose sturgeon adults would spawn successfully in the semi-natural environment year after year.

Researchers were also able to observe an intimate level of individual interactions during the spawning studies in the artificial spawning channel (Kynard et al. 2012). Once females began spawning, they deposited eggs for periods lasting between 16–36h, with short periods between ovulations. Among the 20 females placed in the channel throughout the seven-year study, 18 (90%) spawned. Why two females failed to spawn was unknown. Spawning females lost between 20–40% of pre-spawning weight from egg deposition. Among males, some individuals were more aggressive than others, engaging in more spawning encounters than other males. Males lost between 0–7% of pre-spawning weight. Researchers then described individual spawning behaviors, showing: notable differences of spawning success by males, males mating with multiple females, repeat spawning among the same individuals, and the range of spawning event frequencies. Variations in pre-spawning treatments of females, including different water temperature (ambient water temperatures vs. heated temperatures) and tagging treatments (no tags or incisions, incision only, and incision combined with the placement of an internal dummy tag) had no effect on the spawning success of females.

Semi-natural spawning of shortnose sturgeon in the laboratory offers an alternative to traditional hatchery techniques for producing progeny used in behavioral experiments or population restorations and enhancements. Although many natural selective factors are absent in the semi-natural spawning channel, parents were allowed some level of mate selection. This maximized genetic contributions from a community of adults rather than one set of artificially selected parents, and allowed for a more natural expression of behavioral genetics (dominant vs. subordinate males); both are vast improvements over typical hatchery selection of broodstock. Additionally, eggs, embryos, and larvae reared in the semi-natural spawning channel were subjected to some of the river's natural selective factors, such as temperature, water velocity, egg adhesion success, hatching success, predatory aquatic insects, and aquatic pathogens.

Foraging

Upstream

Behavior and habitat of radio-tagged shortnose sturgeon during the summer-fall foraging period upstream the Holyoke Dam were observed in the early 1990's. The foraging ranges of seven adults and four hatchery-reared juveniles within the Connecticut River's DCA were similar (Kynard et al. 2012). Within the 49-km DCA foraging area, the mean range of foraging adults was 8.4 km (range; 4.0–14.2 km). A companion tracking study described foraging habitat use of adults and juveniles using a hierarchical approach (Kynard et al. 2000). Although sturgeon in the Connecticut River showed individual variation in habitat use and a broad range of habitat use on all spatial scales, foraging shortnose sturgeon preferred curves dominated by sand or cobble substrate and avoided runs (straight river sections). Juveniles used similar depth habitat as adults (0.3–15.0 m) during summer and fall, but used a slower bottom velocity (< 0.4 m/s) during late fall and winter than adults.

Downstream

Downstream the Holyoke Dam food habits were investigated for both adult and juvenile shortnose sturgeon by the CT Department of Environmental Protection (CT DEP) between 2000–2002 (Savoy and Benway 2004). Shortnose sturgeon sampled throughout the year at both riverine and estuarine locations showed a significant difference in feeding between cold- and warm-water periods: 85% of individuals sampled in water temperatures < 12.0°C contained nothing or only trace amounts of food, supporting the life history strategy of a decreased activity as temperatures approach winter conditions. All of the individuals that contained more than trace amounts of food during winter months were < 600 mm (Savoy and Benway 2004).

Results indicated that the estuary was a richer foraging area than the river. Food items sampled from the stomachs of shortnose sturgeon from the estuary were greater in volume and diversity than stomachs sampled from those captured in the river. Growth comparisons shortnose sturgeon upstream the Holyoke Dam (isolated from estuary) were compared to those downstream the dam (accessible to the estuary); mean lengths and weights were greater for adults with access to the estuarine feeding resources than those isolated from the estuary (Kynard et al. 2012). Major taxa represented in stomachs of downstream-segment shortnose sturgeon were Bivalvia, Malacostraca, Polychaeta, and Insecta (Savoy and Benway 2004).

Overwintering/resting

Upstream

Upstream the Holyoke Dam on the Connecticut River researchers identified distinct sites where shortnose sturgeon adults concentrated during the winter (Kynard et al. 2012). Day length appeared to be the driving factor for the onset of wintering behavior. When decreasing day lengths fell below 11.0 h, adults began moving to winter concentration areas. By the time day length had diminished to 9.82-9.60 h, most (>80%) tagged individuals had stopped moving and formed several dense concentrations, corresponding to winter-period dates of roughly 15 November–15 April. Within the DCA, researchers found 5 distinct sites used year after year by wintering shortnose sturgeon: Whitmore (rkm 183), Second Island (rkm 180), S-turn (rkm 170), Hatfield (rkm 168), and Elwell Island (rkm 158; Kynard et al. 2012). Among the 5 sites, the most prominent was the Whitmore site: this area was located nearby the Montague spawning site (10km) and had both the greatest numbers of adults (as observed with an underwater video camera) and the greatest concentration of pre-spawning adults (as observed with radio tracking). A total of 34 tagged adults (31 males and three females) moved to the Montague spawning area from the Whitmore site, while only three tagged males moved to Montague from one of the other four DCA wintering sites. All tagged pre-spawning females (n=3), spent the winter at Whitmore (which included two individuals that had been displaced upstream of the Holyoke Dam earlier that year and one that had been displaced 8 years ago), indicating the Whitmore site was the main pre-spawning staging site.

While shortnose sturgeon were in winter concentration areas, researchers measured habitat conditions and observed their behavior (Kynard et al. 2012). All shortnose sturgeon winter sites occurred in channel habitat (depth > 50% of maximum cross-river transect depth). Micro-habitat used by adults at the DCA wintering sites were: depth; 3.1–8.5 m, bottom velocity; 0.02–0.49 m/s, dissolved oxygen (DO); 11.55–12.84 mg/L, daytime illumination; 200–4,300 lux, and sand substrate.

Downstream

Downstream the Holyoke Dam, shortnose sturgeon wintering sites have been identified. Buckley and Kynard (1985a) identified four wintering sites in the downstream segment: Agawam (rkm 117), Holyoke (rkm 140), Hartford (rkm 86–82) and the lower river reach (rkm

25–0). Several years later, in 1988, CT DEP began annual gillnetting and tracking surveys, confirming a wintering site at Hartford, CT (~ rkm 85), and identifying a site at Portland, CT (~ rkm 50) using telemetry tracking, gillnetting, and observations by SCUBA divers (Savoy 1991a and b). Although little habitat or behavior information was collected during these observations, depth and substrate conditions were similar to those observed upstream at the DCA sites (Savoy 1991a and b).

As part of winter-ecology studies (1996–2002), researchers also examined the wintering site in the downstream segment at Agawam (Kynard et al. 2012). Although individuals observed at Agawam in 2000 were found in micro-habitats similar to those at the Whitmore site during the same winter, locations of these wintering concentrations were more scattered from year to year at Agawam, spanning a reach 900 m in length.

Wintering adults displayed a consistent set of behaviors observed at all wintering sites. Using an underwater camera suspended beneath an anchored boat, researchers observed the majority of adults were in close proximity to one another (touching or no more than 1–2 body widths apart) and were stationary lying on the bottom. Wintering individuals displayed positive rheotaxis (bodies held parallel with water flow and heads into the current) and preferred sand substrate. Location of winter concentrations rarely shifted from year to year, or from month to month (Kynard et al. 2012).

Migration

Early life stages

Several studies have documented downstream dispersal of shortnose sturgeon on the Connecticut River. Kynard and Horgan (2002) conducted laboratory studies of cultured, Connecticut River ELS shortnose sturgeon. Results showed that free embryos were photo-negative for 15 days after hatching. After ELS developed into larvae (approximately day 15 post-hatching), they began swimming up into the water column, mostly during daylight hours. The peak of migration (i.e., “swim up and drift” behavior) occurred over a 3-d period (18–20 d post-hatching). Thus, knowing water velocity during the migration period for wild shortnose sturgeon would help estimate the distance a larvae moved during their 3-day migration and identify likely nursery areas. For example, an ELS sampling effort in 1977 and 1978 (Taubert 1980b) showed embryos and larvae were captured 3–15 km downstream of the Montague spawning areas (identified years later), suggesting a maximum dispersal rate of 7.5 km/day (Kynard and Horgan 2002). On day 20, most larvae observed in the laboratory had ceased migration and started foraging. Larvae were not observed to make additional downstream migrations before observations ceased in late October as winter temperatures approached. These data suggest that live year-0 juveniles spawned at Montague would not likely be in the migratory phase long enough to pass downstream of Holyoke Dam.

A study comparing dispersal of shortnose sturgeon larvae from the Connecticut and Savannah Rivers showed similar dispersal behaviors to Connecticut River ELS studied by Kynard and Horgan (2002). In an endless stream tank with temperatures between 16–23°C, dispersal of all Connecticut River ELS ceased after day-35 (a dispersal period of 30 days with the first major peak lasting 7 days). In a test of dispersal at three temperature levels (10, 15, and 20°C), shortnose sturgeon were found to absorb yolk sacs faster, begin dispersal sooner, and disperse over a longer period of time with multiple peaks of activity at the higher temperature levels.

Comparitively larvae spawned from Savannah River broodstock had a longer dispersal period characterized by multiple peaks and prolonged peaks. These Savannah River larvae also continued downstream dispersal through the entire larval period and some through the early juvenile period (day 62).

Artificial spawning channel studies conducted over six years also described onset and cessation of larval out-migration of ELS produced in a semi-natural spawning channel (Kynard et al. 2012). The number of days between observed spawning activity and initial detection of out-migrating larvae ranged between 12–22 d. Timing of dispersal in the artificial spawning channel was also influenced by temperature, where larvae developed faster in years of warmer temperatures and dispersed earlier than during cooler years. Dispersing larvae were observed over 5–8 d periods, with 90 % of larvae dispersing within 3-d. Evidence indicates that downstream dispersal characteristics of ELS observed in the laboratory are unique to populations relative to river conditions and annual environmental variations and can help define critical habitats or environmental conditions important to spawning recruitment success.

Yearlings and juveniles

Laboratory studies of year-1 juvenile migration behavior between June–November showed a dualistic migration strategy (Kynard et al. 2012). Year-1 shortnose sturgeon that had been spawned under laboratory conditions the previous year showed a similar frequency of up- and down-stream movements in an endless artificial stream structure. Although most juveniles showed both up- and downstream movement, many moved mostly up- or downstream, indicating separate migration strategies. This separation of movement direction persists through to adulthood; some sturgeon moved downstream long enough to reach the downstream segment and some remained in the upstream segment. This dualistic behavior was also observed in tracked wild adults (Kynard et al. 2012), but fewer wild adults tagged with radio transmitters were observed moving downstream past Holyoke Dam, suggesting the greatest migration from the river's upstream segment to the downstream segment is made by young juveniles (year-1–3). These dual movement strategies could also explain the persistence of both up-and downstream population segments and how spawning has continued at Montague for over 150 years following the completion of Holyoke Dam.

Adults

Pre-spawning

During detailed studies of shortnose sturgeon life history, researchers described pre-spawning migrations of radio-tagged adults from wintering areas to the Montague spawning area (Kynard et al. 2012). Pre-spawning adults began to depart the Whitmore wintering site in April when temperatures exceeded 7.0°C (the same temperature at which movement activity ceased in winter). This was also the point at which non-spawning adults also began departing the wintering concentration at Whitmore and moved to foraging areas. By the time temperatures reached 10°C, most tagged individuals had departed wintering sites, indicating the temperature range of 7.0–10.0°C as a transition period between inactive and active periods in the Connecticut River. During years of higher discharge, pre-spawning migrations were more meandering, taking up to two weeks for an individual to travel the 10km to Montague once wintering concentrations dispersed. During years of low discharge, migrations were short and direct where some individuals moved the 10 km distance in less than 24h. In addition, two males captured below the Holyoke Dam that were subsequently radio tagged and released just upstream of the dam, moved 57 km to Montague in 5–6d.

During an earlier study in the downstream segment, Buckley and Kynard (1985a) identified two pre-spawning migration strategies: 1) a major upstream movement from lower river wintering areas in spring just before spawning, and 2) a two-step migration where migrants moved upstream part of the distance towards spawning areas in summer or fall, then move the remaining distance during the higher flows of spring. This migration strategy was further defined during a study where downstream-segment adults were tagged and released upstream of Holyoke Dam (Kynard et al. 2012). Tracking of these displaced individuals showed summer-fall migrations resulted in some adults (many late-stage females) had moved to the pre-spawning wintering area at Whitmore. The two-step strategy allowed individuals to move over riffle areas during high flow events and spend the winter as close to the Montague spawning area as possible (Kynard et al. 2012).

To further understand life history movements related to spawning, researchers experimentally relocated 30 adults from below Holyoke Dam to an upstream location (Kynard et al. 2012). These tagged fish were released either in the exit flume of the Holyoke fish lift, at rkm 142 (two km upstream of the dam) or at rkm 147 (seven km upstream of the dam). The sex and maturity of these migrants (determined with a fiber-optic borescope examination) showed an unusually high occurrence of late-stage females (39.3%) compared with that observed on foraging and wintering sites (0.09%; Kynard et al. 2012). Although most of the displaced individuals passed back downstream that same year, several (both males and females) participated in spawning at Montague the following spring. In addition, several displaced adults remained upstream of the Holyoke Dam for over 10 years (Kynard et al. 2012). Recently, an inflatable rubber dam was installed along the crest of Holyoke Dam and a channel was cut into the bedrock leading out of the main stranding pool, allowing changes in river flow to be gradual and providing sturgeon occupying apron pools an adequate escape route. This has minimized the occurrence of stranded individuals.

Post-spawning

Following spawning, tagged adults departed the Montague spawning site and moved rapidly downstream to the DCA foraging reach. Females generally departed the spawning area immediately following spawning, while males lingered in the area dispersing downstream more slowly. Several females used in a concurrent semi-natural spawning experiment were returned to the downstream segment above the Enfield Dam, and were recaptured at rkm 7 (131–125 km downstream) four weeks later (T. Savoy, CT DEP, pers. comm.). Researchers describe a similar directed downstream movement (30km/d) by post-spawning downstream segment adults to the lower estuarine reaches during late April–early May (Savoy 2004, Buckley and Kynard 1985a).

Inter-basin movements

Movement of one shortnose sturgeon from the Connecticut River to the Housatonic River, CT (~50 km of movement west through Long Island Sound) is known to have occurred (T. Savoy, CT DEP, pers. comm.). Three adults tagged in the Hudson River by Bain (1997) are known to have moved into the lower Connecticut River (~140 km movements east through Long Island Sound) (Savoy 2004) – one of these individuals was captured twice in the Connecticut River, indicating it may have remained in the river for a year. Genetic structure of tissue removed from fish captured in the Connecticut and Hudson Rivers indicate genetic exchange between these two populations is rare (Chapter 4).

Stressors to Riverine System

1. Habitat

Dams and diversions

Dams on the Connecticut River (Gephard and McMenemy 2004) are first encountered by upstream migrants at the log-crib dam at Enfield, CT, completed in 1880. Although the Enfield Dam was submerged during high flows and was a barrier to migration only during lower water levels, the dam fell into disrepair in the 1970s and was eventually breached, allowing a continuous passage route all year. Currently this breached dam diverts sufficient water to service a single co-generation plant. Throughout the last 10 years, recreational boating organizations along with local fire and police departments have supported a proposal to rebuild the dam, raising the impoundment several feet and therefore providing greater recreational and emergency access. Reconstruction of the Enfield Dam would obstruct upstream movement of any migrant fishes. A feasibility study, by graduate student, Karl Meyer, concluded there was no environmental or economic reason to support rebuilding the dam (Strauss 1994).

The first mainstem dam at Holyoke (rkm 140) was built in 1849 and lies in the midst of the Connecticut River shortnose sturgeon population's range. A power facility was originally operated by the Holyoke Water Power Company. The facility is currently operated by Holyoke Gas and Electric pursuant to a license issued in 1999 and amended by a 2005 Settlement Agreement. The license will expire in 2039. Although several fish-passage structures were constructed at the Holyoke Dam since 1873, the first structure to successfully pass migrating fish species was an elevator completed in 1955. Atlantic salmon, alosines, and other diadromous or potamodromous migrants were passed in the lift, but passage for sturgeon remained unsuccessful (Taubert 1980a). Several modifications are ongoing for both the upstream and downstream passage facilities to minimize the risk of impingement and entrainment of downstream migrating fishes, including shortnose sturgeon, and improve the success of attempted upstream passage. Improvements include modifications to the fish lift entrance and the installation of full depth louvers at the entrance to the downstream bypass. Downstream passage for sturgeon can be accomplished through: 1) entering a downstream bypass which takes the sturgeon through a pipe and discharges them into the tailrace, 2) traveling with spill through the bascule gate or over the apron of the dam, or 3) passing through the turbines. Efforts are currently underway to design and build an exclusion/guidance rack that would prevent entrainment in the turbines and guide more individuals to the downstream bypass. Upstream passage is accomplished with two fish lifts. Shortnose sturgeon are occasionally documented in the fish lift; however, due to the lack of safe downstream passage, these individual are manually removed and placed back downstream. Once the exclusion rack is completed, it is anticipated that these sturgeon will be allowed to continue their upstream migration. Efforts are ongoing to improve the rate at which shortnose sturgeon enter the fish lifts. Because shortnose sturgeon are not permitted to move across the dam, these numerous large, reproductively fit adults are not reproductively contributing to the population as they cannot reach spawning habitat. Ongoing injury and mortality to shortnose sturgeon migrationg downstream at the Holyoke Dam continues.

The second mainstem dam at Turners Falls (rkm 198) is also a barrier to fish movements, but all anecdotal and scientific information indicates the historic falls upon which the dam was constructed in the late 1700's was a natural barrier to the movements of shortnose sturgeon. The Turners Falls Dam was built in 1798 and is currently owned and operated by First Light Power Company. Water is diverted from the upstream area into a power canal where a Cabot Electric Generating Station exists. The hydroelectric facility at the Turners Falls Dam operates pursuant to a license issued by FERC in 1990; the license will expire in 2021. The Cabot Station facility is operated pursuant to a FERC license issued in 1980 which will expire in 2018. Additionally, there are several hydroelectric facilities, including the Northfield Mountain Pumped Storage facility, located upstream of the Turners Falls Dam which influence river flow and water quality in the lower Connecticut River. The operations of the Turners Falls Dam, which diverts water for creating industrial and municipal electricity, can dramatically alter natural flow regimes during spawning at the two sites 4 km downstream in Montague. Water regulation conducted to satisfy power generation and flood control in the river's upstream segment has likely reduced the number of years that suitable spawning conditions are present. Furthermore, operations during low-discharge springs can result in periodic exposures of known nursery shoals as well as turbulent water releases that wash debris and sediment over the river's most productive spawning ground.

In the laboratory, researchers are currently examining existing and proposed structures to aid passage of shortnose sturgeon around hydro-power facilities including the effectiveness of a prototype spiral fish ladder for use with upstream-moving shortnose sturgeon (Kynard et al. 2012). The spiral fish ladder is far less expensive than traditional weir-pool designs and is designed specifically to accommodate sturgeon swimming behavior and ability. A two-loop ladder that spirals upward at a 6% slope for 38.3 m (total height) around a 6.1-m diameter circle has been tested. Baffels alternated along the inside and outside walls of the channel, resulting in low velocity in pools below the baffles and high velocity in the slots created by the baffels. The percent of individuals that ascended to the top increased with fish size and time in the ladder. Of the wild males that occupied the ladder for 6 d, 65.0% ascended the ladder and many (34.7%) made repeat trips with most movement occurring at night (Kynard et al. 2012). Most sturgeon climbed the ladder in less than 30 minutes using outside baffle slots (mean velocity =118 cm/s) and a prolonged swimming mode (mean = 1.7 body lengths).

In addition to upstream migration structures, swimming ability and behavior of downstream-migrating shortnose sturgeon has been investigated when encountering bar-rack diversion structures (Kynard and Horgan 2001). Groups of YOY, juvenile, and wild adult shortnose sturgeon were observed in a 120 ft long x 20 ft wide x 14 ft deep experimental flume with a vertical bar-rack (2 in. clear spacing) at the flumes' downstream end. After running all groups in three velocity levels (1, 2, and 3 ft/sec) researchers observed most yearlings could control swimming at 1 and 2 ft/sec velocity, but 33.3–40.0% became impinged on the rack at 3 ft/sec velocity and 66.780.0 became entrained at the high velocity. No adults or juveniles were impinged or entrained at any of the three test velocities. When individuals were tested after a $1m^2$ orifice was built into the bar-rack, about half the juveniles and 1/3 the yearlings entered the orifice, however, no wild adults entered the orifice.

In the early 1990s, a proposal was submitted to divert water from the Connecticut River to the Quabbin Reservoir located about 20 km to the east. The Quabbin Reservoir is a man-made impoundment built to store water to supply the city of Boston, MA. This proposal was denied, but could be reevaluated in the future as the demands for potable water increases in the city.

Other energy projects

Tidal turbines

There are no tidal turbines on the Connecticut River and none have been proposed.

LNG facilities

Broadwater Energy LLC has proposed to install a floating facility in Long Island Sound to receive LNG tankers. However, the state of New York denied the project under its CZMA authority. This denial was recently upheld by the U.S. Secretary of Commerce. The fate of the project is currently unknown. The proposed project would likely present only a minimal threat to coastal wandering shortnose sturgeon in the event of an accident.

Dredging and blasting

Current dredging projects in the Connecticut River occur in the lower river reaches to maintain navigation. A navigational channel between Hartford, CT and the river mouth is dredged periodically by ACOE to maintain a minimum of 4.5 m. Historically, dredge spills were disposed of on tidal wetland islands, but this was discontinued when the area became designated critical habitat. Currently navigation dredge spoils are diposed in-river; the location of some disposal areas have been modified because they were determined to be known shortnose sturgeon concentration areas.

North Cove in Old Saybrook, CT is a historic harbor that was partially obstructed during railroad construction and is becoming too shallow for boating. Excavation for the railroad construction created a reduction of flushing flows and resulted in a deep cove with poor water quality. Dredging is required for commercial marina and was conducted in 2008 at North Cove was most recently conducted in 2008.

Water quality and contaminants

Results of an exhaustive EPA fish contaminants study for the Connecticut River was released in 2000. This interstate effort examined contaminants in fish tissue of commonly consumed fish species from the entire Connecticut River. Among many study results, fish consumption advisories were released for mercury and PCBs for the Connecticut River in all Maine portions and most of the river in Connecticut (Hellyer 2000).

In 2003, the Connecticut River was sampled for a water quality assessment conducted by the MA DEP (Carr and Kennedy 2008). The reach from the NH-VT border to Northfield was found to fully support aquatic life and primary contact activities, but listed impaired fish consumption levels due to PCB’s of unknown causes in fish tissues. Turners Falls power pool, the name for the reach between the MA border and the Turners Falls Dam (rkm 198), received an overall favorable report for supporting aquatic life and primary-contact (swimming) recreational use. Continuing downstream, rkm 198–192, containing the shortnose sturgeon spawning areas at Montague, received a designation of impaired for aquatic life following toxicity tests of industrial effluent from industrial facilities in the village of Turners Falls. The river segments between the Deerfield River and the Holyoke Dam containing juvenile rearing and adult foraging areas received favorable reports on water quality for aquatic wildlife and recreational use.

Downstream of Holyoke Dam to the CT border, water quality was determined to be unsupportive of aquatic life or recreational use. Combined sewage outflows are the major concern below Holyoke Dam along with associated *E. coli* bacteria. In addition, between 2002–2006, deposits of coal tar, a by-product of earlier coal gas production and toxic to shortnose sturgeon embryos and larvae (Kocan et al. 1996) were removed just below the Holyoke Dam; an additional 30 acres of deposits are believed to still exist (Carr and Kennedy 2008). Sewage outflows and PCB contamination resulted in impaired use for aquatic life and recreational use throughout reaches in the state of CT, but improve at the river mouth (EPA 2006). Fish consumption advisories have been issued for the Conneticut River between rkm 140–114 due to PCB contamination from unknown sources.

Water withdrawal

A major water withdrawal event affecting the shortnose sturgeon Montague spawning area is the Northfield Mountain pumped-storage facility. This 1,080 megawatt hydro-electric facility pumps water from the mainstem Connecticut River uphill into a 5.6-billion gallon reservoir. The facility, located 8 km upstream of Montague pumps water into the reservoir during low-demand periods in the early mornings and releases water through turbines during peak-demand periods. Although water is eventually released back to the river, temporary withdraws drastically decrease water level and velocity at the Montague spawning areaparticularly during years of low discharge. In addition to increasing demands of water for the public and industry, the states at the head-water (ME, VT, and NH) withdraw vast amounts of water for snow making, depleting or dewatering Connecticut River tributaries during winter.

2. **Overutilization**

Bycatch

An active gillnet fishery for American shad occurs in the lower Connecticut River. In 2000, fishermen were required to report all captured sturgeon (reports ranged from 15–74 captures per year), but the identifications of shortnose sturgeon, when attempted, were questionable (T. Savoy, CT DEP, pers. comm. 2008).

Poaching

Anecdotal information and witnessed harassment of scientific gillnets indicates some harverst of shortnose sturgeon.

Scientific research

Currently, three separate ESA Section 10 permits authorize scientific activities on wild shortnose sturgeon in the Connecticut River: adults, juveniles, and ELS may be captured and tracked.

3. **Competition, predation and disease**

Competition and predation

The sympatric Atlantic sturgeon inhabits the lower Connecticut River in seemingly low number. A total of 191 individual Atlantic sturgeon sub-adults were captured by the CT DEP 1997–2008; annual captures ranged between 1 and 35 (T. Savoy, CT DEP, pers. comm. 2008). Tagged and tracked Atlantic sturgeon showed seasonal use and likely minimal competition for food resources with the shortnose sturgeon. Shortnose sturgeon with access to the rich estuarine foraging areas downstream the Holyoke Dam have more favorable growth and produces shortnose sturgeon that are more robust than those that are restricted upstream the dam (Kynard et al. in review-B). There appears to be an abundance of foraging resources in the downstream segment for the estimated 1500 – 2000 adult shortnose sturgeon (Savoy 2004).

Although little evidence of predation on shortnose sturgeon exists in the literature, young sturgeon are undoubtedly consumed by a number of larger predacious species in the river. A brief study of the stomach contents of predatory species captured near the Montague spawning areas in spring found shortnose sturgeon eggs that were consumed by the naturally occurring fallfish (*Semotilus corporalis*; Kynard and Horgan 2002). There were numerous top predatory fishes introduced into the Connecticut River over past decades for recreational angling interests, such as the northern pike (*Esox lucius*), walleye (*Stizostedion vitreum*), smallmouth bass (*Micropterus dolomieui*) and largemouth bass (*Micropterus salmoides*) that likely prey on sturgeon yearlings, however, this has never been documented. In a population already affected by several existing recruitment stresses, a small amount of predation on young life stages may be significant.

Competition or interaction of shortnose sturgeon with invasive species is poorly investigated; however, there are several issues with invasive aquatic species in the Connecticut River that threaten to overwhelm aquatic habitats, such as the water chestnut (*Trapa natans*) and the Eurasian water-milfoil (*Myriophyllum sp*.). Although the water chestnut typically occupies shallow water (< 2 m depth), shortnose sturgeon in the Connecticut River have been documented using depths shallower than 2 m (Seibel 1993). There are currently no reports of the exotic zebra mussel (*Dreissena polymorpha*) in the Connecticut River, but the neighboring Hudson River and Lake Champlain waters both contain problematic infestations. In the lower Conneticut River the invasive wetlands reed (*Phragmites australis*) is out-competing native tidal wetland vegetation. Finally, the invasive diatom Didymo (*Didymosphenia geminata)* has recently been observe in the northeast and has been identified in the upper Connecticut River, NH.

Disease

No current information is available on shortnose sturgeon disease in the Connecticut River. In fall of 2007, all Atlantic salmon (*Salmo salar*) broodstock and resulting progeny were euthanized at two Connecticut River basin fish hatcheries due to an outbreak of an infectious pancreatic necrosis virus. This virus, however, is reported to occur only in salmonids and dangerous only in the hatchery environment.

4. Inadequacy of existing regulatory mechanism

Both Connecticut and Maine lists shortnose sturgeon as endangered; NH and VT do not. There is no evidence that shortnose sturgeon occupy the reach of the Connecticut River in NH or VT.

Water withdrawals, including water for public consumption, industry, and snow-making, are likely uncoordinated and not managed on a basin-wide level. These withdrawals analyzed at only a local-level wopuled with a large percentage of water users being exempt from any kind of environmental review continue to limit water resources.

In 2002, the Small Business Liability Relief and Brownfields Revitalization Act was signed into law, providing federal assistance for the assessment, and cleanup of contaminated industrial and small business sites (brownfields) within the Connecticut River watershed in all states. In addition, a section was added to the Comprehensive Environmental Response, Compensation and Liability Act providing grants to state and tribal authorities to create and enhance brownfield response programs.

Federally funded or permitted projects, such as bridge repair or construction must consider impacts to endangered species, including shortnose sturgeon. Additionally, gains have been made in improvement of water quality. Nevertheless, the sturgeon population in the Connecticut River remains truncated and a poor candidate for long-term survival as a result of the Holyoke Dam impeding passage and the lack of ufficient up- and downstream passage for sturgeon.

A license renewal for the Holyoke Hydroelectric Project was issued in 1999. The initial NMFS Section 7 ESA consultation concluded that the ongoing operation of the facility, pursuant to the terms of the 1999 license, was likely to jeopardize the continued existence of shortnose sturgeon. The facility was purchased by the City of Holyoke's Gas and Electric Department and in 2004, a Settlement Agreement was reached. FERC then amended the license in 2005 and the license conditions require major modifications to improve upstream and downstream passage. Until safe and successful passage can be implemented, the Holyoke Dam remains an impediment to the recovery of the shortnose sturgeon. An estimated average 15 adult shortnose sturgeon pass downstream annually at the Holyoke Dam creating concerns about adequate numbers of adult spawners remaining upstream the dam available to spawn as well as their condition given limite prey resources.

The Connecticut River currently benefits from three conservation designations, making the river unique in its recognition as a national resource: 1) the Silvio Conte National Fish and Wildlife Refuge in 1991, 2) RAMSAR wetlands of international importance in 1994, and 3) American Heritage River in 1998.

5. Other natural or man-made factors

Ship strikes

Although there is a moderately-high volume of recreational boating in both the upstream and downstream segments of the Connecticut River with large commercial vessels traversing the river mouth, no ship strikes have been documented.

Impingement and entrainment

The most significant known entrainment of shortnose sturgeon adults has historically been the Hadley 1 and Hadley 2 units at the Holyoke Dam. Individuals could enter the three-tiered canal system just above the Holyoke Dam unimpeded, and could only return to the mainstem via several potentially lethal outlets. In 1992, a permanent louver was installed just after the canal entrance to guide downstream migrants to a 3 foot diameter pipe returning fish to the river downstream of the dam, but the louver extended only part of the way down as it was originally designed for surface migrants. The louver was extended to the canal bottom in 2002 (Ducheney et al. 2006). The guidance efficiency of the louver was tested using 30 tagged year-1 laboratory-reared shortnose sturgeon released at three discharge levels (170, 85, and 42.5 m^3/s). A total of

21 sturgeon (70%) were successfully guided to the bypass, 3 were not and entered the industrial canal system, and the fate of 6 was unknown (Kleinschnidt 2006). The fewest sturgeon (n=4) were guided during the highest discharge level. This structure has successfully guided several shortnose sturgeon adults to the bypass pipe, providing a physical barrier to adults and a behavioral barrier to smaller individuals.

Although there are numerous water withdrawal sites along the river, both agricultural and industrial, records of impingements or entrainments are rare. In the summer of 2006, the carcasses of two juvenile shortnose sturgeons were found in cooling-water outflow screens at a coal-fired power plant (Mt Tom) at rkm 148 in Holyoke, MA. NMFS is currently working with the EPA to address potential impingement and entrainment issues at this facility through the NPDES permitting process.

Enfield's breached log-crib dam was constructed to divert water into a 6-km industrial canal that currently supplies water to a single specialty-paper manufacturer. Anecdotal reports indicate adults can enter this canal and due to its length may have difficulty locating an exit.

Artificial propagation

Shortnose sturgeon have been artificially propagated from Connecticut River adults since 1988 for scientific purposes. All specimens have been held in captivity for laboratory experiments and are destroyed upon completion of the experiments.

Escapement of hatchery/captive fish

In 1989 and 1990, five year-1 and one year-2 shortnose sturgeon were released tagged upstream of Holyoke Dam during a study of behavorial ecology. In addition, several experimental year-1 juveniles (spawned in the CAFRC semi-natural spawning channel and made available for experiments) were not recaptured at the end of a 2006 test of the Holyoke louver bypass system and likely escaped to the river (EPRI 2006).

Current and Recommended Research

Current research

There are numerous shortnose sturgeon research efforts currently ongoing in the Connecticut River. Field studies include: 1) the continuous monitoring of spawning success of the upstream segment at spawning sites in Montague; 2) evaluation of winter ecology; 3) determination of effects of Holyoke Dam on life history; and 4) determining the effects of long-term tagging (using various tag types). In the laboratory, researchers study movement behavior of early life stages and juveniles, including responses to illumination and water flow. A multi-year evaluation of the semi-natural spawning channel including efficiency of the channel design, detailed courtship and spawning behaviors, and the applicability of this technique for use in restoration efforts is underway. Researchers are also studying fish passage including a prototype spiral fishway and the reactions and behaviors of downstream migrants as they encounter diversion structures such as vertical-bar racks.

racking and capture are underway in the Connecticut River's downstream segment as part of a concurrent long-term study begun in 1988 to: 1) estimate population size, 2) identify annual movements, and 3) investigate feeding ecology.

In addition consulting firms hired by the local hydro-power utilities are: 1) capturing and tagging (radio and PIT tagging) 20 adults upstream the Holyoke Dam annually to obtain detailed approach behaviors, 2) identify spawning success downstream of the Holyoke and Enfield dams, and 3) studying behavior of juvenile shortnose sturgeon as they pass downstream and encounter diversion structures.

Recommended research

The following continuing and new research for the shortnose sturgeon population on the Connecticut River is recommended.

- Continue to monitor spawning success at Montague spawning sites.
- Continue gathering information on survival and viability of late stage females that fail to spawn; do females return in one year for spawning, or are eggs expelled/absorbed and females return in 3-5 years for spawning.
- Continue evaluating sturgeon response to passage structures.
- Continue to examine the feasibility of using semi-naturally spawned shortnose sturgeon in life history determinations and population rebuilding.
- Continue to evaluate modifications to current telemetry tag attachment.

New research

- Determine location of critical habitats, annual movements, and migrations of juveniles in the Connecticut River.
- Determine the affect of Holyoke Dam on migrating juveniles.
- Continue to modify and develop unique downstream passage structures for adults and juveniles.
- Evaluate details of migrant shortnose sturgeon movements between the Holyoke and Enfield Dams.
- Determine impact of shoal exposures and forceful water releases on ELS survival at Montague spawning and rearing areas.
- Analyze tissue samples to determine parentage of adults and juveniles below Holyoke Dam.
- Develop survey technique to read PIT tags from shortnose sturgeon within wintering concentrations, allowing an easier way to gather information on passage, winter ecology, and spawning periodicity.
- Develop and test a population estimating technique using video cameras to document and count shortnose sturgeon at winter concentrations.
- Develop an index of spawning success using underwater video.
- Develop modifications to the Holyoke fish elevator entrances to facilitate movement into the spillway fish lift entrance.
- Determine effectiveness of alternative capture methods (seines, trawls, drifting gillnets, encirclements).
- Develop methods for attaching telemetry tags to juveniles and satellite tags to adults.
- Determine presence and affects of coal tar on physiology and behavior.

- Determine approach routes of downstream migrant adults while encountering the Holyoke Dam.
- Determine effects of pectoral fin spine clipping for ageing on long-term sturgeon health using laboratory trials in a flowing channel as well as field releases and recaptures.
- Determine ability of late stage females to regenerate spawned or aborted eggs using long-term tagging and recapture.

Housatonic River

Historic Distribution and Abundance

As in many rivers, no historical information specifically identifies the presence of shortnose sturgeon in the Housatonic River. A document by Coffin (1947) describing the remains of ancient fishing weirs indicates that an abundance of sturgeon were harvested by Native Americans from canoes. A document by Linsley (1844) notes the thriving commercial harvest Americans and capture of large Atlantic sturgeon by commercial fishermen at the mouth of the Housatonic River. However as landings reference common sturgeon, we can only speculate that both Atlantic and shortnose sturgeon were present in the Housatonic River. The large sturgeon capable of upsetting canoes, as described in anecdotal information, were undoubtedly Atlantic sturgeon, apparently of spawning size.

Current distribution and abundance

Until recently there have been no reported shortnose sturgeon captured in the Housatanic River. In 2005 during a gill net survey targeting shortnose sturgeon, one shortnose sturgeon was captured downstream of the first mainstem dam (rkm 23.5) after setting 16 nets during the summer (Savoy and Benway 2006). This adult had been PIT tagged earlier in the Connecticut River the previous year. While shortnose sturgeon may have spawned historically in the Housatonic River, it is unlikely they currently do so. The recent Atlantic Sturgeon Status Review (ASSRT 2007) indicates historic spawning of Atlantic sturgeon was likely; however, it is also believed Atlantic sturgeon (and probably shortnose sturgeon) have been extirpated from the Housatonic River. The shortnose sturgeon captured in 2005 was possibly a migrant moving from the Connecticut River to the Hudson River.

Natural History and Habitat Information

Spawning

There have been no recorded incidents of shortnose sturgeon spawning in the Housatonic River.

Rearing

As spawning has not been recorded, information on rearing habitat also remains unknown.

Foraging

Foraging habitats of shortnose sturgeon in the Housatonic River have not been documented.

Overwintering/resting

Overwintering and resting habitat for shortnose sturgeon in the Housatonic River is unknown.

Migration

Shortnose sturgeon migration to, from, and within the Housatonic River is unknown. It is possible that the shortnose sturgeon captured in the Housatonic in 2005 was a migrant from the Connecticut River moving to the Hudson River. Genetic analysis of this individual, however, showed that it was more similar to shortnose sturgeon inhabiting the Hudson River compared to those in the Connecticut River indicating this migrant was more likely spawned in the Hudson River, migrated to the Connecticut River where it was first captured and PIT-tagged, then was recaptured in the Housatonic River, perhaps on its way back to the Hudson River.

Stressors to Riverine System

1. Habitat

Dams and diversions

The first mainstem dam in the Housatonic River is the Derby Dam built in 1870 near Shelton, CT (rkm 23.5). Whitworth (1996) indicated sturgeon were unlikely able to pass upstream of Great Falls at New Milford, CT (rkm 123) and this was possibly the historical upstream boundary for sturgeon. The Derby Dam likely obstructs movements of any sturgeon to historical spawning grounds.

Other energy projects

Tidal turbines

Natural Currents Energy Serv., LLC was issued a preliminary permit on November 16, 2007, for a hydrokinetic project for tidal energy on the Housatonic River, however, the application for the facility has since been withdrawn.

LNG facilities

There are currently no LNG facilities associated with the Housatonic River.

Dredging and blasting

There is an authorized federal navigation channel in the Housatonic River that is maintained by the ACOE. The ACOE is currently examining a proposal to conduct maintenance dredging in the river. In addition, several smaller scale private dredging projects are conducted to maintenance several commercial marinas. Utilization of channels resulting from sand and gravel mining for deposition of dredge spill is being considered.

Water quality and contaminants

Water quality of the various Housatonic River segments in both MA and CT received consistent impaired classifications for aquatic habitat and primary recreational use and fish consumption. Within MA, PCB contamination from the General Electric facility in Pittsfield, MA (at approximately rkm 185) has resulted in fish consumption advisories in all MA segments and primary contact (swimming) in one segment, although cancer-hazard levels fell below the EPA level of 1.0. Primary contact is also advised against due to high fecal coliform levels, mostly from CSOs. In one segment near Lee, MA (at approximately rkm 165) the assessment found water impaired for secondary contact use (boating) due to objectionable algae growth and occasional sewage or chlorine odors (Carr and Kennedy 2007).

A 2006 EPA Water Quality Assessment Report (Carr and Kennedy 2007) showed impaired fish consumption levels due to PCBs in most upstream reaches of the Housatonic River, but also improvements closer to the river mouth. Primary contact throughout much of the range was impaired, however, due to pathogens in storm water.

2. **Overutilization**

Bycatch/poaching and scientific research

Because shortnose sturgeon are rarely encountered in the Housatanic River, there is likely no bycatch or poaching. Although commercial fishing in the Housatonic River is not prohibited, no information exists to indicate any sustained effort. No shortnose sturgeon research is currently underway on the Housatonic River.

3. **Competition, predation and disease**

No information regarding diseases that effect shortnose sturgeon within the Housatonic River is available and there is currently no evidence of predation on shortnose sturgeon.

4. **Inadequacy of existing regulatory mechanisms**

Shortnose sturgeon are listed as endangered by both Connecticut and Massachutes.

5. **Other natural or manmade factors**

Because of the PCB contamination issues, no water is withdrawn from the Housatonic River for drinking; however, municipal water withdrawals do occur in tributaries to the Housatonic River.

Ship strikes

There is no evidence of ship strike interactions with shortnose sturgeon on the Housatonic River.

Impingement and entrainment

There is no information regarding impingement or entrainment of shortnose sturgeon on the Housatonic River.

Artificial propagation

There is no artificial propagation of shortnose sturgeon occurring on the Housatonic River.

Escapement of hatchery/captive fishes

Because no artificial propagation of shortnose sturgeon occurs on the Housatanic River, there is no threat from escapement.

Current and Recommended Research

Continued periodic surveying for the presence of shortnose sturgeon in the Housatonic River is recommended, particularly following indications of water quality improvements.

Hudson River

Historic Distribution and Abundance

Distribution

Historic records from over a hundred years ago are often vague about shortnose sturgeon use of the Hudson River. Early fishermen often concluded that there were three species of sturgeon in the Hudson, the shortnose (the "roundnoser"), "pelicans" (or long-nose), and the large Atlantics prized for their caviar. Often the "pelicans" were destroyed as they interfered with shad fishing by tearing up nets (Greeley 1937). It was many years before Hudson River fishermen recognized that "pelicans" were actually juvenile Atlantics, which gained them some protection as returning adults were highly valued.

Sturgeon harvest was extremely high at the turn of the 19th century. Sturgeon were so plentiful they gained the nick-name of "Albany beef" and were sold at prices so low that servants were often fed sturgeon several times a week. The historical landings data record the species as Atlantics, supported through anecdotal accounts in weekly newspapers (Harper's Weekly) with sizes of fish harvested ranging up to 12 feet. Because size limits were not manadated, harvest undoubtably consisted of a mix of both Atlantic and shortnose sturgeon. However, the proportion of each species will never by known.

Shortnose were known to use the entire freshwater portion of the Hudson River, up to and including the 35 kilometers lost when the Troy Dam at rkm 245 was built in 1825 (NYHS 1809). Spawning fish congregated at the base of Cohoes Falls where the Mohawk River emptied into the Hudson. Additionally, there is a deep area called "Sturgeon Pool"on the Rondout River (a tributary of the Hudson) at its confluence of the Wallkill River.

Abundance

Hudson River shortnose sturgeon merited much research over the years. There is general agreement that the Hudson River population is the largest and healthiest shortnose sturgeon riverine population.

Results of several major mark/recapture studies suggest that major changes occurred in Hudson River population of shortnose sturgeon within the past thirty years. The first estimate of the Hudson River shortnose sturgeon "spawning" population size was generated in 1978 based on a mark/recapture study performed from 1976 to 1978 (Dovel 1979). Shortnose sturgeon were tagged at an over-wintering, pre-spawn staging site near Kingston (rkm 151), identified from conversations with a local fisherman. Marked individuals were recaptured from Germantown (rkm 171) to Coeymans (rkm 214). The river above Coeyman's was not sampled. Larval shortnose sturgeon were captured near Hudson, NY (rkm 188), with YOY captured further south near Germantown. A modified Petersen closed population model estimatee population size at 5,837 (CI = 1,989 – 21,276; Table 20). Wide confidence intervals were the result of the low number of tagged shortnose sturgeon. This population estimate was most likely biased low due to the use of inappropriate gear to capture adult shortnose (trawls and limited use of gill nets) as noted by the authors; they also suspected that the actual major spawning area had not been identified.

Field sampling during a preliminary power plant siting study in the Coxsackie reach in 1977 and 1978 resulted in the capture of several shortnose in spawning condition (Pekovitch 1979). Subsequent sampling in 1979 and 1980 began in very early spring in the Kingston over-wintering area and included long stretches of river with groups of gill net sets spanning several river kilometers. Net sets were moved northward in the river as catches in the lower net sets declined and increased in the upper sets with net sets continuing as far north as the Troy Dam over the spawning season. Data were analyzed using a modified Petersen model for direct comparison (Dovel et al. 1992) and was 12,669 spawning adults (CI = 9,080–17,735) in 1979, and 13,844 (CI = 10014–19,224) in 1980 (Table 20). These mark/recapture studies focused on the annual spawning migration with individuals older than age five. Based on spawning frequencies of every two years for males and every three years for females, plus a 2:1 male to female sex ratio, the total adult population abundance was estimated at 30,311 individuals. This estimate does not include YOY or immature (< age five) (Dovel 1981).

Dovel et al. (1992) determined that in two successive years, 1979 and 1980, the spawning area encompassed the river stretch from Coeyman's (rkm 214) to the Troy Dam (rkm 245), a 31 km stretch of river. Dovel et al. (1992) suggested that water quality and environmental conditions may influence the extent of river that shortnose use annually.

Fifteen years later, another mark recapture study was conducted over the period 1994 to 1997 (Bain et al. 1998a) that again focused on the Hudson River shortnose sturgeon active spawning stock. Bain et al. (1998a) stated the same sample design was performed as described by Dovel et al. (1992). Initial sampling to mark presumed pre-spawn adults occurred in early spring in the Kingston over-wintering area. However, recapture sampling occurred at only one sampling site (Albany, NY, rkm 235) within the 31 km spawning reach.

A total of 2,064 individuals were marked with only 44 recaptures (Bain et al. 1998a). Several population models were used to analyze the data and discussed below.

CAPTURE (White 1978) was used because it is less restrictive in assumptions than other closed population models and allows for bias-correction of estimates based on heterogeneity (population composed of different parts or elements) and capture periods of the marked population. Three hypotheses were examined: 1) M(o) or null, 2) M(h) test for heterogeneity and, 3) M(th) heterogeneity and time (Bain et al. 1998a). Results of each model type varied between 25,255 and 55,265 (Table 20). Bain et al. (1998a) considered the M(th) model to be most appropriate (n=38,024) as there were changes in capture success over time.

Recall the 1995 CAPTURE estimates (Bain et al. 1998a) and those generated by Dovel (1979, 1980) and Dovel et al. (1992) were based on data collected on spawning adults only. These results underestimate the total shortnose sturgeon population size as not all adult shortnose sturgeon participate in the annual spawning run (Bain et al. 1998a, Dovel et al. 1992). Therefore we found it difficult to compare the 1970s and 1990s population estimates because recapture was limited to a smaller area in 1990s study compared to 1970s.

The most publicized abundance estimate for the Hudson River shortnose population is 61,057 total individuals (Bain et al. 1998b, 2000, 2007). This estimate was generated from all mark/recapture data collected over three years of sampling from 1994-1997. Closed population models used were a Schumacher-Eschmeyer (Bain et al. 1998b) or a Schnabel population model (Bain et al. 2000, 2007). The 1994-1997 estimate of spawning adults comprised 56,708, or 93% of the entire population, "indicating that all or nearly all adult shortnose sturgeon are present annually at the over-wintering and spawning sites" (Bain et al. 2000). The remaining 7% of the population was associated with non-spawning adults (3%) and juveniles (4%).

Sampling methods for the spawning estimates were assumed to be similar to 1979 and 1980 studies (Dovel 1979, 1981 and Dovel et al. 1992) and Bain et al. (1998a) initial estimates. The key difference in estimating the total population size was that a random mark/recapture design was used to sample the entire estuary. This was done to attempt inclusion of both non-spawning adults and juveniles. Data were collected over several years and processed through a model design that allowed for multiple mark/recapture events and several other annual estimates were generated using Jolly-Seber open population models. Shortnose sturgeon population estimates ranged from a high of 80,026 in 1995 to a low of 27, 731 in 1996. These estimates were not discussed in any published papers and most are only presented graphically in Bain et al. (2000) (Fig. 21).

Bain et al. (2000) then compared their spawning population estimate of 56,708 to Dovel et al. (1992) estimates of 12,669 and 13,844 in 1979 and 1980 respectively. While Bain et al. (2000) indicated a significant increase of approximately 400% was observed in population size between 1979 and 1997 (18-year span), comparison of the total population estimates (61,000 to 30,000) indicates size of the population doubled.

Dovel et al. (1992) cautioned about attempting to estimate the total population size for shortnose as the small juvenile shortnose were extremely difficult to sample. Bain et al.’s (2000) estimate with a 4% juvenile component seemingly contradicts the dramatic increase (400%) in adults over 18 years because no comparable increase in juveniles was included in the model time series estimates. Rather to support the 400% increase in Hudson River shortnose strurgeon population size, Bain et al. (2000) used data from the Fall Shoals Survey (FSS) conducted by the Hudson River power generating companies which has been conducted annually since 1974. A dramatic jump in CPUE of shortnose sturgeon was noted in 1992 and 1993 from previous years (Fig. 22). However, this increase was then followed by a slow decline to a stable level after 2000, at approximately twice the values observed prior to 1992.

Woodland and Secor (2007) attempted to identify the cause of the major change stated by Bain et al. (2000). They concluded that the population increase was driven by improved water quality resulting in high survival of several very large year classes produced in 1988 through 1991. They also pointed to the FSS CPUE data to corroborate the increase. However, no shortnose sturgeon less than 450mm TL were collected by the FSS survey prior to 1996.

Therefore the SNS SRT used these data cautiously. The FSS uses a three meter beam trawl and was designed to sample YOY striped bass and any captures of shortnose sturgeon are incidental. The FSS does not randomly sample the entire estuary; rather samples are distributed based on shoal habitat, which concentrates most of its sampling in the shoal areas of the lower, brackish water portions of the Hudson River (Table 21, Fig. 23; ASA 2007). Seventy five percent of the FSS samples taken annually are in the lower half of the Hudson River.

Current Distribution and Abundance

Most recently targeted sampling of shortnose was conducted by Bain et al. (1998a) in the 1990s and Woodland and Secor (2007) in 2003 and 2004. Shortnose continue are known to be caught as bycatch in many sampling programs occurring on the Hudson River. These data have not been collectively summarized. A brief synopsis of available data follows.

The FSS generated shortnose sturgeon CPUE was used by both Bain et al. (1998a) and Woodland and Secor (2007) to corroborate the dramatic increase predicted in shortnose sturgeon population size by models. However when using these FSS data as an abundance indicator for a long-lived species, it hard to reason how a population would dramatically increase over a two-year period (1992 to 1993), and then begin to quickly decay (Fig. 22). Because shortnose sturgeon capture is incidental, the data may indicate change, but the reason may be related to other causes (e.g., change in distribution or habitat availability), not necessarily an increase in abundance.

When the FSS generated CPUE data for both shortnose and juvenile Atlantic sturgeon are examined together, a negative interaction appears to be occurring between the two co-occurring species (Fig. 24). This interaction may center on the historic use of the lower Hudson as nursery habitat for young Atlantic sturgeon. During the late 1980s and early 1990s, the fishery for adult Atlantic sturgeon remained open in the Hudson River. When a stock assessment (Kahnle et al. 2007) concluded that overfishing was occurring in New York, the fishery was closed in 1996. During this same time period, the production of juvenile Atlantics dropped dramatically (Fig. 25) and shortnose may have taken advantage of this decline and moved into under-utilized habitat. However, since the closure of the Atlantic sturgeon fishery, production of young Atlantics has improved and the two sturgeon appear to be seeking a balance in utilization of the lower Hudson River habitat.

Another data collection began when Hudson River generating companies began survey in 1984 and samples were taken from the upper New York harbor for over-wintering juvenile striped bass between November and March. Shortnose sturgeon were rarely taken in this survey until 2004; since then catches have been low but consistent since then (Normandeau Associates, pers. comm. 2008). Perhaps the improvement of water quality has made the area a more suitable habitat for shortnose sturgeon.

Clearly major changes may have occurred in the Hudson's shortnose population from the 1970s to the 1990s, but the exact nature of that change is difficult to measure. The last population study that occurred on shortnose occurred nearly 11 years ago. Overall, a positive change most likely occurred from 1980 to the late 1990s, but the true quantitative level remains unknown. Although these recent population estimates look promising, we caution their use as a management benchmark.

Natural History and Habitat Information

The Hudson River is tidal along its entire 246 km length from New York harbor to the Federal Dam at Troy NY (Fig. 26). The upper two-thirds of the river are freshwater with saltwater intrusion in the lower third. Generally salt water intrusion occurs as far north as West Point (km 83) in the late spring. During the summer months it can move as far north as Poughkeepsie (km 122). The river is classified as a 'drowned' river valley, straight and fairly deep in some sections, especially in the Hudson Highlands near West Point, where the river is greater than 60 m in depth. In the lower 70 km, the river opens into two large wide, shallow "bays", Haverstraw Bay and the Tappan Zee, before narrowing down to a deep section just above New York harbor.

Spawning

The northward spawning migration from the Kingston over-wintering site commences when water temperatures reach 8 to 9°C; and can begin in late March through early April (Dovel et al.

1992). Most spawning occurs at water temperatures between 10 to 18°C in the river reach from Coeyman's, NY (rkm 212) north to the Troy Dam (rkm 245, Fig. 26). Some shortnose sturgeon were captured in the spawning area as early as late March and individuals may remain in this area for up to 30 days.

Both Dovel et al. (1992) and Greeley (1937) indicated the presence of egg-bearing females in the lower sections of the Hudson below Kingston, in the mid-Hudson (Highland, near Poughkeepsie) and farther south in Haverstraw Bay. Dovel et al. (1992) indicated that these individuals were not yet ready to spawn, but thought they were in the pre-spawn development phase. However, Greeley reported a "ripe" female, along with a spent male near Highland NY (rkm 121) in early April. Some roe (females) taken May 1 were also spent. The proximity of spent males with ripe females in the mid-Hudson location is intriguing in light of Dovel's identification of the major spawning area up-river near Albany. Highland is several kilometers south of an identified over-wintering area near Kingston (rkm 140). Spawning has not been verified in Kingston-Highland reach, but the possibility exists that it could occur. Another possibility is that post-spawn adults may move downriver quickly, assisted by the Hudson's strong tides.

Dadswell et al. (1984) described the differences in age at maturation for shortnose along the coast. Shortnose sturgeon from the Hudson River were thought to mature at three to five years for males and six to ten years for females. Males may spawn annually once mature. This was supported by Dovel et al. (1992) who tagged one male on the spawning grounds in 1979, recaptured the same male the following winter in the over-wintering area, and again the following spring on the spawning grounds. Female shortnose sturgeon are thought to spawn less frequently approximately every three years. Maturity patterns for shortnose sturgeon are similar to those of Atlantic sturgeon where males can spawn annually and females spawn on longer term intervals of three to five years (Van Eenennaam et al. 1996). The early work by Bain et al. (1998a) agreed with a three to five year spawning interval for female shortnose sturgeon; however, recent work (Bain et al. 1998b, 2000, 2007) suggested that spawning is an annual event for nearly all of the Hudson's population.

Extensive substrate mapping of the Hudson River began in 1998; classification includes various bottom types, including sediments, size, and hardness. Descriptions of sampling methods can be found at http://www.dec.ny.gov/lands/33607.html. Within the Coeymans-Troy spawning reach, bottom types varied: gravel and sand dominated throughout the deepwater channel areas (Fig. 27).

Prior to 1826 when the Troy Dam was constructed at rkm 256, the first natural barrier occurred at Glens Falls, 32 km farther upriver. Anecdotal notes indicate that shortnose may have congregated at the base of Cohoes Falls, 5 rkm upriver from Troy, where the Mohawk River empties into the Hudson. This suggests that some spawning habitat loss may have occurred when the dam was built.

Rearing

Few researchers have been able to collect YOY or even small (less than 400mm) shortnose (Dovel et al. 1992 and Bain et al. 2000) from the Hudson River. From 1996 through 2004, about ten small shortnose were collected each year as part of the FSS (ASA 2007). Further examination of these data may lend insight to identifying rearing habitat characteristics important for shortnose in the Hudson.

Foraging

Foraging behavior varies for each age/maturity group of shortnose sturgeon: spawning, post-spawn, non-spawn adults and juveniles. Haley (1996) found that shortnose are opportunistic feeders in that they utilize food resources that are seasonally and locally abundant. Salinity and depth affect distribution of fish in the river throughout the year. Most (~80%) of the 48 fish collected were collected from freshwater; a few (<10) were collected in oligo-haline water (<2.9 ppt). Gammarid amphipods, dreissenid mussels, isopods, and chironomids were the most prevalent food items for the freshwater portion of the estuary.

Haley (1999) also attempted to address the issues of resource partitioning. Both shortnose and Atlantic sturgeon co-occur and co-exist in over two-thirds of the Hudson estuary from Catskill to New York Harbor. Haley (1999) noted that spatial and food overlaps occurred between the species, attributed to the marked abundance of prey species in the lower estuary. However, she stated the need for further studies to understand habitat preferences for each section of the river and if there are “differences in habitat and food use between allopatric and sympatric populations of the shortnose and Atlantic populations” in the river. It appears that there is some interaction between the two species in areas where the two species co-occur (see above).

Overwintering/resting

Two over-wintering sites were identified from previous studies on the river: 1) Dovel et al. (1992) indicated that the largest over-wintering site occurred near Esopus Meadows, just south of Kingston, NY primarily comprised of pre-spawn adults; and 2) Geoghegan et al. (1992) agreed with Dovel et al. (1992), but suggested that other similar, but smaller, deepwater areas in the mid-Hudson may also serve as over-wintering sites. Both conclusions are based on scattered catches of shortnose sturgeon that occurred throughout the greater Kingston reach from Saugerties to Hyde Park during the late fall and winter. Both groups of authors also indicated a downriver over-wintering site in the Croton-Haverstraw Bay area.

Sampling by the New York State Department of Environmental Conservation (NY DEC) for juvenile Atlantic sturgeon in late winter/ early spring confirmed that shortnose utilize the Haverstraw Bay area. Annual winter-trawl sampling for striped bass in the upper New York harbor has consistently collected low numbers of shortnose sturgeon off Manhattan during the winter (November to March) since 2004. Improved water quality in the mid 1990s may have opened up additional habitat that shortnose can now utilize in the harbor.

Benthic mapping of the Kingston-Esopus Meadows reach of the Hudson River indicates a variety of bottom types. “Habitat” types were derived from original bottom mapping and grain size analysis. Depth was divided into two categories based on a four meter contour line; areas less than four meters was considered "shallow" and those greater than four meters was considered "deep". Three substrate types, consisting primarily of mud, were grouped to form a "fine" sediment type (Fig. 27). Other categories consisting primarily of sand and/or gravel were grouped to form a "coarse" sediment type that predominates the benthos (Fig. 28).

Migration

Shortnose sturgeon spawning migration n the Hudson River was described above. Post-spawning shortnose sturgeon begin a downriver movement through the entire lower river. Dovel et al. (1992) indicated that some spawning adults tagged at Troy were recaptured in Haverstraw Bay in early June, indicating some individuals moved quickly downriver while others move more slowly as confirmed by both Geoghegan et al. (1992) and Woodland and Secor (2007).

Although shortnose sturgeon are assumed to remain within their natal river, some out migration from the Hudson River has been documented. Two individuals tagged in 1995 in the over-wintering area near Kingston, NY were later recaptured in the Connecticut River (Table 22). One fish was at large for over two years and was recaptured at the mouth of the Connecticut River at Saybrook, CT; the other was at large for over eight years and recaptured in the lower Connecticut River.

Stressors to Riverine System

1. Habitat

Dams and diversions

When the Troy Dam was built in 1825 up to 30 km of river habitat were lost. It is not known if shortnose used this entire reach for spawning as sturgeon were only known to congregate below Cohoes Falls, 5 km above Troy. In 1914 a concrete dam was built at Troy and in 1923 the Ford Motor Company installed a powerhouse at the dam; this facility has been operational since 1923 and was last licensed by FERC in 1977. The dam remains under Federal ownership and is maintained by the ACOE. The ACOE has also been operating a navigational lock at the eastern end of the dam since 1914. The Lock, which adjoins the New York State Canal System, operates from May 1 to November 15. The electric generating facility is currently owned and operated by the Green Island Power Authority under the terms of the 1977 FERC license. Relicensing is currently ongoing and is expected to include major modifications to the existing powerhouse, replacement of the existing turbines, addition of new turbines and increased generating capacity. No upstream or downstream fish passage facilities currently exist at the dam. While shortnose sturgeon appear to spawn successfully below the dam, the impact of the dam and associated generating facilities on the population is largely unknown.

Other energy projects

Tidal turbines

A prototype tidal turbine was constructed in the East River by Verdant Power Company, above New York harbor on the east side of Manhattan in 2006. This turbine array operates pursuant to a preliminary permit issued by FERC. The turbines have not been fully operational and are still in the testing phase. Studies will focus on distribution of fish species in the project area with the need to better understand how fishes act around or with turbines and the potential expansion of habitat range of Atlantic and shortnose sturgeon into the East River is included. Because use of the East River by shortnose sturgeon is undocumented, the effects of the tidal turbines on this species are unknown. On December 1, 2008 FERC issued a public notice indicating that Verdant intended to submit an application for a license for the installation of 30 tidal turbines within the East River.

Two other preliminary permits have been issued for hydrokinetic projects on the East River, NY: 1) Natural Currents Energy Serv., LLC was issued a preliminary permit on April 16, 2007 for a project off of Wards Island on the East River, and 2) Oceana was issued a preliminary permit for a hydrokinetic project out of Astoria on the East River, NY on May 31, 2007.

LNG facilities

There are no LNG facilities on the Hudson River or in New York harbor and none are currently proposed.

Dredging and Blasting

Portions of both foraging and spawning habitat utilized by shortnose sturgeon in the Hudson River upper and middle estuary are subject to periodic dredging to maintain the navigation channel extending from New York Harbor to the Port of Albany. These ACOE dredging activities are limited to windows when shortnose sturgeon are least likely to be present in the particular river reaches. Any dredging in the upper portion of the Hudson River estuary is generally condicted between August and November of each year to provide protection to spawners and young of the year. Additionally, there are smaller scale private dredging operations that occur all along the Hudson River.

Historically, much shallower water habitat was lost in the upper half of Hudson River due to dredge and fill operations to develop and maintain the river's shipping channel. Most habitat loss occurred between the turn of the 19th century (NY DOS 1990) and the first half of the 20th century. Preliminary estimates are that approximately 57% of the shallow-water habitat (1,821 hectares or 4,500 acres) north of Hudson (km 190) was lost to filling (Miller and Ladd 2004). The filling of shallow water habitat suggests that a great deal of deep water habitat was altered through dredging. Therefore dredging may have resulted in loss of spawning habitat or disturbance during the spawning season. The state of New York has not received any requests for blasting.

Water quality and contaminants

The Hudson River has long history of water pollution: as early at 1909 the NYC DEP recognized pollution, primarily sewage, as a growing problem. Over one billion gallons of untreated sewage were dumped in the harbor daily during the 1930's (NYC DEP).

New York City was not the only source of sewage; most major towns and cities along the Hudson River contributed. Sewer was so prevelant in the Hudson River that it was often referred to as an open sewer. Biological demand created by the sewage created oxygen blocks that occurred seasonally (generally mid to late summer) in some river sections. One of the best-known blocks occurred near the city of Albany from 1960 through the 1970s near the northern segment of shortnose spawning and nursery habitat limiting the use of the upper 25 miles of the river. A second oxygen block occurred in the lower river nearby New York City in late summer for decades until 1989 when a major improvement to a sewage treatment plant in upper Manhattan came online. Water quality has generally greatly improved in both these areas following the implementation of the Clean Water Act in the 1970s along with reducing sewage loading into the river. Due to these remedies, shortnose sturgeon have been captured in New York Harbor during the Hudson River utility sampling programs since 2004.

There are other persistent chemical pollutants in the Hudson River. The best-known and most pervasive chemical contamination is from polychlorinated biphenyls (PCBs). The major source of the chemical is approximately 40 miles north of the Troy Dam, where General Electric discharged up to 1.3 million pounds of PCBs into the river for over 25 years beginning in the 1940s. The EPA declared 200 miles of the Hudson below Hudson Falls and Fort Edward, NY, a Superfund site in the 1970s. The removal of the contaminated sediments via a controversial dredging clean-up project has yet to begin.

Because of the PCB contamination of fish flesh, the NY DEC, under recommendation from the New York Department of Health, closed many of the Hudson River fisheries in 1976. Other contaminants have also been found in the Hudson River and its fishes (PAHs, some metals, etc.), but are minor concentrations compared to PCBs. Research is ongoing to try to determine effects of these contaminants on fishes.

While the Clean Water Act greatly improved the water quality in the Hudson River, some sewage issues remain due to the presence of combined storm water/sewage outfalls near Albany located adjacent to shortnose sturgeon spawning/nursery habitat. During large rainfall events, sewage treatment plants are over-whelmed by the high volume of runoff resulting in un-treated sewage being dumped into the Hudson River. Notably, low dissolved oxygen concentrations usually associated with sewage have not been reported.

Six shortnose sturgeon from the Hudson River have been tested for contaminants over the past 37 years; most carried very high burden load of PCBs or one of its derivatives (Table 24). Recall PCBs were dumped into the Hudson River for 30 years prior to the mid-1970s. While remnant contaminant deposits are located nearly 64 km above the Troy Dam, PCB contaminated sediments are found the entire length of the estuary to New York harbor. Only one of the six shortnose sturgeon carcasses was tested for metals; mercury was found in measurable levels.

In 1997, USGS, in cooperation with NY DEC, began a series of studies to evaluate the sensitivity of American shad and Atlantic sturgeon to contaminant exposures (Dwyer et al. 2000). Acute toxicity tests (96-h LC50) were conducted with early life-stages of American shad, Atlantic sturgeon, and shortnose sturgeon using different classes of chemicals and modes of toxic action. These chemicals have been tested in previous cooperative research conducted between the EPA, USFWS, and USGS with early life-stages of rainbow trout, fathead minnows, and 13 other threatened and endangered species. Results for shortnose and Atlantic sturgeon indicate sturgeon are somewhat more sensitive to contaminant exposure than the rainbow trout. However, it was noted that sturgeon are difficult to test, and conclusions regarding the chemical sensitivity of the sturgeon need to be interpreted with caution.

Water withdrawals

Water withdrawals for drinking water occur throughout the Hudson River from Poughkeepsie to Catkskill. A new water withdrawal facility to provide for a desalinization plant to produce drinking water is proposed for upper Haverstraw Bay. Effects of water withdrawals are unknown.

2. Overutilization

Bycatch

Fishing for shortnose sturgeon occurred in the Hudson River until the species was declared a federally endangered species in the 1973. Since then no shortnose landings were recorded;

harvest temporarily was focused on the larger Atlantic sturgeon. Size limit for Atlantic sturgeon was initiated in 1973 at 42 inches; and increased to 48 inches in 1984.

Commercial American shad fishery bycatch

Since 1980, NY DEC has monitored the commercial American shad gill net fishery using onboard observers. Observers record data on all catch and bycatch, condition and disposition of the catch and bycatch, along with effort expended. The shad fishery has two gear categories: fixed gear which is fished in the lower river from the Tappan Zee to Peekskill (km 45 to 69), and the drift gear fishery from Poughkeepsie to Catskill (km 113 to 182).

Observed bycatch in the fixed gear fishery has been low during the 28-year program and consists of over-wintering adult, and perhaps some immature, shortnose sturgeon. Bycatch was sporadic between 1980 and 1992 when effort in the fishery began to decrease as abundance of American shad declined (Table 23). All sturgeon were reported released alive and in good condition. While shad nets are fished up to 12 hours, cool water temperatures (6 to 12^{o}C) allow good survival.

Bycatch in the shad drift fishery is also reported sporadically, but is usually lower than fixed gear. These nets are set by mid-April in an area that overlaps over-wintering habitat of pre-spawn adults. Usually migration to these areas by shortnose from their over-wintering areas has been complete prior to the period when this shad fishery operates.

NY DEC recently proposed to close the Hudson River shad fisheries due to poor stock condition. A closure of the shad fishery would eliminate the potential shortnose sturgeon bycatch (both recreational and commercial) in the Hudson River in these fisheries (K. Hattalla, NY DEC, pers. comm. 2009).

Recreational fishery bycatch

A small but popular fishery for American shad used to occur in the upper Hudson River just south of the Troy Dam. However, with the new regulations prohibiting all shad fisheries, this is no longer a threat to shortnose sturgeon. A growing bait fishery for river herring (alewife and blueback herring) occurs concurrent with the sport fishery for striped bass. Shortnose sturgeon are sometimes caught as bycatch by recreational anglers seeking any one of these species. NY DEC police heavily patrol this entire region writing citations for incidental catch of shortnose sturgeon. As mentioned closure of the shad fishery would effectively eliminate the potential for any bycatch of shortnose sturgeon (K. Hattalla, NY DEC, pers. comm. 2009).

Poaching

Although possession of shortnose sturgeon is illegal in New York waters it is not clear if poaching occurs. Citations issued for illegal recreational fishing of shortnose in the vicinity of Troy, NY were for possession, and/or targeting (snagging) of sturgeon, not deliberate capture.

Scientific research

No shortnose sturgeon are killed for scientific use. A few individuals have been analyzed for contaminants, but these specimens were found dead, impinged at power plant water intakes.

NMFS has issued three ESA Section 10 Permits for shortnose sturgeon on the Hudson River. One permit is held by the NYDEC DEC for take associated with New York's juvenile Atlantic sturgeon sampling program. The others are held by Dynegy Inc. for take collected during the Hudson River generating utilities Long River biological monitoring program, and EarthTech for sampling to determine potential environmental impacts associate with the replacement of the Tappan Zee Bridge.

3. Competition, Predation and disease

Competition and predation

No known sources of competition or predation have been reported for shortnose in the Hudson River. However channel catfish are abundant in the Hudson River and they have been documented to feed on white sturgeon (Gadomksi and Parsely 2005).

The effects of exotic invasive introductions are unknown. The introduction of zebra mussels in the Hudson in 1991, and their subsequent explosive growth in the river, quickly caused pervasive changes in the phytoplankton (80% drop) and micro and macro-zooplankton (76% and 50% drop, respectively) communities (Caraco et al. 1997). Water clarity improved dramatically (up by 45%) and shallow water zoobenthos increased by 10%. Given these massive changes, Strayer et al. (2004) explored potential effects of zebra mussel impact on YOY fishes. Some effects included a decrease in observed growth rate and abundance of YOY fishes, primarily affecting open water species such as American shad. It is not clear if such changes also occurred in YOY or immature (ages one through four) shortnose sturgeon. Some recent anecdotal information suggests that adult shortnose sturgeon sometimes feed on zebra mussels.

Another exotic invasive, the Chinese mitten crab, has recently been found throughout the mid to lower Hudson estuary and tributaries. It is not known how these new invasive crabs will affect the food web or shortnose sturgeon.

Disease

Dovel et al. (1992) reported a morphological abnormality for shortnose collected in the Hudson River: the deformity was a "U" shaped snout, occurring in a wide size range of fishes. The NY DEC has on rare occasion observed the same deformity. The deformity appears to be a growth defect, perhaps genetic in nature.

Another observed abnormality is "black blotch" where there is the appearance of black spots or blotches present on the skin of shortnose sturgeon. Generally these blotches are small, about 3 cm in diameter. One or more blotches may be present on an individual. Occurrence is fairly rare. Results from initial research on black blotch were inconclusive: no apparent correlation between black blotch occurrence and PCB contamination was evident based on the limited number of samples available. However, melatonin stimulation is known with exposures to excessive lead, possibly mercury, and perhaps other metals (L. Skinner, NY DEC, pers. comm. 2009). No definitive study has ever confirmed the occurrence, or cause, of black blotch, or any other abnormality, since no individuals are sacrificed to be measured for any systematic look at contaminant loading.

Dovel et al. (1992) also often noted "fin rot", a redness and deterioration of fin edges caused by fungal infections. The cause of the fin rot was suggested to be related to pollution or to contaminants compromising the immune system of the affected individuals. In recent sampling targeting juvenile Atlantic sturgeon, shortnose sturgeon captured appeared to be in good health with no sign of the "fin rot" noted by Dovel et al. (1992).

New York enacted regulations in 2007 to curb the movement of fishes, primarily bait fish, through-out the state due to the presence of Viral Hemorrhagic Septicemia (VHS) in fishes of the Great Lakes and a few of the state's Finger Lakes in central New York. The disease is a mutated form of a trout and salmon virus which affects warm-water species, and has been identified as the cause of several large fish kills in the affected waters. Many fish species are carriers of the disease, and not all die of the disease. In 2008 this disease was not detected in the Hudson River basin. It is not known if VHS affects shortnose sturgeon.

4. Inadequacy of existing regulatory mechanisms

Shortnose sturgeon was listed as endangered by New York State on March 30, 1971. This Endangered Listing status continues to the present and no possession of shortnose sturgeon is allowed for any reason. The "no possession" rule is clear-cut and is fairly easy to enforce. Generally, listing in New York follows the federal status listing.

Some enforcement issues have occurred when shortnose sturgeon are spawning below the Troy Dam in the midst of popular sport fisheries for American shad, striped bass, and river herring. Enforcement presence during this time period has been increased to limit problems associated with catch and possession of shortnose sturgeon.

5. Other natural or man-made factors

Ship strikes

There is no evidence of ship strikes with shortnose sturgeon on the Hudson River.

Impingement and entrainment

Until 2002 a power plant located within shortnose sturgeon spawning/nursery area was known to impinge and entraine; the "old" Albany Steam Electric generating station, located in Bethlehem, NY, has since been sold and re-constructed. The new Bethlehem Energy Center was completed in July 2005 (M. Calaban, NY DEC, pers. comm.).

Prior to construction of the new Bethlehem facility, the Albany Steam Electric generating used once-through cooling water intakes during power generation. Monitoring occurred for impingement and entrainment occurred sporadically: 1974-1976, October 1982-September 1983, and April 1984-April 1985. In 1982, following a large year class, 163 YOY shortnose were impinged at the plant (Table 25, LMS 1984, 1985); many fewer shortnose sturgeon were impinged during 1984-85. Sampling only for entrainment occurred 1982-83: no eggs or other early life stages of shortnose were recorded. Since 1990 the NY DEC-Bureau of Habitat has worked with the facility to institute new standards to reduce fishery impacts. First, the State NPDES permit was modified to incorporate a cooling water flow reduction program requiring a reduction in cooling water (50% annual reduction and 70% seasonal reduction). Next in 1997 a closed cycle cooling and wedge wire/Gunderboom combination intake design was implemented resulting in a 98% reduction in cooling water use.

Shortnose are occasionally collected in impingement sampling at other power generating stations in the mid-Hudson River area, mostly reported at 1-2 annually (Table 26; CHGE et al. 1999). Water withdrawals also occur for large air conditioning system at the Empire State Plaza in downtown Albany; however no impingement or entrainment data are available for this facility.

Artificial propagation

There is no artificial propagation of shortnose or Atlantic sturgeon occurring on the Hudson River.

Escapement of hatchery/captive fishes

Since there is no artificial propagation of shortnose sturgeon on this river, there is no threat from escapement.

Other

Little data exist to determine cause and effect of other potential impacts on the Hudson River shortnose sturgeon population (loss of coolwater refugia due to groundwater withdrawal, agriculture, forestry, changing land use patterns, development, transportation projects, mining, construction and ship strikes).

Current and Recommended Research

Currently, no directed shortnose sturgeon research is occurring in the Hudson River. Shortnose sturgeon are caught as bycatch in three sampling programs: 1) NY DEC survey of juvenile Atlantic sturgeon in the lower Hudson, and 2) two surveys conducted by the Hudson River power generating companies (FSS and a winter striped bass trawl survey in the NY harbor). Data from these programs were summarized above.

NY DEC has identified a suite of future research summarized below.

- Revisit all population estimates made for shortnose over the past thirty years. The wide disparity in the range of values reported for the recent annual estimates from the 1990s is of particular interest. Available data indicate changes are occurring in the stock, but the level of magnitude and the reasons behind these changes are not clear as detailed above in the abundance section.

- Clarify the shortnose sturgeon's role in the ecosystem by identifying specific life history characteristics and habitat use for the various life stages of the stock: spawners, post-spawning movement, over-wintering segments (mid river, downriver and NY harbor areas) and juveniles. The recent documentation of shortnose in the New York harbor area indicates habitat use expansion, perhaps due to improved water quality. The study will include a sonic tagging/tracking program similar to the study the NY DEC and partners have conducted for adult Atlantic sturgeon. Food habits studies will be conducted alogn with estimating length of the resting stage for post–spawn adults and immature shortnose sturgeon, and confirming spawning periodicity.

Table 20. Estimates of size of the shortnose sturgeon population inhabiting Hudson River, NY.

Publication	Model Name	Model Type	Year	Estimate	95% CI	Population Segment
Dovel 1979	Peterson	closed	1976-1978	5,837	1,989-21,276	Spawning
Dovel et al. 1992	Peterson	closed	1979	12,669	9,080-17,735	Spawning
Dovel et al. 1992	Peterson	closed	1980	13,844	10,014-19,224	Spawning
Extrapolation of Dovel			1980	30,311		Total
Bain et al. 1998a	CAPTURE M(h)	closed	1995	55,265	38,397-79,901	Spawning
	CAPTURE M(th)	closed	1995	38,024	26,427-55,072	Spawning
	CAPTURE M(o)	closed	1995	25,255	18,931-33,906	Spawning
Bain et al. 1998b, 2000, 2007	Schumacher-Eschmeyer or Schnabel	closed	1994-1997	56,708	50,862-64,072	Spawning
	Schumacher-Eschmeyer or Schnabel	closed	1994-1997	61,057	52,898-72,191	Total
Bain et al. 2000*	Jolly-Seber	open	1994-1997	65,000*	55,000-75000	Unknown
	Jolly-Seber	open	1995	80,026	30,000-125,000	Unknown
	Jolly-Seber	open	1995	50,000*	15,000-75000	Unknown
	Jolly-Seber	open	1995	40,000*	15,000-60,000	Unknown
	Jolly-Seber	open	1996	65,000*	30,000-90,000	Unknown
	Jolly-Seber	open	1996	27,731	5,000-50,000	Unknown

*Estimate approximated from graph in Bain et al. 2000, others as stated in text.

Table 21. Sample design of the Fall Shoals Survey of the Hudson River Power Generating Companies, with approximate number of samples taken by three meter beam trawl per section of the Hudson River, NY. 2006 data presented as an example (ASA 2007).

				Jul - mid Oct			Late Oct-Dec			
River section	**Key**	**RKM**	**km /section**	**Shoal**	**bottom**	**total**	**shoal**	**Bottom**	**total**	**ALL**
Battery	BT	1-19	18		64	64		36	36	100
Yonkers	YK	19-39	20	16	64	80	15	33	48	128
TZ	TZ	39-55	16	48	48	96	15	24	39	135
Croton-Haverstraw	CH	55-63	8	40	48	88	15	18	33	121
Indian Point	WP	63-76	13	32	56	88	15	30	45	133
West Point	IP	76-90	14		80	80		36	36	116
Cornwall	CW	90-100	10	40	48	88	15	29	44	132
Poughkeepsie	PK	100-124	24		88	88		30	30	118
Hyde Park	HP	124-138	14		64	64		30	30	94
Kingston	KG	138-151	13		32	32		24	24	56
Saugerties	SG	151-172	21		32	32		30	30	62
Catskill	CS	172-201	29		24	24		30	30	54
Albany	AL	201-246	45		32	32		24	24	56
Total			245	176	680	856	75	374	449	1305

Table 22. Shortnose sturgeon tagged and released in the Hudson River and recaptured in the Connecticut River. Data are from the US Fish and Wildlife Coastal Cooperative Sturgeon Tagging Database. CORNELL = Cornell University; CT DEP = Connecticut Department of Environmental Protection.

Release data								
Agency	**Fish ID**	**Date**	**Waterbody**	**TL(mm)**	**FL(mm)**	**Wt(kg)**	**DAL**	
CORNELL	351950717	3/27/1995	Hudson River (km 166)	-	575	2.04	805	
CORNELL	351950856	3/29/1995	Hudson River (km 166)	-	880	5.5	3001	
Recapture data								
							Growth	
Agency	**Fish ID**	**Date**	**Waterbody**	**TL(mm)**	**FL(mm)**	**Wt(kg)**	**TL**	**FL**
CT DEP	351950717	6/9/1997	Connecticut River Saybrook CT	805	695	5.7		120
CT DEP	351950856	6/16/2003	Connecticut River Lower river	1070	935	11.2	1070	55

Table 23. Bycatch of shortnose sturgeon in the commercial gill net fishery for American shad in the Hudson River Estuary, NY DEC commercial fishery monitoring program.

	Observed bycatch in fixed gill net				Observed bycatch in drift gill net				Reported bycatch of gill net fishermen	
Year	N-trips	Effort*	N-fish	c/f*100	N-trips	Effort*	N-fish	c/f*100	Fixed	Drift
1980	30	697.0	4	0.574	10	31.6	0	0.000		
1981	24	822.5	7	0.851	29	128.0	0	0.000		
1982	53	1193.0	1	0.084	32	118.9	4	3.363		
1983	46	941.5	1	0.106	17	63.6	3	4.717		
1984	61	1053.1	0	0.000	7	52.1	0	0.000		
1985	53	904.7	3	0.332	7	21.1	0	0.000		
1986	52	624.5	2	0.320	13	36.9	0	0.000		
1987	63	893.9	2	0.224	6	36.0	0	0.000		
1988	54	754.1	1	0.133	18	84.8	0	0.000		
1989	38	537.5	0	0.000	7	22.8	0	0.000		
1990	30	497.7	2	0.402			0	0.000		
1991	28	526.6	2	0.380			0	0.000		
1992	32	704.2	6	0.852	11	27.7	0	0.000		
1993	8	159.3	1	0.628	1	2.8	0	0.000		
1994	10	158.6	2	1.261			0	0.000		
1995	11	251.2	1	0.398	2	10.9	0	0.000	8	1
1996	19	389.1	3	0.771	5	29.6	0	0.000	12	12
1997	26	509.4	3	0.589	3	24.9	3	12.039	9	4
1998	17	252.6	2	0.792	5	36.9	0	0.000	5	2
1999	27	383.4	2	0.522	13	67.9	0	0.000	2	6
2000	16	132.9	3	2.258	24	93.0	7	7.526	0	9
2001	23	194.4	0	0.000	13	57.0	0	0.000	0	1
2002	4	23.7	0	0.000	11	54.8	0	0.000	3	3
2003	1	9.6	0	0.000	7	30.4	0	0.000	0	0
2004	2	8.8	0	0.000	13	60.1	0	0.000	5	3
2005	1	3.0	0	0.000	21	106.8	0	0.000	10	0
2006	2	11.4	0	0.000	17	84.1	1	1.189	3	13
2007	3	3.3	0	0.000	4	25.3	0	0.000	9	5

Table 24. Contaminant analyses of six shortnose sturgeon collected in the Hudson River Estuary, NY DEC Bureau of Habitat.

Date	River km	Sex	Total length (mm)	Weight (g)	Sample type	PCB aroclors* Percent Lipid	Total PCB (wet weight)	Total PCB (lipid based)	Total DDT	Metals**
7/17/1970	159.6	U	472	636	unknown				9.7	
5/4/1976	121.8	F	648		Standard fillet	3.1	26.3	843.3	1.4	
5/12/1976	117.6	F	787		Standard fillet	5.3	28.6	537.8	1.4	
7/1/1992	104.6	U	614	586	Standard fillet	7.7	28.4	371.2		
3/6/1980	53.3	M	530	1162	Dorsal fin steak	1.1	1.7	155.9		
					Liver	5.8	7.0	120.5		
					Gonad	20.0	29.6	147.8		
										Mercury
7/14/1998	96.5	U	631	1660	Brain cavity	56.2	66.0	117.4		0.16
					Stomach contents	1.0	0.1	5.2		0.07
					Testes	56.1	42.1	75.0		0.10
					Gonad fat	85.2	77.0	90.4		0.20
					Liver	28.2	76.5	271.3		0.02
					Spleen	1.4	0.1	3.6		0.09
					Heart	13.1	9.6	73.3		0.06
					Intestinal tract growth	0.7	0.1	19.1		0.07
					Muscle	11.1	8.7	78.4		0.03

*PCB aroclors tests include:% lipid, aroclors-16,21,42,48,54,60, total pcb (wet weight and lipid based)

**Metals: Arsenic, silver, cadmium, cobalt, chromium, copper, lead and mercury

Table 25. Impingement of shortnose sturgeon at the Albany Steam Electric Generating Station 1974-1985 (LMS 1984, 1985).

Sample year	Life stage	Number impinged	Time of year	Mean TL (mm)	Mean weight (g)
1974-1976		5			
1982-83	Young-of-year	86	Jul-Sep	113.1	6.3
	Adult	2	Apr-May	581.0	947.8
Estimated total annual impingement		163			
1984-85	Immature	11	May-Sept	278.8	99.0
Estimated total annual impingement		54			

Table 26. Actual numbers of shortnose sturgeon impinged at power generating plant in the mid-Hudson River area (CHGE 1999).

Year	Bowline Haverstraw	Lovett Stony Point	Indian Point-Unit 2 Peekskill	Indian Point-Unit 3 Peekskill	Roseton Newburgh	Danskammer Newburgh	Total
1972	NS	NS	1	NO	NO	4	5
1973	1	0	2	NO	0	2	5
1974	1	0	3	NO	1	0	5
1975	0	0	1	NO	0	0	1
1976	1	0	2	0	0	0	3
1977	0	0	6	1	0	1	8
1978	0	0	2	3	0	0	5
1979	0	0	2	2	0	0	4
1980	0	0	0	1	0	0	1
1981	0	0	0	0	0	0	0
1982	0	0	0	0	0	3	3
1983	0	0	0	0	0	1	1
1984	0	0	1	1	2	3	7
1985	0	0	0	0	1	2	3
1986	0	0	0	0	0	0	0
1987	0	0	2	1	0	0	3
1988	0	0	3	1	1	0	5
1989	0	0	0	1	0	0	1
1990	0	0	1	0	0	2	3
1991	0	0	NS	NS	0	0	0
1992	0	0	NS	NS	0	1	1
1993	0	0	NS	NS	0	0	0
1994	0	0	NS	NS	1	0	1
1995	0	0	NS	NS	1	1	2
1996	0	0	NS	NS	0	0	0
1997	0	0	NS	NS	0	0	0
1998	0	0	NS	NS	0	2	2
Total by plant	3	0	26	11	7	22	69

NO-not operational, NS- no sampling

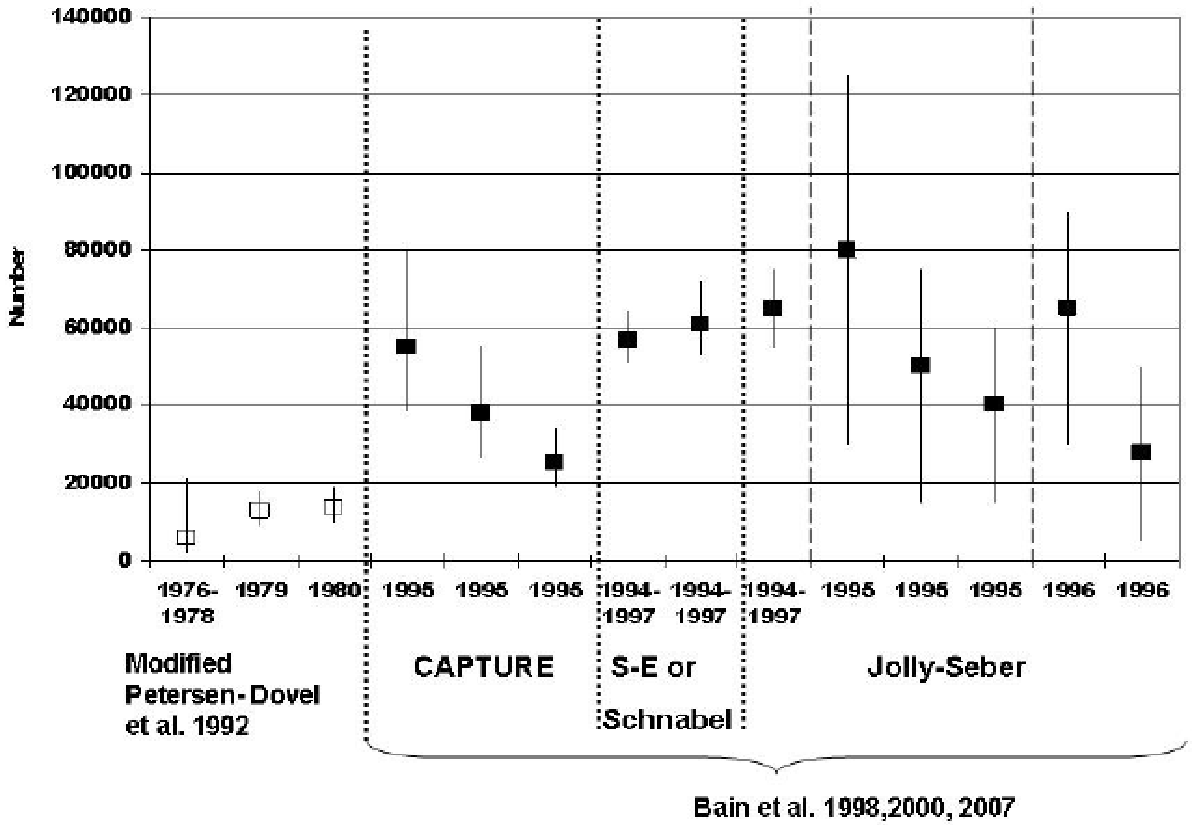


Figure 21. Various population estimates of shortnose sturgeon in the Hudson River, NY.

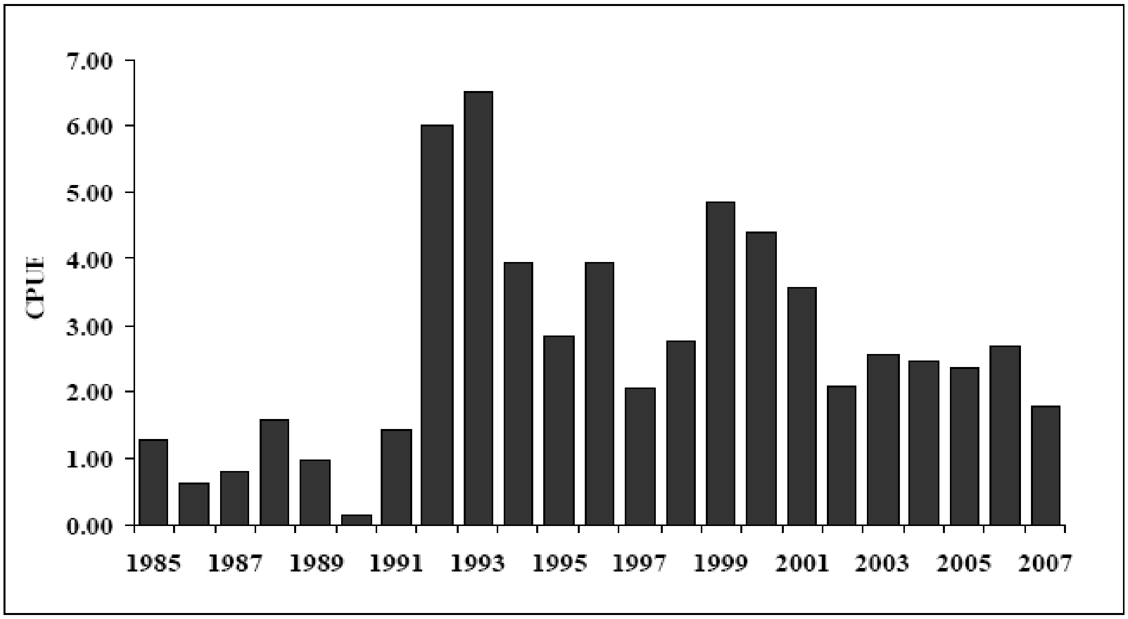


Figure 22. Catch per unit effort of shortnose sturgeon collected by three meter beam trawl in the Hudson River Generating Companies Fall Shoals Survey.

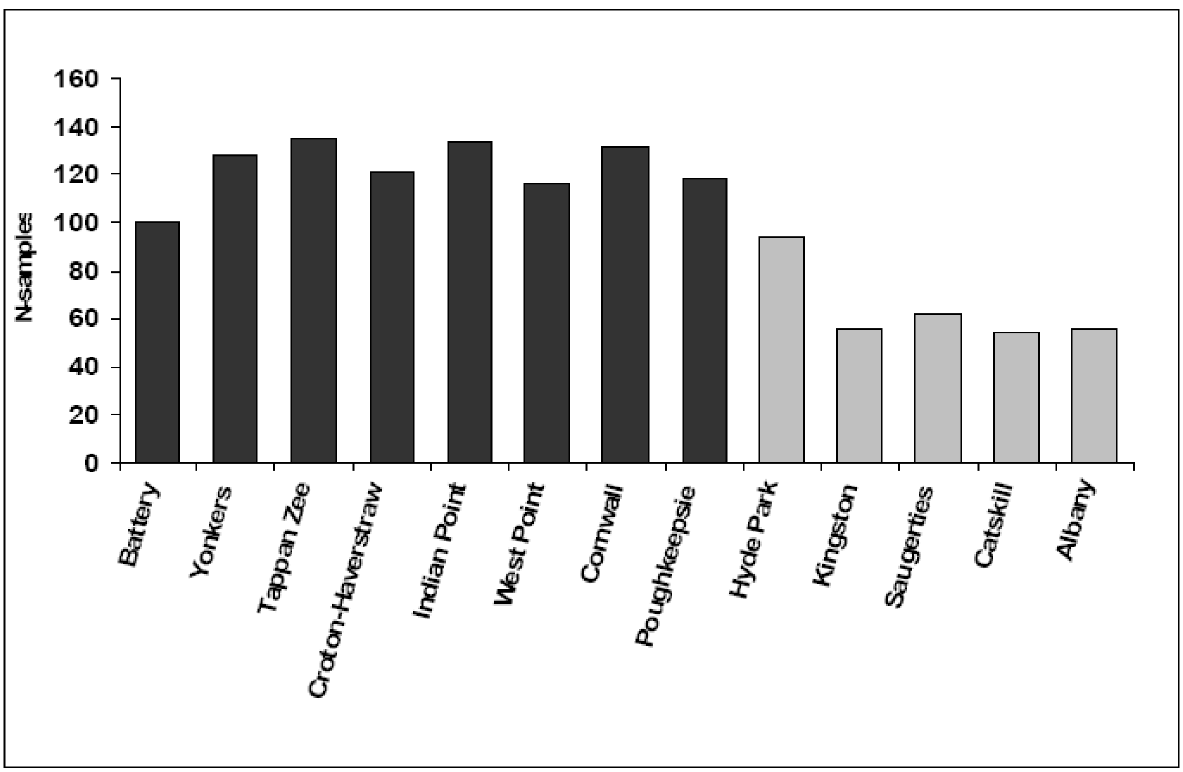


Figure 23. Number of samples taken annually during the Hudson River Generating Companies Fall Shoals Survey. Listed left to right downriver to upriver; combined sections from Battery to Poughkeepsie (black) and Hyde Park to Albany (grey) are of equal length.

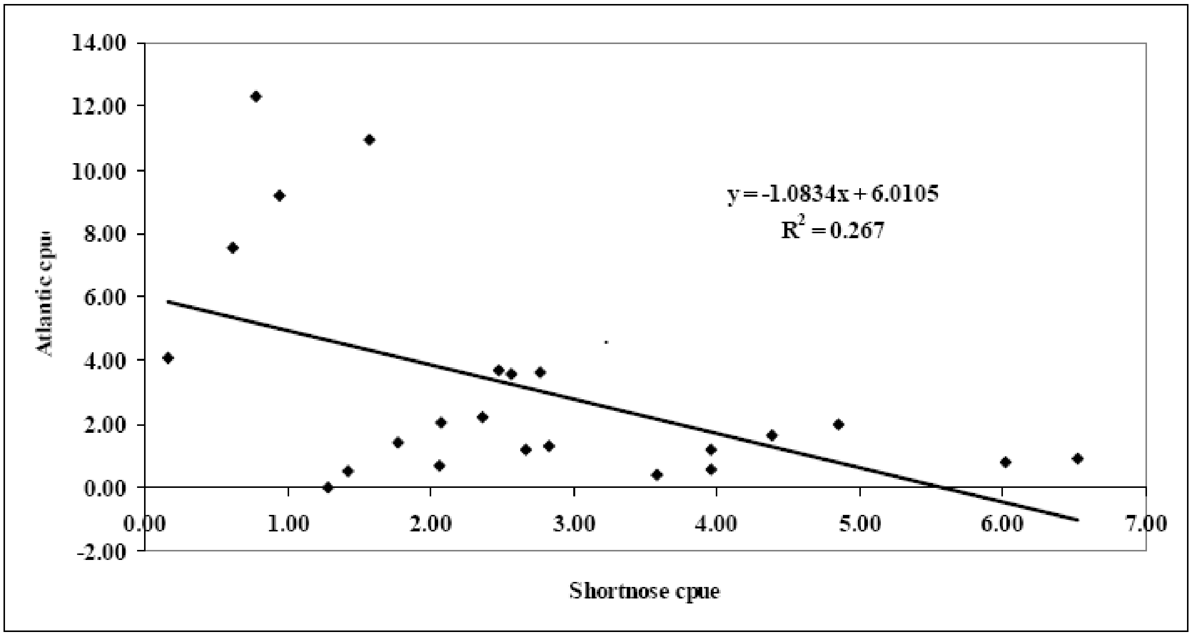


Figure 24. Catch per unit effort of shortnose sturgeon compared to CPUE of juvenile Atlantic sturgeon collected by three meter beam trawl in the Hudson River Generating Companies Fall Shoals Survey.

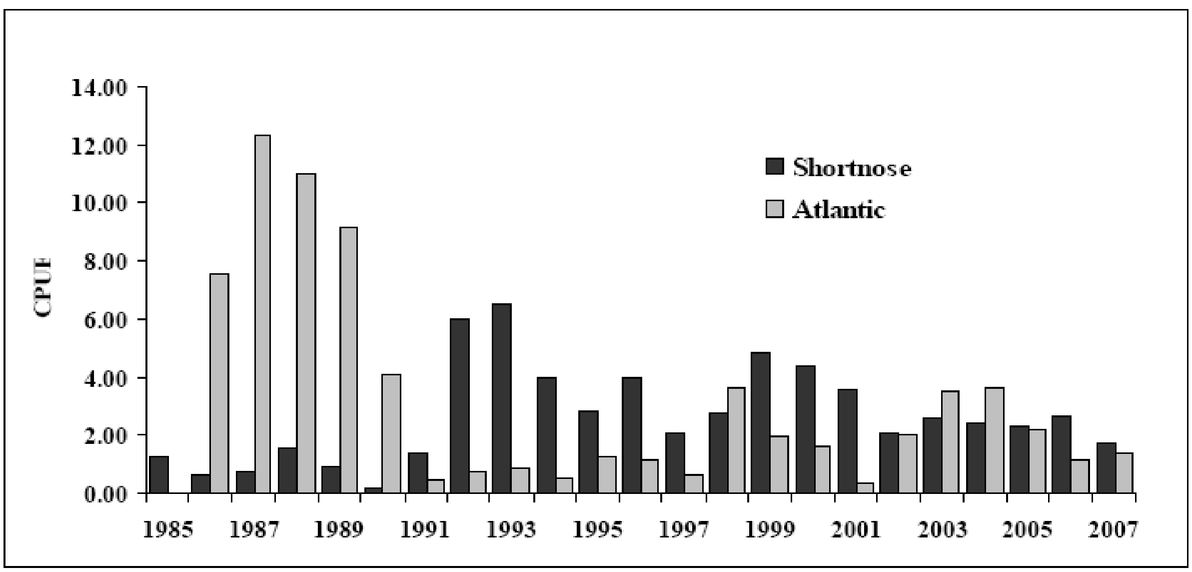


Figure 25. Catch per unit effort of shortnose and juvenile Atlantic sturgeon collected by three meter beam trawl in the Hudson River Generating Companies Fall Shoals Survey.

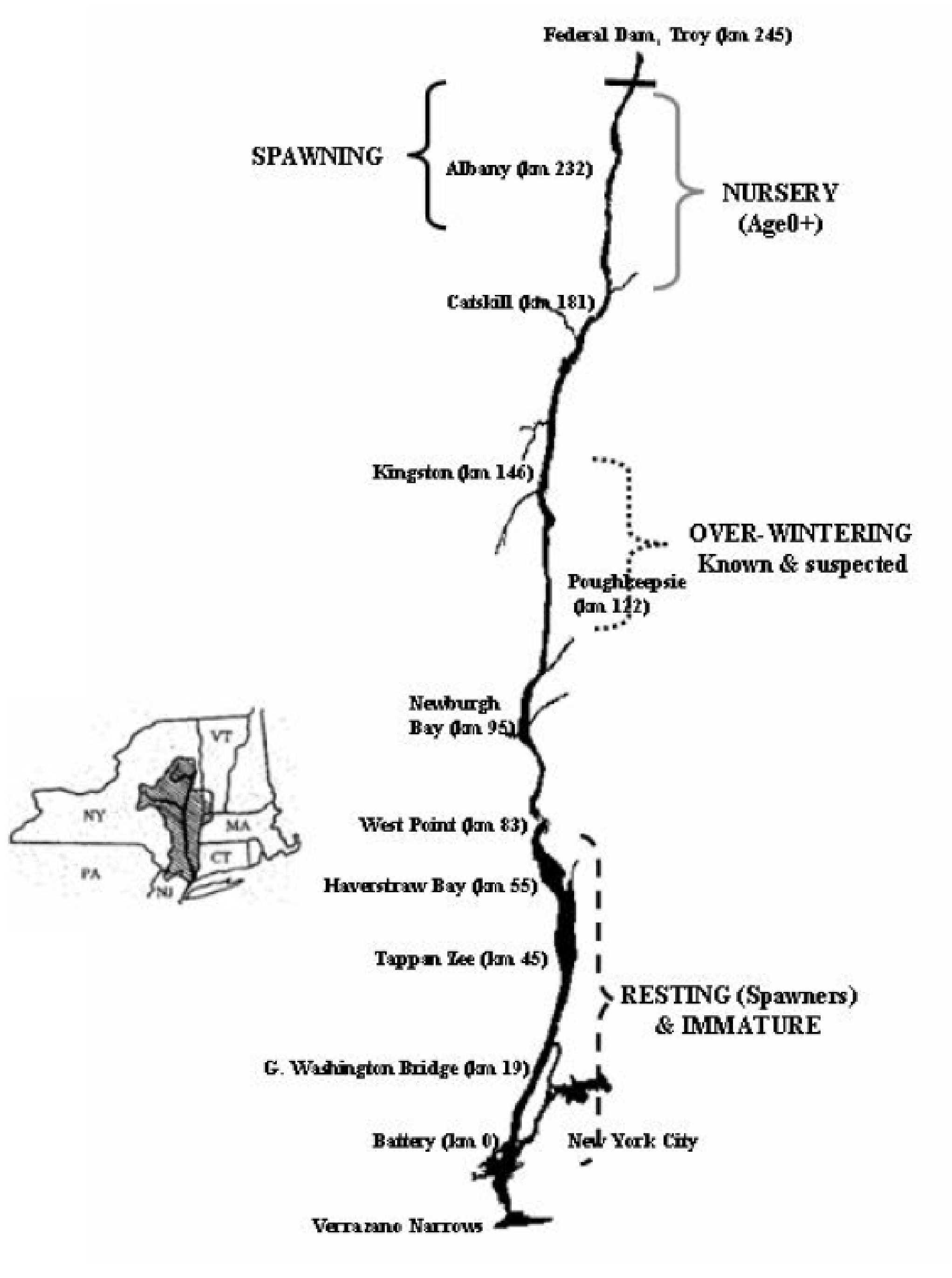


Figure 26. The Hudson River Estuary, with shortnose sturgeon spawning, over-wintering and resting areas.

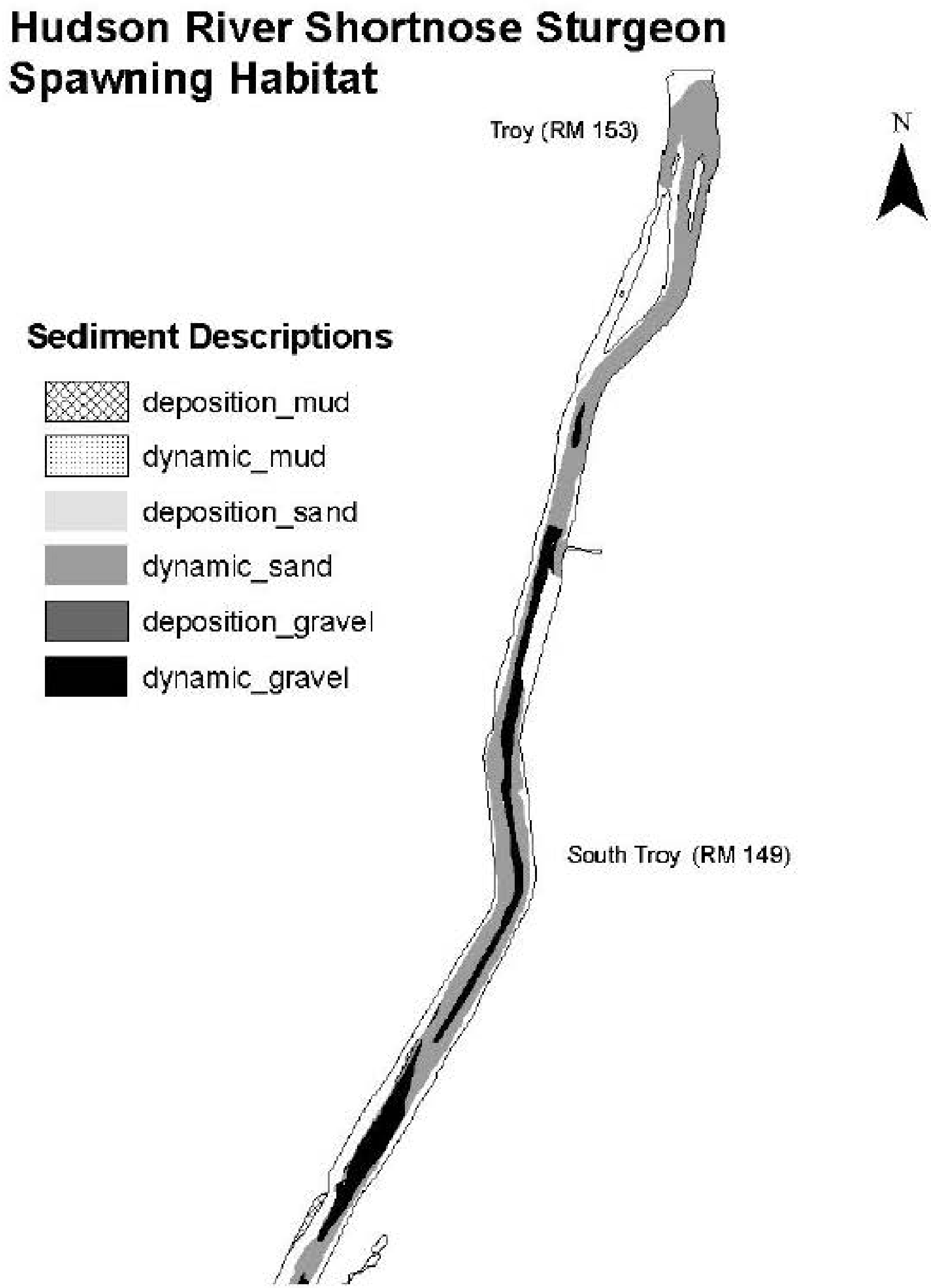


Figure 27. Hudson River shortnose sturgeon spawning habitat, showing a portion of the spawning above Albany NY in the area near Troy.

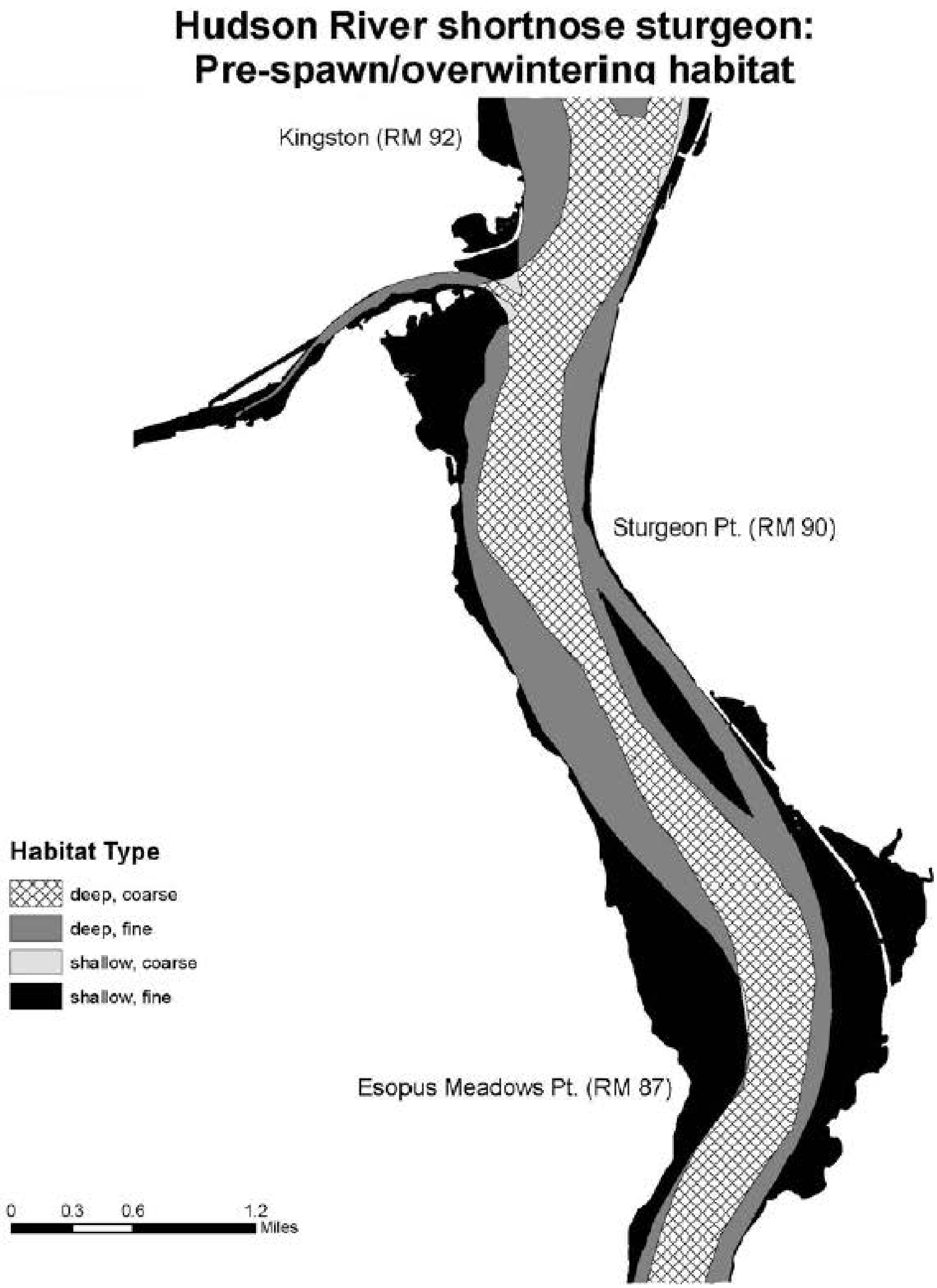


Figure 28. Bottom habitat types in the mid-Hudson over-wintering area for shortnose sturgeon near Kingston NY.

Delaware River

Historic Distribution and Abundance

Sturgeon capture records in the Delaware River between 1817-1954 were reviewed by Brundage and Meadows (1982b). The historic distribution of shortnose sturgeon in the Delaware River is somewhat unknown, though there are reports of the species as far south as Delaware City, Delaware (rkm 97) and north to Bristol, PA (rkm 192). The initial species description by LeSueur (1818) was from a Delaware River specimen. LeSueur reported the occurrence of shortnose sturgeon at the Philadelphia markets in the spring and noted that the species was "more sought after, and commands a higher price, than the common larger species." Abundance of sturgeon in the river is reported to have been substantial according to Cope (1883), Bean (1893) and Cobb (1900). Cope reported the capture and sale of shortnose sturgeon in Philadelphia and other markets, commenting that "the catch is often very large". Bean reported the sale of 1,817 shortnose sturgeon in Philadelphia that were taken in the shad fishery. Ryder (1890), however, reported no apparent utilization of the species as a food fish in 1888, concluding that the shortnose sturgeon was rare after securing only five specimens from the herring and shad fishery near Delaware City. Cobb reported the killing by shad fishermen of young sturgeon (which probably included Atlantic sturgeon) that became entangled in and damaged their nets, and indicated that the species was common as far upriver as the fall line in Trenton (rkm 214).

Other reports of shortnose sturgeon in the early 1900's reviewed by Brundage and Meadows (1982) are from Meehan (1910), Vladykov and Greeley (1963), and Fowler (1910, 1912). Meehan noted that approximately 106 shortnose sturgeon were taken by shad gill-netters in Torresdale, PA (rkm 178) between 1906-1909. Vladykov and Greeley provided collection data for eight specimens taken in the estuary between 1907 and 1913, while Fowler reported one specimen from Bristol, PA (rkm 192) in 1908. No documented captures were reported in the literature from 1913-1953 (Brundage and Meadows 1982b).

In addition to the Brundage and Meadows (1982) review, Saffron (2004) reported on the abundance of sturgeon in the Delaware River in her description of the "American Caviar Rush". According to Saffron (2004), America's caviar industry began in the Delaware River and lasted roughly 30 years, between the 1870's and early 1900's. The author describes rich sturgeon grounds in the vicinity of Penn's Grove (rkm 116) and notes "the fish coursed up the Delaware in huge numbers, far more than in the Hudson, and in the calm waters the advancing horde could be virtually skimmed off the bottom with seine nets". After three decades of sturgeon fishing, stocks crashed in rivers all along the east coast (Saffron 2004). The author does not, however, differentiate between shortnose and Atlantic sturgeon.

Current Distribution and Abundance

Shortnose sturgeon occur throughout the Delaware River estuary and occasionally enter the nearshore ocean off Delaware Bay (Brundage and Meadows 1982a & b). In spring, spawning adults occur in the non-tidal river, and are common at least as far upstream as Scudders Falls (rkm 223). According to Dadswell et al. (1984), ripe adults have been captured as far upstream as Lambertville (rkm 239). The farthest upstream confirmed account of a shortnose sturgeon in the river is from 1998, with a individual captured during electrofishing for American shad below the lower tip of Old Sow Island, Raubsville, PA (rkm 287) (M. Kaufmann, PA Fish and Boat

Commission, pers. comm. 2008). There are unconfirmed reports of individuals seen at Stockton (rkm 244) and Prahls Island (rkm 255), Hunterdon County.

Hastings et al. (1987) calculated a modified Schnabel population estimate for adult shortnose sturgeon in the Delaware River of 12,796 (95% CI = 10,228-16,367) based on mark recapture data collected during 1981-1984. ERC, Inc. (ERC 2006b) estimated a population of 12,047 adult shortnose sturgeon (95% CI = 10,757 – 13,580) based on mark-recapture data collected during January 1999 through March 2003. Abundance was derived using a Chapman modification of the Schnabel estimate.

Similarity between the Hastings et al. (1987) and ERC, Inc. (2006b) estimates suggest that the Delaware River shortnose sturgeon population is stable but has not increased in the 20+ years between studies. The recent collection of 168 shortnose sturgeon tagged as adults by Hastings et al. (1987) suggests that older individuals comprise a substantial portion of the Delaware River population (ERC, Inc. 2006b).

Natural History and Habitat Information

Spawning

Delaware River shortnose sturgeon spawn from late March through early May. Spawning occurs primarily between Scudders Falls and the Trenton rapids (rkm approx. 223-214) in Mercer County, although shortnose sturgeon eggs were collected upstream of Titusville, NJ (rkm 229) in spring 2008 (H. Brundage, ERC, pers. comm. 2008). The river in this area is non-tidal (river is nontidal beginning at the fall line at Trenton Rapids) and is characterized by pools, riffles and rapids (O'Herron et al. 1993). It is relatively shallow about the fall line (<3 meters in summer). According to O'Herron et al. (1993), the substrate is composed primarily of sand, gravel, and cobble, with soft sediments found in areas of weaker currents. Spawning apparently occurs in fast water over cobble, gravel, boulders, and clean sand (J. O'Herron, Amitrone O'Herron, Inc., pers. comm.). Spawning can occur between 8 and 25°C, with most spawning occurring within the 10-18°C range. Recent surveys by ERC, Inc. for early life stages, as well as observations from impingement/entrainment studies, confirm the presence of shortnose sturgeon larvae and/or eggs between Scudders Falls (rkm 223) and Trenton (rkm 214) (see Sections 4e and 5). Larvae collected at a Fairless Hills, PA (approximately rkm 191) cogeneration plant well south of the spawning/rearing area may have been carried there during a one day flood event (see "Other natural or manmade factors" below).

Foraging

After spawning, most adult shortnose sturgeon spend the summer and early fall foraging throughout the river, between the vicinity of Trenton south to Artificial Island (rkm 79) (J. O'Herron, Amitrone O'Herron, Inc., pers. comm. 2008). Some foraging may also occur in winter, though sturgeon are not foraging heavily at this time (J. O'Herron, Amitrone O'Herron, Inc., pers. comm. 2008). Predominate substrates in the tidal river include fine grain sediments (silt, sand and clay). Larger substrates ranging from gravel to bedrock can be found in certain areas (ERC, Inc. 2006b). While gut content analysis has not been performed on Delaware River shortnose sturgeon, according to J. O'Herron (Amitrone O'Herron, Inc., pers. comm. 2008), oligochaetes, Asian clams, and chironomids were observed over occupied sturgeon habitats during macroinvertebrate sampling conducted in the early 1980's.

Overwintering/resting

Shortnose sturgeon were found to overwinter in the Roebling (rkm 199), Bordentown, (rkm 207) or Trenton reaches from December-March. The channel off Duck Island (rkm 208) is known to be used heavily by overwintering shortnose sturgeon (O'Herron 1993). Recent acoustic tagging studies (see below) indicate the existence of an overwintering area in the lower portion of the river, below Wilmington, DE (ERC, Inc. 2006a). Wintering adults are normally observed in tight aggregations and movement at this time appears to be minimal. In addition, results from a preliminary tracking study of juvenile shortnose sturgeon suggest that the entire lower Delaware River from Philadelphia (~ rkm 161) to below Artificial Island may be utilized as an overwintering area by juvenile shortnose sturgeon (ERC, Inc. 2007b). According to ERC, Inc. (2007b), juvenile sturgeon in the Delaware River appear to overwinter in a dispersed fashion rather than in dense aggregations like adults.

Migration

Acoustic tagging studies by ERC, Inc. (2006a) indicate that adult shortnose sturgeon demonstrate one of two generalized movement patterns: long excursions from the upper to the lower tidal river (Pattern A), or remaining in and utilizing the upper tidal river (Pattern B) (ERC, Inc. 2006a). Shortnose sturgeon with Pattern A movements made long distance excursions, often moving between the upper tidal river and the area of the Chesapeake and Delaware Canal (C&D Canal) (rkm 95) or farther downstream. Movements were often rapid, with one individual swimming 121 kilometers in six days. These long distance excursions often occurred in spring, after the spawning period (likely movement to summer foraging areas), and in early to mid-winter (likely movement to overwintering areas) (ERC, Inc. 2006a). Most of the tagged shortnose sturgeon occupied known overwintering areas in the Roebling, Bordentown, and Trenton reaches of the upper tidal river during December through March. Three sturgeon, however, appear to have overwintered in the downriver, below Wilmington (rkm 113). This suggests the existence of an overwintering area in the lower river. Downriver overwintering areas are known to occur in other river systems, but previously there had been no evidence of such in the Delaware River (ERC, Inc. 2006a). Movement patterns observed in the ERC study indicate that some, but not all, of the adult shortnose sturgeon that overwinter in the upper tidal Delaware River move to the spawning area in the lower non-tidal river in late March and April (ERC, Inc. 2006a).

Preliminary tracking studies of juvenile shortnose sturgeon showed different patterns of movements in the winter (n=3), indicating that the entire lower Delaware River (Philadelphia to below Artificial Island; approx. rkm 161-79) may be utilized for overwintering (ERC, Inc. 2007b). One individual, whose tag was active in late spring and summer, showed movement spanning approximately 25 kms between the Chester and Deepwater Point ranges (rkm 130-101), spending much of its time in the vicinity of Marcus Hook (rkm 128; ERC, Inc. 2007b).

Stressors to Riverine System

1. **Habitat**

Dams and diversions

The Delaware River is the largest un-dammed river east of the Mississippi with a total length of 530 km and a tidal range of 220 km (DRBC 2007, Simpson 2008). There are several water diversions that may pose a threat, including three Catskill reservoirs that require up to 800,000,000 gallons/day from the river. In addition there are NJ diversions, including transfer through the D and R Canal at the Bulls Island wing dam into the Raritan Basin, that use up to 130,000,000 gallons of river water/day. Although these water diversions occur upstream of the spawning area, periodic water releases may increase flow and potentially affect early life stages. About 15 million people rely on the Delaware River for drinking water and industrial use (DRBC 2007).

Other energy projects

Tidal turbines

There are currently no existing or proposed tidal turbines associated with the Delaware River.

LNG facilities

A proposal by Crown Landing LNG–BP to build an LNG terminal along the Delaware River at Logan Township, NJ was approved by FERC. One other potential site for an LNG terminal on the Delaware River has been identified by Freedom Energy Center PGW as Philadelphia, PA. Both facilities are proposed closed loop systems. Potential threats/impacts to shortnose sturgeon associated with the approved facility would include increased risk of ship strikes, loss of foraging habitat via dredging, and YOY/sub-adult losses via ballast water uptake and facility intakes, and changes in ambient water temperature (usually cooling) of water withdrawn and then discharged.

Dredging and blasting

Congress authorized the Delaware River-Philadelphia to the Sea Federal Navigation Project in 1910. This 96.5 mile long channel is authorized for depths of 37 to 40 feet. To date the project has not been completed although annual maintenance occurs. The ACOE also maintains a separately authorized channel between Philadelphia and Trenton that is also periodically dredged to maintain the authorized depth and width. Several mortalities of shortnose sturgeon have been documented during dredging operations in the Delaware River (NMFS 2009). In December 2008, the ACOE announced that they had reactivated the Delaware River Deepening Project which was authorized by Congress in 1996. This project began in 2009 and will increase the authorized depth of the Philadelphia to the Sea channel to 45 feet. The initial dredging cycle is scheduled from 2009-2014. Annual maintenance will be necessary after this time. The ACOE consulted with NMFS on the effects of the proposed deepening project. NMFS determined that proposed action is likely to adversely affect but is not likely to jeopardize the continued existence of shortnose sturgeon (NMFS Biological Opinion on Deepening of the Delaware River, July 2009). In addition to dredging, the project involves blasting over two winters at the Marcus Hook anchorage in order to remove rock and increase water depths at this site. Furthermore, private dredging operations are authorized throughout the river by the ACOE. Various time of year restrictions are employed to minimize effects on anadromous species; however, as these windows are not designed to be protective of shortnose sturgeon, dredging does occur at times of year when shortnose sturgeon are present.

Water quality and contaminants

Water quality in the Delaware River is generally improving. ERC, Inc. (2002) indicated that contaminants posing the most serious threats to shortnose sturgeon are endocrine disrupting chemicals (EDCs), which have been linked to reproductive and developmental disorders in many species. These contaminants, found in tissue from two shortnose sturgeon collected in the Delaware River in 2001, include PCDD's/TCDF's, DDE, PCB's, and cadmium. EDCs have also been linked in fishes to reduced fecundity and egg viability, increased early life stage mortality, anatomical defects in larvae, delayed puberty and decreased testicular growth (Leung et al. 2002, Monosson 1997).

2. Overutilization

Bycatch

There are no reported recent mortalities of shortnose sturgeon from the drift gillnet fishery for American shad (R. Allen, NJ Bureau of Marine Fisheries, pers. comm. 2008). Bycatch is occurring, however, as evidenced by reports of interactions between shortnose sturgeon and gillnet fishermen in the form of caught and released shortnose sturgeon (1 in 2007, 1 in 2006, 15 in 2005, and 12 in 2004). In addition, almost every year between late March and early April during the American shad fishing season, the NJ DFW receives reports from hook and line anglers of foul hooked and released shortnose sturgeon in the vicinity of Scudder's Falls (M. Boriek, NJ Bureau of Freshwater Fisheries, pers. comm. 2008).

Poaching

In spring 2006, a NJ DFW Conservation Officer discovered a shortnose sturgeon in an angler's car trunk. The angler had caught the sturgeon while bottom fishing in Trenton City and was observed placing the fish in a plastic bag and then into the car trunk. The officer apprehended the bag, took pictures of the fish and released it live (B. Herrighty, NJ DFW Conservation Officer, pers. comm. 2007). Photos confirmed it was a shortnose sturgeon. It is likely that other incidents similar to this have occurred and gone undetected.

Scientific research

Minimal collections of eggs and larvae are undergoing per a NMFS ESA Section 10 permit. ERC's acoustic tracking project is ongoing and up to 30 adult and 30 juvenile shortnose sturgeon may be acoustically tagged and tracked.

3. Competition, predation and disease

Competition and predation

Potential predators include flathead catfish, snakeheads, other bottom dwellers, and mitten crabs (R. Allen, NJ Bureau of Marine Fisheries, pers. comm.). Catfish and other bottom feeders would be the most likely competitors for food. Channel catfish are quite piscivorous and relatively highly abundant compared to flatheads, snakeheads, and mitten crabs. Channel catfish may have more potential to impact shortnose sturgeon less than one year old than any other predator (J. O'Herron, Amitrone O'Herron Inc., pers. comm. 2008).

Disease

There is no information available for diseases associated with the Delaware River shortnose sturgeon population.

4. Inadequacy of existing regulatory mechanisms

Protection of the Delaware River shortnose sturgeon population is provided by the state under N.J.S.A. 23:2A-7E. Shortnose sturgeon are also covered under CZMA-Finfish Migratory Pathways (N.J.A.C. 7:7E-3.5), Endangered or Threatened Species Habitat (N.J.A.C.7:7E-3.38). The shortnose sturgeon are listed as endangered in NJ, DE, and PA.

Lack of Conservation Officers and insufficient numbers of Division staff dedicated to environmental review (both due to budget limitations) pose challenges to shortnose sturgeon protection. Existing regulatory programs allow Division/Department personnel to impose timing restrictions (e.g., dredging), recommend BMPs, deny permit applications, etc. but are somewhat limited in authority under certain circumstances (e.g., LNG facilities).

5. **Other natural or manmade factors**

Ship strikes

There have been increased reports of dead sturgeon (mostly Atlantic sturgeon) in the lower portion of the river. On November 28, 2007, one adult female shortnose sturgeon was removed dead from the intake trash racks at the Salem Nuclear Generating Station; the carcass appeared to have been lacerated, with a pattern of injuries suggesting ship strike (PSEG Nuclear LLC 2007). Without any directed surveys in place to document strikes, ten carcasses of adult Atlantic sturgeon were found in the Delaware River in 2004, six in 2005, and six in 2006; all were evidently struck by a passing ship or boat (Kahnle et al. 2005, Murphy 2006). These observations are not unique as four to eight dead sturgeon are reported each spring to DE DFW. These fish have averaged approximately 120 cm to 240 cm in length so presumably large shortnose sturgeon (in the 120cm range) could be vulnerable to ship strike. The majority of the strikes on sturgeon are believed to be from large, ocean-going vessels based on the pattern of the observed injuries although at least one fisherman has reported hitting a large sturgeon with his small craft (C. Shirey, DNREC, pers. comm. 2005). The Delaware River Port Complex is the largest freshwater port in the world receiving more than 3,000 deep-draft shipping vessels per year. Along with roughly 42 million gallons of crude oil, the port receives other imports such as steel, paper, fruits, and cocoa beans (DRBC 2012). Given the level of ship traffic and the number of documented strikes to date, the risk of ship strikes remains a threat to both sturgeon species.

Impingement and entrainment

There is potential for impingement/entrainment of early life stage shortnose sturgeon to occur in the vicinity and downstream of the spawning area. On April 24, 2006, 26 larvae were observed during an entrainment study for a small cogeneration plant in Fairless Hills, PA along the Delaware River: all larvae were found in a single day during a flood event and could have been flushed out of an upstream location (J. Crocker, NMFS, pers. comm. 2006). The Fairless Hills plant intakes were several miles below the presumed larval range in the river. The Mercer Generating Station, downstream of the spawning area, withdraws about 1.5 million gallons of water per year. PSE&G collected five shortnose sturgeon larvae (four immediately in front of the cooling water intake) at the Mercer plant in late April/early May 2006 (K. Strait, PSE&G, pers. comm. 2006). Other industrial and potable water companies withdraw less, but significant amounts of water from the same general area. The Trenton and Morrisville water treatment plant intakes are located just upstream of the Calhoun Street bridge in the presumptive area of the spawning grounds. Larvae were collected a few hundred meters above these two plants in 2007

(ERC, Inc. 2008). Larvae originating from spawning at least as far upstream as the Titusville pool to these intakes have potential to be impinged/entrained by the intakes as they out-migrate to tidal waters.

Salem Nuclear Generating Station (SNGS) is located on the southern end of Artificial Island, NJ, on the eastern shore of the Delaware River Estuary, about 30 miles south of PhiladeÌphia. Artificial Island is a peninsula created from a natural sand bar in the early 1900's by the ÀCOE. The tidal river in this area narrows upstream of Artificial Island and turns nearly 60 degrees. Most of the river in this area is less than 18 feet deep; deeper portions include the navigation channel that extends from the mouth of the bay to Trenton, NJ, and has depths of up to 40 feet near Àrtificial Island. There is a long history of impingement and entrainment of mostly adult shortnose sturgeon at SNGS. Adult impingement between 1979 and 1998 averaged 0-3 shortnose sturgeon annually (NMFS 1999); since 1999 only 2 shortnose sturgeon were taken incidentally (J Crocker, NMFS, pers. comm. 2009). The reduction in take since 1999 is attributed to modifications to the intake system at the facility.

Artificial propagation

There is no artificial propagation of shortnose sturgeon occurring on the Delaware River.

Escapement of hatchery/captive fishes

Because there are no shortnose sturgeon hatcheries on the Delaware River, there is no threat of escapement.

Other threats to shortnose sturgeon include waterfront development and heavy industrialization (including numerous refineries) along the shoreline.

Current and Recommended Research

Environmental Research and Consulting (ERC), Inc. recently investigated early life stage distribution of Delaware River shortnose sturgeon using artificial substrates and D-frame plankton nets. Goals of the project were to define the spawning/nursery area boundaries in order to identify essential habitats..

ERC, Inc. initiated field sampling for eggs and larvae on May 1, 2007. While the project was initated later than planned due to contract issuance, spawning was likely delayed somewhat due to low water temperatures in April 2007 (ERC Inc. 2008). Artificial egg samplers (floor buffering pads) were attached to concrete pavers and deployed May 1, 2007 and removed May 14, 2007 at four locations between Scudders Falls and the I-95 bridge (suspected spawning area) and at a fifth location near the upstream end of Rotary Island. One shortnose sturgeon egg (3.1 mm diameter, non-viable) was collected on immediately downstream of Scudders Falls on May 7 (ERC, Inc. 2008).

D-frame net sampling was conducted May 4, 2007 through May 23, 2007 by ERC Inc. Thirty-two collections, filtering a total of 84,344 m^3 of water, were made in the vicinity of Scudders Falls and along a cross-river transect 600 meters downstream of Blauguard Island. One shortnose sturgeon egg (3.2 mm diameter, unfertilized; sample density=0.031/100 m^3) and three shortnose sturgeon larvae (10 mm total length, 11 mm TL, and one that could not be measured;

sample density = $0.093/100m^3$) were collected about 50 m downstream of the I-95 bridge on May 4, 2007. One confirmed (15.2 mm) and one probable shortnose sturgeon larvae (that could not be measured) were collected downstream of Blauguard Island on the Pennsylvania side of the Delaware River on May 11, 2007 (sample density = $0.059/100m^3$; ERC Inc. 2008).

The following season, ERC, Inc. deployed artificial substrate samplers on March 27 and checked for presence of shortnose sturgeon eggs through May 30, 2008. Egg mats were set at 10 locations (two pads at each location) from the head of the Titusville pool downstream to Rotary Island. Shortnose sturgeon eggs were collected downstream of the I-95 bridge on April 14 (n=2), April 18 (n=1), and 22 (n=1); in the Yardley pool on April 14 (n=2) and April 18 (n=1); at the head of the Titusville pool on April 30 (n=1) and May 6 (n=4) (ERC Inc. 2008).

Sampling with D-frame ichthyoplankton nets was initiated by ERC, Inc. on April 18, 2008 and continued through May 22, 2008. Samples were collected weekly: 1) immediately upstream of the riffle at the head of the Titusville pool, 2) downstream of I-95, and 3) along a cross-river transect downstream of Blauguard Island. Sixty-eight samples, filtering a total of 116,355 m^3 of water were collected. The D-frame net samples yielded a total of 150 shortnose sturgeon eggs, collected during April 18 through May 22, 2008. Egg density in individual samples ranged from $0.024\text{-}3.480/100m^3$. Egg density by sampling area was $0.012/100m^3$ upstream of the Titusville pool, $0.035/100m^3$ downstream of I-95, and $0.362/100m^3$ downstream of Blauguard Island (ERC Inc. 2008).

Three shortnose sturgeon larvae were collected by D-frame net in 2008. One larva (sample density = $0.160/100m^3$; 13.0 mm TL) was collected downstream of the I-95 Bridge (PA side) on April 25, 2008. Two shortnose sturgeon larvae (sample density = $0.102/100m^3$; 10.6 and 14.0 mm TL) were collected downstream of the I-95 Bridge (NJ side) on May 5, 2008 (ERC Inc. 2008).

In addition to the early life stage study, ERC Inc. recently initiated a new acoustic telemetry study of juvenile shortnose and Atlantic sturgeon in the Delaware Estuary, with particular reference to the oligohaline reach of the river. This project is being funded by the Seaboard Fisheries Institute through a Section 22 grant from the ACOE. The objectives of this study are to: 1) examine the seasonal distribution and movements of acoustically-tagged juvenile sturgeon in relation to water temperature, salinity, and DO concentration, and 2) integrate the telemetry data with a water quality model (ROM v.3) being developed by Rutgers University to examine effects of seasonal and long-term changes in water quality parameters on habitat available to juvenile sturgeon (H. Brundage, ERC Inc., pers. comm. 2008).

Recommendations for future shortnose sturgeon research in the Delaware River include:

- Continue surveys for early life stages to collect multi-year data.
- Continue acoustic tracking study to further define juvenile overwintering areas and general movement patterns.
- Collect shortnose sturgeon tissue (using accidental mortalities) for contaminants analysis; also use eggs from running females during the spawning season.
- Investigate the effects of water intake systems on early life stage shortnose sturgeon.

Chesapeake Bay

Historic Distribution and Abundance

The first published account of shortnose sturgeon in the Chesapeake system was from a specimen collected in 1876 from the Potomac River as reported in a general list of the fishes of Maryland (Uhler and Lugger 1876). There is evidence that at one time Atlantic and shortnose sturgeon were prolific in the Potomac River but it is generally accepted that at the turn of the 20^{th} century shortnose sturgeon were essentially extirpated from the Potomac and rarely seen in Chesapeake Bay (Hildebrand and Schroeder 1928). Dadswell et al. 1984, reports 13 records of shortnose sturgeon in the upper Chesapeake Bay during the 1970s and 1980s.

Because Atlantic and shortnose sturgeon co-occur in many of the large river systems throughout their range, and shortnose sturgeon were known to be harvested with Atlantic sturgeon, it is worth noting that there was a substantial historical sturgeon fishery in the Chesapeake Bay. Commercial landings data during the 1880s are available for the Rappahannock (8 mt), York (23 mt), and James (49 mt) providing evidence that Atlantic sturgeon were historically present in these rivers (Secor 2002, Bushnoe et al. 2005). Historical Atlantic sturgeon harvests were also reported in the Patuxent, Potomac, Choptank, Nanticoke, and Wicomico/Pocomoke rivers (Secor 2002, S. Minkkinen, USFWS, pers. comm. 2006 as referenced in ASSRT 2007).

Current Distribution and Abundance

The current abundance of shortnose sturgeons in the Chesapeake Bay is unknown. There are limited data available regarding distribution. The USFWS and MD DNR jointly implemented an Atlantic sturgeon reward program in 1996. The program was aimed at collecting data on Atlantic sturgeon incidentally caught in commercial fisheries in the Bay. In the first year of the program the incidental capture of two shortnose sturgeon was reported. These individuals were carefully identified by USFWS and MD DNR staff. As of November 30, 2008, a total of 80 individual shortnose sturgeon have been captured in the Chesapeake Bay and its tributaries; an additional three were recaptures (M. Mangold, USFWS, pers. comm. 2008). Most of the shortnose sturgeon documented in the reward program have been caught in the upper Bay, from Kent Island to the mouth of the Susquehanna River and the C&D Canal, in Fishing Bay and around Hoopers Island in the middle Bay, and in the Potomac River (Skjeveland et al. 2000, Litwiler 2001, Welsh et al. 2002; Fig. 29). These shortnose sturgeon released alive following initial capture via the following gears: gillnets, poundnets, fykenets, eel pots, catfish traps, hoop nets, and hook and line (S. Eyler, USFWS, pers. comm. 2008).

In addition to implementing the Reward Program for Atlantic sturgeon, the USFWS conducted two sampling studies between 1998 and 2000 in the Maryland waters of the Potomac River to determine occurrence and distribution of sturgeon within proposed dredge material placement sites in the Potomac River (Eyler et al. 2000). A two-year bottom gillnetting study was conducted at five sites located in the middle Potomac River. Although the sites were sampled for a total of 4,590 hours, no shortnose sturgeon were captured (Eyler et al. 2000).

A similar USFWS sampling study was conducted in the upper Chesapeake Bay mainstem, lower Susquehanna River, and C and D Canal during 1998 and 2000. This study was recommended by NMFS in conjunction with a review of the Baltimore Harbor and Channels Federal Navigation

Project. This study involved bottom-gillnetting at 19 sites within the upper Chesapeake Bay mainstem and lower Susquehanna River, and tracking tagged shortnose sturgeon within the upper Bay and the C& D Canal. No shortnose sturgeon were captured at any of the 19 sites (Skjeveland et al. 2000). Nevertheless, several shortnose sturgeon were captured in commercial fishing gear within the proposed dredge fill sites during the period of the study via drift gillnet (n-=2) and eel pots (n=1) (Skjeveland et al. 2000).

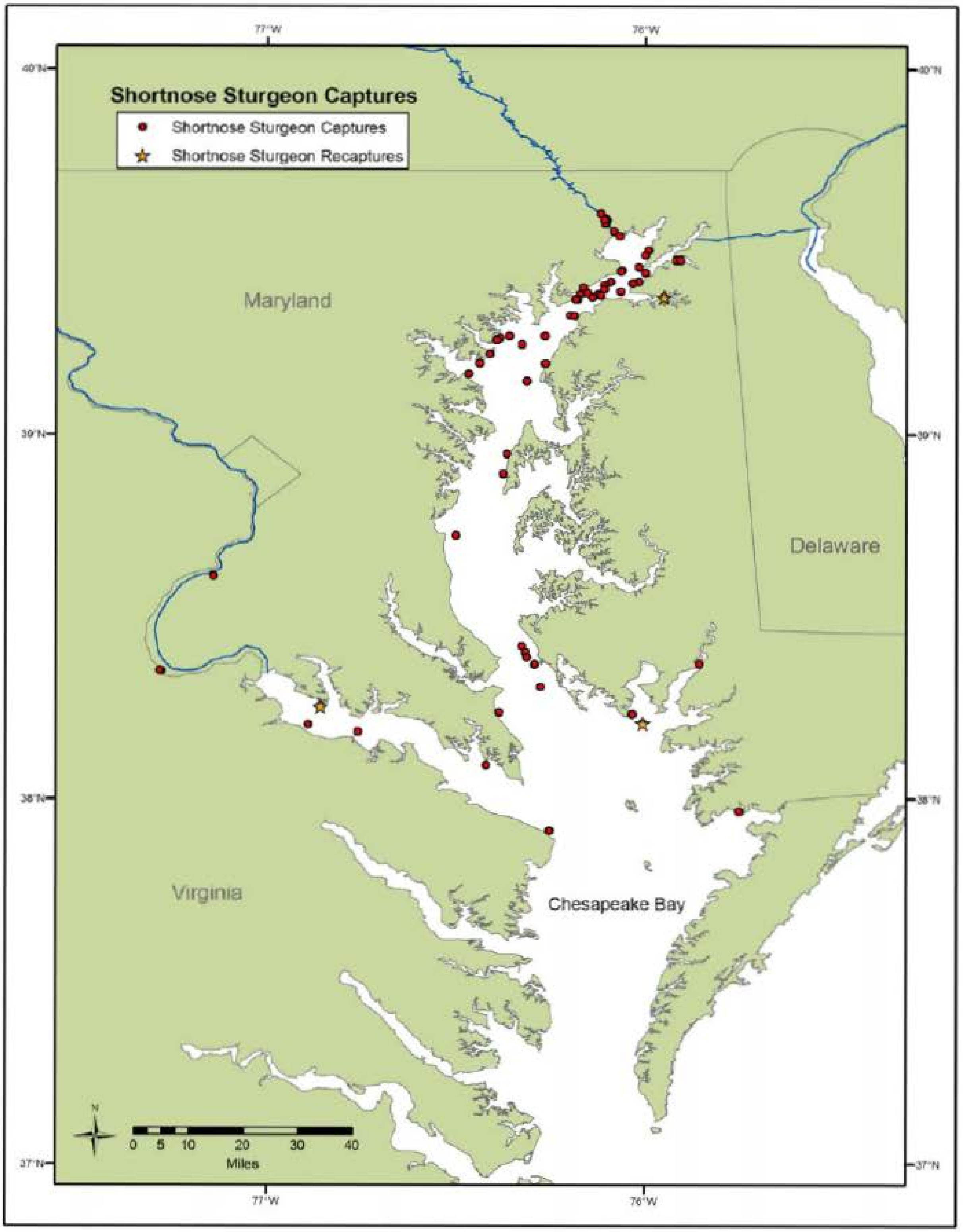


Figure 29. Shortnose sturgeon captures in the sturgeon reward program (January 1996 through November 2008).

To investigate if shortnose sturgeon utilize the C and D Canal, tags were attached to 13 shortnose sturgeon incidentally captured in commercial fishing gear and reported to the USFWS via the reward program from the upper Chesapeake Bay, and 26 shortnose sturgeon captured near Scudders Falls in the Delaware River. Three of the 13 shortnose sturgeon initially tagged and released into the Chesapeake Bay, were later relocated in the C and D canal or the Delaware River, thus confirming the use of the C and D canal as proposed by Welsh et al. (2002).

It has long been thought that shortnose sturgeon were extirpated from the Potomac/Chesapeake Bay proior to their listing in 1967. Many researchers believe that shortnose sturgeon found in Chesapeake Bay and its tributaries are colonizers from the Delaware River that enter via the C and D Canal. The tag data indicating shortnose sturgeon use of the C and D canal coupled with recent genetic analysis using mtDNA (Grunwald et al. 2002, Wirgin et al. 2005) and microsatellite DNA analysis (King et al. in press) support this theory.

Natural History and Habitat Information

Spawning

No information indicates shortnose sturgeon are currently spawning in the Chesapeake Bay. Based on known spawning habitat preferences that indicates typically spawning habitat often at the fall line (Kynard 1997) characterized by cobble/gravel substrate and areas of high flow, appropriate habitats are available. A recent study in the Potomac attempted to identify important habitats for this species (See “Potomac River” in this section).

Anecdotal reports from watermen indicate shortnose sturgeon presence in Gunpowder Falls, which enters the Gunpowder River in Baltimore County, although there has not been any documentation of spawning activity (J.Nichols, NOAA, pers. comm. as referenced in NMFS 2002). Incidental capture of shortnose sturgeon has been reported to the USFWS Reward Program in the Susquehanna River (April 4, 1996; April 24, 1997; April 28, 1998; February 19, 1999; February 6 and 17, 2001; June 2, 2002) and near the mouth of the Rappahannock River (May 1998) (Spells 1998, unpubl. report). No spawning activity has been documented in any of these tributaries to the Chesapeake Bay.

Foraging

There is no information available for shortnose sturgeon foraging areas in the Chesapeake Bay. Foraging areas were identified in the Potomac River (See “Potomac River” in this section). Niklitschek (2001) indicated via modeling that suitable habitats were very restricted during summer months with favorable foraging habitat limited to the upper tidal portions of the upper Bay, the Potomac, and James rivers (work referenced in Secor and Niklitschek 2002). During the summer (May – September) foraging period, 17 shortnose sturgeon have been caught (of 82 overall, including 3 recaptures) and reported to the sturgeon reward program in summer months (M. Mangold, USFWS, pers. comm. 2008).

Overwintering/resting habitat

No information is available for shortnose sturgeon overwintering areas in the Chesapeake Bay or its tributaries. Results of models indicates juvenile shortnose sturgeon probably do not encounter sub-lethal low temperatures during winter months (Niklitschek 2001). In the Hudson River, shortnose sturgeon remain active and vigorous at temperatures less than 5°C (Woodland and

Secor 2007). A total of 82 shortnose sturgeon captures have been reported to the sturgeon reward program during winter months; 803 of the 82 were recaptures, and 28 were reported between November and February (M. Mangold, USFWS, pers. comm. 2008).

Migration
Tagging data from shortnose sturgeon in the upper Chesapeake Bay and Delaware River suggest movements through the C and D Canal (Skjeveland et al. 2000, Welsh et al. 2002). Distances traveled by shortnose sturgeon (0 to 5.7 km/day) in the upper Chesapeake Bay were similar to those reported by Dadswell et al. (1984), but did not appear to follow a specific pattern, such as migrations to spawning grounds (Litwiler 2001).

If shortnose sturgeon spawn in tributaries to the Chesapeake Bay, spawning migration to upriver spawning grounds would likely begin when water temperatures in the Bay reach between 8 and 15°C. These temperatures correspond to about mid March to May first . There is no information regarding movements to foraging or overwintering areas.

Stressors to Riverine System

1. **Habitat**

Dams and diversions

Susquehanna River
Four dams constructed on the Susquehanna River from 1904 – 1932, have impeded diadromous fish migration. The lowermost dam (Conowingo) may obstruct shortnose sturgeon access to historic spawning grounds; however, location of historic spawning grounds, if shortnose spawned here, is unknown (see "Susquehanna River" in this section for more information).

Rappahannock River
The Embrey Dam (built in 1910), is located above the fall line on the Rappahannock River. The dam may have potentially blocked the upstream migration of shortnose sturgeon; however, this dam was breached in 2004.

James River
Constructed in 1823, the Bosher Dam on the James River impeded upstream diadromous fish migration until a vertical slot fish passage way was installed in 1999.[3] No Atlantic or shortnose sturgeon have been observed to pass through this fishway (Bushnoe et al. 2005).

Potomac River
The Little Falls Dam, built on the Potomac River in 1959, hindered diadromous fish like American shad and blueback herring from moving upstream to spawn. Shortnose sturgeon spawning habitat on the Potomac River likely occurred below Little Falls Dam. This is supported by an observation made in 1915, prior to the dam being erected, where McAtee and Weed state "two [species] of sturgeon ascend to Little Falls but no further." A large fish passage

[3] Originally, the James River had two additional impediments downstream of Bosher Dam; Browns Island Dam and Williams Island Dam were breached and notched in 1989 and 1993, respectively.

project was completed at the Little Falls Dam in 2000 that combined a series of weirs with a 36-foot wide by 4-foot deep notch in the dam and resulting in 10 miles of historic spawning habitat becoming available to American shad and herring, as well as other species of migratory fish.

Other energy projects

Tidal turbines

No tidal turbines are located in the Chesapeake Bay or its tributaries and currently none are proposed.

LNG facilities

LNG Dominion Cove Point LNG, LP is located on the Chesapeake Bay in Cove Point, Maryland, south of Baltimore. It is one of the nation's largest liquefied natural gas (LNG) import facilities. While it is a closed loop system, some level of water withdrawal is required. Expansion of this facility has been approved. Potential threats/impacts to shortnose sturgeon associated with the LNG facility include risk of ship strikes due to increased vessel traffic, potential YOY sub-adult losses via ballast water and facility intakes, and changes in ambient water temperature (usually cooling) as water is discharged.

A second LNG facility, AES Sparrows Point LNG, LLC and Mid-Atlantic Express, LLC, is proposed near Baltimore, MD. This facility has been proposed as a closed loop system and impacts would likely be the same as those identified for Cove Point (above).

Dredging and blasting

Periodic maintenance dredging of harbors and navigational channels occurs throughout the Chesapeake Bay. Approximately 5.3 million cubic yards of sediments must be dredged annually to maintain naviagation channels serving the Port of Baltimore (Blankenship 1996). Dredge spoils are generally placed in an open water site or at Hart-Miller Island (Shin 2007). No takes of shortnose sturgeon have been documented in dredge operations in the Chesapeake Bay from 1990 -2005 (Dickerson 2006).

Water quality and contaminants

During the past 100 years, increased rates of urbanization along with residential and industrial development along the banks of sub-estuaries have continued to contribute to historical trends in sedimentation, deforestation, and pollution (Cooper and Lipton 1994). It is plausible that overharvesting of sturgeon in the 1890s led to the dramatic decline in the fishery, and poor water quality since then has not been conducive to recovery. Secor and Gunderson (1998) showed that juvenile Atlantic sturgeon are less tolerant of summer-time hypoxia than juveniles of other estuarine species. Campbell and Goodman (2004) performing laboratory tests on progeny of shortnose sturgeon from the Savannah River found similar sensitivity to low oxygen temperature combinations as Secor and Gunderson (1998). This sensitivity prompted the Chesapeake Bay Program to establish its most protective summer-time DO criterion specifically for shortnose sturgeon (Anonymous 2003).

Over the last 50 years, high nutrient inputs have contributed to high spatial and temporal incidence of summer-time hypoxia and anoxia in bottom waters (Taft 1980, Officer et al. 1984, Malone et al. 1993, Boesch et al. 2001). During spring and summer algal blooms, the

Chesapeake Bay supports extremely high primary production rates. Algal blooms accelerate bottom microbial respiration, which results in oxygen depletion in benthic waters. Chesapeake Bay is especially vulnerable to the effects of nutrients due to its large surface area-volume ratio, relatively low rates of water exchange, and strong vertical stratification during spring and summer months.

Niklitschek and Secor (2005) modeled habitat availability for juvenile Atlantic sturgeon in the Chesapeake Bay and results indicated that the cumulative stresses of hypoxia and high temperatures during summer months caused large reductions in potential habitats and carrying capacity during the period 1993-2002. Projected warming in the Chesapeake Bay together with continued hypoxic stress could result in virtual elimination of sturgeon nursery habitats (Niklitschek and Secor 2005). Similar to the habitat modeling for juvenile Atlantic sturgeon, Niklitschek (2001) showed a similar summertime habitat squeeze for shortnose sturgeon. Similar trends in low DO concentration during the summer months have been observed in the lower portions of both the York and Potomac rivers (C.Hager, VIMS, pers. comm. 2005 as referenced in ASSRT 2007). Since 1984, the Chesapeake Bay Program and its member states (PA, MD, DC, and VA) have instituted programs related to nutrient abatement (Cooper and Lipton 1994, Boesch et al. 2001).

Portions of Chesapeake Bay and its tidal tributaries are contaminated with chemical pollutants that can be found in fish tissue. Concentrations of chemical contaminants are reported to be highest in tributaries to the Bay (Bricker et al. 2007). Exposure to contaminants in ambient water and sediment from the Potomac River significantly reduced survival of striped bass and sheepshead minnow larvae and contaminant studies in the upper Chesapeake Bay, including the C and D canal, reported reduced survival of striped bass larvae and histological gill abnormalities in yearling striped bass (CBP 1994). Fish consumption advisories are in effect for at least 10 species in the Chesapeake Bay due to PCB, mercury, and kepone (a pesticide) contamination.

Whether or not environmental conditions within the entire Chesapeake Bay ecosystem can support shortnose sturgeon nursery habitat remains an open question. A 1996 study where hatchery-reared young Atlantic sturgeon were released into the Nanticoke River investigated whether or not the Bay could function as a nursery. Individuals survived and grew at favorable rates, indicating that the Bay is still able to support juvenile Atlantic sturgeon (Secor et al. 2000). However, ecophysiological modeling showed that conditions during the 1996 study were abnormally favorable when compared to a ten year period (Niklitschek and Secor 2005). Reported capture of over 1,100 sturgeon (Atlantic and shortnose) reported to the USFWS Reward Program since 1996 indicates that sturgeon still utilize the Chesapeake Bay.

2. Overutilization

Bycatch

There are numerous active commercial fishing efforts in the Chesapeake Bay and the majority of sturgeons (both Atlantic and shortnose) reported to the USFWS Reward Program are captured by commercial fishermen. Of the shortnose sturgeon reported via the Reward Program 35% were incidentally caught in gill nets (most targeting striped bass) and 33% were incidentally caught in pound nets, with most of the remaining incidental captures occurring in fyke/hoop nets (M.

Mangold, USFWS, pers. comm. 2008). Although fishermen can collect a reward for providing live Atlantic sturgeon captures which resulted in an increase in reporting of incidental sturgeon captures, under-reporting is still suspected (Skjeveland et al. 2000, Welsh et al. 2002).

Poaching

Because so few shortnose sturgeon are documented in the Chesapeake Bay it is unlikely that there is any targeted poaching effort.

Scientific research

No shortnose sturgeon are removed from the Chesapeake Bay for scientific purposes. Eighty shortnose sturgeon and three additional recaptures have been incidentally caught in the Chesapeake Bay and its tributaries since 1996 (S. Eyler, USFWS, pers. comm. 2008). There is ongoing directed research on shortnose sturgeon in the Potomac River (See Potomac River in this section).

3. Competition, predation and disease

Competition

Competition between shortnose and Atlantic sturgeon is likely minimal due to the low number of sturgeon observed in this system (Skjeveland et al. 2000, Welsh et al. 2002, and Kynard et al. 2007).

Predation

Snakehead (*Channa argus*) were recently introduced into the Chesapeake Bay and may be a predator of shortnose sturgeon. Flathead catfish (*Pylodictus olivaris*) have been documented in the Susquehanna River and may be reproducing (Brown et al. 2005); however they are not known predators. Moser et al. (2000b) tested whether flathead catfish preyed on shortnose sturgeon (30 cm) in a laboratory system, and despite sturgeon being the only prey available none were consumed.

Disease

There is no information available for diseases associated with the Chesapeake Bay population of shortnose sturgeon.

4. Inadequacy of existing regulatory mechanisms

Shortnose sturgeon are listed as endangered by the states of DE, MD, and VA. Due to the low number of sturgeon present in the Chesapeake Bay, it is difficult to assess whether or not regulatory mechanisms have been adequate.

5. Other natural or manmade factors

Ship strikes

There is no information documenting ship strikes of shortnose sturgeon in the Chesapeake Bay or its tributaries.

Impingement and entrainment

Data regarding impingement or entrainment of early life stage shortnose sturgeon in the Chesapeake Bay are not available. However, a number of intakes located throughout the

Chesapeake Bay have the potential to impinge or entrain shortnose sturgeon. One example is the Calvert Cliffs nuclear generating station located in Lusby, Maryland. The station, which began operating Unit 1 in 1975 and Unit 2 in 1977, is owned and operated by Constellation Energy. The station includes two steam generators which withdraw 3.5 billion gallons of water per day for once-through cooling.

Artificial propagation

There is no artificial propagation of shortnose sturgeon in the Chesapeake Bay or its tributaries.

Escapement of hatchery/captive fishes

Because there are no shortnose sturgeon hatcheries on the Chesapeake Bay or its tributaries, there is no threat from escapement.

Current and Recommended Research

Current research

Currently, a life-history study of shortnose sturgeon in the Potomac River is underway by the USFWS to monitor the potential spawning site at Fletchers Marina, monitor tagged shortnose sturgeon in the river, and gillnet pre-spawning adults. Efforts to tag captured shortnose sturgeon will be made during these upcoming field study years.

Recommended research

- Distribution, abundance, and migration studies of shortnose sturgeon via acoustic telemetry.

- Identify important habitats including spawning, foraging, and overwintering grounds within Chesapeake Bay.
- Modeling and characterization of spawning and nursery habitats directed at the question of whether Chesapeake Bay can support reproduction and recruitment of shortnose sturgeon.
- Both short- and long-term effects of contaminants on shortnose sturgeon in the Chesapeake Bay.

Susquehanna River

Historic Distribution and Abundance

The Susquehanna River is the main tributary to the Chesapeake Bay and contributes more than 50% of annual freshwater flow (Risser and Siwiec 1996). Although historic distribution and abundance of shortnose sturgeon in the Susquehanna River is difficult to determine, sturgeon did exist here historically. The SRT agreed that the Susquehanna, because of its size, was likely important to shortnose sturgeon in this region. Unfortunately, similar to other locations, historical landings do not distinguish between shortnose and Atlantic sturgeon and therefore there is no estimate of the historical population abundance of shortnose sturgeon in the Susquehanna River. Some reports describe sturgeon on the Susquehanna River as navigational hazards, due to both number and tendency to leap out of the water. A message on the Fishery Treaty from the U.S. Senate reported in 1888 that sturgeon were taken in small quantities on the

Susquehanna (Anonymous 1888). There are further reports of sturgeon among the many fishes that are found within the Susquehanna River though most of the accounts are anecdotal and again, failed to identify the sturgeon as Atlantic or shortnose.

Current Distribution and Abundance

Shortnose sturgeon are currently present in the Chesapeake Bay and some of its tributaries, including the Susquehanna River. Several sturgeon sightings were reported by commercial fishermen and researchers between 1978 through 1987, but they did not distinguish between shortnose and Atlantic sturgeon. There is a deep hole (19m) on the Susquehanna River near Perryville, MD (rkm 1) that once supported a small sturgeon fishery, again not distinguishing between the two species (R. St. Pierre, USFWS, pers. comm. 1998). In addition, there have been reports of sturgeon staging in deep holes near Lapidum (rkm7) which is approximately eight km downstream of the Conowingo Dam (Richardson et al. 2007).

The most recent information on shortnose sturgeon presence in the Susquehanna River comes from the USFWS Atlantic sturgeon Reward Program where incidental captures of shortnose and Atlantic sturgeon have been reported since 1996. The incidental capture of eight shortnose sturgeon has been reported in the lower Susquehanna River; most recently in 2003 (M. Mangold, USFWS, pers. comm. 2008). Additionally, just two days prior to the program's commencement in 1996, two fishers caught three sturgeon in one net near the Susquehanna which were confirmed by the USFWS to be adult shortnose sturgeon. This was the first sighting of a shortnose sturgeon in the Bay since 1986 (USFWS 1996). Prior in 1986, two separate incidents involving shortnose sturgeon were reported by a biologist working at the Conowingo Dam: 1) a single shortnose sturgeon was caught in the tailrace of the dam by a recreational fisher, and returned safely to the water (T. Brush, pers. comm. 2008, Diamond 1986, Neale 1986), and 2) a recreational fisherman caught a shortnose sturgeon in the tailrace, and being unaware of its endangered status, left it on the riverbank. This incident was observed, but the sturgeon could not be revived (T. Brush, pers. comm. 2008; McKnight, pers. comm. 1986).

Natural History and Habitat Information

Spawning

There are no current records of shortnose sturgeon spawning in the Susquehanna River, nor are there any records of historical spawning grounds. Any spawning migrations that may have occurred into the upstream reaches have since been blocked by dams. The lowermost dam on the Susquehanna River is the Conowingo Dam, a hydroelectric facility built in 1926 at rkm 16. Two fish lifts were installed at the Conowingo Dam; one in 1972 and one in 1991; prior to the lift in 1956-1966 fishes were transferred upstream by use of a fish bucket. No shortnose sturgeon has been recorded using the lifts at the dam (Speir and O'Connell 1996). Since there are no other means of passage above the dam, shortnose sturgeon are precluded from accessing any historical spawning sites that may have existed above the dam.

There are historic and recent records of Atlantic sturgeon congregating below the Conowingo Dam which suggests that spawning may be occurring (Richardson et al. 2007).

Foraging

Little information exists on the foraging habits of shortnose sturgeon in the Susquehanna River; however tagging studies from other rivers indicate that shortnose sturgeon migrate downstream to estuaries and bays presumably for foraging (Kynard et al. 2012; Brundage 1986). These findings suggest that shortnose sturgeon in the Susquehanna River would likely utilize the Chesapeake Bay for foraging.

Overwintering/resting

Although overwintering in the Susquehanna River has not been confirmed, shortnose sturgeon are known to move upriver and seek deep, channel-like habitats for overwintering (Buckley and Kynard 1983, Bain et al. 1998a and b, Squiers 2000, Li et al. 2007). Anecdotal reports of congregations of sturgeon found in deep holes near Lapidum and Perrysville, could indicate habitat that was utilized for overwintering and resting (Richardson et al. 2007; R. St. Pierre, USFWS, pers. comm. 1998).

Migration

There has been no documentation of shortnose sturgeon migrating in the Susquehanna River. Anecdotal evidence of annual congregations of sturgeon at the base of the Conowingo Dam suggests that migrations may have occurred, presumably for spawning; however these reports did not differentiate between shortnose and Atlantic sturgeon (Richardson et al. 2007). Down-stream migration of shortnose sturgeon in the Susquehanna River to the ocean has not been documented.

Stressors to Riverine System

1. **Habitat**

Dams and diversions

Migratory fish access to the upstream reaches of the Susquehanna River have been restricted since the construction of the York Haven hydroelectric dam at rkm 90 in 1905. Since that time, three more dams were built downstream: 1) the Safe Harbor hydroelectric facility was built at rkm 52 in 1931, 2) the Holtwood hydroelectric dam was built at rkm 40 in 1910, and 3) the Conowingo Dam was completed at rkm 16 in 1928. As noted earlier, the Conowingo Dam has two fish lifts but no shortnose sturgeon have been observed using the lifts, but two have been caught in the tailrace (Speir and O'Connell 1996, T. Brush pers. comm. 2008). The Conowingo Hydroelectric Facility is owned and operated by the Exelon Generating Company pursuant to a license issued by FERC in 1980; the license will expire in 2014.

In addition to blocking sturgeon passage, the Conowingo Dam affects the lower Susquehanna River by altering river flow conditions, DO, and water temperature (ERM 1980). During high-flow and low-flow periods (March/April and August/September respectively), discharge is highly regulated through the dam and modified on an hourly and daily basis. During low flow periods, released flow may be entirely stopped during high flow periods, discharge from the dam displaces the leading edge of the salt-wedge seaward, causing the longitudinal salinity gradient as well as the vertical gradient to be sharpened (Schubel and Pritchard 1986).

The Susquehanna River contributes roughly 61% of the total sediment in the Chesapeake Bay and about 87% of the total freshwater input to the northern portion of the Bay (Officer et al. 1984, Schubel and Pritchard 1986). Before sediment reaches the Bay it must pass through the

Conowingo Dam, which is reported to retain an estimated 400,000 to 1,500,000 metric tons per year (McLean et al. 1991). Taking the quantities of retained sediment into account, approximately 600,000 metric tons of suspended sediment passes through the dam and is discharged to Havre de Grace, MD at the mouth of the Susquehanna and the northern portion of the Bay (Schubel 1968).

The Muddy Run Pumped-Storage Hydroelectric Facility (rkm 35) and the Peach Bottom Atomic Power Station (rkm 26) are two facilities that withdraw water from and discharge to the Conowingo Reservoir between the Holtwood and Conowingo dams. Muddy Run, which began operation in 1966, pumps water from the Conowingo Reservoir up into the Muddy Run Reservoir, and cycles water back and forth to generate power. This withdrawal affects the water level and flow of the Conowingo Reservoir.

The Peach Bottom Atomic Power Station is also located on the Conowingo Reservoir; it is a two unit nuclear generating facility that commenced operation of its two boiling water reactors in 1973 and 1974. In order to cool these units, water is pumped from the Conowingo and Muddy Run Reservoirs for the purpose of industrial cooling through heat transfer. The heated effluent is then discharged back into the Conowingo Reservoir (SRBC 2006).

Other energy projects

Tidal turbines

No tidal turbines are present or proposed on the Susquehanna River.

LNG facilities

No LNG facilities are currently associated with the Susquehanna River.

Dredging and blasting

Since the 1800's, almost 30 billion tons of coal was mined in Pennsylvania. The bulk of the coal was mined from the Susquehanna River Basin where it was plentiful and highly exploited in the late 1890's to the mid 1900's (Jackson et al. 2005). The coal was mined and then washed with water that drained back into the river carrying with it coal particles. These particles (i.e., coal dust) would sink to the river floor and build up over the coal season. In the spring, boats would dredge and pump the coal from the riverbed onto flat boats again allowing excess water to drain into the river. At this time, around 100 tons of coal was dredged daily (Anonymous 1938). The remaining coal was either suspended and washed farther downriver, or settled and built up in the riverbed. Of the suspended sediment that washed downstream over the years, three million tons were found behind the Holtwood Dam from 1920 to 1950 and about ten million tons behind the Safe Harbor Dam from 1951 to 1973 (Benke and Cushing 2005). While discussions regarding removal of these sediments have occurred there are no current dredging plans to remove the coal.

Water quality and contaminants

Research indicates that the Susquehanna River Basin contributes the major portion of nutrients and a significant portion of toxins to the northern Chesapeake Bay (Langland 1998; Ko and Baker 2004). According to a 1998 water quality assessment of the Susquehanna River Basin, nutrient enrichment and habitat alteration were the major causes of stream impairment. Habitat alteration occurred in the form of agricultural runoff, and coal mining activities including abandoned mine drainage, dredging, and dams. Further causes of impairment were found to include metals, low pH levels due to acid mine drainage, and total dissolved solids (Edwards and Stoe 1998).

The Susquehanna River Basin begins in Lake Otsego, New York and runs 444 miles through Pennsylvania and Maryland to the Chesapeake Bay providing the majority of freshwater into the northern portion of the Chesapeake Bay. Much of the land surrounding the river is undeveloped, forested, or used for agricultural purposes. Agricultural runoff is known to transport high amounts of nitrogen and phosphorous into lake and river systems. The USGS estimates the Susquehanna contributes over 60% of the nitrogen and about 40% of the phosphorous load to the upper Chesapeake Bay (Langland 1998).

Further contaminants that occur within the Susquehanna River are PCBs and PAHs. Ko and Baker (2004) sampled water downstream of the Conowingo Dam every nine days between March 1997 and March 1998, and discovered that PCB and PAH concentrations in suspended sediments from the river were twice as high as those in the northern portion of the Bay demonstrating that the Susquehanna River is an important source of contaminants to the Bay. The total annual loading was 76 kgs of PCBs and 3,160 kgs of PAHs and 75% of these contaminant were in particulate form; transport of suspended sediments was greatest during periods of high flow, particularly during early spring (Ko and Baker 2004)

2. Overutilization

Bycatch

Since the inception of the Atlantic Sturgeon Reward Program in 1996, the USFWS has reported the incidental capture of eight shortnose sturgeon in commercial fisheries operating in the Susquehanna River: six individuals were caught in catfish traps, and the other two were captured in a hoop net and a gill net (M. Mangold, USFWS, pers. comm. 2008). Some incidental capture also occurs in recreational fisheries as noted previously regarding the two shortnose sturgeon in the tailrace of the Conowingo Dam in 1986 (Diamond 1986, Neale 1986, T. Brush pers. comm. 2008).

Poaching

Shortnose sturgeon are likely not abundant enough in the Susquehanna River to be the target of any illegal poaching activity. It is possible that shortnose sturgeon are taken for personal consumption by recreational fishermen that are unaware of their endangered status. As noted previously, a recreational fisherman in 1986 caught and attempted to keep a shortnose sturgeon from the Susquehanna River until it was confiscated by a biologist employed at the Conowingo Dam (Neale 1986, Diamond 1986).

Scientific research

Currently there is no scientific research on shortnose sturgeon occurring in the Susquehanna River.

3. Competition, predation and disease

Competition and predation

Potential predators of shortnose sturgeon in the early life stage include flathead catfish and snakeheads. Potential competition might be found with catfish species and other benthic feeders (Brown et al. 2005).

Disease

There is no information available on diseases that affect shortnose sturgeon in the Susquehanna River.

4. Inadequacy of existing regulatory mechanisms

Shortnose sturgeon are protected and listed as “endangered” in the states of Maryland and Pennslyvania. It should be noted that affects to shortnose sturgeon were not considered when the aforementioned hydroelectric facilities, dams and power plants along the Susquehanna River were first licensed. This is largely due to the lack of information on historical use of the river by shortnose sturgeon and the completion of the relicensing process without the knowledge that shortnose sturgeon still occurred in the river. For example, when the Conowingo facility was relicensed in 1980, there was no information to suggest that shortnose sturgeon still existed below the dam.

Both Maryland and Pennslyvania have mechanisms to protect shortnose sturgeon within the Susquehanna River via regulatory restrictions on actions such as dredging, and imposing actions such as installation of fish passages, and efforts towards increased water quality. The Susquehanna River Compact (Act 181) was signed in 1968 which created the Susquehanna River Basin Commission (SRBC) as the agency to coordinate the water resources efforts of Pennsylvania, Maryland, New York and the Federal government. SRBC serves in a regulatory capacity mainly in interstate matters or where signatory authority is not being effectively exercised or where the signatory has little or no authority to act.

5. Other natural or manmade factors

Ship strikes

There have been no reports of shortnose sturgeon being struck by boats in the Susquehanna River and no reports of sturgeon carcasses on the riverbank except for the single shortnose sturgeon found on the bank of the Susquehanna below the Conowingo Dam; that fish was the result of recreational fishing and not ship strike (T. Brush, pers. comm. 2008).

Impingement and entrainment

There are multiple intakes along the mainstem of the Susquehanna River for various purposes including water withdrawal and treatment for human consumption, industrial cooling through heat transfer at the Peach Bottom facility, pumped storage hydroelectric generating systems at the Muddy Run facility, and irrigation for agricultural purposes. Because no shortnose sturgeon are known to occur above the Conowingo Dam, these intakes do not impinge or entrain shortnose sturgeon.

Artificial propagation

There is no artificial propagation of shortnose sturgeon currently occurring on the Susquehanna River.

Escapement of hatchery/captive fishes

There is no reported escapement of hatchery reared/captive shortnose sturgeon as there is no artificial propagation of shortnose sturgeon currently occurring on the Susquehanna River.

Current and Recommended Research

Current research

There no research currently being conducted on shortnose sturgeon in the Susquehanna River.

Recommended research

- Conduct surveys to determine current presence in the river and, if possible, estimate population size.
- Collect non-invasive tissue samples under the appropriate research permit for genetic testing to determine river of origin.
- Survey for early life stages.
- Research to improve fish passage at mainstem dams.

Potomac River

Historic Distribution and Abundance

Little historic information exists about shortnose sturgeon in the Potomac River. Four documents between 1876 and 1929 state that shortnose sturgeon inhabited the Potomac River; however, the only specimen that remains was collected by J. W. Milner, on 19 March 1876 at Washington, D.C. This specimen was largely the reason the shortnose sturgeon is included on Potomac River species lists in the following years (Uhler and Lugger 1876, Smith and Bean 1898). The Smith and Bean (1898) publication reports the presence of both shortnose and Atlantic sturgeon (*Acipenser sturio* later changed to *Acipenser oxyrhinchus oxyrhinchus*) in the Potomac River. Smith and Bean (1898) also explained that fishermen did not typically differentiate between the two species of sturgeon and noted that Atlantic sturgeon ascend the Potomac River to spawn in the spring. Historic reports indicate that shortnose sturgeon likely spawned in the vicinity of Little Falls (rkm 198). In 1915, McAtee and Weed stated: “two [species] of sturgeon ascend to Little Falls but no further.”

Current Distribution and Abundance

Twelve shortnose sturgeon have been captured in the Potomac River since 1996. Eleven of these captures were documented via an ongoing reward program sponsored by the USFWS to compensate commercial fishermen who report captures of Atlantic sturgeon in the Chesapeake Bay system. These captures are part of the total capture of 80 shortnose sturgeon in the Chesapeake Bay and its tributaries reported in the reward program since 1996 (See Chesapeake Bay section). All shortnose sturgeon captured in the Potomac River were collected between the river mouth and Indian Head (rkm 103). The eleven incidental captures reported via the USFWS reward program were documented in the following locations: six at the mouth of the river (May 3, 2000, March 26, 2001, two on March 8, 2002, December 10, 2004, May 22, 2005); one at the mouth of the Saint Mary’s River (rkm14) (April 21, 1998); one at the mouth of Potomac Creek (rkm 101) (May 17, 1996); one at rkm 63 (March 22, 2006); one at rkm 57 (Cobb Bar; December 23, 2007); and, one at rkm 48 (March 14, 2008). Additionally, one adult female was captured by

USGS and NPS researchers within the Potomac River (at rkm 103) in September 2005 (Kynard et al. 2007 and 2009).
The USGS and NPS conducted a telemetry study of shortnose sturgeon in the Potomac River from 2004–2007. Although a total of 5,400 gillnetting hours was conducted during this project in addition to the continuation of the USFWS reward program, only four individual shortnose sturgeon were captured in the Potomac River from 2004–2007 (Kynard et al. 2007 and 2009). The limited capture of shortnose sturgeon as well as the fact that one of the tagged individuals was recaptured three times, indicates a very small number of shortnose sturgeon were present.

Natural History and Habitat Information

Spawning

Although two late-stage females were captured and tracked, only one was observed to make an apparent spawning migration in the spring. Remote and manual tracking showed one female arrived at the Fletchers Marina (rkm 184.5) on April 9 and remained within a 2-km reach (rkm 187–185) for six days. During this time, mean daily river temperatures were 12.0–16.0 °C and mean daily river discharge was 157–178 m^3/s. Video camera monitoring along three sampling transects within the reach used by this migrant showed the substrate was predominantly large and small boulders (70–80%), along with the suitable spawning substrate of gravel-pebble and cobble-rubble (15.5–24.0%). During spring 2007, researchers determined mean bottom velocity along the channel shoulder in the Fletcher's Marina-Chain Bridge reach (rkm 184.5–187.0) was 1.05 m/s and mean depth was 6.3 m. The Potomac River is considered to be tidally influenced up to the Chain Bridge (rkm 187) which lies just 2 km upstream of the suspected spawning area at Fletcher's Marina (Kynard et al. 2007 and 2009). Although researchers filtered 100,000 m^3 of water at the Fletcher's site through 2-mm mesh anchored D-nets, no sturgeon ELS were captured (Kynard et al. 2007 and 2009).

Foraging

During the years when the two female shortnose sturgeon were tracked (2005–2007) they spent the summer-fall in a 78-km reach (rkm 141–63). Most of this area was in tidal freshwater, however, the downstream section of the range experiences tidal salinity. The two individuals shared the same 10-20 km reach in June–July of 2006 (they were never tracked in the same specific location); however, winter sites used by each individual were about 35 km apart or greater. The two female shortnose sturgeon used depths between 4.1–21.3 m, but most locations (89.2%) were recorded in the channel. Throughout the summer and winter, they were observed in a wide range of water temperature (1.8–32.0°C), DO (4.8–14.6 mg/L), and salinity (0.1–5.6 ppt) (Kynard et al. 2007 and 2009). Substrate types recorded at locations where these females were present were mud (80.7%), sand/mud (15.8%), and gravel-mud (3.5%). The foraging area was also characterized by prolific tracts of submerged aquatic vegetation and algal blooms. In addition, tidal cycles caused currents to reverse throughout the entire summer-winter range.

Overwintering/resting

Researchers tracked one female throughout an entire winter season (2005–2006). All winter sites selected by this female occurred within the 78-km summer-fall reach. This female returned to the same reach for wintering three consecutive years (2005-2007) and occupied < 2 km during winter. The other female that was tagged in spring 2006, was tracked only until February 2007, after which, it was not found again; it was noted at a site at rkm 85, which is the farthest downstream location tracked during the study. It is unknown if this sturgeon's tag stopped functioning or if it subseqnently left the river.

Migration
Annual movements of shortnose sturgeon in the Potomac River seem typical of north-central adults. Both of the tracked female shortnose sturgeon remained in freshwater for at least one year with pre-spawning migration occurs in spring during mid-April, and is a one-step spawning migration as described by Kynard (1997).

Shortnose sturgeon found in Chesapeake Bay may be migrants from the Delaware River. A movement study of 13 shortnose sturgeon radio-tagged in the upper Chesapeake Bay and 26 tagged in the Delaware River (near Scudders Falls) showed movement through the C and D canal (joining the Delaware River and Chesapeake Bay; Welsh et al. 2002).

Stressors to Riverine System

1. **Habitat**

Dams and diversions
The first mainstem dam on the Potomac River occurs at Little Falls (rkm 189). Although passage upstream of the low-head dam by sturgeon is not known, the 2-km reach downstream of the dam is a high gradient, boulder strewn reach of rapids, characterized by a small but turbulent falls that are likely prohibitive for sturgeon swimming abilities, especially egg-laden females. As the Little Falls Dam is thought to occur near the natural upstream limit of shortnose sturgeon it is not thought to block passage to historic habitat. In 1999, construction began on a fishway resulting in the removal of a 10.1 m dam segment for fish passage. Baffles designed to diffuse water energy pouring through the removed section were placed immediately downstream of the opening, but it is unknown if the opening is used by sturgeons. During gillnet sampling occurring over three spring periods, and two years of remote tracking just below the Little Falls Dam, no sturgeon were captured or tracked there (Kynard et al. 2007).

Diversion of water from the Potomac River mainstem just upstream of the potential spawning site at Fletcher's Marina occurs at two sites associated with the Little Falls Dam: 1) an old diversion dam (rkm 189) completed early in the canal's construction (late 1700s) to channel water from the mainstem into the Chesapeake and Ohio Canal currently diverts a small amount of water to maintain a recreational kayak course - the water is reintroduced back into the river about a kilometer downstream; and 2) the ACOE maintains a pumping station just upstream of the Little Falls Dam that removes water from the ponded reservoir for municipal use.

Other energy projects

Tidal turbines
There are currently no tidal turbines existing or proposed for the Potomac River.

LNG facilities
Although no LNG terminals exist on the Potomac River, a natural gas pipeline connecting the the Cove Point facility at Cove Point, MD to the Potomac River is proposed.

Dredging and blasting

Dredging in the Potomac River was authorized by the River and Harbor Act of 1899 to maintain a navigable channel from the Chesapeake Bay to Washington DC that was 24 feet deep by 200 feet wide. Because the Potomac River is naturally deeper than 24 feet, only eleven disjointed segments are routinely dredged. While a gillnetting study by the Maryland Fisheries Resource Office (MFRO) did not incidate shortnose sturgeon utilize the proposed disposal areas in Chesapeake Bay (Skjeveland et al. 2000), commercial fishermen have caught both shortnose and Atlantic sturgeon at these locations. In addition, USGS researchers tracked one telemetry-tagged Potomac River female over a shallow dredge spoil area in winter of 2006 (Kynard et al. 2007 and 2009).

Water quality and contaminants

The Interstate Commission on the Potomac River Basin (ICPRB) in 2007 conducted a review of PCB contamination for tidal portions of the Potomac and Anacostia rivers (Haywood and Buchanan 2007). The Potomac River is considered tidal up to the Chain Bridge (rkm 187) which lies just 2 km upstream of the suspected spawning area at Fletcher's Marina (Kynard et al. 2007). This three-district collaboration (MD, VA, and the District of Columbia) examined how extensively the total maximum daily limits (TMDL) were exceeded in the water bodies assessed. The executive summary lists numerous water quality impairments over the past 10 years including high levels of nutrients, sediments, toxins (PCBs in fish tissues), bacteria, metals, and trash/debris. The report goes on to identify point and non-point sources of PCB contamination and establishes TMDL targets.

The discharge of sediments related to the operation of the ACOE's Washington Aqueduct facility, which withdraws water for subsequent treatment for drinking water, has been an issue of concern for many years (ACOE 2005; NMFS 2003). As part of the water treatment process, water is stored in large settling basins and the sediment that settles out is then periodically discharged into the Potomac River. In 2003, EPA and the ACOE entered into a Federal Facilities Compliance Agreement, which in conjunction with the facility's NPDES permit, outlines a series of steps the ACOE must take to build an alternative treatment facility which will serve to eliminate the discharge of sediments into the river. Construction of the residuals processing facility is currently ongoing and the facility is mandated to be operational by November 30, 2010 after which residual sediments will no longer be discharged into the Potomac River. NMFS has completed several Biological Opinions on the effects of the various NPDES permits issued by the EPA.

In addition to contaminants and sediment issues, a recent ecology study of the sections of the river inhabited by shortnose sturgeon showed that during warm summer months DO concentration routinely fell below 6.0 mg/L (Kynard et al. 2007 and 2009). Although overall monitoring reports indicate DO levels are generally suitable for aquatic life, algal blooms resulting in periods of low DO have likely caused frequent fish kills. These fish kills are reported not only by numerous private "river watch" organizations, but also by state water quality monitoring agencies.

Finally, a 2006 USFWS Division of Environmental Quality news article discussed the observation of male smallmouth bass found with eggs; between 80 and 100% of male smallmouth bass sampled at five sites along the Potomac River displayed this condition. These “intersex” fishes are believed to have been affected by endocrine disruptors, but scientists remain uncertain as to the exact cause. Some suggest the presence of pharmaceuticals in the water perhaps in combination with other pollutants. One of the sites where intersex individuals were located was at the Woodrow Wilson Bridge (rkm 165) located between the summer-fall foraging and suspected spawning areas of shortnose sturgeon.

Water withdrawals

Removal of water from the Potomac River for drinking water occurs through the ACOE pumping facility located at Little Falls Dam. Up to 180 million gallons of water/day are diverted by the ACOE just upstream of the suspected spawning area at Fletcher’s Marina and into the Washington Aqueduct system (ACOE 2005).

2. Overutilization

Bycatch

There are numerous active commercial fishing efforts in the Potomac River and the majority of sturgeon (both Atlantic and shortnose) reported via the USFWS Atlantic Sturgeon Reward Program are captured by commercial fishermen, mostly in gillnets set for striped bass. Although fishermen can collect a reward for reporting live Atlantic sturgeon captures (which likely results in an increase in reports), under-reporting is still suspected (Skjeveland et al. 2000, Welsh et al. 2002).

Poaching

Shortnose sturgeon are rare on the Potomac River, which likely results in few sturgeon being caught. However, it is possible that some subsistence-level harverst occurs near potential spawning areas.

Scientific research

No shortnose sturgeon are removed from the Potomac River for scientific purposes, and only 12 have been captured in the river since 1996; one during a recent research effort (Kynard et al. 2007 and 2009) funded by the NPS and the remainder via the ongoing USFWS Atlantic Sturgeon Reward Program.

3. Competition, predation and disease

Competition and predation

Competition between sturgeon species is likely minimal due to the low number of shortnose sturgeon in the river system (Skjeveland et al. 2000, Welsh et al. 2002, and Kynard et al. 2007 and 2009). Predation on early life stages would likely be a factor based on the capture of benthic predators such as catfish and suckers near the likely spawning site at Fletcher’s Marina (rkm 187.5; Kynard et al. 2007 and 2009).

In addition to predation, the Potomac River is home to several threatening invasive species that may be sources of additional stress to sturgeon in the Potomac. The water chestnut (*Trapa natans*) is present in the Potomac River and had major impacts years ago. Water chestnut alters fish habitat by increasing the amount of vegetative cover and spatial complexity throughout the littoral zone and has affected the dynamics of dissolved oxygen and nutrients (Caraco and Cole

2002). A massive removal effort ending around 1965 cleared up much of the infestations, but is still a problem in several tributaties to the Potomac River.

The most recent predatory fish introduction is the snakehead (*Channa argus*), first discovered in the Potomac River in 2002. Although still believed to occur in isolated areas, this voracious predator, adept in surviving in harsh conditions and already producing gravid adult females and recruitment of juveniles may, in greater numbers, have a significant impact on juvenile sturgeon. State and federal resources are in place to provide immediate eradication responses to sighting reports. A 2005 article in the Potomac Basin Reporter described a single day's electro-shocking effort in a Potomac River tributary (Dogue Creek) resulted in the capture of 200 snakeheads; the mouth of this tributary lies approximately 30 km downstream of the suspected Fletchers Marina-Chain Bridge spawning reach (Kynard et al. 2007 and 2009).

Disease

There is no information regarding sturgeon diseases in the Potomac River or the Chesapeake Bay.

4. Inadequacy of existing regulatory mechanisms

Shortnose sturgeon in the Potomac River are listed as endangered in both the states of Maryland and Virginia, and receive benefits from the Clean Water Act. The Potomac River is an American Heritage Designated River. Enforcement limitations include inadequate policing of bycatch reporting from commercial fishing, and failure of contaminated sediment and nutrient controls.

5. Other natural or manmade factors

Ship strikes

There is no evidence of ship strike interactions with shortnose sturgeon on the Potomac River or the Chesapeake Bay.

Impingement and entrainment

There has been no reported impingement or entrainment of shortnose sturgeon in Potomac River industries. However, there are numerous industrial intakes located downstream of Fletcher's Marina.

Artificial propagation

There is no artificial propagation of shortnose sturgeon occurring on the Potomac River or the Chesapeake Bay.

Escapement of hatchery/captive fishes

Since there is no artificial propagation of shortnose sturgeon, there is no threat from escapement.

Current and Recommended Research

Currently, a life-history study of shortnose sturgeon in the Potomac River is being continued beyond the USGS efforts (Kynard et al. 2007 and 2009) by the USFWS. The effort will continue to monitor the potential spawning site at Fletchers Marina, continue monitoring tagged shortnose sturgeon in the river, and continue gillnetting for pre-spawning adults.

North Carolina
Historic Distribution and Abundance

Prehistoric
Information about the prehistoric distribution of sturgeon in NC and VA is available from archaeological research. The prehistoric record for shortnose sturgeon is clouded by the fact that at present, there is no identified method to distinguish the scutes of shortnose from those of young Atlantic sturgeon (VanDerwarker 2001b). In the future, extraction of DNA from prehistoric sturgeon scutes may enable discrimination of shortnose sturgeon as the technique has proven successful when employed on sturgeon scutes from the Jamestown, VA, archaeological site (T. King, USGS, pers. comm.).

Native American subsistence remains from 93 NC sites were compiled and analyzed by Scarry and Scarry (1997). Sturgeon remains were present at two of the coastal plain sites: Jordan's Landing on the Roanoke River located in Bertie County, and Flynt Site at Sneads Ferry on the New River, Onslow County, NC. Sturgeon scutes have also been identified from two sites presently flooded by Gaston and Roanoke Rapids reservoirs (VanDerwarker 2001a, 2002) indicating that sturgeon species were present in the Roanoke River above the location for the current dams. VanDerwarker (2001a and b) believes it unlikely that the remains were present at the sites due solely to trade activities of Native Americans.

Historic
John Lawson (1709) provided the first report of sturgeon in NC; he reported sturgeon as a freshwater species, stating that "...we have Plenty, all the fresh Parts of our Rivers being well stor'd therewith.". Given that Atlantic sturgeon adults are generally only seasonally in freshwater, this reference could include shortnose in addition to Atlantic juveniles. The presence of both species may be further implied by the fact that Lawson continues, "...the *Indians* near the Salt-Waters will not eat them. I have seen an *Indian* strike one of these Fish, seven Foot long, and leave him on the Sands to be eaten by the Gulls." (Lawson 1709). Fish seven feet in length clearly had to be Atlantic sturgeon and therefore Lawson may have been describing both species.

Later, Brickell (1737) also reported that sturgeon were abundant in NC. Nearly two centuries later, Yarrow (1877) and Jordan (1886) reported sturgeon from the North, New, and Neuse rivers and Beaufort, respectively. Ross et al. (1988) view these records as doubtful because they didn't see the specimens and notes that this is the only reference stating shortnose sturgeon were "abundant" in NC.

McDonald (1887) indicated that in NC sturgeons supported fisheries in the Cape Fear River and in Albemarle Sound. Smith (1893) reported sturgeon runs in the Chowan and Roanoke rivers, but did not identify the species. Later when Worth (1904),reported on sturgeon in the Roanoke River at Weldon, hefailed to mention shortnose. While Smith (1907) stated that the shortnose sturgeon "...doubtless ascends all suitable streams in NC, [but] actual records of its occurrence are rare.". Unfortunately, no museum specimens were deposited to verify these statements. While Fowler (1945) includes shortnose sturgeon in fishes of the Neuse River drainage, there is no account for the species in his text detailing NC fishes and therefore the record source is unknown.

More recently, multiple authors summarized the historic literature in the 1960's and 1970's when shortnose sturgeon was first federally-listed (Udall 1967, USDOI 1973), through the preparation of the Final Recovery Plan (NMFS 1998). These include: Vladykov and Greeley (1963), Schwartz and Link (1976), Schwartz et al. (1977), Lee et al. (1980), Rulifson et al. (1982a and b), Schwartz et al. (1982), Dadswell et al. (1984), Ross et al. (1988), Gilbert (1989) and Menhinick (1991).

Current Distribution and Abundance

The first shortnose sturgeon specimen from NC was deposited in a museum by Vladykov and Greeley (1963). Shortly thereafter, Schwartz and his co-authors (Schwartz and Link 1976 and Schwartz et al. 1977) as well as Rulifson et al. (1982a and b) reported the species was believed to be extirpated in NC, and consequently Schwartz et al. (1982) didn't include it in the listing of fishes documented from the Cape Fear River Estuary. Dadswell et al. (1984) reiterated these reports. More recently, Ross et al. (1988) conducted a thorough review of the shortnose sturgeon literature for NC, and reported on the second confirmed specimen collected from NC waters. Notably, Gilbert (1989), Gruchy and Parker (1980) in Lee et al. (1980), and Menhinick (1991) all published distribution maps that depicted shortnose sturgeon reports in NC and indicated erroneous localities where no shortnose had actually been documented.

Shortnose sturgeon were also reported offshore of NC in the Atlantic Ocean primarily between Cape Lookout and the VA border by Holland and Yelverton (1973): between 1968 and 1971, five shortnose sturgeon were reported captured between Cape Fear and Cape Lookout and five more between Cape Hatteras and the VA border. Species identification of all these offshore specimens is questionable (Ross et al. 1988) and it is believed they were all likely juvenile Atlantic sturgeon (M.Street, NCDMF, pers. comm.).

Moser and Ross (1995) reported on the shortnose in the Cape Fear River via results of radio telemetry. Moser et al. (1998) compiled NC sturgeon catch data for both species from Federal, state and privately-funded fish surveys to develop a database of sturgeon occurrence in NC waters: fishermen in areas where sturgeon had historically been reported were contacted and their anecdotal accounts of sturgeon distribution and seasonality throughout the state were recorded. This was complimented by a two-year gillnet survey for adult shortnose and juvenile Atlantics in the Cape Fear River drainage, and a buffer pad survey for sturgeon eggs in likely spawning habitat (Moser et al. 1998).

Based on literature and subsequent sampling (Moser et al. 1998, Armstrong and Hightower 1999, 2002; Oakley and Hightower 2007, B. Price, NCDMF, pers. comm., F. Rohde, NMFS, pers. comm.) today it is likely that shortnose sturgeon only occur, if at all, in the Cape Fear River and Pee Dee River in NC (the Pee Dee population is addressed in the SC section of this report). Anecdotal information from fishermen indicated that the species might still exist in the Neuse River, Pamlico Sound and Albemarle Sound (Moser et al. 1998); however, no specimens have been definitively documented there since 1998 despite survey. In the interest of inclusiveness for this report, anecdotal reports are considered sufficient and indicative of potential occurrence.

The most recent report of shortnose sturgeon in NC is from fishery observers monitoring commercial gillnet fisheries in Pamlico Sound: in 2005 a shortnose sturgeon was reported (R. Rulifson, ECU, pers. comm.; B. Price, NC DMF, pers. comm. and unpubl. data); however, no documentation for these specimens (tissue, photographs, or preserved specimens) exists and presently it is thought to be a misidentified Atlantic sturgeon given location and timing (B. Price, NC DMF, pers. comm.).

While a majority of river systems in NC may not presently support shortnose sturgeon populations, it is likely that they did so historically and therefore the present condition of *all* these habitats and their associated threats are assessed herein with the intention for future restoration opportunities. Adjacent estuaries are also considered to facilitate discussion of habitat condition and stressors.

Information on threats is taken from river basin summaries provided in the NC Wildlife Action Plan (NC WRC 2005), the NC Coastal Habitat Protection Plan (Street et al. 2005), and the Basinwide Water Quality Plans published for each basin by the NC Division of Environmental Quality (Basinwide Planning Section, 2002, 2004, 2005, 2006, and 2007a-c), as well as from publications focused on the estuaries (Giese et al. 1979, Copeland et al. 1983, 1984, Epperly and Ross 1986, Stanley 1992, Waite et al. 1994, Martin et al. 1996, Jones et al. 1997, Paul et al. 1998, Bricker et al. 1999, Dame et al. 2000, Summers 2001, 2004, and Kiddon et al. 2002).

Tables are included to provide state-wide summaries of shortnose sturgeon distribution as well as threats to their habitat: 1) Table 25 summarizes all located reports of shortnose sturgeon for VA/NC watersheds, by water body, year of report and source; 2) Table 26 presents a summary of river-specific shortnose sturgeon distribution and habitat factors for basins terminating in NC coastal waters, based on the literature review with drover-specific details provided in the text; 3) Table 27 provides summary data for all recorded shortnose sturgeon captured in NC waters, including the location, date, collector/observer, size and reference; 4) Table 28 summarizes historic and current reports on shortnose sturgeon life stages documented from river basins terminating in NC estuaries; 5) Table 29 provides river basin statistics for VA/NC systems reported to support shortnose sturgeon; 6) Table 30 lists the threats confronting potential shortnose sturgeon habitats in Albemarle and Pamlico Sounds and their watersheds; 7) Tables 31 and 32 summarize the threat factors by water body; 8) Table 33 summarizes listing status for sturgeons in VA, NC and SC; and 9) Table 34 provides documentation for known existing "dead zones" in NC waters where shortnose sturgeon may or may not occur. Extensive supporting detail for all tables is provided in the following river-specific sections. For those threats that are generic across all the VA/NC watersheds, a single discussion is provided. On the other hand, spatially or temporally variable threats are discussed individually.

Albemarle Sound

In 1987, both Albemarle Sound and the adjacent Pamlico Sound were designated as Nationally Significant Estuaries (Martin et al. 1996). The Albemarle-Pamlico Sound complex has an open water surface area of 3,000 square miles, with a watershed area of over 30,000 square miles, including portions of 36 counties in NC and 16 counties in VA. Albemarle Sound and its associated connected tributary sounds (Currituck, Croatan, and Roanoke) and estuaries (North

River, Pasquotank River, Little River, Perquimans River, Yeopim River, Chowan River, Roanoke River, Scuppernong River, and Alligator River) in northeastern NC comprise an extensive complex of freshwater to brackish water creeks, rivers and open water sounds (Copeland et al. 1983, NC Division of Water Resources NC DWR 2001). The Albemarle Sound Basin alone comprises 3,906 square miles. The NC DWR (2001) considers the basin to include Currituck Sound, Croatan Sound, Roanoke Sound and a portion of the Pamlico Sound paralleling the Outer Banks as far south as Ocracoke Inlet. Albemarle Sound is the receiving waters of the Chowan, Roanoke and Pasquotank rivers which together drain over 18,000 square miles of northern NC and southern VA (NC DWR 2001, Basin 12 Albemarle Sound). The two major western tributaries, the Chowan and Roanoke rivers, provide well over half the mean annual freshwater discharge into the sound (mean annual total freshwater inflow value 17,000 cfs). The watershed includes approximately 9,300 miles of freshwater rivers and streams. Albemarle Sound alone covers 500 square miles and is a significant portion of the NC coastal ecosystem. Details of the geological origins and evolution of Albemarle Sound are presented in Copeland et al. (1983) and Stanley (1992).

Albemarle Sound and tributaries have long been recognized as providing habitat of prime importance for diadromous fish species (Copeland et al. 1983, Epperly and Ross 1986, Stanley 1992, Waite et al. 1994, Martin et al. 1996). The sound is used by many anadromous fish including Atlantic sturgeon. Juveniles of all the diadromous species use the shallow, protected areas of Albemarle Sound from spring through fall (Epperly and Ross 1986, Armstrong and Hightower 2002) as nursery habitat; migrating out to the Atlantic Ocean by late fall (Epperly and Ross 1986).

Historically, Albemarle Sound was the epicenter for commercial anadromous fisheries on the east coast, so the habitat provided must have been exceptional, and perhaps can be so again. Historical trends in abundance of American shad and river herring in Albemarle Sound were documented by Hightower et al. (1996), and those for sturgeon by Secor (2002). At their peak, annual Albemarle Sound landings for American shad were three thousand metric tons (mt); those for river herring (alewife and blueback herring combined) exceeded eight thousand mt; and those for sturgeon (presumably both species combined), 118 mt.

Historic Distribution and Abundance

The historical presence of sturgeon in Albemarle Sound and tributaries was reviewed by Armstrong and Hightower (2002). Most historic commercial sturgeon landings records were from Albemarle Sound, but given that sturgeon species were not differentiated (Moser et al. 1998), it cannot be determined if they were shortnose or Atlantic sturgeon. There are no historic reports of shortnose sturgeon from the open sound.

There are only two documented records of shortnose sturgeon in the Albemarle Sound watershed, both from within tributaries of Albemarle Sound: 1) a juvenile specimen was collected in 1881 (Vladykov and Greeley 1963) from Salmon Creek (Chowan River drainage, see details below) and 2) an adult was collected in 1998 (NC DMF, unpubl data; Armstrong 1999; Oakley and Hightower 2007) from western Batchelor Bay near the mouth of the Roanoke River.

Current Distribution and Abundance

No shortnose sturgeon have been definitively documented in Albemarle Sound or its tributaries since 1998. When Moser et al. (1998) surveyed commercial fishermen to determine whether they had captured shortnose sturgeon in NC waters, shortnose sturgeon were reported as occasional captures in pound and gill nets in Bachelor's Bay at the mouth of the Roanoke River, and in gill nets set in the North River (see below).

Natural History and Habitat

There is no information available regarding life history of shortnose sturgeon in Albemarle Sound. Inferences may be made from the behavior of juvenile Atlantic sturgeon in Albemarle Sound, as they are sympatric with shortnose sturgeon.

Spawning

Based on description of spawning habitats from other systems (Crance 1986, Dadswell 1979, Taubert 1980a and b, Squiers 1982 Buckley and Kynard 1985b) it appears unlikely that either species of sturgeon ever spawned within Albemarle Sound. Spawning grounds were and are more likely located in riverine tributaries upstream.

Foraging

There is no definitive information regarding foraging habitats of shortnose sturgeon in Albemarle Sound. Based on the capture of the single adult in Bachelors Bay, as well as the anecdotal reports from commercial fishermen (Moser et al. 1998), shortnose may have seasonally used areas of organic-rich mud (Riggs 1996) which are most likely to support the benthic prey favored by shortnose sturgeon.

Numerous juvenile Atlantic sturgeon have been captured during the last decade in northeastern and western Albemarle Sound (Armstrong and Hightower 1999, 2002; Armstrong and White 2000), and may provide some indication of the habitats that might be used by shortnose sturgeon for foraging, since in other systems where both species are present, there is some co-occurrence in habitat utilization (Haley et al. 1996, Bain 1997, Haley 1999). Juvenile shortnose and Atlantic sturgeon both use the oligohaline zone of the Hudson River Estuary, which contains the biologically productive salt/freshwater interface (Haley et al. 1996, Bain 1997). Given that large portions of Albemarle Sound are oligohaline much of the time, it seems likely that any shortnose sturgeon within the system may have used the shallow portions of Albemarle Sound as a nursery habitat.

Overwintering/resting

There is no information regarding overwintering or resting habitat used by shortnose sturgeon in the sound. If juvenile Atlantic sturgeon were employed as a surrogate to indicate possible behavior of shortnose, it is likely that the sound would be used as overwintering and resting habitat as Atlantic juveniles are commonly caught in the sound from November through February (Armstrong and Hightower 2002).

Migration

Migration corridors for any shortnose sturgeon present in the Albemarle Sound ecosystem would likely include at least the western portion of the sound, and the river corridors up to the first dam on each system (Roanoke Rapids Dam at rm 137.5 on the Roanoke River; Emporia Dam on the Meherrin River; and Baskerville Mill Dam on the Nottoway River). Juvenile Atlantic sturgeon did not move from the sound into the Roanoke River or upstream of the US 17 bridge in the Chowan River system (Armstrong 1999, Armstrong and Hightower 1999, 2002).

Stressors to Estuarine System

Stressors to the Albemarle Sound ecosystem were addressed by Copeland et al. (1983), Epperly and Ross (1986), Stanley (1992), Waite et al. (1994), Martin et al. (1996), NC Wildlife Resources Commission (2005), and Street et al. (2005). Specific threats which these authors identified are presented in Table 30; details are provided in the following river-specific sections.

1. Habitat

Albemarle Sound is characterized by low salinity, high turbidity and relatively shallow water (Copeland et al. 1983, Epperly and Ross 1986, Stanley 1992, Waite et al. 1994, Armstrong and Hightower 2002). The average depth is 4.6 meters and bottom sediments are composed of silt, clay and sand. The salinity regime within Albemarle Sound is typically oligohaline (0.5 to 5 ppt; Heath 1975, Bowden and Hobbie 1977). The diverse physiographic and hydrologic regimes present create diverse estuarine habitats, including primarily freshwater submerged aquatic vegetation (SAV), tidal and irregularly-flooded marshes, sandy substrates, and finer sediments (Epperly and Ross 1986, Riggs 1996). Organic-rich mud (ORM) constituted about 70% of the benthic habitat within the Albemarle Sound Estuary. The characteristics of the ORM greatly affect the benthic community structure, chemical quality of the sediments, and water quality of the estuary (Riggs 1996). Because of the large distance to the nearest tidal inlet (i.e., Oregon Inlet), lunar tidal amplitude is considerably dampened and the hydrology of Albemarle Sound is driven by river flows and wind tides (Copeland et al. 1983, Epperly and Ross 1986). A detailed description of all the habitats present within Albemarle Sound is presented in Copeland et al. (1983).

Dams and Diversions

There are no dams or diversions within the waters of Albemarle Sound; however, the sound is affected by dams and/or diversions located in its tributaries (see discussions below). Copeland et al. (1983) indicated that long-term residents living around Albemarle Sound claim that there has been a change in the salinity patterns of the sound after the construction and operation of reservoirs on the Roanoke River. High salinity water was said to historically have penetrated Albemarle Sound as far as the Chowan River during dry years. During drought conditions in 1981, saltwater penetrated Albemarle Sound up into the Chowan River, the usual blue-green algal bloom failed to occur, and production of other phytoplankton was increased (H. Paerl, UNC Chapel Hill, pers comm. to Copeland et al.). If such changes have in fact occurred, nursery habitat for shortnose and Atlantic sturgeon could well have shifted in location and extent, as both species are documented as using the zone of the salt-freshwater interface of estuaries.

Other energy projects

Tidal Turbines

There are currently no existing or proposed tidal turbines associated the Albermarly Sound; emplacement is highly unlikely due to the sporadic and inconsistent nature of the largely wind-drive local tides.

LNG Facilities
There are currently no LNG facilities located or proposed for locations within Albemarle Sound.

Dredging and Blasting
The impacts of maintaining navigation channels and boat basins in NC are addressed in detail in Street et al. (2005). The most obvious impact is the conversion of shallow water habitats to deep water that can result in a proportional loss of nursery habitats for estuarine-dependent species. Elevated turbidity during and after dredging can also clog the gills of juvenile fishes with resultant mortality (Ross and Lancaster 1996). Other impacts of dredging-related turbidity include reduced recruitment of invertebrate larvae, reduced growth of filter-feeding invertebrates, and impacted visual foraging for prey by juvenile and adult fishes (Reilly and Bellis 1983, Hackney et al. 1996, Peterson et al. 2000). Dredging may also expose fishes and other aquatic organisms to heavy metals and other pollutants stored in the sediments (Street et al. 2005). Dredged channels and boat harbors act as sediment traps, where fine silt and associated pollutants accumulate and may easily be resuspended by boat wakes, wind, or channel maintenance (DEHNR 1990a).

The direct and indirect impacts of dredging upon shortnose and Atlantic sturgeon have been investigated by a number of authors (Moser and Ross 1995, Nellis et al. 2007, Hatin et al. 2007, and McQuinn and Nellis 2007). Dredging in a NC harbor did not appear to disrupt migration of shortnose and Atlantic sturgeon (Moser and Ross 1995, see Cape Fear River section below for details). Sediment from dredging deposited in the St. Lawrence River estuary was tracked using modeling and post-deposition sampling for validation of the model results. The stations impacted by the sediment plume showed a significant reduction in average biomass of tubificids, the most important food item of juvenile Atlantic sturgeons in the St. Lawrence. Both model and field results indicated that sand drift generated from disposal operations reduced benthic productivity, thereby also reducing juvenile sturgeon habitat quality (Nellis et al. 2007). Catches of Atlantic sturgeon decreased significantly (3 to 7 times lower) following dredging (Hatin et al. 2007); a significant reduction in CPUE was also noted in the area downstream of disposal. Acoustic and trawl surveys of the St. Lawrence Estuary further confirmed that demersal fishes, including sturgeons, avoided areas of dredged sediment dumping and associated habitats (McQuinn and Nellis 2007).

The ACOE maintains navigation channels through portions of the North and Alligator River tributaries of Albemarle Sound as part of the Atlantic Intracoastal Waterway (AIWW; see Street et al. 2005); blasting is not required to maintain these channels. In addition, there are also other privately maintained channels serving marinas and private dock facilities throughout the sound that require periodic dredging.

Dredging in estuarine waters in NC is prohibited between April 1 to October 1 to avoid disturbing the bottom in nursery areas when juvenile fishes are present, except in specific areas where dredging is allowed during the moratorium period (Street et al. 2005).

Water Quality and Contaminants
Water quality and contaminants have been identified as issues in Albemarle Sound by most authors who have studied them for the past quarter-century (Table 30). The history of water

quality studies in the Albemarle-Pamlico system was reviewed by Stanley (1992); unfortunately little hydrographic and water quality data has been collected for the open waters of the sound, except for a two-year period of intensive sampling during the early 1970's (Bowden and Hobbie 1977) as most researchers focus on the western sound (Chowan River and the lower Roanoke River). Copeland et al. (1983) noted that in the Albemarle Basin, the amount of phosphorus in the receiving waters was estimated to be about three times the background level, with nitrogen estimated to be twice background levels (NC DEM 1982). These excess nutrient loads resulted in changes in phytoplankton composition in Albemarle Sound and the development of bluegreen algal blooms (Stanley and Hobbie 1977, Bowden and Hobbie 1977).

Albemarle Sound has been combined with Pamlico Sound and identified in past reports as the location of a “dead zone,” an area where DO levels are low or absent, with consequent reductions in use by riverine or estuarine organisms (Table 34, Bricker et al. 1999, Bricker et al. 2007, Diaz and Rosenberg 2008). However based on examination of the cited references, it appears that the “dead zone” was actually located in Pamlico Sound (see discussion below). Data for Albemarle Sound were insufficient to rate eutrophic conditions in 1999 (Bricker et al. 1999). Of the six factors (chlorophyll a, epiphytes, macroalgae, low DO, SAV loss, and nuisance/toxic blooms) used to determine eutrophication condition, four (chlorophyll a, low DO, SAV loss and nuisance/toxic blooms) were rated as occurring with “low” frequency in the Albemarle Sound estuary (Bricker et al. 1999). The current National Estuarine Eutrophication Assessment (Bricker et al. 2007) also was unable to determine the eutrophication condition for Albemarle Sound. Other NC systems have been rated as having high levels of eutrophic conditions and are discussed below (i.e., Pamlico/Pungo Rivers, Neuse River, and New River).

Water Quantity

Factors affecting water demand are addressed in NC DWR (2001). The Albemarle Sound Basin is home to about 2% of NC residents and contains all or part of 12 municipalities in 12 counties. Portions of the basin are in VA, including the Norfolk-VA Beach-Newport News Metropolitan Statistical Area. Three counties in this latter portion of the basin had population growth of over 10% from 1990 through 1997 (NC DWR 2001). The 1995 USGS summary of water use estimated total water use in the basin at 23.4 mgd with just over two-thirds coming from surface water sources (Walters 1997). Additional water is withdrawn for agricultural and non-agricultural use, and any user withdrawing more than 1.0 mgd of surface or ground water for agricultural use, or more than 100,000 gallons per day for other uses is required to register with the NC Division of Water Resources (NC DWR 2001). In 1999, there were 15 such users withdrawing 58.2 mgd (NC DWR 2001).

The maintenance of normative freshwater inflows to Albemarle Sound through its many tributaries is a concern, as is the rate of runoff from the altered landscape surrounding the sound. Burgeoning human populations associated with the development of retirement and second homes in the landscape surrounding the sound (currently designated the Inner Banks) is placing additional pressure and demand on water resources. Historic hydrographic delivery patterns in Albemarle Sound and its tributaries have been and are being altered by: 1) water management for flood control and hydropower; 2) water withdrawals for agricultural and municipal water supply purposes; 3) increased water discharges from agricultural drainage systems; and 4) accelerated delivery from streams historically channelized and/or snagged by the activities of the U.S.

Department of Agriculture, Soil Conservation Service (PL 566 projects), ACOE Wilmington District; and the NC Division of Water Resources. Local Soil Conservation Districts have partnered in many of these projects in the interest of facilitating drainage for agricultural purposes.

Loss of Coolwater Refugia from Groundwater Withdrawal

To our knowledge, the existence of cool-water refugia within the waters of Albemarle Sound has not been documented. However, during experimental electrofishing operations in 1992, one such possible refugium was discovered at the confluence of a small tributary stream with the sound, as evidenced by the presence of large numbers of striped bass concentrated in a very small area (USFWS, SAFCO, Raleigh, NC, unpubl. data).

2. Overutilization

There are currently no directed fisheries for sturgeon in NC as a consequence of the federal listing of shortnose (NMFS1998) and the moratorium imposed on the Atlantic sturgeon fishery by the ASMFC (ASMFC 1998): the commercial fishery for Atlantic sturgeon was closed in 1991, and possession is prohibited. However, bycatch of both juvenile and adult shortnose sturgeon in fisheries for other species is a potential issue.

Bycatch

Given the current level of commercial fishing activity in Albemarle Sound, potential exists for any shortnose sturgeon present in the system to encounter commercial gear, primarily crab pots and gill nets. Commercial fisheries present in Albemarle Sound were documented by Diaby (2000) and more recently in 2007 by NC DMF (2008).

The most recent capture of a shortnose sturgeon in Albemarle Sound/Roanoke River was in a gillnet (NCDMF, unpubl. data, Armstrong 1999, Oakley and Hightower 2007). Bycatch of juvenile Atlantic sturgeon in Albemarle Sound was addressed by Armstrong and Hightower (2002) and Armstrong and White (2000). Juveniles occur as bycatch primarily in the southern flounder (*Paralichthys lethostigma*) gillnet fishery. Between 1998 and 2000, 131 captures of 122 different individuals in flounder gill nets in northeastern Albemarle Sound were recorded in one individuals' net sets during the study period (gillnetting activities conducted from Sept 1, 1998 -Dec 31, 1998; JunJun 1, 1999 -Dec 31, 1999; and JunJun 1,2000 -Aug 31, 2000) (Armstrong and White 2000). The reported number of bycatch is likely lower than otherwise would have occurred, since hurricanes in 1999 greatly reduced fishing effort (Armstrong and White 2000; see also Paerl et al. 2001, Luczkovich et al. 2001, and Burkholder et al. 2004). Armstrong and Hightower (2002) suggest that survey data (see below under *Scientific* Research) combined with information on the seasonality of commercial fishing may provide some indication of bycatch risk for juvenile Atlantic sturgeon in Albemarle Sound (page 476). Should the shortnose sturgeon population in the Albemarle Sound Basin expand or be restored, bycatch in commercial fisheries would likely increase and have to be addressed.

Poaching

Given the likely paucity of shortnose sturgeon in Albemarle Sound, poaching is presently not likely a significant source of mortality. Should the population expand or be restored, poaching may become a concern. Poaching of Atlantic sturgeon has been documented by law enforcement agents (ASSRT 2007); poaching of shortnose sturgeon has been documented in SC (Collins et al. 2000a). In one case, a team of poachers removed about 50 shortnose sturgeon from the Cooper River in 1995 (D. Cooke, SCDNR, pers. comm. to NMFS 1998; cited in Collins et al. 2000a); a black market for Atlantic sturgeon peddles the meat as "Canadian bacon" (ASSRT 2007). Poaching may be more prevalent where legal markets for sturgeon exist from importations, commercial harvest or commercial aquaculture (NMFS 1998). There is also concern that as foreign caviar becomes limited, illegal harvest of caviar from American species will increase (Speer et al. 2000).

Scientific research

While there are no current academic or agency studies targeting shortnose sturgeon, many ongoing surveys are conducted in Albemarle Sound, and some regularly capture juvenile Atlantic sturgeon. One of these surveys captured a shortnose sturgeon in 1998. These sampling programs conducted by NC DMF include: fishery independent gillnet survey for striped bass, trawl survey and beach seine survey programs for anadromous juveniles, anadromous species spawning survey using gill nets and a perch spawning survey using pots. In addition, an experimental crab pot program testing biodegradable panels is occurring (K. Rawls, NC DENR, pers. comm.).

Juvenile Atlantic sturgeon (age 0 and 1) are routinely captured in the fishery independent gillnet survey (Armstrong and Hightower 2002). Given the relatively short set times for the gear used and awareness by staff of the status of shortnose sturgeon, any specimens captured are likely to either be returned to the water unharmed, or if accidental mortalities occur, transferred to the NC State Museum of Natural Sciences as voucher specimens. These programs are at present not considered a significant potential source of mortality for any expanded or restored population of shortnose sturgeon.

3. Competition, Predation and Disease

Competition and predation

As there are few exotic predators present, competition and predation from other native species may be the primary concern in Albermarle Sound; however, there is concern about the introduction and expanding distribution of non-native predatory fishes that already exist, or have been introduced upstream (Brown et al. 2005). Competition between shortnose sturgeon and native species with which they co-evolved is not generally perceived as a significant threat. YOY shortnose sturgeon, approximately 50 mm FL, were found in the stomachs of yellow perch (*Perca flavescens*) in the Androscoggin River, Maine (Dadswell et al. 1984), a species that occurs in Albemarle Sound. Dadswell et al. (1984) indicated it is likely that sharks and seals may occasionally prey on shortnose sturgeon based on occasional specimen found lacking a caudal fin: both sharks and seals rarely occur in Albemarle Sound and therefore are not likely to constitute a major threat. The American alligator (*Alligator mississippiensis*) is native to the sound and clearly attains a size large enough to prey on shortnose sturgeon. Other native piscivorous predators present in or adjacent to the sound include birds (e.g., bald eagles, ospreys, egrets, herons, cormorants, mergansers); reptiles (e.g., common snapping turtles, brown and northern water snakes, water moccasins); and mammals (e.g., mink, river otter, raccoon, bottlenose dolphin). Because all these species co-evolved with shortnose sturgeon, and as many are spatiotemporally segregated from the habitats seasonally inhabit, all are considered as insignificant stressors to future shortnose sturgeon population expansion or restoration.

Competition with other native sturgeon species is again unlikely due to coevolutionary relationships between the species. The most likely competitor with shortnose would be the congeneric Atlantic sturgeon; these sympatric species have seemingly different diets (Bain 1997, Haley et al. 1996, Haley 1999, Collins et al. 2006).

The blue catfish (*Ictalurus furcatus*), a non-native predator, is present in the Chowan River tributary (NC DMF, unpubl. data, K. Rawls, NC DNR, pers. com.) and the non-native flathead catfish (*Pylodictis olivaris*) has been introduced along with the blue catfish to most of the reservoirs above the dams within the Albemarle Sound watershed (VA DGIF 2002), and is likely to migrate downstream. Both introduced catfish species prey on fishes, the flathead obligatorily and the blue cat opportunistically (Fuller 2008a-b), both attain very large sizes, and both have been recently shown to tolerate estuarine salinities and have the capacity for expanding their ranges into or through estuarine waters (Bringolf et al. 2005, Higgins 2006).

Moser et al. (2000b) found no evidence that flathead catfish would feed preferentially on shortnose sturgeon juveniles; instead they fed most readily on juvenile striped bass and channel catfish were preferred over shortnose sturgeon when striped bass were not available. Moser et al. (2000b) noted that the flathead catfish in their experiments fed sparingly perhaps due to water temperatures as feeding was observed during the lowest temperatures but not at higher temperatures.

While unlikely to prey on juvenile shortnose sturgeon under experimental conditions (Moser et al. 2000b), flatheads are considered to have the potential to adversely affect ongoing anadromous fish restoration programs and native fish conservation efforts in watersheds where it is not native (Brown et al. 2005). Given the recent distribution in areas of higher salinity, marine fishery agencies are concerned about the potential impacts on native marine invertebrate and fish resources (Bringolf et al. 2005). Simulation modeling of the food web further supports the hypothesis that direct predation by introduced flathead and blue catfish suppresses native freshwater resident and anadromous fish populations in coastal rivers (Pine 2003, Kwak et al. 2004, Bringolf et al. 2005).

The recently introduced northern snakehead (*Channa argus*) is another potential predator of shortnose sturgeon. Snakeheads are present and reproducing in the Potomac River watershed in VA, and isolated specimens have been documented from NC watersheds to the west of Albemarle Sound (Fuller and Benson 2008). The species has been reported to be an obligate air-breather, capable of living in oxygen-depleted waters by gulping air at the surface and surviving several days out of water if kept moist. Snakeheads compete with native species for food and habitat: juveniles eat zooplankton, insect larvae, small crustaceans and the fry of other fishes; adults feed primarily on fishes, and also crustaceans, frogs, small reptiles and sometimes small birds and mammals (Fuller and Benson 2008).

Disease

Fish diseases have been of concern in Albemarle Sound since the 1970s and have been addressed by Esch and Hazen (1980), Copeland et al. (1983), Epperly and Ross (1986), Stanley (1992), Waite et al. (1994), and Martin et al. (1996). “”Red sore disease” was prevalent in Albemarle Sound in the past (Esch and Hazen 1980, Copeland et al. 1983, Epperly and Ross 1986): the implicated causative microbe is *Aeromonas hydrophila*, a gram negative bacterium found in fresh to brackish water (Hazen 1979). Presence of the organism appears to be associated with high concentrations of decaying organic residue (Esch and Hazen 1980). The occurrence of the disease in Albemarle Sound may be associated with the input of high concentrations of organic materials from some of the tributaries (Copeland et al. 1983, page 31). The threshold level at which *A. hydrophila* becomes problematic is thought to be 40 colony-forming units (cfu) per milliliter (Esch and Hazen 1980). This concentration was exceeded during winter and spring at several stations in Albemarle Sound (see Copeland et al. 1983, page 31). It is unknown whether shortnose sturgeon are susceptible to *A. hydrophila*.

While there have been no reported incidences of disease for shortnose sturgeon in the wild (NMFS 1998), an epizootic of *Columnaris* sp. occurred at the USFWS Orangeburg National Fish Hatchery in SC. COSEWIC (2005) notes that the introduction of diseases via aquaculture as a potential threat.

4. Inadequacy of Existing Regulatory Mechanisms

A summary of listing status by state is provided in Table 33. The shortnose sturgeon is state-listed as endangered in VA, NC and SC, tracking the federal status, in all three states. Shortnose is also considered a high priority species for action under the VA Comprehensive Wildlife Conservation Strategy (VA DGIF 2005), NC Wildlife Action Plan (NCWRC 2005), and SC Comprehensive Wildlife Conservation Strategy (SCDNR 2005).

Virginia (VA DGIF 2005) considers shortnose sturgeon a Tier I species with critical conservation need: tier I species are defined as: 1) they face an extremely high risk of extinction or extirpation; 2) populations of these species are at critically low levels; 3) they face immediate threat(s), or occur within an extremely limited range; and 4) intense and immediate management action is needed (VA DGIF 2005). In addition, VDNH rate shortnose sturgeon globally as G3, consistent with NC and SC (Roble 2006); the state ranks shortnose sturgeon as SXB (believed to be extirpated in VA with practically no expectation of rediscovery, during the breeding season) and S1N (nonbreeding status, being extremely rare and critically imperiled with 5 or fewer occurrences or very few remaining individuals in VA; or because of some factor(s) making it especially vulnerable to extirpation in VA.

NC lists shortnose sturgeon as the number one priority freshwater fish species (NCWRC, 2005). NC NHP classifies shortnose from a state perspective as S1, which means there are only 1-5 extant populations in the state, which are critically imperiled because of extreme rarity or because of some factor(s) making the species especially vulnerable to extirpation from NC. Atlantic sturgeon are ranked S3 - rare or uncommon in NC.

SC considers both the Atlantic and shortnose sturgeon highest priority species; the highest category for action under the state’s Comprehensive Wildlife Conservation strategy (SCDNR 2005). The ranking was determined by a Diadromous Fishes Taxonomic Committee using a nine-point ranking criteria (SCDNR 2005). SC ranks both sturgeon species identical to NC and VA as state-ranked as S3 indicating rare or uncommon in the state, and globally as G3 (SCDNR 2005).

5. Other Natural or Manmade Factors

Ship Strikes

Given the low abundance of shortnose sturgeon in Albermarle Sound, ship strikes are not likely a major threat at the present time and we are not aware of any documented ship strikes. Given the high rate of navigation in the Albemarle Sound, strikes by vessels on shortnose sturgeon is a potential threat if shortnose sturgeon abundance were to increase.

Impingement and Entrainment

Given existing water withdrawals from the Albemarle watershed (see Street et al. 2005), impingement and/or entrainment of juvenile shortnose sturgeon is a possibility.

Artificial Propagation

Artificial propagation is presently not a threat as there are no captive propagation facilities rearing shortnose sturgeon in the Albemarle Sound watershed.

Escapement of Hatchery/Captive Fishes

Escapement of hatchery or other captive shortnose sturgeon does not appear presently to be a threat in the Albemarle Sound watershed. Shortnose sturgeon were at one time held in captivity at Edenton National Fish Hatchery, located on Pembroke Creek a tributary to Edenton Bay and a part of Albemarle Sound, but none are presently held there. The public aquarium associated with the hatchery does not currently display sturgeon. No shortnose sturgeon are currently on display at the NC Aquarium in Manteo.

Current Research and Recommended Research

Currently no research targeting shortnose sturgeon is occurring within Albemarle Sound. A researcher targeting Atlantic sturgeon could encounter shortnose as well. Research recommendations for Atlantic sturgeon listed below as proposed by Armstrong and Hightower (2002) would be applicable to shortnose sturgeon in Albemarle Sound and its tributaries:

- Field studies are needed to refine estimates of immediate and longer term mortality associated with bycatch from the gillnet fishery.
- Information on the spatial distribution of commercial gill netting effort would be valuable, given that abundance of juvenile Atlantic sturgeon varies spatially within the sound.
- The adequacy of existing spawning habitat should be assessed periodically.
- A recovery plan that includes monitoring of adult abundance and a schedule for reestablishing a fishery will be important for maintaining support for restoration efforts.

North River Basin (Albemarle Sound)

The North River is a small coastal system tributary to Albemarle Sound: it is approximately 29 km (18 mi) in length and forms the boundary between Camden and Currituck Counties, NC. The

North River originates in Great Swamp, ten miles east of Elizabeth City, NC, and terminates in a four-mile wide mouth at Albemarle Sound. Portions of the watershed are included in the North River Game Land, administered by the NC Wildlife Resources Commission. The North River Basin lies between the Pasquotank River to the west and the south end of Currituck Sound to the east. The lower two-thirds of the river is part of the AIWW.

Historic Distribution and Abundance

There are no evident historic reports of shortnose sturgeon from the North River Basin of Albemarle Sound.

Current Distribution and Abundance

Rulifson et al. (1982b) indicated that the species was extirpated in the North River (Albemarle) drainage, based on the responses they received to a survey of federal, state and other agencies. Moser et al. (1998) interviewed local commercial fishermen, and posted fliers in the North River Basin to identify historic distribution of shortnose: one gillnetter who operated near Point Harbor reported that he had captured what he believed to be a shortnose sturgeon in the spring of 1994; he described the fish as having a "round nose" and indicated he was confident of his identification based on drawings and a photograph.

The NC Division of Water Quality, Basinwide Planning Section (2007b) lists shortnose sturgeon as currently occurring in the Pasquotank Basin (of which the North River Basin is a portion). The text further indicates that "Current distribution is not well known, and the shortnose sturgeon has not been reported from the Pasquotank basin for more than 20 years". No citations are provided to document any occurrences, so the basis for the statement is uncertain.

Natural History and Habitat Information

Because the only reports of shortnose sturgeon from the North River (Albemarle) are anecdotal, information in this section should be considered theoretical.

Spawning

Given the small size of the North River and being entirely a coastal drainage, it is unlikely that suitable spawning habitat for shortnose sturgeon is present.

Foraging

Suitable foraging habitat for shortnose sturgeon is likely present in the North River.

Overwintering/resting

Overwintering and/or resting habitat for shortnose sturgeon could be present in the North River (Albemarle) if deep holes are present.

Migration

No information is available on seasonal movement or migrations of shortnose sturgeon in the North River.

Stressors to Riverine System

1. **Habitat**

Dams and diversions

There are no dams located on the North River.

Other energy projects

Tidal Turbines

Emplacement of tidal turbines within the North River (Albemarle) is viewed as unlikely due to the sporadic and inconsistent nature of the largely wind-drive tides within the river.

LNG Facilities

There are currently no LNG facilities located or proposed for locations within the North River.

2. Overutilization

Refer to preceding information provided for Albemarle Sound for details on bycatch, poaching and scientific research.

3. Competition, Predation and Disease

Refer to preceding information provided for Albemarle Sound for details on competition, predation and disease.

4. Inadequacy of Existing Regulatory Mechanisms

Refer to preceding information provided for Albemarle Sound for details that include NC, SC and VA.

5. Other Natural or Manmade Factors

Refer to preceding information provided for Albemarle Sound for details on impingement and entrainment, ship strikes, artificial propagation, and escapement of hatchery/captive fishes.

Current Research and Recommended Research

Refer to preceding information provided for Albemarle Sound for details on current and recommended research.

Chowan River Basin

The Chowan River Basin is located in the northeastern Coastal Plain of NC and southeastern VA and occupies approximately 5,415 square miles: approximately 75% of the basin (4,061 square miles) is located in the VA portion of the watershed (Basinwide Planning Section 2007a), with the remaining 1,378 square miles in NC (NC DENR, NCSU 2008). The Chowan River is formed at the border of NC and VA by the confluence of the Nottoway and Blackwater Rivers. A third major tributary, the Meherrin River, joins the Chowan River south of the VA border. There are 782 stream miles in the basin (NCSU 2008). The basin is part of the Albemarle-Pamlico National Estuary Program.

Historic Distribution and Abundance

A single juvenile shortnose specimen (185 mm FL; USNM 64330) was collected from Salmon Creek (a tributary near the mouth of the Chowan River, close to Albemarle Sound) April 12, 1881 by J. Kite (see Table 29).

Current Distribution and Abundance

No other specimens of shortnose sturgeon have been documented from the Chowan River Basin since1881, although one additional adult was captured nearby at the mouth of the Roanoke River (see below). Interviews with commercial fishermen did not indicate captures of shortnose sturgeon within the Chowan River (Moser et al. 1998), but did indicate that sturgeon were captured infrequently at the mouth of the river.

Natural History and Habitat Information

Given the documented capture of only one small juvenile shortnose sturgeon from the Chowan River Basin, the information regarding natural history and habitat information for this basin is theoretical in nature and based primarily on the available information about juvenile Atlantic sturgeon, under the presumption that juvenile shortnose are likely to be sympatric with juvenile Atlantics in the salt/fresh interface portion of the estuary.

Spawning

Neither spawning activity nor spawning habitat has been documented for shortnose sturgeon in the Chowan River or any of its tributaries in recent history. However, the juvenile specimen taken from Salmon Creek in 1881 suggests that spawning was likely occurring somewhere in the system at that time. Based on the shortnose sturgeon growth curves for the Pee Dee and Altamaha rivers in SC and GA respectively (Dadswell et al. 1984) and assuming a similar growth pattern for Albemarle Sound and its tributaries, this individual would have been approximately one year old or slightly older. It is unlikely that such a young, small sturgeon would have migrated to Salmon Creek from spawning grounds outside Albemarle Sound.

Foraging

The capture of the juvenile shortnose sturgeon from Salmon Creek in 1881 may suggest that Salmon Creek was at least, in the past, used by shortnose sturgeon juveniles as a nursery and possible foraging habitat area.

Overwintering/resting

There is no information on overwintering or resting habitat use by shortnose sturgeon in the Chowan drainage. Telemetered juvenile Atlantic sturgeon entered the mouth of the river to within a kilometer or so of the US 17 bridge; however no winter tracking was done, so no data are available for the winter months (Armstrong and Hightower 2002).

Migration

If there were shortnose spawning habitats within the Chowan River or its major tributaries, the mainstem channel would be the most likely migration route for adults to follow. Migration pathways could include the Meherrin, Nottoway and Blackwater Rivers, as well as the Chowan River.

Stressors to Riverine System

1. **Habitat**

Dams and diversions

The major dams in the Chowan River and tributaries were summarized by Street et al. (2005). The lowermost dam, the Emporia Dam (VA) is a hydropower facility located on the Meherrin River that has blocked diadromous fish movement for over 90 years. In 1990, a fish lift was constructed at the dam to facilitate migration of American shad and river herring. The effectiveness of the lift is unknown and it is likely that this would be the upstream limit for shortnose sturgeon if they were present on the Chowan River. There is also a dam on the Nottoway River, the Baskerville Mill Dam that restricts the historical migration of striped bass and would likely restrict passage of shortnose sturgeon if they were present. Additional dams located in the VA portion of the watershed are present in the system on the Blackwater and Nottoway tributaries of the Chowan, and may also block access to historic shortnose sturgeon spawning habitat.

Other energy projects

Tidal Turbines

Given that tides within the lower Chowan River are largely wind-drive and of generally low magnitude, emplacement of tidal turbines is unlikely.

LNG Facilities

There are currently no LNG facilities located or proposed for locations within the Chowan River or its tributaries.

Dredging and Blasting

There are three authorized ACOE navigation channels in the Chowan Basin: 1) a 10-foot deep channel along the Meherrin River, from the mouth to Murfreesboro, NC for a distance of approximately 10.5 miles; 2) a 12-foot deep channel along the Chowan River, between the Meherrin River and the confluence of the Blackwater and Nottoway rivers - a distance of 11.4 miles; and 3) a 12-foot deep channel on the Blackwater River from the mouth to Franklin, VA, a distance of about 13 miles. All of these projects are considered inactive and are not maintained (ACOE 2008b). To our knowledge, there is no blasting required for any of the navigational dredging projects in the Chowan River Basin.

Water Quality and Contaminants

All of the waters in the Chowan River Basin are presently designated as Nutrient Sensitive Waters (NSW): water quality in the basin is presently considered generally good (Basinwide Planning Section 2007a). However, the Chowan River has historically experienced severe problems attributed to declining water quality as a result of excessive nutrient inputs from 1973-1983 (Copeland et al. 1983 citing NC DEM 1979, 1982; Sauer and Kuenzler 1981, Paerl 1982) with nuisance blue-green algal blooms were the most noticeable manifestation of the water quality problem (Witherspoon et al. 1979, Paerl 1982). Nonpoint sources have been identified as the major sources of nutrients that were affecting the ecosystem (Sauer and Kuenzler 1981; Paerl 1982); the loadings varied as a function of flow. Blue-green algal blooms were greatest between 1972 and 1978, when high spring tributary discharges were coupled with relatively long water residency times during summer months. In association, increasingly higher summer chlorophyll values were noted (NC DEM 1982). Other indications of degraded water quality in the Chowan River have included fish kills (Johnson 1982), declining commercial fisheries (Street 1982) and decreases in recreational activities (NC DEM 1982).

Recently a request by International Paper (Franklin, VA) was made to extend the discharge period for their mill on the Blackwater River into the month of April: NC DMF noted that during periods of low river discharge, effluent from the mill constitutes a high (as much as 26%) of the flow and has adversely impacted spawning river herring downstream. The NC DMF has requested additional information relative to the request, and is recommending effluent toxicity testing on early life stages of river herring.

Water withdrawals

There is one municipal water intake for Norfolk, VA, located on the Blackwater River. Remaining withdrawals consist of small agricultural withdrawals which do not presently require permits (Street et al. 2005).

Loss of Coolwater Refugia from Groundwater Withdrawal

Coolwater refugia within Chowan River has not been documented. However, if they in fact existed, they may have also been affected by extensive pumping of groundwater from the underlying aquifer (see discussion above for Albemarle Sound).

2. Overutilization

Given the unlikely presence of shortnose sturgeon in the Chowan River, overutilization (including bycatch, poaching and scientific research) is not presently viewed as a threat.

3. Competition, Predation and Disease

Refer to preceding information provided for Albemarle Sound for details on competition, predation and disease.

4. Inadequacy of Existing Regulatory Mechanisms

Refer to preceding information provided for Albemarle Sound for details on NC, SC and VA regulatory mechanisms.

5. Other Natural or Manmade Factors

Refer to preceding information provided for Albemarle Sound for details on impingement and entrainment, ship strikes, artificial propagation and escapement of hatchery/captive.

Current Research and Recommended Research

Refer to preceding information provided for Albemarle Sound for details on current and recommended research.

Roanoke River Basin

The Roanoke River Basin begins in the Blue Ridge Mountains of northwestern VA and flows for more than 400 miles in a generally southeastern direction, emptying into Albemarle Sound in northeastern NC (TNC and SARP 2005, Basinwide Planning Section 2006). At the fall line near Roanoke Rapids, the drainage area is nearly 8,000 square miles; from Roanoke Rapids to the coast, the river drains another 2,000 square miles. Discharge from Roanoke River is greater than any other NC river (Basinwide Planning Section 2006). About 36% of the watershed is within

NC with the remainder in VA; much of the NC portion is comprised by the Dan River and its tributaries.

The upper Dan River is classified as trout waters and part of the area is also designated as a State Water Trail by the NC Division of Parks and Recreation. The lower portion of the basin below Roanoke Rapids Dam contains the largest intact and least-disturbed remaining bottomland hardwood floodplain ecosystem in the mid-Atlantic region (TNC and the Southeast Aquatic Resources Partnership 2005). TNC's Board of Governors has designated the lower river as one of "The Last Great Places," making it one of only 200 such sites in America, Asia and the Pacific designated. Large tracts of floodplain on the lower river are owned and managed by the NCWRC, TNC and USFWS (USFWS 2005). NC WRC has designated a portion of the river as an Inland Primary Nursery Area due to its importance as spawning habitat for anadromous fish. The river supports world-class recreational fisheries for migratory striped bass and hickory shad (Basinwide Planning Section 2006).

Historic Distribution and Abundance

Smith (1893) reported that the Roanoke River had a larger spawning run of sturgeon than the Chowan River. Sturgeon were caught within the fall zone of the Roanoke in fish slides, a type of trap or grating that stranded fishes moving through rapids (Yarrow 1874). Worth (1904) reported the capture of a 50 mm sturgeon as well as numerous larger juveniles "...of a hand's length..." and adults up to 90 kg within the fall zone.

Current Distribution and Abundance

An adult shortnose sturgeon (ca. 730 mm TL) was captured in northern Batchelor Bay on April 18, 1998, in a gillnet set by NCDMF staff; the specimen resides in the NC State Museum of Natural Sciences (NCSM #27062). This specimen may have escaped from the Edenton National Fish Hatchery (D. Cole, retired Assistant Manager, Edenton National Fish Hatchery, pers. comm.) that held shortnose sturgeon removerd from the Savannah River as reports indicate an accidental release and discharge into Pembroke Creek, a tributary to Edenton Bay. Alternatively, this shortnose sturgeon could have moved in to the sound from Chesapeake Bay via the AIWW.

There have been no reported captures of shortnose sturgeon within the Roanoke River since 1998. If shortnose sturgeon are present in the river, it is likely that more captures would have occurred during sampling programs conducted by Dominion Generation; NCSU, NC DENR or NC WRC. However, it should be noted that none of these programs are utilizing the sampling protocol recommended to detect shortnose sturgeon (Moser et al. 2000a).

Natural History and Habitat Information

Because only a single specimen has been documented from near the mouth of the Roanoke River, information on natural history and habitat use is minimal. Possible use of habitats summarized on Table 28 infers patterns of juvenile Atlantic sturgeon, and historic use by spawning sturgeon, as well as predictions for shortnose sturgeon habitat use undertaken by scientists studying anadromous fish spawning runs in the Roanoke River (Hewitt 2003).

Spawning

Hewitt (2003) predicted that if shortnose sturgeon were to spawn in the Roanoke River, they would do so between early March and early April, when water temperatures are between 9 to 14^{o}C. Because of Roanoke Rapids Dam at rkm 221, any shortnose sturgeon spawning in the Roanoke River would occur below the dam. Historically, if shortnose sturgeon used similar habitat to Atlantic sturgeon, they may have used that section of the river considered the fall zone, between rkm 206 and 242 (Carnes 1965). Armstrong and Hightower (2002) note that if archaeological sites with sturgeon remains reflect sturgeon migration, sturgeon moved up to at least rkm 261 (VanDerwarker 2001a).

Foraging
The single adult captured within the Roanoke River watershed was in Batchelor Bay. This channel likely offered foraging habitat, certainly for juveniles and probably for adults, for any shortnose population. The channel is currently considered Atlantic sturgeon foraging habitat for juveniles as evidenced by recent catches by anglers (Kornegay 2005).

Overwintering/resting
There is no information on overwintering or resting habitat for shortnose sturgeon in the Roanoke River watershed; deep holes are present in the lower river that could provide habitat.

Migration
There is no information on potential shortnose sturgeon migratory pathways in the Roanoke River.

Stressors to Riverine System

Stressors to the lower Roanoke River ecosystem are identified in Basinwide Planning Section (2005) and TNC and Southeast Aquatic Resources Partnership (2005). The most critical threat to the river is the altered hydrological regime that is significantly and negatively influenced by construction of three dams around the 1950s (see below) located at the fall line between the Piedmont and the Coastal Plain. In addition to hydrologic alteration from dams, a large silt deposit presumably developed between the mid-1800s and the 1950s: this deposit may have contributed to significant entrenchment of the river and impacts are unclear. The Roanoke River is subject to all of the stresses associated with global climate change; most notably, impacts are expected from higher temperatures, higher carbon dioxide levels, invasive species, more frequent and more powerful storms, and rising sea level.

Habitat presently accessible to shortnose (and Atlantic) sturgeon includes the lower Roanoke River from the base of Roanoke Rapids Dam (variously reported as between 135- 137.5 miles upstream of Albemarle Sound).

1. **Habitat**

Dams and diversions

There are multiple large hydropower and water supply dams on the Roanoke River upstream of Roanoke Rapids (Street et al. 2005, Appalachian Power Company 2008). From downstream to upriver on the main stem, they are Roanoke Rapids Dam (rm 137.5 operated by VA Electric and Power Company and completed 1955); Gaston Dam (rm145 operated by VA Electric and Power Company and completed 1963); John H. Kerr Dam (rm 179 operated by ACOE and completed

1952); Leesville Dam (rm296 operated by Appalachian Power Company and completed 1965); and the Smith Mountain Dam (rm 314 operated by Appalachian Power Company and completed 1963). Other dams occur on the Dan River and its tributaries including: Pinnacles Hydro Project, Hydro Dam, Mayo Dam, and Philpott Dam. The dams and their associated reservoirs alter the connectivity of aquatic habitats for diadromous and other types of fish species.

Based on archaeological remains and historic reports, it is highly likely that a significant percentage of former sturgeon spawning habitat in the Roanoke River is no longer accessible due to Roanoke Rapids and Gaston Dams. Armstrong and Hightower (2002) estimated that from 21 to 40 km of potential sturgeon spawning habitat was either filled or inundated by reservoir construction. This translates to a loss of from 58 to 73% of historic sturgeon spawning habitat.

Other energy projects

Tidal Turbines

Given that the Roanoke River and its tributaries are non-tidal, it is unlikely that tidal turbines would be installed.

LNG Facilities

There are currently no LNG facilities located or proposed for locations within the Roanoke River or its tributaries.

2. Overutilization

Given the apparent absence of shortnose sturgeon from the Roanoke River, overutilization (including bycatch, poaching and scientific research) is not presently viewed as a threat.

3. Competition, Predation and Disease

Refer to preceding information provided for Albemarle Sound for details on competition, predation and disease.

4. Inadequacy of Existing Regulatory Mechanisms

Refer to preceding information provided for Albemarle Sound for details on NC, SC and VA regulatory mechanisms.

5. Other Natural or Manmade Factors

Refer to preceding information provided for Albemarle Sound for details on impingement and entrainment, ship strikes, artificial propagation and escapement of hatchery/captive fishes.

Current Research and Recommended Research

Refer to preceding information provided for Albemarle Sound for details on current and recommended research.

Pamlico Sound

Although shortnose sturgeon may not presently inhabit the water bodies listed below, we include background information to assess stressors as they may be present and were so historically.

Stressors to Riverine System

1. Habitat

Dams and diversions

There are no dams in Pamlico Sound. There are some portions of the AIWW which connect the sound with other nearby water bodies via land cuts, thereby diverting water from them into Pamlico Sound, or vice versa.

Other energy projects

Tidal Turbines

Emplacement of tidal turbines within Pamlico Sound is highly unlikely due to the sporadic and inconsistent nature of the largely wind-driven local tides.

LNG Facilities

There are currently no LNG facilities located or proposed within Pamlico Sound.

Dredging and Blasting

The ACOE maintains navigation channels through portions of Pamlico Sound as part of the AIWW (Street et al. 2005), navigation channels through inlets, and entrance channels to state ferry landings. There is no blasting required for the maintenance of these channels. There are also other small, privately maintained channels serving marinas and private dock facilities throughout the sound (Street et al. 2005).

Dredging in estuarine waters in NC is prohibited between April 1 and October 1 to avoid disturbing the bottom in nursery areas when juvenile fishes are present, except in specific areas where dredging is allowed during the moratorium period (Street et al. 2005).

2. Inadequacy of Existing Regulatory Mechanisms

Refer to preceding information provided for Albemarle Sound for details regarding NC, SC, and VA regulatory mechanisms.

Tar-Pamlico River Basin

Stressors to Riverine System

1. Habitat

Other energy projects

Tidal Turbines

Emplacement of tidal turbines within tidal portions of the Tar-Pamlico River is highly unlikely due to the sporadic and inconsistent nature of the largely wind-driven local tides.

LNG Facilities

There are currently no existing or proposed LNG facilities in the Tar-Pamlico River basin.

Water Quality and Contaminants

The Pamlico and adjacent Pungo Rivers have been identified in past reports as the location of a “dead zone,” an area where DO levels are low or absent, with consequent reductions in use by riverine or estuarine organisms (Table 36; Bricker et al. 1999, Bricker et al. 2007, Diaz and

Rosenberg 2008). In 1999, the Pamlico/Pungo Rivers were rated as highly eutrophic (Bricker et al. 1999). Of the six factors (chlorophyll a, epiphytes, macroalgae, low DO, SAV loss, and nuisance/toxic blooms) used to determine eutrophication condition, one (chlorophyll a) was rated as "high" and three factors (i.e., low DO, SAV loss and nuisance/toxic blooms) were rated as occurring with "moderate" frequency in the Pamlico and Pungo rivers (Bricker et al. 1999). The current National Estuarine Eutrophication Assessment (Bricker et al. 2007) also was unable to determine the eutrophication condition for this location. Other NC systems were rated as having high levels of eutrophic conditions (see Neuse River and New River).

2. Overutilization

Given the apparent present absence of shortnose sturgeon from the Tar-Pamlico System, overutilization (including bycatch, poaching and scientific research) is not presently viewed as a threat.

3. Inadequacy of Existing Regulatory Mechanisms

Refer to preceding information provided for Albemarle Sound for NC, SC and VA.

Neuse River Basin

Stressors to Riverine System

1. Habitat

Dams and diversions

The lowermost dam on the Neuse River is at rkm 328 (Oakley and Hightower 2007). In 1997, the Quaker Neck Dam was removed opening 121 kms of main stem river to diadromous fishes. The current lowermost Dam on the Nuese River is Milburnie Dam, located at rkm 341.

Other energy projects

Tidal Turbines

Emplacement of tidal turbines within the tidal portion of the Neuse River is highly unlikely due to the sporadic and inconsistent nature of the largely wind-driven local tides.

LNG Facilities

There are currently no existing or proposed LNG facilities in the Neuse River watershed.

2. Overutilization

Given the apparent present absence of shortnose sturgeon from the Nuese River, overutilization (including bycatch, poaching and scientific research) is not presently viewed as a threat.

3. Inadequacy of Existing Regulatory Mechanisms

Refer to preceding information provided for Albemarle Sound for details on NC, SC and VA regulatory mechanisms.

North River Basin (Back Sound)

Stressors to Riverine System

1. Habitat

Other energy projects

Tidal Turbines

Placement of tidal turbines within the tidal portion of the North River is highly unlikely due to the sporadic and inconsistent nature of the largely wind-drive tides within the river.

LNG Facilities

There are currently no existing or proposed LNG facilities in the North River watershed.

2. Overutilization

Given the apparent present absence of shortnose sturgeon from the North River, overutilization (including bycatch, poaching and scientific research) is not presently viewed as a threat.

3. Inadequacy of Existing Regulatory Mechanisms

Refer to preceding information provided for Albemarle Sound for details regarding NC, SC, and VA regulatory mechanisms.

New River Basin

Stressors to Riverine System

1. Habitat

Other energy projects

Tidal Turbines

Emplacement of tidal turbines within the tidal portion of the New River is highly unlikely due to the sporadic and inconsistent nature of the largely wind-driven local tides.

LNG Facilities

There are currently no existing or proposed LNG facilities in the New River watershed.

2. Overutilization

Given the apparent present absence of shortnose sturgeon from the New River, overutilization (including bycatch, poaching and scientific research) is not presently viewed as a threat.

3. Inadequacy of Existing Regulatory Mechanisms

Refer to preceding information provided for Albemarle Sound for details on NC, SC, and VA regulatory mechanisms.

Cape Fear River Estuary (including the Brunswick River)

This description of the estuary is partially paraphrased after Schwartz et al. (1982) and Moser and Ross (1995). *The Cape Fear River Estuary is unique in NC in that it is the only estuary which opens directly into the Atlantic Ocean (Street et al. 2005), and it has the highest tidal range (± 2 m) of any NC estuary (Schwartz et al. 1982). Tidal range attenuates up the estuary and decreases from 1.2 m at rkm 49 to 0.3 m at rkm 96 (Moser and Ross 1995). The estuary is 0.3 km wide at Wilmington, widens to 2.1 km at Snow's Cut in mid-estuary, and 2.0 km at its mouth. The estuarine portion of the Cape Fear River Basin occupies 880 km^2 of the entire* *system (approximately 6%). A side channel of the Cape Fear River which parallels the main channel runs from rkm 37 to 46 and is named the Brunswick River (Moser and Ross 1995).*

Historic Distribution and Abundance

Sturgeons historically supported a valuable commercial fishery in NC (Moser and Ross 1995, Secor 2002), and in the late 1800's the largest sturgeon landings in the southeastern US were recorded from the Cape Fear River system (McDonald 1887). The proportion of shortnose and Atlantic sturgeon in the landings, as well as proportion derived from the estuary and the basin is unknown as commercial landings of sturgeonwere not separated by species at that time (Moser et al. 1998). The only specific locality noted for commercial fishing operations in the Cape Fear River Estuary was a haul-seine "...at the mouth of the river in the vicinity of New Inlet" (McDonald 1887) although the text does not indicate whether sturgeon were taken at this locality. No other historic information on the distribution and abundance of shortnose sturgeon in the estuarine portion of the Cape Fear River Basin has been located.

Current Distribution and Abundance

Extensive surveys of the lower Cape Fear River conducted from 1973 through 1980 by Schwartz et al. (1981) yielded no shortnose sturgeon. Sampling, conducted in association with environmental studies for the Brunswick Steam Electric Plant (BSEP), a nuclear power station, was extensive and employed beach seine, rotenone, gill net, plankton net, otter trawl and BSEP traveling screens for gear. Subsequent to these investigations, voucher specimens were deposited in the collection of the NC State Museum of Natural Sciences, and re-examination of these sturgeon specimens some years later by Dr. Wayne Starnes and other museum staff determined that one labeled as an Atlantic sturgeon was actually a shortnose sturgeon that had been collected in the Cape Fear River Estuary (NCSM #28520; W.Starnes, Director, NC State Museum of Natural Sciences Research Laboratory, pers. comm.). This individual was collected on April 30, 1978, in the lower estuary just east of Buoy 18, approximately 0.8 air miles southeast of the center of Southport (Table 29).

Subsequent investigations by Moser and Ross (1989, 1993, 1995) determined shortnose sturgeon were present in the upper estuary (Brunswick River side channel) and lower Cape Fear River proper below Lock and Dam #1 (details below). Shortnose were captured in the Brunswick River in February, 1989; January, 1990; February, 1991; and February, 1992. One of these individuals died during capture (Table 29) and two were gravid females (Moser and Ross 1995).

The current distribution and abundance of shortnose sturgeon in the Cape Fear River Estuary is unknown. No specimens have been encountered since 1997.

Natural History and Habitat Information

Given that only a small number of shortnose sturgeon have recently been captured in the Cape Fear River estuary, and even fewer have been tagged and tracked, information on natural history and habitat use is sparse and the information in this section is theoretical.

Spawning

Three gravid female shortnose were captured in the Brunswick River reach of the estuary during the months of January and February in 1989, 1990, 1991 and 1992 (Moser and Ross 1995).

Based on several females whose movements were tracked using sonic transmitters, Moser and Ross (1995) concluded that the directed upstream movements they observed were occurring "...at rates similar to those reported for prespawning shortnose sturgeon in other systems (Buckley and Kynard 1985a; Hall et al. 1991), indicating that shortnose sturgeons in the Cape Fear River drainage participate in spawning migrations." They noted as well that both Cape Fear River specimens deposited at the NC State Museum of Natural Sciences (NCSM #13827, and NCSM #17539) were gravid females, as were two of the individuals they used for sonic tracking.

The Cape Fear River estuary most likely serves as a migration and/or staging corridor for spawning, rather than for spawning activity. Although Schwartz et al. (1982) report that a series of rock ledges existed in the lower estuary, it is unlikely that spawning would take place there because of the relatively high salinities. Salinities determined lethal to 50% of juvenile shortnose sturgeon tested after 48 h ranged from 14.8-20.9 ppt (Ziegeweid et al. 2008), which is well within the reported range occurring in the Cape Fear River Estuary (Schwartz et al. 1982, Moser and Ross 1995).

Foraging
Based on capture locations, it seems likely that shortnose sturgeon foraging habitat includes the lower Cape Fear estuary and Brunswick River channel. The literature reports gut contents for only one shortnose sturgeon captured from the Cape Fear River Estuary: a gravid female contained two slender isopods (*Cyathura polita*), detritus and sand grains (Moser and Ross 1995).

Overwintering/resting
Given capture dates, adult shortnose sturgeon overwinter primarily in the Brunswick River portion of the estuary (Table 29).

Migration
Moser and Ross (1995) tracked five shortnose sturgeon for up to three months; three individuals were captured in the Brunswick River during January and February. Tagged shortnose sturgeon were observed occupying the entire river from rkm 16 to 96 (Lock and Dam #1, see below) from January to mid-July, moving through both the un-dredged Brunswick River and the regularly-dredged Wilmington Harbor even during maintenance operations (Moser and Ross 1995). Recaptured shortnose sturgeon moved downstream at rates of 8.5-36.0 km/d. One individual captured initially by a commercial fisherman in the Brunswick River was subsequently recaptured twice in a stationary gillnet in the same river; this sturgeon moved downstream rapidly after the second recapture and did not move back upstream while being monitored.

Stressors to Riverine System
The Cape Fear River basin and estuary is the most industrialized river basin in NC (Mallin et al. 2003) and perhaps the most highly altered hydrodynamically as a consequence of dams in the estuary and on the main stem, water diversions and withdrawals, and navigational channel construction (Snow's Cut) and deepening, all of which facilitate the upstream excursion and intrusion of saline waters into areas that were historically fresh.

The estuary is a drowned river valley, characterized by tidally driven currents, high turbidity and vertical salinity stratification (Moser and Ross 1995). Mean bottom salinity at rkm 21 in the lower estuary (south of Snow's Cut, Moser and Ross 1995) ranges from 9 to 25 ppt, varying with seasonal changes in river discharge (50-900 m^3/s). Sediment in the estuary ranges from soft mud to sand. The main ship channel has a mud-clay substrate for most of its length, with silting occurring north of the city of Wilmington. Shoals exist on either side of the ship channel. From Wilmington south to Buoy 42 the narrow east and west shoals, on either side of the channel, are composed of sandy-mud. South of Snow's Cut eastern shoals are typically sandy while mud dominates the western shoals. Extensive mud flats are present in the vicinity of the mouth of the river at Caswell Beach. A Pleistocene sandstone and the porous Castle Hayne formation create a series of rock ledges that pass from southwest to northeast across the river at Buoy 18 and produce a sill on the east side of the river near the buoy.

River discharge that once passed through New Inlet (more recently known as Corn Cake Inlet) to the north of Bald Head Island (also known as Smith Island) was diverted by construction of dams (see below) and navigational channel dredging, to enter the sea between Bald Head Island and Oak Island (Caswell Beach). Spring runoff varies from lows of 0.5 to highs of 3.1 m/sec (Schwartz and Dalhberg 1978) and is often influenced by tropical hurricanes, inland storms, rainfall, and occasional snow melt from inland tributaries. The river channel is regularly dredged: initially in 1822 by the State of NC and recently by the ACOE in collaboration with the state (Sprunt 1916, NCDWR 2006, and discussion below).

1. **Habitat**

Dams and diversions

There are no dams in the main stem Cape Fear River Estuary; however, there are several structures constructed to block lateral transport of sediment from the Atlantic Ocean into the Cape Fear River Estuary. The first is a structure variously referenced as a "tidal dam" or "defensive dike" begun in 1875 and completed by the ACOE in 1881, to prevent sedimentation into the navigation channel of the lower Cape Fear River Estuary. This stone structure originates on the south end of Zekes Island and terminates at Bald Head (Smith) extending 5,300 feet in length. Historically known as the New Inlet Dam, it is generally referred to by locals today as "The Rocks." A second structure, Swash Defense Dam, was constructed from stone between 1883 and 1889 and is 12,800 ft in length (Sprunt 1914). These two dams block any direct easterly access from the lower Cape Fear River to the Atlantic Ocean, and instead alter migration routes via Oak Island Channel to the south through the mouth of the river, and via Snow's Cut through Myrtle Grove Sound and out several inlets to the ocean.

A channel was excavated through high ground between Myrtle Grove Sound and the lower Cape Fear River Estuary to divert high salinity ocean water into the estuary. Snow's Creek Cut is a navigational channel which is part of the AIWW; constructed by the ACOE in 1929, it diverts some portion of the lower river's flow to the east from the main channel, as well as diverting the higher salinity water from Myrtle Grove Sound and the Atlantic Ocean, into the river. The change in hydrodynamics of the estuary resulting from Snow's Cut construction which allowed higher salinity water to enter the estuary near its midpoint, "...has had far-reaching effects on the physical, chemical and biological functioning of the estuary" (NCDWR 2006).

The impact of dam and diversion construction within the lower Cape Fear River Estuary on shortnose sturgeon use of the estuary is unknown. Clearly, once-open migration routes to the Atlantic Ocean have been closed for decades, and large portions of the estuary that were once meso- or oligohaline for significant portions of the year are now mesohaline or higher. The fact that one shortnose was collected in the lower estuary as recently as 1978 suggests that at least some shortnose sturgeon still utilize these habitats.

Other energy projects

Tidal Turbines

Given that the Cape Fear River Estuary has the strongest currents and highest tidal range of any coastal locality in NC, proposals for tidal turbine emplacement in this estuary could be forthcoming. At least one such conceptual proposal has been made for tidal turbines to be located within and along the SC portion of the AIWW, just to the south of the Cape Fear River Estuary. In the proposal, tidal turbines are envisioned as integral parts of way stations designed for kayakers. The ecological impacts of the turbines are not addressed; however, it is likely that such turbines could pose a hazard to any shortnose sturgeon using the AIWW as a migratory pathway. Members of the SNS SRT speculated that shortnose sturgeon from the Pee Dee River-Winyah Bay population may be the source of the shortnose sturgeon in the Cape Fear River, as the AIWW connects the two estuaries and provides a potential migratory pathway. Shortnose sturgeon from the Savannah River, reared at Orangeburg National Fish Hatchery in the Edisto River Basin, and released in the Savannah River, may have used the AIWW to return to the Edisto River (Smith et al. 2002a). Given that such migration using the AIWW has been documented to occur, tidal turbines emplaced in the AIWW in either NC or SC should be considered a potential threat to migrating shortnose sturgeon. A review of the concerns associated with emplacement of tidal turbines in estuaries with macrotidal currents is contained in Dadswell and Rulifson (1994).

LNG Facilities

There are currently no existing or proposed LNG terminals located on the Cape Fear River Basin. However, because Wilmington is a major port, and because construction of another port downstream at Southport is being considered, it would be possible to locate a LNG facility or facilities in the watershed.

Dredging and Blasting

Excavation to support navigation in the lower Cape Fear River Estuary began in 1822 (Sprunt 1914) and has continued relatively unabated to the present day (Rice and Hall 2000). The Brunswick River channel has not been extensively dredged since the 1940's (Moser and Ross 1995). The estuary has been dredged annually from rkm 37 to 46 (Wilmington Harbor) to maintain a depth of 12 m (Moser and Ross 1995) and in recent years (since 1997) the channel was deepened to 12.8 m (NC DWR 2006). Additional excavation is occurring to construct a passing lane (200 foot widening of the channel for a distance of six miles) and construction of wideners at major turns and bends in the Cape Fear River navigation channel (NCDWR 2006).

Moser and Ross (1995) indicated that “Atlantic and shortnose sturgeons occupied both relatively undisturbed and regularly dredged areas and were tracked through the Wilmington Harbor during dredging operations.” They indicated that the sturgeon appeared to seek out deep areas and stay in midchannel, behaviors that would put them in the proximity of dredges. However, they found evidence that shortnose sturgeon remain within 2 m of the surface while moving, and noted that would limit their entrainment in dredges. McCleave et al. (1977) also reported that shortnose sturgeon move closer to the water surface.

Water Quality and Contaminants

Commercial fishermen from the Cape Fear region interviewed by NC DMF indicated that pollution and water quality was the most important issue facing them, with a rating of 9.19 out of a possible 10 (Cheuvront 2003). Many of the fishermen felt that reductions in the targeted species were due to increased pollution and degradation of estuarine water quality. Fish dealers in the region perceive pollution as the primary reason for reduced stocks (Cheuvront 2003).

2. Overutilization

Given the present extremely low population level of shortnose sturgeon within the Cape Fear River, "overutilization" could be occurring if there is any removal whatsoever of mature adults from the population.

Bycatch

Multiple commercial fisheries occur in the Cape Fear estuary (Cheuvront 2003) and bycatch of shortnose sturgeon has occurred (Moser and Ross, 1989, 1995). In 2003, a survey conducted by the NC DMF indicated the following fisheries were occurring in the region including the Cape Fear River Estuary: clams (*Mercenaria mercenaria*), oysters (*Crassostrea virginica*), and scallops (*Argopecten irradians*)gathered by hand or using mechanical means, tongs, rakes or scoops; shrimp were taken by trawl, skimmer trawl or channel net; blue crabs (*Callinectes sapidus*) by pots; and flounders (*Paralichthys* spp.), spot (*Leiostomus xanthurus*), striped (*Mugil cephalus*) and white mullet (*M. curema*), Atlantic croaker (*Micropogonias undulatus*) and weakfish (*Cynoscion regalis*) by gillnets or gigs (flounder only).

Bycatch in a commercial gillnet in 1987 provided the first documented capture of a shortnose sturgeon (gravid female) from the Brunswick River (Moser et al. 1998). Moser and Ross (1989) interviewed individual gillnet fishermen, providing them with photographs and keys to identification. They were able to obtain information on the number of shortnose sturgeon that were regularly captured and their likely distribution and seasonality in the lower Cape Fear River drainage. Moser and Ross (1995) indicated that "Shortnose sturgeons are very rare in the Cape Fear River drainage and are extremely susceptible to both set and drifting gill nets that target striped bass (*Morone saxatilis*) and American shad (*Alosa sapidissima*). Several commercial fishermen reported capturing shortnose sturgeon regularly in the past, but always in small numbers. Some of these fishermen may have captured and released the same individual on several occasions, as occurred twice during this study...."shortnose sturgeons may still suffer significant mortality from incidental capture." As noted by Collins et al. (1996), both species of sturgeon are captured in American shad and striped bass commercial fisheries in southeastern rivers and are very susceptible to both stationary and drift gillnets.

Current commercial fisheries and associated gear in the Cape Fear River estuary include the following: drift and set large-mesh gill nets for American shad and flounder; small-mesh gill nets for Atlantic croaker, mullet, pompano (*Trachynotus carolinensis*) and spot; trawling for shrimp (genera *Farfantepenaeus*, *Litopenaeus* and *Trachypenaeus*); pots for blue crab; and clamming and oystering by hand. The vast majority of these fisheries (the exception being that for American shad) occur in the lower estuary below Snow's Cut (F.Rohde, NMFS, pers. comm.). It is possible for all net and pot fisheries to encounter shortnose sturgeon; by hand fisheries for shellfish are not likely to entail any shortnose sturgeon bycatch. Current commercial effort in the lower estuary and river is down relative to historical levels (F. Rohde, NMFS, pers. comm.).

Poaching

No poaching of shortnose sturgeon from the Cape Fear River Estuary has been documented. A case of shortnose sturgeon poaching was documented from adjacent SC (Collins et al. 2000a); however, the species appears more abundant there and may be more susceptible to illegal take.

Scientific research

A single shortnose sturgeon was captured in the estuary during scientific sampling associated with environmental studies by UNC. Additional studies by Moser, Ross and others (Moser and Ross 1989, 1993, 1995; Moser et al. 1998) resulted in incidental capture of additional shortnose sturgeon and resulted in the mortality of one individual in 1991 (Table 29).

3. Inadequacy of Existing Regulatory Mechanisms

Refer to preceding information provided for Albemarle Sound for details on NC, SC, and VA regulatory mechanisms.

4. Other natural or manmade factors

Artificial Propagation

See the discussion in the Cape Fear River section.

Escapement of Hatchery/Captive Fishes

See the discussion inthe Cape Fear River section.

Current Research and Recommended Research

See the discussion in the Cape Fear River section.

Northeast Cape Fear River Basin

Stressors to Riverine System

1. Habitat

Other energy projects

Tidal Turbines

Emplacement of tidal turbines within the tidal portion of the Northeast Cape Fear River is highly unlikely due to the sporadic and inconsistent nature of the largely wind-driven local tides.

LNG Facilities

There are currently no existing or proposed LNG facilities in the Northeast Cape Fear River watershed.

Overutilization

Given the apparent present absence of shortnose sturgeon from the Northeast Cape Fear River, overutilization (including bycatch, poaching and scientific research) is not presently viewed as a threat.

Inadequacy of Existing Regulatory Mechanisms
Refer to preceding information provided for Albemarle Sound for details on NC, SC, and VA regulatory mechanisms.

Black River Basin

Stressors to Riverine System

1. **Other natural or manmade factors**

Ship Strikes

Ship strikes are not likely a significant threat on the Black River as ships are not able to navigate up the river.

Artificial Propagation

It is probable that any shortnose sturgeon using the Black River are part of the Cape Fear River population. Artificial propagation of Cape Fear River shortnose sturgeon is not presently a threat as none are presently in captivity.

Escapement of Hatchery/Captive Fishes

Escapement of hatchery-reared fish is an unlikely threat but see detailed discussion below in the Cape Fear River section.

Current Research and Recommended Research

Additional research is needed to determine:

- the extent of use of the Black River by shortnose sturgeon from the Cape Fear River population, and
- the potential existence of shortnose sturgeon spawning habitat in the Black River.

Cape Fear River

Historic Distribution and Abundance

Yarrow (1874) stated that “Sturgeon are so numerous in the Cape Fear as almost to preclude the possibility of drift-fishing in the month of April.” There is no indication given as to whether any of them were shortnose. Earll (1884) indicates only that “...sturgeon...” were one of the principal species fished at Wilmington but provides no details of gear, location or the size of sturgeon taken. McDonald (1887) indicates only that the sturgeon fishery in the Cape Fear was conducted nearly year-round, with a spring fishery from March 10 through April to supply the New York market, a summer fishery to meet local demand and supply “...interior towns of the State” and a fall fishery from September 10 to November 1. He refers to the “...average catch of a net for the fall fishing season...” being “...about 200 fish...” but doesn’t say what type of net was used, or where in the river they were set. Again, there is no indication as to what proportion of the catch, if any, were shortnose. To our knowledge there are no historic specimens from the Cape Fear drainage in any museum collections.

Current Distribution and Abundance

Prompted by the report of a gravid female shortnose sturgeon captured in the NC portion of the Pee Dee River in 1985 (Ross et al. 1988), commercial shad fishermen from the Cape Fear River drainage were interviewed as toencounters with small or unusual sturgeon. On January 29, 1987, a shortnose sturgeon (768 mm TL) was obtained from the Brunswick River, a tributary to the Cape Fear, in Brunswick County (Table 29, specimen NCSM #13827, reported in Ross et al. 1988). The capture was followed by subsequent investigations that detected approximately 15 additional individuals in the same area. Between 1989 and 1993, eight additional shortnose were caught in the Cape Fear River drainage, during an extensive gillnet survey below Lock and Dam # 1 (Moser and Ross 1993, 1995). Ross et al. (1988) later concluded that "...the Cape Fear River drainage probably contains a self-sustaining population of shortnose sturgeon."

Moser et al. (1998) targeted shortnose sturgeon in the upper Cape Fear River using gill nets between March-July 1996 and 1997. Additional sites were added in 1997, in the Cape Fear River below Lock and Dam #1 and in the Northeast Cape Fear River (survey results for the Northeast Cape Fear River are discussed in the preceding section). A total of 313 days of effort with 50 m nets yielded no shortnose sturgeon. Notably, Moser et al. (1998) reported capture ofseveral individuals that possessed shortnose sturgeon characters among the total of 88 Atlantic sturgeon captured during the study: while many had mouth width/interorbital distance ratios that were characteristic of shortnose sturgeon, all other meristics (paired pre-anal shields, 6-8 rows of subdermal plates between lateral and dorsal scutes, greater than 22 anal rays, scutes along the anal fin base) described Atlantic sturgeon (Menhinick 1991), with the exception of three individuals lacking pre-anal shields.

Subsequent to the captures of shortnose sturgeon by Moser and Ross (1993, 1995) and studies by Moser et al. (1998), several other large-scale fish sampling programs have been conducted by university researchers along with fishery-independent sampling byNC DMF and NC WRC: all of these programs have encountered Atlantic sturgeon but failed to capture any additional shortnose sturgeon.

The lower Cape Fear River Program conducted by UNC-W, is a large-scale water quality and environmental assessment program encompassing the Cape Fear River Estuary and a large portion of the lower Cape Fear watershed (see the web site: http://www.uncwil.edu/cmsr/aquaticecology/LCFRP/). The program includes a fin fish monitoring component (http://www.uncwil.edu/cmsr/aquaticecology/LCFRP/Fisheries/finfish.htm) from 1995 through 2003, which was a collaborative endeavor between UNC-W and NC DMF; no shortnose sturgeon were captured in the lower Cape Fear River or estuary.

Natural History and Habitat Information

Spawning

Gravid female shortnose sturgeon tracked by Moser and Ross (1995) engaged in a directed upstream migration and their behavior suggested that a reproducing population of shortnose sturgeon might exist above Lock and Dam #1 (Moser et al. 1998).

Moser et al. (1998) conducted a pilot survey for shortnose sturgeon eggs in the upper Cape Fear River from March-July in 1996 and 1997 using buffer pad collectors. Sites sampled included likely spawning areas between Locks and Dams #1 and #3; sites below Lock and Dam #1 were added in 1997. Buffer pads wer soaked for eggs a total of 212 days (one 51 cm sampler set for 24 h) in 1996; 230 days were sampled in 1997. Although the eggs of other species were collected, no shortnose sturgeon eggs were found.

Stressors to Riverine System

1. Habitat

Dams and diversions

Multiple low-head dams on the main stem Cape Fear River presently block access to what were the likely historic spawning habitats for both Atlantic and shortnose sturgeon. As noted by Ross et al. (1988), survivability of this population "...has been reduced because upriver areas necessary for spawning and nurseries have been increasingly modified or destroyed..." (Ross et al. 1988).

Other energy projects

Tidal Turbines

As noted above, due to the strength of the tidal currents in the Cape Fear River, there is potential for the development of tidal turbines. No documentation was located for tidal turbine plans under consideration at the present time for the Cape Fear River.

LNG Facilities

There are currently no existing or proposed LNG terminals within the Black River Basin System. However, given the presence of a deepwater port at Wilmington, there is potential for an LNG facility to be located there although no such facility is currently present.

Dredging and Blasting

The potential impacts of navigation channel deepening on chemical, physical and biological integrity of the lower Cape Fear River and estuary were summarized most recently in Culbertson et al. (2008) and in prior reports (see reports by CZR, Inc.,2001 and 2002, and Hackney et al. 2002-2008, all available online) from the Wilmington Harbor Project. Because Wilmington is one of only two major ports in NC, ship traffic through the estuary and lower river is relatively heavy. Trends over the last two decades have been to reduce costs by building larger ships. These ships require deeper channels to operate safely; therefore, the ACOE and NC Ports Authority initiated a project to deepen the Cape Fear River shipping channel from the mouth of the river up to the city of Wilmington. Such deepening has several potential impacts including the shifting of the tidal salt wedge upstream, changes in tidal amplitude, subsequent shifts in wetland flooding intensity, and changes in inundation time. All of these changes have potential to impact use of the estuary and lower river by shortnose sturgeon and their benthic prey. Significant impacts on critical nursery habitats in the Cape Fear River estuary are likely, potentially altering physical and chemical characteristics of the sediment, or the inundation period leading to alterations in the vegetation along the fringing marsh and shifts in dominant infauna, and utilization habits by resident and transient fishes (Culbertson et al. 2008, CZR, Inc. 2001 and 2002, and Hackney et al. 2002-2008).

2. Overutilization

Bycatch

Moser et al. (1998) failed to capture any shortnose sturgeon in this portion of the river using gill nets. Bycatch of shortnose sturgeon in the Cape Fear River above Lock and Dam #1 therefore appears unlikely, although there is the remote possibility that individuals could be captured with hook and line, or trotline gear, as juvenile Atlantics have been so taken in other VA and NC rivers (A. Spells, USFWS, pers. comm.; K. Nelson, NC WR, NC, pers. comm.).

Poaching

There are no documented cases of shortnose sturgeon poaching in the Cape Fear River.

Scientific research

Scientific sampling is being conducted annually in the Cape Fear River and estuary; no program has encountered any shortnose sturgeon in recent years and therefore it appears that scientific research is not a threat at this time. Should shortnose sturgeon increase and research efforts increase, it is likely that existing state and federal permitting programs would be effective in reducing the threat from this activity.

3. Inadequacy of Existing Regulatory Mechanisms

Refer to preceding information provided for Albermarle Sound for details on NC, SC, and VA regulatory mechanisms.

4. Other Natural or Manmade Factors

Artificial Propagation

Artificial propagation of Cape Fear River shortnose sturgeon is not presently a threat as none are being held in captivity.

Escapement of Hatchery/Captive Fishes

We do not believe escapement of captive fish is an issue within the basin. Currently both the NC Zoolgical Park and the NC Aquarium have permission to display shortnose sturgeon under stringent conditions. Other captive shortnose sturgeon in the southeast U.S. are Savannah River strain shortnose sturgeon held by the USFWS at Orangeburg National Fish Hatchery, SC, and at the University of Florida, Gainesville. These do not likely to pose any threat due to the security of the facilities in which they are held, and the distance they would have to travel to reach the Cape Fear River, should they escape, although such travel is not beyond the realm of possibility (Smith et al. 2002a, 2002b).

Current Research and Recommended Research

Ross et al. (1988) recommended the following: 1) circulation of a description of shortnose sturgeon and its importance in the areas where it is most likely to be encountered, including the Cape Fear River; 2) conducting an initial gillnet survey of the Cape Fear and Brunswick rivers near Wilmington; and 3) if shortnose sturgeon were found, collection of extensive biological data. They noted also that size limit and other conservation measures recommended for Atlantic sturgeon would protect shortnose sturgeon as well. The first two recommendations have been implemented; the third has proven difficult given the small numbers of shortnose sturgeon present in this system.

The Shortnose Sturgeon Recovery Plan (NMFS 1998) identifies a number of tasks and priorities for the Cape Fear River population as follows:

- Determine abundance, age structure, and recruitment.
- Conduct status review.
- Document distribution and map sturgeon concentration areas.
- Assess mortality factors and define take limits.
- Assess mortality from incidental capture.
- Identify critical habitat for population segments.
- Assess shortnose sturgeon use of any designated critical habitat.
- Insure that proposed structures provide passage.
- Minimize impacts of dredging, blasting and disposal (stated as ongoing in 1998).
- Assess mortality from impingement.
- Analyze contaminant loads in sturgeon tissue and habitat.
- Collect continuous DO data (stated as ongoing in 1998).
- Determine effects of introduced species.
- Identify movement patterns and eliminate barriers to movement.
- Restore flows and spawning substrate.
- Identify contaminant sources and reduce loading.

A number of the tasks have been initiated and/or completed to the limited degree allowed by captures of Cape Fear River shortnose sturgeon have allowed. All state and federal fishery management agencies are currently working hard to provide passage for sturgeon at the three ACOE Locks and Dams and to minimize impacts of dredging, blasting and disposal. Some continuous oxygen data have been collected from the system, and some information has been collected on the effects of introduced species. Moser and Ross (1995) were able to identify movement patterns to some extent although their sample size was very small. There have been some contaminant studies in the system.

Table 27. Reported observations of shortnose sturgeon in VA/NC water bodies, by water body, year and source[1] (X = reported present in system; blank cell = reported but for no specific system; E = considered extinct in system; T=threatened in system, if present; date in cell indicates year specimen collected; green, supporting specimen; yellow, doubtful written record; red, verbal report based on interview only).

Table 27. Reported observations of shortnose sturgeon in VA/NC water bodies, by water body, year and source[1] (X = reported present in system; blank cell = reported but for no specific system; E = considered extinct in system; T=threatened in system, if present; date in cell indicates year specimen collected; green, supporting specimen; yellow, doubtful written record; red, verbal report based on interview only).

WATER BODY	1877	1886	1887	1907	1945	1963	1973	1976	1979-80	1982	1984	1988	1989	1991	1995	1998	1998	2005	2008
Atlantic Ocean							X		X	E									
North-Alb										E						X, 1994			
Chowan						1881			1881	E/T	1881			1881					
Roanoke									X	E/T			X				1998		1998
Albemarle Sound									X	E/T			X			X	1998		1998
Tar-Pamlico										E/T									
Neuse	X				X				X	E/T	X	X		E		X		X	
Pamlico Sound									X	E			X						
North-Back	X	X							X	E	X	X		E					
New	X								X	E	X	X							
NE Cape Fear										E/T									
Black										E					X				
Cape Fear										E/T					X				
(Brunswick)										E		1987		1987	X				1991
Cape Fear Estuary									X	E				E					1978

[1]Yarrow (1877), Jordan (1886), McDonald (1887), Smith (1907), Vladykov and Greely (1963), Holland and Yelverton (1973), Schwartz and Link (1976), Lee et al. (1980), Rulifson et al. (1982b), Dadswell et al. (1984), Ross et al. (1988), Gilbert (1989), Menhinick (1991), Moser and Ross (1995), Moser et al. (1998), Armstrong and Hightower (1999), NCDMF, unpublished data (2005), Starnes, pers. comm. (2008).

Table 28. Summary of river-specific shortnose sturgeon distribution and habitat factors for basins terminating in NC coastal waters (see text for details).

RIVER-ESTUARY	HISTORIC	PRESENT NOW	SPAWNING	FORAGING	RESTING	MIGRATION
North-Albemarle	No records	Anecdotal report (Moser et al. 1998)	Not likely, habitat absent	Potential	Potential	Potential
Chowan-Albemarle	Yes: 1881	Not likely?	Potential	Potential	Potential	Potential
Roanoke-Albemarle	Yes?	Possible?	Potential	Potential	Potential	Potential
Albemarle Sound	Yes?	one in 1998, Possible based on anecdotal reports (Moser et al. 1998)	Not likely, habitat absent	Potential	Potential	Potential
Tar-Pamlico	No records	Not likely	Limited	Potential	Potential	Potential
Neuse-Pamlico	Yes?: 1877	Yes?: observer reports in 2005; no expert verification	Potential	Potential	Potential	Potential
Pamlico Sound	No	Yes?	Not likely, habitat absent	Potential	Potential	Potential
New	Yes?: 1877, 1886	Not likely	Potential ?	Potential	Potential	Potential
North-Back Sound	Yes: 1877	Not likely	Potential ?	Potential	Potential	Potential
Northeast Cape Fear	No records	Possible	Unknown	Potential	Potential	Potential
Black-Cape Fear	No records	Yes?: Moser and Ross 1995	Unknown	Potential	Potential	Potential
Cape Fear	Yes: 1987 ff	Yes ?	Potential	Potential	Yes?	Yes?
Brunswick	No records	Yes	Not likely	Yes?	Yes?	Yes?
Cape Fear Estuary	Yes: 1978	Yes?	Not likely	Yes?	Yes?	Yes?

Table 29. Summary data for all recorded shortnose sturgeon captures in NC waters (all specimens except the juvenile from Salmon Creek were captured in gill nets; Pee Dee River capture not included since the undammed portion of that watershed is largely in SC). FL = fork length, SL = standard length, and TL = total length.

WATERBODY	DATE: COLLECTOR/OBSERVER	LENGTH(S)	CATALOG #	REFERENCE
Chowan River (Salmon Creek)	April 12, 1881: J. Kite	185 mm TL	USNM 64330	Vladykov and Greely 1963
Cape Fear River Estuary	April 30, 1978: F.J. Schwartz et al.	575 mm TL	NCSM 28520	W.C. Starnes, NCSM, pers. comm.
Cape Fear River (Brunswick River)	January 29, 1987: S.W. Ross et al.	688 mm FL, 768 mm TL	NCSM 13827	Ross et al. 1988
Cape Fear River (Brunswick River)	February 16, 1989: M.L. Moser et al.	942 mm TL	released	Moser and Ross 1995
Cape Fear River (Brunswick River)	January 9, 1990: M.L. Moser et al.	900 mm TL	released	Moser and Ross 1995
Cape Fear River (Black River mouth)	May 4, 1991: M.L. Moser et al.	715 mm TL	released	Moser and Ross 1995
Cape Fear River (Brunswick River)	February 6, 1991: M.L. Moser	870 mm SL, 990 mm TL	NCSM 17539	Moser and Ross 1995
Cape Fear River (Brunswick River)	February 14, 1992: M.L. Moser et al.	812 mm TL	released	Moser and Ross 1995
Cape Fear River (rkm 90)	February 26, 1992: M.L. Moser et al.	753 mm TL	released	Moser and Ross 1995
Cape Fear River (rkm 90)	February 1, 1993: M.L. Moser et al.	525 mm FL, 623 mm TL	released	Moser and Ross 1995
Cape Fear River (rkm 90)	February 4, 1993: M.L. Moser et al.	568 mm FL, 643 mm TL	released	Moser and Ross 1995
Roanoke River (Bachelor's Bay)	April 18, 1998: J. Armstrong	730 mm TL	NCSM 27062	Armstrong and Hightower 1999

Table 30. Summary of shortnose sturgeon life stages documented from river basins terminating in NC estuaries (both historic and current records). Negative data, red highlighting; positive data, green; and uncertified reports, yellow.

ESTUARY/RIVER	EGGS/LARVAE	JUVENILES	ADULTS	GRAVID ADULTS
Albemarle Sound	No	No?	Anecdotal reports	No
North-Albemarle	No	No	Anecdotal report	No
Chowan	No	Yes, 185 mm TL (1, 1881)	No	No
Roanoke	No	No	Yes, approx. 730 mm TL (1, 1998)	No?
Pamlico Sound	No	No	No	No
Tar-Pamlico	No	No	No	No
Neuse	No	No	Yes, but not expert confirmed	No
North-Beaufort	No	No	No?	No
New	No	No	No?	No
Northeast Cape Fear	No	No	No	No
Black	No	No	Yes (one at river mouth, 1991)	No
Brunswick	No	No	Yes	Yes?
Cape Fear	No	No	Yes (multiple, 1978-1993)	Yes (1, 1987?[1]; 1, 1989; 1, 1990; 1, 1991)

1 Moser and Ross (1995) indicate the 1987 individual was a gravid female; however, Ross et al. (1988) do not indicate its status.

Table 31. River basin statistics for VA/NC systems reported to support shortnose sturgeon.

BASIN	AREA (sq mi)	ESTUARY (ac)	STREAM MILES	NPDES	POP-2000	SWINE OPS		REFS
North-Alb	?	?	?	?	?	?		
Chowan	5,439 (4,061VA; 1,378-NC)	16,970	5,826 (5,023-VA; 803-NC)	??-VA 10-NC	339,236-VA 61,034-NC			
Roanoke	9,801 (6,298 VA; 3,503-NC)	1,476	11,600 (9,387-VA; 2,213-NC)	??-VA 77-NC	675,844-VA 344,638-NC			
Tar-Pamlico	5,571	663,593	2,566	68	414,929			
Neuse	6,235	369,977	3,880	157	1,320,379			
North-Back	?	39,749	3	4				
New	462	22,840	204	27				
NE Cape Fear	1,743	0	1,743	26		576		
Black	1,577	0	1.039	12		497		
Brunswick								
Cape Fear	9,149	31,753	6,386	244	1,833,701			

Table 32. Identified issues and stressors to the habitats within the Albemarle-Pamlico Sound ecosystems.

THREAT	Copeland et al. (1983); Copeland et al. (1984)	Epperly and Ross (1986)	Stanley (1992)	Waite et al. (1994)	Martin et al. (1996)	NCWRC (2005)[1]	Street et al. (2005)2
Land use pattern alteration	X	X					X
Development/Urbanization	X	X				X	
Large scale land development	X	X					
Wetlands loss			X		X		X
Submerged aquatic vegetation loss		X	X		X	X	X
Nutrient inputs-eutrophication	X	X	X	X	X	X	X
Contaminant inputs, nonpoint sources	X	X		X		X	X
Sediment inputs, associated turbidity		X		X		X	X
Contaminant inputs from point sources	X	X		X		X	X
Septic tank effluent	X						
Increased BOD, low DO, anoxia		X		X		X	X
Toxic contamination	X	X	X	X	X	X	X
Migration blockages due to dams	X						X
Flow alterations from upstream dams	X					X	X
Channelization/ditching	X	X				X	X
Increasing human population growth		X			X	X	
Fish/shellfish diseases and kills		X	X	X		X	X
Impairment of nursery area function			X	X			X
Fecal coliform/pathogen contamination	X			X	X		X
Water quality decline					X	X	X

Large/small animal operations			X		X	X	
Increasing demand for water supply					X	X	X
Shoreline trash on estuarine shorelines					X		
Agricultural runoff					X	X	X
Stormwater runoff					X		X
Aquatic habitat destruction						X	
Atmospheric deposition of nitrogen						X	
Impingement/entrainment							X
Road fill and culverts							X
Dredging (navigation and boat basins)							X
Mining (sand/gravel, stone, phosphate)	X						X
Shoreline hardening/stabilization							X
Marinas and multi-slip docks							X
Pesticide spraying	X						X
Non-native or nuisance species							X
Floodplain development	X						

1 Since NCWRC (2005) does not address the Albemarle-Pamlico Sound complex per se, stressors identified for each of the major tributaries are all indicated, to yield the cumulative stressors impacting the downstream sounds.

2 The stressors indicated in the column for Street et al. (2005) are derived largely from Section 2.4 of that report, the Threats and Management Needs section of the Water Column chapter.

Table 33. Summary of VA and NC river-specific threat factors to existing or potential future shortnose sturgeon habitats (see text for details). For this table, the Brunswick River is considered part of the Cape Fear River.

THREAT	NORTH ALB.	CHOWAN	ROANOKE	TAR	NEUSE	NEW	NORTH BACK	NE CAPE FEAR	BLACK	CAPE FEAR
Dams and Diversions	No	Yes	Yes	Yes	Yes	No	No	No	No?	Yes
Tidal Turbines	No	No	No	No	No	No	No	No	No	Possible
Liquid Natural Gas Facilities	No	No	No	No	No	No	Possible	Possible	No	Possible
Dredging and Blasting	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes
Water Quality and Contaminants	Yes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes?	Yes
Loss of Coolwater Refugia	?	?	?	?	Yes	?	?	?	Yes?	Yes?
Bycatch	Yes	Yes	No	No	Yes	Yes	Yes	No	No	Yes
Poaching	Yes	Yes	Yes	Yes	Yes	Yes	No?	Yes	Yes?	Yes
Scientific research	No?	No?	Yes	Yes	Yes	Yes	Yes	Yes	No?	Yes
Competition and Predation	No?	No	No	No	Yes?	No	No	Yes?	Yes?	Yes?
Disease	No	No	No	No	No	No	No	No	No	No
Inadequate Regulatory Mechanisms	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Enforcement Issues	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Impingement or Entrainment	No	Yes?	Yes?	No	Yes?	No	No	No?	No	Yes
Ship Strikes	No	Yes	Yes	No	Yes	No	No	Yes	No	Yes

THREAT	NORTH ALB.	CHOWAN	ROANOKE	TAR	NEUSE	NEW	NORTH BACK	NE CAPE FEAR	BLACK	CAPE FEAR
Artificial Propagation	No	No	No	No	No	No	No	No	No	No
Loss of Genetic Diversity	No	No	No	No	No	No	No	No	No	Yes
Escapement of Hatchery/Captive Fish	No	No	No	No	No	No	No	No	No	No

Table 34. Summary of estuary-specific threat factors to existing or potential future shortnose sturgeon habitats (see text for details).

THREAT	ALBEMARLE SOUND	PAMLICO SOUND	CAPE FEAR ESTUARY
Dams and Diversions	Yes-indirect effects on inflow	No	No
Tidal Turbines	No	No	Potential
Liquid Natural Gas Facilities	No	No	Potential
Dredging and Blasting	Yes	Yes	Yes
Water Quality and Contaminants	Yes	Yes	Yes
Loss of Coolwater Refugia	Possible?	Possible	Possible
Bycatch	Yes	Yes	Yes
Poaching	Yes	Yes	Yes
Scientific research	Yes	Yes	Yes
Competition and Predation	No?	No?	No?
Disease	Possible	Possible	No?
Inadequate Regulatory Mechanisms	Yes	Yes	Yes
Enforcement Issues	Yes	Yes	Yes
Impingement and/or Entrainment	No	No	Yes
Ship Strikes	Possible	Possible	Yes
Artificial Propagation	No	No	No
Loss of Genetic Diversity	No	No	No
Escapement of Hatchery/Captive Fish	Not at present	No	No

Table 35. Listing status of Atlantic and shortnose sturgeon in VA, NC and SC as of 2008 (E = endangered; NHP = Natural Heritage Program; SE = State Endangered; SSC = state special concern; T = threatened; SC = special concern; WAP = Wildlife Action Plan).

Species	State	List Status	NHP State/Global Rank	WAP Status	Reference
Atlantic Sturgeon	VA	SSC	S2/G3	Tier II	Roble (2006), VDGIF (2005, 2008)
	NC	SC	S3/G3	Priority Species	NCWRC (2005)
	SC	Of Concern, State	S3/G3	Highest Priority	SCDNR (2005, 2006)
Shortnose Sturgeon	VA	SE	SXB, S1N/G3	Tier I	Roble (2006), VDGIF (2005, 2008)
	NC	E	S1/G3	Priority Species	NCWRC (2005)
	SC	SE	S3/G3	Highest Priority	SCDNR (2005, 2006)

Table 36. Documented estuarine or riverine "dead zones" in NC which either do or could potentially host shortnose sturgeon (Bricker et al. 1999; Hobbie et al. 1975; Lenihan 1999; Lenihan and Peterson 1998; MacPherson et al. 2007; Mallin et al. 1999; Paerl et al. 1995, 1998; Paerl et al. 2000; Posey et al. 1999; Sanger et al. 2002; Stanley and Nixon 1992; Tenore 1972; table compiled from Diaz and Rosenberg 2008). Some of these were historic and may no longer exist as a consequence of water quality or other improvements.

YEAR	SYSTEM	HYPOXIA TYPE	AREA (km^2)	BENTHIC RESPONSE	FISH RESPONSE	REFERENCE(S)
1990	Albemarle and Pamlico Sounds	Seasonal	464	Mortality	Mortality	Bricker et al. 1999
1990	Cape Fear River	Episodic		Reduced	Fish kills	Mallin et al. 1999; Posey et al. 1999
2000	Futch Creek	Episodic				MacPherson et al. 2007
2000	Hewletts Creek	Episodic				MacPherson et al. 2007
1990	Masonboro Inlet	Unknown				Sanger et al. 2002
1990	Neuse River Estuary	Seasonal	230	Mortality/avoidance	Fish kills, oyster mortality	Paerl et al. 1995, 1998; Lenihan and Peterson 1998; Lenihan 1999
2000	New River	Periodic	21			Bricker et al. 1999
2000	Pages Creek	Periodic				MacPherson et al. 2007
1960	Pamlico and Pungo Rivers	Seasonal	44	Mass mortality, low macrobenthic diversity and density in summer, recolonization by winter	Mortality	Tenore 1972; Hobbie et al. 1975; Stanley and Nixon 1992
1990	Pamlico Sound	Episodic			Common finfish species with skin lesions, bacterial infections	Paerl et al. 2000

Winyah Bay System: Waccamaw, Pee Dee, Black, and Sampit Rivers and their tributaries

Historic Distribution and Abundance

This system historically supported the largest commercial sturgeon fishery in the south; however landings did not differentiate between shortnose and Atlantic sturgeon. Although presence of both species has been known for many years, historical abundance of shortnose sturgeon is not known. The first confirmed presence was a single shortnose sturgeon specimen collected in the 1970s and preserved; it was taken from below the first dam on the Great Pee Dee, at Blewett Falls Dam (~ rkm 330) in North Carolina.

Current Distribution and Abundance

Current distribution and abundance in this system is not known. A study of the bycatch in the American shad gillnet fishery in Winyah Bay was conducted during 1994-1995; this study confirmed that shortnose sturgeon still inhabit the system (Collins et al. 1996). Although records exist for the occurrence of shortnose sturgeon in the Sampit River, this is a very small, short river and it is likely only utilized as a foraging area and does not support a spawning group. Similarly, there are records of collections in the Black and Waccamaw rivers, but these were before the use of GPS, so precise locations are unknown; it is quite possible that they are from near the confluence of the Black, Pee Dee, and Waccamaw rivers. There are no records from any of the tributaries in this system such as the Little Pee Dee and Lynches rivers

Natural History and Habitat Information

Spawning

It is presently thought that most if not all shortnose sturgeon spawning in the Winyah Bay system takes place at a gravel bar well upriver in the Great Pee Dee River (rkm 206.5). The spawning area was discovered via a recent telemetry study (2002-2003) and spawning was confirmed for two consecutive years, and again in 2007 and 2008 through egg collection. It is not unlikely that other spawning sites exist. However, no shortnose sturgeon tracked in the study traveled as far as the dam (~rkm 330) (M. Collins, SC DNR, pers. comm. 2008).

Rearing

Eggs were collected at the spawning site in the Great Pee Dee River (rkm 206.5), but no larvae or early juveniles have been collected.

Foraging

Foraging appears to take place in fall, early winter, and late spring (i.e., omitting spawning season and summer). Foraging shortnose sturgeon are dispersed over a wide area of the estuary. Depending on flows, foraging can take place anywhere from the jetties (i.e., nearshore ocean in the reduced salinity of the freshwater plume) throughout the Bay and into the lower portions of the various rivers.

Stressors to Riverine System

1. **Habitat**

Dams and diversions

The first dam on the Great Pee Dee is the Blewett Falls Dam, located at ~ rkm 330 in North Carolina; it does not appear to block access to historical spawning habitat. The dams on the Great Pee Dee cause interrupted flow regimes and flow prescriptions are included in ongoing negotiations regarding FERC relicensing.

Other energy projects

Tidal turbines

There are not any tidal turbines in this system and none are currently proposed.

LNG facilities

There are currently no existing or proposed LNG facilities in the Winyah Bay system.

Dredging and blasting

No blasting takes place. However, Winyah Bay itself is dredged to maintain the shipping channel.

Water quality and contaminants

The system experiences industrial pollution from a paper mill and a steel mill in Georgetown (~rkm 22). As noted in section 5.1.3, a study conducted by USFWS in the early 1990s found elevated levels of dioxins in the ovaries of wild shortnose sturgeon collected from this system. Municipal sewage discharge from Georgetown, Cheraw, and the smaller municipalities in this system is also a concern.

2. Overutilization

Bycatch

A 16% bycatch mortality of shortnose sturgeon has been documented in the American shad gillnet fishery; another 20% of individuals were visibly injured in this fishery (Collins et al. 1996).

Poaching

Directed poaching of shortnose sturgeon in this system has not been documented, but may be occurring because poaching has been documented for Atlantic sturgeon.

Scientific research

A telemetry study was recenltly concluded. Results to date confirm the conclusions of the earlier telemetry study.

3. Competition, predation and disease

Levels of disease and predation/competition in this river system are unknown.

4. Inadequacy of existing regulatory mechanisms

Existing regulatory mechanisms are adequate with the exception of the level of law enforcement available.

5. Other natural or manmade factors

Ship strikes

There is no evidence of ship strike interactions with shortnose sturgeon in the Winyah Bay System.

Artificial propagation

There is no artificial propagation of shortnose sturgeon occurring in the Winyah Bay System.

Escapement of hatchery/captive fishes

Since there is no artificial propagation of shortnose or Atlantic sturgeon in the Winyah Bay System so there is no threat from escapement.

Santee-Cooper System: Santee, Cooper, Congaree, Wateree rivers and their tributaries, and Lakes Marion and Moultrie

The Santee-Cooper System is a complex system that includes three dams that form two reservoirs, additional dams upriver regulate downstream flow (Fig. 30). Shortnose sturgeon are known to occur both above and below these three dams (Collins et al. 2003).

Historic Distribution and Abundance

This system has been highly modified over the years. Because the Santee River was historically so large prior to construction of numerous dams, it is likely that the population in that river (and the Congaree River) was also large. The Cooper River, before being incorporated into the Santee system, was previously a short blackwater river; a historic population of shortnose sturgeon may or may not have been present prior to damming.

Current Distribution and Abundance

Cooper River

During 1996-1998, a mark-recapture population study focusing only on adult shortnose sturgeon at the spawning site below the Pinopolis Dam resulted estimate about 300 spawning adults in this area (Cooke et al. 2004). It should be emphasized that any non-spawning adults that did not make the migration to the dam would not have been included in this estimate. Telemetry studies indicate that shortnose sturgeon do not pass upriver through the vessel lock in the Pinopolis Dam. Shortnose sturgeon have been documented entering the lock but have never passed into the reservoir, probably because there is a 12 m vertical wall at the upstream end.

The Reservoirs: Lake Marion and Lake Moultrie

With a single documented exception, shortnose sturgeon inhabit only the upper of the two reservoirs, Lake Marion. There is currently no estimate for the portion of the population that inhabits the reservoirs and rivers above the dam.

Santee River

Abundance and seasonal movements have not been documented for the Santee River group.

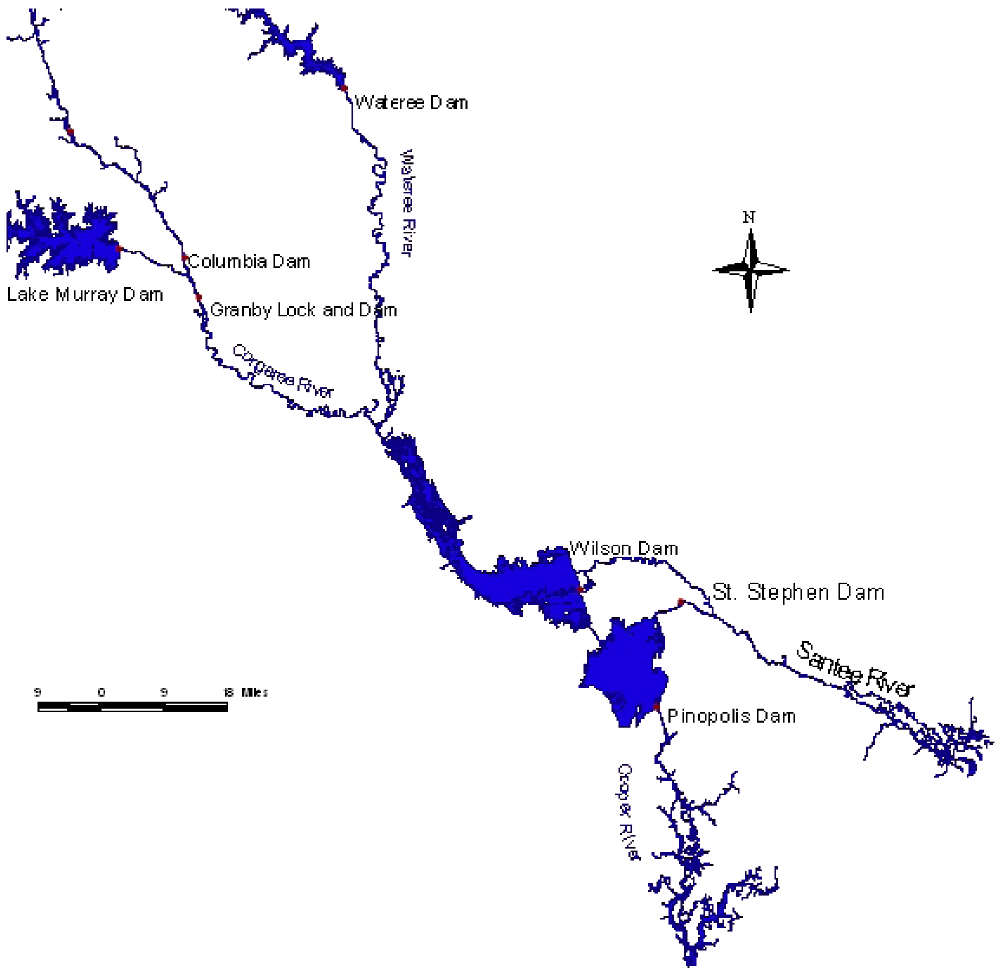


Figure 30. Map of the Santee River Basin area nearby Charleston, South Carolina. Note that the upper Lake is Marion and the Lower is Moultrie with a Diversion Canal between. St. Stephen Dam is located on the Re-Diversion Canal that links Lake Moultrie and the Santee River.

Spawning

Cooper River

In the Cooper River, shortnose sturgeon spawn at the base of the Pinopolis Dam at rkm76.8. This was verified by egg collections. However, this dam operates as a peaking facility, which limits spawning, hatching, and recruitment success.

The Reservoirs: Lake Marion and Lake Moultrie

Spawning shortnose sturgeon ascend from the reservoirs to the Congaree River. Eggs have been collected from a gravel bar at the city of Columbia, SC (Congaree River, rkm 70). No telemetered individuals chose to ascend the Wateree River. Successful recruitment in the reservoirs has been verified by collection of a single juvenile.

Santee River

Spawning has not been documented in the Santee River.

Rearing

Cooper River

Eggs have been collected from the tailrace of the Pinopolis Dam in the Cooper River. Survival of early life stages is questionable because conditions below the dam are not consistent with parameters that support survival in other river systems (Cooke and Leach 2004). Recruitment to older age groups has not been verified in this part of the system since juveniles have not been collected.

Congaree River

Shortnose sturgeon eggs have been collected on the Congaree River at the city of Columbia, SC (rkm 70), and a single small juvenile, presumed YOY, was recorded downstream in Lake Marion (Collins et al. 2003). Recent telemetry data indicate that individuals tracked during the spawning-season do pass the Granby Dam (an old low-head dam with open lock), so there is likely spawning upriver of the identified location (M. Collins, SC DNR, pers. comm. 2008).

Foraging

Cooper River

After spawning, Cooper River shortnose sturgeon disperse downriver and are fairly mobile (exhibiting foraging behavior); they are much more sedentary during summer, and then become mobile again as water temperatures drop in the fall.

The Reservoirs: Lake Marion and Lake Moultrie

Telemetry work indicates that in summer shortnose sturgeon tend to concentrate in a part of Lake Marion known as Brown's Lake (this is not a lake per se, but rather a slightly deeper portion of Lake Marion). When temperatures decline they become more mobile and use the upper portion of Lake Marion as well as the channel of the Upper Santee River (this is a short section of river that flows into Lake Marion and that is formed by the confluence of the Congaree and Wateree rivers).

Collins et al. (2003) noted poor condition of individuals collected from the reservoies above the dams compared to those in the Cooper River below the dam and suggested that this was due to poor habitat quality (e.g., inadequate food or lack of access to physiologically important habitat) despite the abundance of molluscs. In addition, the high incidence of shortnose captured on baited hooks during their study was hypothesized to be due to the limited food source above the dams (Collins et al. 2003). A recent diet study on adult shortnose sturgeon (60-90 cm; 23-35 inches) captured within the project area in Lake Marion indicated that diet consists primarily of insect larvae (94% frequency) and was comprised mainly of Mayfly larvae and a few (1.3%) invertebrates, mainly *Corbicula* (Collins et al. 2006). This is in contrast to the diet of shortnose sturgeon in the rivers of this system that have a specialized diet of amphipods (Collins et al. 2006). The absence of amphipods in the guts of the shortnose collected from Lake Marion was further investigated. Periodic sediment grabs in the lake were conducted, and results of the sediment grabs were consistent with what was found in the sturgeon's stomach content as Lake Marion sediment grabs were predominated by Mayfly larvae (Collins et al. 2006).

Santee River

Less is known about shortnose sturgeon in the Santee River. Telemetry efforts have not been extensive enough to identify seasonal movements, and spawning has not been verified. However, several telemetered individuals moved into Winyah Bay, which is close to the mouth of the river and is connected by the Intracoastal Waterway. St. Stephen Dam on the Rediversion canal that leads into the Santee River has a fish lift, but no telemetered shortnose sturgeon were passed over the dam.

Stressors to Riverine System

1. Habitat

Dams and diversions

Minimum flows are prescribed, but the Pinopolis Dam is a peaking facility and releases could wash away eggs deposited at the base of the dam. Flow prescriptions are being considered as two of the dams (Pinopolis Dam on the Cooper River and the Wilson Dam on the Santee River) are undergoing FERC re-licensing.

Other energy projects

Tidal Turbines

There are no tidal turbines in this system and none are currently proposed.

LNG facilities

There are currently no existing or proposed LNG facilities in the Santee-Cooper System.

Dredging and Blasting

There is no dredging or blasting in either the reservoirs or Santee River. The lower Cooper River and Charleston Harbor are dredged frequently to maintain the shipping channel. Telemetered shortnose sturgeon in the Cooper River did not move downstream into the dredged area. Mortalities of subadult Atlantic sturgeon have been documented by dredging observers in Charleston Harbor, but no shortnose sturgeon have been recorded.

Water Quality and Contaminants

Pollution could be considered a threat because the spawning site identified in the Congaree River is adjacent to the sewage outfall for the city of Columbia, but heavy industrialization is not present in most of the system.

2. Overutilization

Bycatch

There is shortnose sturgeon bycatch mortality in the commercial American shad fishery in the Santee River, which is heavily fished. Gillnets are not permitted in the Cooper River. Bycatch in commercial catfish traps in the Congaree River has been documented and, unusually, in the commercial catfish trotline (longline) fishery as well as in the recreational hook-and-line fishery in Lake Marion. Both of the latter fisheries generally use fish as bait (e.g., cut herring, live minnows), suggesting the possibility that shortnose sturgeon in the reservoir may exhibit a greater degree of piscivory than riverine groups, as a recent diet study of riverine sturgeon in South Carolina found no fish in the stomach contents (Collins et al. 2008).

Poaching

At least one case of poaching has been documented on the Cooper River.

Scientific research

Several recent studies of movements and diet have been conducted, but none are ongoing and none are planned.

3. Competition, Predation and Disease

No studies regarding competition, predation, or disease have been conducted. American alligators are exceptionally common throughout the system and could be a source of predation.

4. Inadequacy of Existing Regulatory Mechanisms

Regulatory mechanisms are adequate except for the general shortage of law enforcement.

5. Other Natural or Manmade Factors

Ship Strikes

There have been no ship strikes of sturgeons documented in this system. Large vessels do not ascend as upriver into areas ultized by the shortnose sturgeon on the Cooper River.

Impingement and Entrainment

Although there is some industrial development on the lower Cooper River, it is downriver from the reaches documented as being used by shortnose sturgeon.

Artificial Propagation

There is no artificial propagation of shortnose sturgeon in the Santee-Cooper River System

Escapement of Hatchery/Captive Fishes

One tagged shortnose sturgeon was captured in the Cooper River that was originally released into the Savannah River as part of the 1985-1992 stocking event described later in the Savannah River section. This individual could have moved through the Intracoastal Waterway, many stretches are usually full strength seawater, supporting observations that adult shortnose sturgeon can withstand high salinities, at least seasonally.

Charleston Harbor System: Wando, Ashley, and Cooper rivers and their tributaries

Shortnose sturgeon inhabiting the Cooper River were discussed above in the Santee-Cooper System (above). No evidence exists to suggest that shortnose sturgeon inhabit the Ashley or Wando Rivers or that they ever did so historically. A single dead shortnose sturgeon was found in Charleston Harbor proper, but there are several possible sources for this individual (e.g., a fishing or shrimping vessel may have caught it and then discarded it just before entering the docking area at Shem Creek, or it may have died well up the Cooper River and drifted downstream). An ongoing fishery-independent trammel net survey throughout much of the estuarine portions of this system has not collected a shortnose sturgeon.

ACE Basin (aka St. Helena Sound System): Ashepoo, Combahee, and Edisto rivers and their tributaries

Historic Distribution and Abundance

The ACE Basin is a pristine, undammed, minimally developed system. Sturgeon have not been reported from the Ashepoo River, and despite recently collecting good numbers of adult Atlantic sturgeon from the Combahee River, shortnose sturgeon have not been reported from that river, either. The Edisto River is a bit of a conundrum. Other than a claim by a biologist to have captured four shortnose sturgeon far upriver in the 1970's, there are no historical records from this river.

Current Distribution and Abundance

The Edisto River is fished with moderate intensity in the commercial shad fishery. In 1994 a fishermen contacted SC DNR and reported catching a tagged shortnose sturgeon in a gillnet. A SC DNR biologist responded, confirmed the identification, retrieved the tag information, and released the fish. A search of tagging records indicated the fish had previously been stocked into the Savannah River between 1985-1992. In ensuing years, fishery-independent sampling for American shad produced several more specimens, including more individuals that were a part of the Savannah River stocking event. The collection of several young juveniles suggests on-going reproduction in the river. While the Edisto River may not have historically supported a population of shortnose sturgeon, recent immigration of the hatchery-produced shortnose sturgeon stocked into the Savannah River may have colonized. Because stocked individuals were at advanced ages, they may not have imprinted on the target river and had a greater propensity to wander into other systems (Smith et al. 2002a). Sample size is inadequate to provide even a rough idea of abundance in this river.

Natural History and Habitat Information

Spawning

There is likely successful spawning in the Edisto River as evidenced by the capture of juvenile individuals, but spawning site(s) have not been identified or characterized.

Foraging
Most shortnose sturgeon collected in the Edisto River have occurred at the salt-freshwater interface (oligohaline estuary) in salinities of 0-5 ppt.

Overwintering/resting
Wintering behavior and habitat of shortnose sturgeon on the Edisto River is unknown, but individuals have been collected during all seasons in the oligohaline estuary.

Migration
Movements and habitat use are poorly known for shortnose sturgeon in the Edisto River.

Stressors to Riverine System

The ACE Basin is a pristine system with minimal development or industrialization and threats to shortnose sturgeon are few.

1. **Habitat**

Dams and diversions
There are no dams in the main stem rivers of the ACE Basin.

Other energy projects
Tidal turbines
There are no tidal turbines in this system and none are currently proposed.

LNG facilities
There are currently no existing or proposed LNG facilities in this system.

Dredging and blasting
There is no dredging in this system.

Water quality and contaminants
Water quality is monitored by the ACE Basin NERRS. This system is considered among the most pristine in the state.

2. **Overutilization**

Bycatch mortality in the commercial fishery for American shad represents some threat, but fishing effort has declined dramatically in recent years, perhaps due to the decline in shad abundance.

3. **Competition, predation and disease**

There is no information on competition or disease effects to shortnose strurgeon. Both alligators and flathead catfish are very common in this system and are potential predators.

4. **Inadequacy of existing regulatory mechanisms**

SCDNR maintains a list of threatened and endangered species. Regulatory mechanisms are adequate except for the general shortage of law enforcement.

5. Other Natural or Manmade Factors

Ship Strikes

There have been no ship strikes of sturgeons documented in this system.

Impingement and Entrainment

There are no intakes that would impinge or entrain shortnose sturgeon in this system.

Artificial Propagation

The USFWS Bears Bluff National Fish Hatchery previously propagated shortnose sturgeon of Savannah River origin. It is situated on Wadmalaw Sound, which is indirectly connected to the ACE Basin. All sturgeon were euthanized or removed from the facility in early 2008. No stocking or escapement into the system has been reported.

Escapement of Hatchery/Captive Fishes

Hatchery-reared shortnose sturgeon released in the Savannah River between 1985-1992 have since been documented in the Edisto River.

Current Research and Recommended Research

- Further genetic studies to investigate movement of hatchery-reared fish released into the Savannah River and their subsequent occurrence in other rivers.
- Telemetry studies to:
  - Identify seasonal movement patterns
  - Identify and characterize important habitats
  - Estimate population size
  - Confirm spawning via egg and larvae collection.

Port Royal Sound System: May, Broad, and Coosawhatchie rivers and their tributaries

These are all small rivers and there is no evidence shortnose sturgeon occur presently or historically.

Savannah River and Tributaries

Historic Distribution and Abundance

Shortnose sturgeon likely utilized the entire Savannah River downriver Augusta Shoals. Augusta Shoals is located at the city of Augusta, GA about 11 rkm above New Savannah Bluff Lock and Dam (NSBL&D), which is the downriver-most dam on the river.

Current Distribution and Abundance

Shortnose sturgeon have been studied more intensively in this river than in any other in South Carolina. They have been documented as far upriver as the first dam, NSBL&D at the city of Augusta, GA (rkm~330) and downriver below the city of Savannah, GA (rkm~16). Abundance of adults was (weakly) estimated at approximately 2,000 individuals.

In addition to the distribution of wild (native) shortnose sturgeon in the Savannah River, broodstock are currently held at the University if Florida, Gainesville, and the USFWS Warm Springs Fish Technology Center (GA and SC), USGS Conte Research Center (MA), and Alden Research Lab (MA). These research facilities conduct a variety of research to investiage sturgeon culture, tagging technology, fish passage, embryonic development, and other biological studies. Shortnose sturgeon of Savannah River origin are also currently being held at several educational facilities for public displayincluding North Carolina Aquarium, Wilmington, NC; North Carolina Zoo Asheboro, NC; and Riverbanks Zoo Columbia, SC. Although, captive shortnose sturgeon may not typically be released into the wild and measures are taken to ensure escapement does not occur. Because wild and cultured shortnose sturgeon share similar genetic, physical, physiological, ecological, and behavioral characteristics, all individuals and components of shortnose sturgeon derived from or by those initially removed from the Savannah River, including populations of natural individuals and hatchery stocks derived from similar populations, are included in the ESA listing of the species.

During approximately 1985-1992, the USFWS and SC DNR jointly released 97,483 hatchery-reared shortnose sturgeon that were progency of Savannah River broodfish reared at the USFWS Bears Bluff facility. At the same time, movements of both wild and stocked adult shortnose sturgeon were monitoried via telemetery. Hatchery-produced individuals were stocked at various ages, locations, and across all seasons. The total estimated number of shortnose sturgeon stocked (97,483) is great; most were stocked as larvae and early juveniles. Only 18,210 individuals were large enough to be tagged in some fashion. Survival of the very young sturgeon was probably low but unknown. A study conducted years post-stocking that coincided with estimated age of maturity indicated hatchery-reared shortnose sturgeon preceeded wild fish in spawning migrations but behaved similarly (Trested et al. 2003). Some competiton between males at the spawning sites was observed (Trested et al. 2003). Population estimates of adult shortnose sturgeon pre- and post-stocking suggest that the numbers had increased substantially, but many tags were shed, few fish were marked and these estimates were never published as statistical assumptions were violated and the estimates were biased (but biased similarly). Some believe the stocking event was successful; however without information on the survivability and emigration of both the wild and stocked fish impacts and effects of the stocking event cannot be assessed. A few of the fish that retained their tags have been found in other rivers, suggesting they emigrated and may have been released at an age too late to imprint on the Savannah River.

Natural History and Habitat Information

Spawning

Hall et al. (1991) and Collins and Smith (1993) used telemetry techniques to identify maximum upriver positions of shortnose sturgeon during the spawning season. These locations were between Savannah River rkm 179 and rkm 278. It is likely, however, that additional locations exist farther upriver based on the capture of shortnose sturgeon at the base of NSBL&D during their spawning season. Spawning locations have not been verified by collection of eggs.

Foraging

Shortnose sturgeon disperse through the estuary and exhibit foraging behavior when water temperatures are cool; this area is in close proximity to the city of Savannah, GA.

Rearing
Telemetry studies have identified nursery habitats for juveniles, a primary example being just inside the mouth of the distributary Middle River in the heavily industrialized Port of Savannah.

Overwintering/resting
Savannah River shortnose sturgeon are mobile in winter months ranging throughout the estuary.

Migration
Seasonal movements of adults have been documented. Shortnose sturgeon range widely during cooler winter months and aggregate and become relatively sedentary during summer. One summer aggregation area has been identified in the vicinity of rkm 40 in the oligohaline estuary.

Stressors to Riverine System
Stressors to shortnose sturgeon in this river are perhaps more severe than in other South Carolina rivers.

1. **Habitat**

Dams and diversions
NSBL&D does not generate electricity and provides little economic benefit; however it precludes shortnose sturgeon access to likely spawning habitat upstream. Attempts to have the dam removed have involved considerable political and private maneuvering with no success to date.

Other energy projects

Tidal Turbines
There are no tidal turbineson the Savannah River and none are currently proposed.

LNG Facilities
There is a LNG terminal in the mesohaline portion of the Savannah River at Elba Island operated by El Paso-Southern LNG. This facility is a closed loop system and an expansion to this facility has been approved by FERC. Potential threats/impacts to shortnose sturgeon associated with the approved facility would include increased risk of ship strikes, loss of foraging habitat via maintenance dredging around the terminal, and YOY/sub-adult losses via ballast water uptake and facility intakes, and changes in ambient water temperature (usually cooling) of water withdrawn and then discharged.

Dredging and Blasting
No blasting has been conducted. Regular maintenance dredging takes place occurs from the mouth up to approximately rkm 38, that overlaps both juvenile and adult habitats. Plans are underway by the Port to expand and increase channel depth significantly; water quality models predict that DO will be severely impacted and the salt wedge will migrate upriver. . Public release of the EIS is anticipated for 2010. Construction of an additional port on the Savannah River is being considered in Jasper County, SC downstream of the Port of Savannah.

Water Quality and Contaminants

The greatest long-term danger is probably the planned expansion, deepening, and modification of the Port of Savannah and shipping channel. In addition to direct mortality, water quality models predict a significant upriver shift of the salt wedge and greatly reduced (as low as zero) concentration of dissolved oxygen. Because this area is used extensively by both juvenile and adult shortnose sturgeon, the only hope for the population would be to possess enough behavioral flexibility to abandon their currently used areas and move to habitats that allow survival.

Contaminants in the Savannah River include those from both municipal (Savannah, GA) and industrial effluents. The area around the Port is heavily developed by a wide variety of industries. Other contaminants arise from two nuclear facilities farther upriver; nuclear isotopes have been detected in the sediment downriver in the estuary.

2. Overutilization

Bycatch

Bycatch in the commercial shad fishery in the Savannah River has been substantial, with one fisherman catching at least 123 adults in a single shad season that unfortunately coincides with the sturgeon spawning-migration period. However, actual bycatch-induced mortality has not been studied in this system.

Poaching

No poaching has been reported.

Scientific research

Biologists have and still do study this population. Currently there are two ESA Section 10 permits allowing take of shortnose sturgeon from the Savannah River. No adult mortalities have been recorded during this research.

3. Competition, Predation and Disease

Competition and disease are not known. Alligators are numerous and a potential source of predation.

4. Inadequacy of Existing Regulatory Mechanisms

Existing regulations appear to be adequate except for the ongoing bycatch from the shad fishery. Law enforcement coverage is minimal, perpahs because the river is a boundary between two states and each state may be relying on the other to monitor the river for natural resource violations.

5. Other natural or manmade factors

Ship strikes

No reported ship strikes have been documented in the Savannah River.

Impingement and entrainment

Rates of impingement and entrainment are not known, but the death of one telemetered adult in the intake structure of a factory in the Port of Savannah has been documented. Larvae have been recorded from the intake canals at the Savannah River Site, a federal nuclear facility.

Artificial propagation

There are no hatcheries or facilities supporting artificial propagation of shortnose sturgeon along the Savannah River.

Current and Recommended Research

Ongoing research involves collection of shortnose sturgeon from the Savannah River for ageing, and to attempt to generate an additional population estimate. Tagging and telementry is occurring to identify upstream spawning locataion and the effects of reduced flow on spawning habitat. Recommended research includes:

- Estimating population size and structure.
- Identification of spawning sites and substrate.
- Assessmengt of areas upstream NSBL&D as spawning habitat.
- Effects of regulated flow on spawning habitat.
- Effects of proposed port expansion on nursery habitat.
- Effects of water quality changes resulting from port expansion on shortnose sturgeon and their foraging and nursery habitats.

Ogeechee River

Historic Distribution and Abundance

Shortnose sturgeon were first documented in the Ogeechee system in 1973 by Georgia Department of Natural Resources (GA DNR) personnel as bycatch in various commercial fisheries and scientific surveys. A commercial fishery for Atlantic sturgeon historically existed in the Ogeechee River until 1997. Although shortnose sturgeon were likely bycatch of the Atlantic sturgeon fishery, self-reported catch reports rarely differentiated between the two species so little information was available on shortnose sturgeon abundance in the Ogeechee River until targeted scientific surveys began in the early 1990s.

Current Distribution and Abundance

The first survey of shortnose sturgeon occurrence, distribution, and abundance was conducted from 1993 to 1995 in the tidal portion of the drainage (Rogers and Weber 1994a, Weber 1996, Weber et al. 1998). Through mark/recapture analysis, the highest point estimate of shortnose sturgeon population size was determined at 266 (95%CI=236-300) in 1993 (Weber 1996, Weber et al. 1998). Further, information obtained on size frequency, abundance, and catch rate indicated that shortnose sturgeon may be experiencing juvenile mortality rates greater than other southeastern rivers.

The abundance and population attributes of shortnose sturgeon in the Ogeechee River were most recently assessed from 1999-2004 (Fleming et al. 2003); population size was estimated at 147 (95% CI = 104-249). While this estimate was lower that the 1993 estimate it was not significantly different (Fleming et al. 2003).

Both of these population estimates were highly variable between years, primarily due to changes in yearly capture/recapture rates, which were strongly correlated to weather conditions (river flow and temperature). This is similar to results from other rivers in the southeastern U.S. During dry years, other fish species inhabiting southeastern rivers are "pushed" into relatively deep holes by the upriver encroachment of the saltwater/freshwater interface and an overall increase in water temperature (often-exceeding 30° C). During these dry periods, the majority of the shortnose sturgeon within a river system becomes highly susceptible to gillnet sampling, significantly increasing capture rates and providing the most reliable mark/recapture population estimates. Such conditions were experienced in the summers of 1993 and 2000. Population sizes were estimated in additional years during both of these studies; however the results were highly variable and were deemed invalid. With that stated, all point estimates of population size in the Ogeechee River, including 1993 and 2000, have consistently been well under 1,000 individuals.

Assessment of size frequency, abundance, and catch rate during the 1999-2004 study revealed a low number of young (1-2 year old) individuals in the population, further indicating either high yearly variability in spawning activity or recruitment failure during many years (Fleming et al. 2003). No young-of-year (or even one-year-old) shortnose sturgeon were collected during this study between 1999 and 2003. However, in 2004, ten one-year-old (less than 45 cm. TL) fish were captured with gill nets. Back-calculating age indicates that these fish would likely have spawned during the spring of 2003. Ongoing sampling efforts in the Ogeechee River have revealed a relatively large number of fish that potentially fall into this year-class (D. Peterson, UGA, pers. comm. 2008) indicating that this year-class has successfully recruited to the adult population at a significant level. These studies indicate spawning/recruitment success is highly variable between years, with potentially complete periodic recruitment failure. However, modeling efforts on this population have indicated that only small levels of annual recruitment (approximately 30 fish per year) may be required to maintain this population at current levels (Fleming et al. 2003). Therefore, annual spawning/recruitment success may not be necessary to sustain the population, and may not have naturally occurred. However additional assessment of population growth will likely require encompass the influence of environmental factors that may be restricting regular spawning success.

Natural History and Habitat Information

Spawning

Spawning likely occurs in the Ogeechee River as indicated by the presence and upriver migration of several gravid fish during at least three different spawning seasons (Weber 1996, Fort Stewart Fish and Wildlife Branch, pers. comm.). The recent collection of one-year-old fish supports in-river spawning activity, and more importantly may indicate successful recruitment. The locations of spawning habitats have not yet been identified.

Foraging

Shortnose sturgeon typically do not inhabit the upper 60km of the Ogeechee River outside of spawning season; spawning occurs near the confluence of the Canoochee and Ogeechee Rivers (Rogers and Weber 1994a, Weber 1996, Weber et al. 1998, Fleming et al. 2003). During periods of low-discharge during the summer season, the population seems to become concentrated in a few relatively deep holes slightly downstream of this point. As river discharge increases, fish tend to occupy a greater portion of the river but still typically remain in areas above the saltwater/freshwater interface at about rkm 60 during the summer. During the winter, fish are typically found near the freshwater/saltwater interface and routinely inhabit more saline waters for brief periods of time.

Overwintering/resting
There is no indication that fish in this system utilize any pre-spawn overwintering/resting areas. Fish engaged in the spawning migration are believed to move directly from the estuary upriver to the spawning area.

Migration
The exact time and environmental conditions that trigger the initiation of the spawning migration in the Ogeechee is not known. However, gravid female fish have been captured during January. Therefore it is likely that the timing and conditions are similar to those found in other southeastern rivers: January to March at water temperatures of approximately 10^{o}C.

Stressors to Riverine System

1. **Habitat**

Dams and diversions
Jordan Mill Pond Dam is located 10km downstream of the fall line on the Ogeechee River. It is unlikely that shortnose sturgeon inhabit the area below the dam due to its location upstream and the small stream size at that location. Therefore, shortnose sturgeon likely have access to 100% of their likely historical spawning habitat.

Other energy Projects
Tidal turbines
There are no tidal turbines on the Ogeechee River and currently none are proposed.

LNG facilities
There are currently no existing or proposed LNG facilities associated with the Ogeechee River.

Dredging and blasting
Dredging only occurs on a relatively small scale in this system in order to maintain the Intracoastal Waterway.

Water quality and contaminants
One of the primary concerns for water quality in this and most other southeastern U.S. rivers is depressed DO levels during the warmer months of the year. In most systems, these seasonally depressed levels are thought to be primarily a naturally occurring condition; however these conditions are likely exacerbated by the input of additional nutrients through municipal and industrial discharges and non-point source pollution, driving levels below 2.5 mg/L in some situations. Although this may be a factor in the Ogeechee River, thorough examinations of the conditions have not been conducted and the amount of potentially compromised habitat is currently unknown.

Thermal refuge*:*
Excerpt taken from NMFS 1998 Shortnose Sturgeon Recovery Plan (NMFS 1998):

"*During summer months, especially in southern rivers, shortnose sturgeon must cope with the physiological stress of water temperatures that often exceed 28^{o}C. Flournoy et al. (1992) suspected that, during these periods, shortnose sturgeon congregate in river regions which support conditions that relieve physiological stress. In southern rivers where sturgeon movements have been tracked, sturgeon refrain from moving during warm water conditions and are often captured at release locations during these periods (Flournoy et al. 1992, Rogers and Weber 1994[a], Weber 1996). Gulf sturgeon (A. oxyrinchus. desotoi) are reported to fast at high water temperatures and occupy river reaches of the Suwannee River (Florida) near flowing spring heads (Mason and Clugston 1993). Flournoy et al. (1992) suggest that, in the Altamaha River, shortnose sturgeon also seek deep, artesian spring-fed habitats that provide thermal refugia*."

Although a relatively new concept, the loss and/or manipulation of these discrete refugia habitats may limit or be limiting population survival, particularly in southern river systems. For example, Krause and Randolph (1989) report that subterranean aquifers are severely depleted in the Savannah and Ogeechee rivers (Georgia) and the Satilla and St. Marys rivers (Florida). Interestingly, these river systems either exhibit signs of juvenile mortality (Savannah: Collins and Smith 1993, Ogeechee: Rogers and Weber 1994a, Rogers and Weber 1995b, Weber 1996) or may no longer support shortnose sturgeon (Satilla and St. Marys: Rogers and Weber 1995b**).**"

2. Overutilization

Bycatch

An American shad fishery via gillnetting occurs from January 1 - March 31 on the Ogeechee River. While this is a relatively small fishery, bycatch of shortnose sturgeon by commercial fishermen has been documented. Impacts of this fishery on the Ogeechee River shortnose sturgeon population have not been evaluated; however some information can be gleaned from recent efforts on the Altamaha River (See Altamaha River Section).

3. Competition, predation and disease

Competition, disease and predation do not appear to be a significant issue in this system.

4. Inadequacy of existing regulatory mechanisms

Shortnse sturgeon are identified as a "Protected Species" in the state of Georgia under GA DNR Rule 391-4-10-.09. GA DNR Rule 391-4-10-.06 prohibits "activities which are intended to harass, capture, kill, or otherwise directly cause death of any protected animal species."

5. Other natural or manmade factors

Ship strikes

Ship strikes have not been documented in the Ogeechee River.

Impingement and entrainment

Information regarding impingement and entrainment of shortnose sturgeon is not available.

Artificial propagation

There is no known artificial propagation of shortnose sturgeon in the Ogeechee River System.

Escapement of hatchery/captive fishes

Hatchery-reared shortnose sturgeon that were released into the Savannah River between 1985-1992 have been found in the Ogeechee River (Fleming et al. 2003, Smith et al. 2002a). Although the long-term impacts of this immigration of fish into the Ogeechee may have not yet been realized, it is possible that these immigrants from the Savannah River could have contributed to population abundance. Shortnose sturgeon tagged in, and perhaps native to, the Altamaha River have also been located in the Ogeechee River (UGA and GA DNR unpubl. data), suggesting that the migration of fish from one river to another is not a behavior unique to the hatchery fish, and likely occurs naturally across shortnose sturgeon range.

Current and Recommended Research

Researchers are currently sampling and conducting telemetry evaluations on the shortnose sturgeon population in the Ogeechee River: the study aims to estimate abundance and evaluate age structure of the population; seasonal habitat will also be quantified with particular emphasis on spawning, nursery, and wintering habitats. Finally, seasonal habitat availability for various life stages of shortnose sturgeon based on seasonal changes in water quality will be assessed.

Altamaha River

Historic Distribution and Abundance

Shortnose sturgeon were first documented in the Altamaha River in the early 1970's (Dadswell et al. 1984) and later by Heidt and Gilbert (1978). Since then, numerous studies have been conducted to evaluate population size and habitat use in the Altamaha system.

Current Distribution and Abundance

Population estimates have been calculated several times for the shortnose sturgeon in the Altamaha between 1988 and 1993; abundances have ranged between 400 and 2900 fish (Flournoy et al. 1992, Rogers and Weber 1994b). Population estimates, similar to trends in the Ogeechee River, have been highly variable between years.

Most recently, a population estimate of 6,320 individuals (95% CI = 4,387-9,249) was calculated; there was a disproportionate number of juveniles (DeVries 2006). This suggests that the Altamaha River system shortnose sturgeon population likely remains the largest population south of Cape Hatteras, NC, and may be increasing in size. Mortality of shortnose sturgeon between juvenile and adult stages is unusually high in the Altamaha River and possibly a result of incidental mortality associated with the commercial shad fishery and the concurrent spawning migration/period (DeVries 2006).

Natural History and Habitat Information

Spawning

Studies on the Altamaha River indicate that shortnose sturgeon successfully spawn (historically and currently) in this system as demonstrated through the presence of spawning adults, eggs, and YOY fish. While recent surveys suggest a single-step spawning migration with no overwintering in upstream areas prior to spawning (DeVries 2006, Heidt and Gilbert 1978, Flournoy et al. 1992, Rogers and Weber 1994b), Rogers and Weber (1995a) previously suggested that a fall "pre-spawn" migration may occur in at least a portion of this population.

Early studies suggest that shortnose spawn in upstream areas near limestone bluffs with gravel-size to boulder-size hard substrate in the Altamaha River (Rogers and Weber 1995a). More recently DeVries (2006) collected eggs on coarse sand substrate near the converging currents of the Ocmulgee and Oconee rivers. There appears to be numerous shortnose sturgeon spawning areas on the Altamaha River between Doctortown (rkm 89) and the confluence of the Ocmulgee and Oconee rivers at about rkm 215 (DeVries 2006, Rogers and Weber 1995a). The exact spawning location may vary annually and may be determined by environmental conditions during any given spawning season.

In earlier studies, spawning appeared to occur between January and March (Heidt and Gilbert 1978, Rogers and Weber 1995a). More recently, shortnose sturgeon eggs were collected on 20 March 2005, when the water temperature was 12° C (DeVries 2006) providing confirmation of the January to March spawning period.

Foraging

Shortnose sturgeon not engaged in spawning activity typically remain within the tidal portions of the river and estuary, as they do in most southeastern rivers. During periods of low-discharge during the summer season, most of the population becomes concentrated in a few relatively deep holes slightly upstream of the saltwater/freshwater interface. As river discharge decrease along with increasing water temperatures, fish tend to occupy a greater downstream portion of the river but still typically remain in areas above the saltwater/freshwater interface during the summer (Dadswell et al. 1984, Buckley and Kynard 1985a, Rogers and Weber 1994b, Weber 1996, Collins and Smith 1997, Palmer 2001). During the winter, fish are still typically found near the freshwater/saltwater interface but also routinely inhabit more saline waters for brief periods of time.

Although most relatively deep areas above saltwater/freshwater interface are utilized to some extent by shortnose during the summer months, at least two areas in the Altamaha River appear to be of particular importance: 1) Ebenezer Bend is located in the main segment of the Altamaha Delta, and 2) a hole in the Champney River segment of the delta, just downstream of Interstate Highway 95 (DeVries 2006, Rogers and Weber 1995a). As the saltwater/freshwater interface moves from year to year during the warmer seasons with varying flow patterns, and areas of suitable shortnose sturgeon habitat change, these areas are nearly always inhabited by shortnose sturgeon.

Overwintering/resting

Rogers and Weber (1995a) suggest that a fall "pre-spawn" migration may occur in at least a portion of this population. During their study Rogers and Weber (1995a) report shortnose sgturgeon migrated into an area in the upper tidal portion of the river in the fall and appeared to complete their migration in the spring.

Migration corridor/seasonal movements

The spawning migration for the majority of shortnose sturgeon is likely to be from January to March, beginning when water temperatures reach approximately 10°C (Heidt and Gilbert 1978, Rogers and Weber 1995a, DeVries 2006).

Stressors to Riverine System

1. Habitat

Dams and diversions

No mainstem dams currently exist on this Altamaha River. Dams do exist upstream on both the Ocmulgee and Oconee rivers but these dams are located above known shortnose sturgeon habitat.

Other energy projects

Tidal turbines

There are currently no tidal turbine proposals for the Altamaha River.

LNG facilities

There are currently no existing or proposed LNG facilities for the Altamana River.

Impingement and entrainment

Hatch Nuclear Power Plant is located on the Altamaha in Appling County. Rates of impingement and entrainment are unknown.

Dredging and blasting

Dredging occurs on a relatively small scale to maintain the Intracoastal Waterway as well as the intakes for the Hatch Nuclear Power Plant.

Water quality and contaminants

One of the primary concerns for water quality in this and most other rivers in the southeastern U.S. is depressed DO levels during the warmer months of the year. While these seasonally depressed levels may occur naturally, these conditions are exacerbated by low flow input on regulated rivers coupled with the additional nutrients through municipal and industrial discharges and non-point source pollution, driving levels below 2.5 mg/L in some situations. This may be a factor in the Altamaha River, thorough examinations of the conditions have not been conducted and the amount of potentially compromised habitat is currently unknown.

Thermal Refugia

See Ogeechee River Section

2. Overutilization

Bycatch

A study of shortnose sturgeon bycatch resulting from the American shad gillnet fisheryhas recently been conducted on the Altamaha River. This fishery is estimated to consist of 13 to 20 fishers annually; weekly effort varied from 6-35 nets per week (Bahn et al. 2010). Total estimated bycatch of shortnose sturgeon varied from a low of 53 to a high of 498 (Bahn et al. 2012). Most fish appeared to be in good condition upon release from the nets. While preliminary information suggests that this fishery does not present a lethal threat to shortnose sturgeon, this study has not evaluated the non-lethal impacts that capture in commercial shad nets may have on the population and further studies should be conducted to evaluate such impacts (Bahn et al. 2012).

3. **Competition, predation and disease**

Competition, disease and predation effects are not known and do not appear to be a significant issue in this system.

4. **Inadequacy of existing regulatory mechanisms**

Shortnose sturgeon are identified as a "Protected Species" in the state of Georgia under GA DNR Rule 391-4-10-.09. GA DNR Rule 391-4-10-.06 prohibits "activities which are intended to harass, capture, kill, or otherwise directly cause death of any protected animal species."

5. **Other natural or manmade factors**

Ship strikes

Ship strikes have not been documented.

Artificial propagation

There is no artificial propagation of shortnose sturgeon in the Altamaha River System. Shortnose sturgeon were reared at the USFWS Bears Bluff facility and released into the Savannah River.

Escapement of hatchery/captive fishes

Hatchery-reared fish from Bears Bluff that were stocked into the Savannah River were subsequently found in non-target river systems in South Carolina and Georgia (Fleming et al. 2003, Smith et al. 2002a). However, shortnose sturgeon tagged in, and likely native to, the Altamaha River have also been located in other systems (UGA and GA DNR unpubl. data), suggesting that the migration of fish from one river to another is not a behavior unique to the hatchery fish, and likely occurs naturally, to some degree, in many southeastern populations.

Current and Recommended Research

More research has been conducted on the Altamaha River shortnose sturgeon population than any other in Georgia. Although this research has provided excellent information pertaining to the population dynamics on this system, a large amount of information is still lacking regarding exact spawning locations; these data would allow managers to properly protect critical spawning habitats through land acquisition programs and protective regulation. In addition to collection of the biological/population information on shortnose sturgeon, research should also be expanded to further identify the degree of environmental alterations in this system, such as depressed DO levels, and determine the significance of these alterations to habitat and fish.

Satilla River

Historic Distribution and Abundance

Collections of shortnose sturgeon were made in the estuaries of this system during the late 1980's and early 1990's during crustacean monitoring (G. Rogers, GA DNR, pers. comm.). Additionally, commercial catches of the sympatric Atlantic sturgeon were documented in this system until 1991 (Rogers and Weber 1994a).

Current Distribution and Abundance

Surveys for sturgeon in the Satilla (1995, 74 net hours) failed to yield any shortnose sturgeon (Rogers and Weber 1995b). Subsequently sturgeon were reported during crustacean survey in early 1990's during crustacean monitoring (G. Rogers, Georgia Department of Natural Resources, personal communication, NMFS 1998). A survey is underway; recent results indicated both shortnose and Atlantic sturgeon have been captured in the Satilla River (D. Peterson, UGA, pers. comm., 2010).

Natural History and Habitat Information

Spawning

Shortnose sturgeon spawning information is unknown for the Satilla River population.

Foraging

Foraging information for shortnose sturgeon in the Satilla River is unknown.

Overwintering/resting

Information regarding overwintering and resting habitat and behaviors for the Satilla River population of shortnose sturgeon is not known.

Migration

There is no information regarding seasonal movements and use of habitat for the Satilla River population of shortnose sturgeon.

Stressors to the Riverine System

1. **Habitat**

Dams and diversions

No mainstem dams currently exist on the Satilla River.

Other energy projects

Tidal turbines

No tidal turbines exist in this system and none are currently proposed.

LNG facilities

There are currently no existing or proposed LNG facilities associated with this system.

Dredging and blasting

Dredging only occurs on a relatively small scale in this system in order to maintain the Intracoastal Waterway.

Water quality and contaminants

One of the primary concerns for water quality in this and most other rivers in the southeastern U.S. is depressed DO levels during the warmer months of the year. These seasonally depressed levels may occur naturally; however these conditions are likely exacerbated by regulated flow coupled with the input of additional nutrients through municipal and industrial discharges and non-point source pollution, driving levels below 2.5 mg/L in some situations. Although this may be a factor in the Satilla River, thorough examinations of the conditions have not been conducted and the amount of potentially available or compromised habitat is currently unknown.

Thermal Refugia

See Ogeechee River Section

2. Overutilization

Bycatch

Because commercial shad fishing is limited, bycatch may not be a significant factor. However, if the shad stocks were to recover to the point that shad fishing increased it could be a potential threat to shortnose sturgeon in the Satilla River.

3. Competition, predation and disease

Disease and predation

Disease and predation do not appear to be a significant issue in this system.

4. Inadequacy of existing regulatory mechanisms

Shortnose sturgeon are identified as a "Protected Species" in the state of Georgia under GA DNR Rule 391-4-10-.09. GA DNR Rule 391-4-10-.06 prohibits "activities which are intended to harass, capture, kill, or otherwise directly cause death of any protected animal species."

5. Other natural or manmade factors

Ship strikes

Ship strikes have not been documented in the Satilla River.

Impingement and entrainment

Incidences of impingement and entrainment are unknown.

Artificial propagation

There is no artificial propagation of shortnose sturgeon in the Satilla River System.

Escapement of hatchery/captive fishes

Hatchery-reared shortnose sturgeon released into the Savannah River between 1985 – 1992 have been found in other rivers in both SC and GA (Fleming et al. 2003, Smith et al. 2002a). It is unknown if fish stocked in the Savannah River migrated to the Satilla River.

Current and Recommended Research

A survey has found shortnose sturgeon in the Satilla River. A population estimate should follow this survey including both population dynamics and habitat availability along with potential spawning. If approprioate habitat is available, stock recovery efforts could be considered.

St. Mary's River

Historic Distribution and Abundance

Collections of shortnose sturgeon were made in the estuaries of this system during the late 1980's and early 1990's during crustacean monitoring (G. Rogers, Georgia Department of Natural Resources, personal communication). Additionally, commercial catches of the sympatric Atlantic sturgeon were documented in this system until 1991 (cited in Rogers and Weber 1995b).

Current Distribution and Abundance

The most recent directed surveys for sturgeon in the St. Marys (1994 and 1995, 117 net hours) failed to yield any shortnose sturgeon (Rogers and Weber 1995b). Shortnose sturgeon were observed in the early 1990's during crustacean monitoring (G. Rogers, Georgia Department of Natural Resources, personal communication). Surveys currently underway have captured both shortnose and Atlantic sturgeon in the St. Marys River (D. Peterson, UGA, pers. comm., 2010).

Natural History and Habitat Information

Spawning

Shortnose sturgeon spawning information is unknown for the Satilla River population.

Foraging

Foraging information for shortnose sturgeon in the St. Marys River is unknown.

Overwintering/resting

Information regarding overwintering and resting habitat, and behavior of shortnose sturgeon in the St. Marys River is not known.

Migration

There is no information regarding shortnose sturgeon seasonal movements and use of habitat in the St. Marys River.

Stressors to the Riverine System

1. Habitat

Dams and diversions

No mainstem dams currently exist on the St. Marys River.

Other energy projects

Tidal turbines

No tidal turbines exist in this system and none are currently proposed.

LNG facilities

There are currently no existing or proposed LNG facilities associated with this system.

Dredging and blasting

Dredging only occurs on a relatively small scale in this system in order to maintain the Intracoastal Waterway.

Water quality and contaminants

A remote blackwater stream, the St. Marys River is located in southeastern Georgia and northeastern Florida, forming the easternmost border between the two states. The St. Marys River begins deep within the Okefenokee Swamp and flows along a twisting 130-mile-long path into the Cumberland Sound and the Atlantic Ocean only 40 air-miles from its headwaters.
A relatively long section of the St. Marys River near mid-rived has been found to have DO levels of about 1.0mg/L during summer months (D. Peterson, UGA, pers. comm., 2010). While low

DO levels would be expected near the head of the river due to its proximity to the Okefenokee Swamp, this area of exceptionally low DO is downriver. Durango Paper Plant was previously located at the mouth of the St. Marys and plant effulent was attributed to poor water quality; the plant ceased operations in 2002. The 750 acres previously occupied by Durango is being planned for urban development.

The biggest concern for the water quality of the St. Marys River and other coastal rivers is secondary impacts from development, such as chemical and pesticide runoff from lawns and streets, and leaking septic tanks. A top priority of the St. Marys River Management Committee is to minimize septic tank leakage into the river, by working with counties to introduce procedures, ordinances, and regulations to implement setback rules, and identify and remediate failing systems (St. Johns River Water Management District website, 2010).

Thermal Refugia

See Ogeechee River Section

2. Competition, predation and disease

Potential disease and predation impacts are unknown.

3. Inadequacy of existing regulatory mechanisms

Shortnose sturgeon are identified as a "Protected Species" in the state of Georgia under GA DNR Rule 391-4-10-.09. GA DNR Rule 391-4-10-.06 prohibits "activities which are intended to harass, capture, kill, or otherwise directly cause death of any protected animal species."

Shortnose sturgeon are identified as an endangered species by the state of Florida. The state of Florida has two laws dealing with the protection of listed wildlife species:

1. The Florida Endangered and Threatened Species Act of 1977 – includes no specific prohibitions or penalties, but does establish the conservation and wise management of endangered and threatened species as state policy; and
2. Endangered Species Preservation Act – prohibits the intentional wounding or killing of any fish or wildlife species designated by the Florida Game and Freshwater Commission as "endangered", "Threatened", or of "special concern". This prohibition also extends to the intentional destruction of the nests of any such species.

4. Other natural or manmade factors

Ship strikes

Ship strikes of shortnose sturgeon have not been documented in the St. Mary's River.

Impingement and entrainment*:*

Impingement and entrainment are unknown.

Artificial propagation

There is no artificial propagation of shortnose sturgeon in the St. Mary's River System.

Escapement of hatchery/captive fishes

Shortnose sturgeon released into the Savannah River between 1982 and 1995 have been found in other rivers in SC and GA (Fleming et al. 2003, Smith et al. 2002a). It is unknown if individuals stocked in the Savannah River have migrated into the St. Mary's River.

Current and Recommended Research

A survey has found shortnose sturgeon in the St. Marys River. A population estimate should follow this survey including both population dynamics and habitat availability along with potential spawning. If approprioate habitat is available, stock recovery efforts could be considered.

St. John's River

Historic Distribution and Abundance

Historically, commercial landings for sturgeon in Florida were low compared to other states along the Atlantic seaboard. Although records did not differentiate between Atlantic and shortnose sturgeon, nor inshore or coastal captures, total Florida east coast landings of both species have totaled only 1.7 metric tons between 1950 - 1983; sturgeon were only recorded in 13 of those 33 census years averaging 131 kg (288 lbs) annually. The last commercial landings occurred in 1983.

Current Distribution and Abundance

Shortnose sturgeon were regularly caught, but unreported, in the Bostwick area between 1979 and 1981 (Cox and Moody 1981). Anecdotal and archival data indicate that sturgeon were frequently caught in the St. Johns as bycatch in commercial gill nets between 1970 and 1990. Many recent reports of sturgeon captures have been misidentified Orinoco sailfin catfish (*Pterygoplichthys multiradiatus*). Eleven shortnose sturgeon were collected in the St. Johns between 1949 through 1999; eight of those captures occurred between 1977 – 1981. In August 2000, a shortnose sturgeon was captured in a cast net near Racy Point just north of Palatka; the fish carried a tag inserted near St. Simon Island, GA (FL FWC website). No sturgeon were caught incidentally during a survey aimed at other species between 1980 through 1993 when a total of 21, 381 hours of effort with 100 yard gill nets was conducted. The most recent directed survey for sturgeon in the St. Johns River was conducted by FL FWC between January 2002 and June 2003. A single sturgeon was captured south of Federal Point nearby Palatka (rkm 127) on 22 January, 2002 during the two-year directed effort (4,493 net hours). This individual was captured within three kilometers of the area where most historical catches occurred (FL FWC). Interestingly, none of the collections were large speciemens and none werer captured in the estuarine portion of the basin; all captures were less than 10 pounds and occurred far upstream in an area heavily influenced by artesian springs with high mineral content.

Natural History and Habitat Information

Spawning

Shortnose sturgeon spawning information is unknown for the St. Johns River population. It is unknown if large adult shortnose sturgeon inhabit the river as captures have been limited to smaller individuals.

Foraging

Foraging information for shortnose sturgeon in the St. Johns River is unknown.

Overwintering/resting
Information regarding overwintering and resting habitat and behaviors for the St. Johns River population of shortnose sturgeon is not known.

Migration
There is no information regarding seasonal movements and use of habitat for shortnose sturgeon in the St. Johns River.

Stressors to the Riverine System

1. Habitat

Dams and diversions

In 1968 Rodman Dam was constructed about 8 miles (~12.9 km) upstream from the St. Johns on the Ocklawaha River (the largest tributary to the St. Johns) as part of the Cross Florida Barge Canal. About three years later the barge canal project was stopped by court order and Presidential decree. In 1999 Rodman Dam was renamed the Kirkpatrick Dam in honor of Senator George Kirkpatrick. The Rodman/Kirkpatrick Dam is 22 feet above natural ground elevation, and has a 300 ft wide base and a 30 foot crown constructed by earth fill. There are four spillway gates that control the water elevation in the adjacent Rodman Reservoir; both the reservoir and St. Johns River are popular for bass fishing. The Ocklawaha River has been speculated as the spawning area for many diadromous fishes including the shortnose sturgeon. If shortnose sturgeon utilized the Ocklawaha River for spawning, the dam impedes passage to that habitat.

Other energy projects

Tidal turbines
No tidal turbines exist in this system and none are currently proposed.

LNG facilities
There are currently no existing or proposed LNG facilities associated with this system.

Dredging and blasting

The ship channel from the outer entrance channel at the sea buoy to downtown Jacksonville is dredged regularly, approximately 30 nautical miles, to maintain 38 ft msl to 42 ft msl. Dredging maintains the existing bank lines and bank slopes, extending the existing bank slope down to the deeper channel bottom, effectively reducing the channel width from 24 to 40 ft dependent on the bank slope. The U.S. Navy maintains the Naval Air Station Jacksonville south of downtown and Naval Station Mayport near the mouth of the St. Johns River: plans to deepen the channel to 54 ft msl to allow passage of aircraft carriers into Mayport are currently being considered. Dredging also occurs, on a relatively smaller scale, in order to maintain the Intracoastal Waterway.

Water quality and contaminants

Pollution in the St. Johns River is abundant; it is unsafe to swim in the river on a regular basis. Similar to other rivers in the southeastern U.S., one of the primary concerns for water quality in the St. Johns is depressed DO levels combined with elevated water temperatures during the warmer months of the year. These seasonally depressed levels may occur naturally; however they are undoubtedly exacerbated by input of additional nutrients through municipal and industrial discharges and non-point source pollution.

Thermal Refugia:

No sturgeon have been observed in the numerous springs located on the St. Johns River.

2. Competition, predation and disease

Potential disease and predation impacts are unknown.

3. Inadequacy of existing regulatory mechanisms

Shortnose sturgeon are identified as an endangered species by the state of Florida. The state of Florida has two laws dealing with the protection of listed wildlife species:

- The Florida Endangered and Threatened Species Act of 1977 – includes no specific prohibitions or penalties, but does establish the conservation and wise management of endangered and threatened species as state policy; and
- Endangered Species Preservation Act – prohibits the intentional wounding or killing of any fish or wildlife species designated by the Florida Game and Freshwater Commission as “endangered”, “Threatened”, or of “special concern”. This prohibition also extends to the intentional destruction of the nests of any such species.

The Florida Water Resources Act of 1972 resulted in the creation of five regional water management districts in Florida: the St. Johns River Water Management District (SJRWMD) manages 10 major watersheds including the St. Johns. The Act also established a permit system allocating water use. SJRMD is an agency of the state of Florida and is responsible for balancing people’s need for water with nature’s needs; generally, regulating water use and protecting wetlands, waterways and drinking water supplies. The SJRWMD protects water quality and quantity by maintaining minimum flows and levels, establishing state standards, and explores opportunities for energy and water conservation. Since 1997, reducing point source pollution has been a primary focus of the SJRWMD Lower Basin Executive District; improved treatment and reuse of reclaimed water are sought. In addition, the Florida Department of Environmental Protection is developing a total maximum daily load (TMDL) for the basin: the main focus of the lower St. Johns River TMDL is to decrease excess nutrients, algal blooms, low DO and decreased transparency that can result in loss of aquatic vegetation. TMDLs have been adopted for the middle and lower basins of the St. Johns, but not the upper.

4. Other natural or manmade factors

Ship strikes

Ship strikes have not been documented in the St. Johns River.

Impingement and entrainment

Impacts from impingement and entrainment are unknown.

Artificial propagation

There is no artificial propagation of shortnose sturgeon in the St. Johns River.

Escapement of hatchery/captive fishes

At least four sturgeon farms are located within Florida; none are permitted to hold shortnose sturgeon. Instead these farms focus on culture of non-native sturgeon and caviar as permitted by the state of Florida in 1996. Best Management Practices for Sturgeon govern the conduct of aquaculture in Florida as managed by the Florida Department of Agriculture and Consumer Services. In addition shortnose sturgeon are currently held in captivity for research purposes at the University of Florida in Gainesville (see Table 43) but presumably any accidental escapement or release would occur in the Gulf of Mexico potentially impacting Gulf sturgeon.

Current and Recommended Research

Utilizing the NMFS survey protocol, the 2001-2004 FL FWC shortnose survey in the St. Johns yielded a single individual (63.5 cm TL; 1,589 grams). At that time it was realized that the protocol may need modification for use within the St. John system given the broad river coupled with fast moving water. A subsequent survey would either validate the existing record, or may reveal a larger population. Habitat characterization of the substrate would identify any potential spawning gravel beds.

Risk Assessment

After assembling information for each river known to support shortnose sturgeon in Section 6, the SRT next wanted to examine the status of individual riverine populations of shortnose sturgeon while considering the stressors identified above.

Previous Assessments of Extinction Risk and Listing/De-Listing Criteria for Shortnose Sturgeon

The SRT examined previous inquiries conducted for shortnose sturgeon including the 1998 Recovery Plan that identified 19 shortnose sturgeon populations as well as the 1987 determination that differences in life history and habitat preferences in the northern and southern rivers coupled with the their anadromous life history suggested it was unlikely that populations in adjacent river systems interbred with any regularity (NMFS 1987). Using the five listing factors from section 4 (a) of the ESA, the NMFS 1987 assessment qualitatively evaluated threats to riverine populations of shortnose sturgeon and with population estimates and recommended:

1. The Connecticut (800 adults), Delaware (10,000 adults), and Hudson (27,000 adults) should be down-listed to threatened.The Connecticut (800 adults), Delaware (10,000 adults) and Hudson (27,000 adults) River populations would be downlisted to threatened;
2. The Kennebec River population (10,000 adults) and the Saint John River, New Brunswick (18,000 adults) population of shortnostose sturgeon should be de-listed; and
3. All other riverine populations of shortnose sturgeon should remain listed as endangered.

These potential modifications to the ESA listing were met with some disagreement from the scientific community in response to the request to public comment. As a result NMFS did not modify the shortnose sturgeon listing per recommendations from the 1987 Status Review Report.

Later in response to a petition, NMFS evaluated the status of shortnose sturgeon in the Kennebec River system in Maine (Androscoggin, Kennebec and Sheepscot rivers) in 1996 (NMFS 1996).

NMFS concluded that the petitioned action of de-listing was not warranted (61 FR 53893) for two reasons: 1) shortnose sturgeon in the Androscoggin and Kennebec rivers continued to face substantial threats to their habitat and/or range, and the existing regulatory mechanisms at the time, other than the ESA, were inadequate to ensure for ongoing appraisal and management of these threats; and 2) questions regarding the population estimates were raised and information was lacking regarding population dynamics (e.g., natality, natural mortality, age or size structure) that could inform how the breeding populations were replacing themselves over time. Two criteria were detailed that *both* must be met for de-listing of the shortnose sturgeon in the Kennebec River System: 1) "census population size" which was defined as the number of spawning shortnose sturgeon in a given year, and 2) the need to establish that there was a full age-class structure for shortnose in the Kennebec system.

Risk Assessment Conducted by the SRT

When discussing the methodology to determine the risk shortnose sturgeon face due to the stressors idenitified at the riverine scale, the present SNS SRT realized that data availability is an important factor to consider. Even a simple quantitative model (i.e., one which is often used by American Fisheries Society (AFS), the Convention on International Trade in Endangered Species (CITES), and the International Union for the Conservation of Nature and Natural Resources (IUCN) requires at least ten years or three generations of time-series population abundance data, and 15 years of data are preferable (Dulvy et al. 2004). For all the rivers considered in this analysis, only the data collected from the Hudson River might support the most simplistic quantitative population viability analysis.

Because abundance estimates and demography data varied greately across the range of the shortnose sturgeon, and in some cases was extremely limited or even or non-existent, the SRT determined that the best approach was to weigh and rank effects of the stressors on shortnose sturgeon at a riverine scale. The ranking system was similar to an extinction risk method developed by the ASSRT (2007) but incorporated a weighting system in calculating overall scores for hazards.

Further the SNS SRT firmly believed that the size and demographics of a population was an important consideration when assessing risk to riverine populations. A larger population was likely more resilient than a smaller one. For example a population of 50,000 individuals would have more resilience than a population of 2,000. A population that had three life stages (eggs, young and adults) was probably better equipped to withstand an extreme event compared to a population with only one life class. Therefore the SNS SRT developed a function to express the "population health" that is described in more detail below.

Risk Assesmment – 3 steps

The SRT conducted a three step risk assessment for shortnose sturgeon at a riverine scale. Each step is listed here and detailed below:

1. Assess population health,
2. Populate a "matrix of stressors" by ranking threats, and
3. Review assessment by comparing population health scores to stressors scores.

Step 1: Assess Population Health

A population health score was calculated to represent shortnose sturgeon viability at a riverine scale (Table 38). The population health score considered number of individuals, demographics, and abundance trends as defined below. Scores for each criterion were then summed for the total population health score (Table 39).

- Number of individuals - The number of shortnose sturgeon in each river was identified by reports or estimated by experts. The Hudson River has the greatest number of individuals and was given a rank of 5; a 0 was given to those rivers where shortnose sturgeon had not been recently surveyed or with abundance in the tens of fish. Other rivers received a score between 1 and 4 depending on their abundance estimates. It is important to note that a score of zero does not mean that there are no shortnose sturgeon present but rather the SNS SRT was uncertain about the presence of shortnose sturgeon in the river due to lack of recent sampling or insufficient sampling.

Table 37. Abundance scores for number of shortnose sturgeon by river. Scores ranged between 0 (fewest fish) to 5 (greatest number of fish). "Rounded" scores represent the best available information for adult abundance rounded to the nearest 1, 10, 100, or 1,000. Log abundance estimates are present along with the calculated rank.

River	Abundance Estimate	log(pop)	Final Score
Penobscot	1000	3.00	3.35
Kennebec Complex	9000	3.95	4.42
Piscataqua	1	0.00	0.00
Merrimack	30	1.48	1.65
CT	1000	3.00	3.35
Housatonic	1	0.00	0.00
Hudson	30000	4.48	5.00
Delaware	12000	4.08	4.56
Chesapeake	100	2.00	2.23
Susquehanna	10	1.00	1.12
Potomac	10	1.00	1.12
Roanoke	1	0.00	0.00
Chowan	1	0.00	0.00
Tar Pamlico	1	0.00	0.00
Neuse	1	0.00	0.00
New	1	0.00	0.00
North	1	0.00	0.00
Cape Fear	10	1.00	1.12
Winyah Bay Complex	100	2.00	2.23
Santee	10	1.00	1.12
Cooper	100	2.00	2.23
Lakes Marion and Moultrie	10	1.00	1.12
ACE Basin	10	1.00	1.12
Savannah	1000	3.00	3.35
Ogeechee	100	2.00	2.23
Altamaha	6000	3.78	4.22
Satilla	1	0.00	0.00
St Mary's	1	0.00	0.00
St John's	1	0.00	0.00

- Demographic points were awarded for each shortnose sturgeon life stage present in a river up to three total points: one point each was awarded for each life stage as described below:
  - Eggs, larvae or young-of-year
  - Juveniles (immature fish)
  - Adults (mature fish)
- Abundance trends were ranked on a scale of 0-3: increasing populations were given three points and unknown trends were given 0 with other ranks listed below:
  - Inceasing trend in abundance = 3 points
  - Potentially stable abundance estimates= 2 points
  - Declining abundance estimare= 1 point
  - No estimates or unknown trend = 0 points

Table 38. Viability of shortnose sturgeon by river. Scores for total number of individuals range from a low of 0 to a high of 5; demographics scores range between a low of 0 and a high of 3; abundance trends scores range from a low of 0 to a high of 4. A population health score of 12 is the total possible.

River	Total Number	Demographics	Abundance Trend	Population Health Score
Penobscot	3.35	1	0	4.35
Kennebec Complex	4.42	3	3	10.42
Piscataqua	0.00	1	0	1.00
Merrimack	1.65	2	2	5.65
Connecticut	3.35	3	2	8.35
Housatonic	0.00	1	0	1.00
Hudson	5.00	3	2	10.00
Delaware	4.56	3	2	9.56
Chesapeake	2.23	1	0	3.23
Susquehanna	1.12	0	0	1.12
Potomac	1.12	1	0	2.12
Roanoke	0.00	1	0	1.00
Chowan	0.00	0	0	0.00
Tar Pamlico	0.00	0	0	0.00
Neuse	0.00	0	0	0.00
New	0.00	0	0	0.00
North	0.00	0	0	0.00
Cape Fear	1.12	1	1	3.12
Winyah Bay Complex	2.23	2	2	6.23
Santee	1.12	1	0	2.12
Cooper	2.23	2	2	6.23
S-C Reservoir system	1.12	3	0	4.12
ACE Basin	1.12	2	3	6.12
Savannah	3.35	3	2	8.35
Ogeechee	2.23	3	2	7.23
Altamaha	4.22	3	2	9.22
Satilla	0.00	0	0	0.00
St Mary's	0.00	0	0	0.00
St John's	0.00	1	0	1.00

The SRT then examined the population health scores of shortnose sturgeon at the riverine scale; recall a total of 12 points is available. Four grouping of shortnose sturgeon were apparent to the SNS SRT: 1) scores greater than 10 were assigned to the Kennebec and Hudson rivers; 2) scores between 9-10 were assigned to the Delaware and Altamaha rivers; 3) scores between 6-9 were assigned to Conneticut, Winyah Bay, Cooper, ACE Basin, Savannah, and Ogeechee rivers; 4) the remiaing 18 rivers received less than ½ of the available points (i.e., 6 or less points out of 12).

The SNS SRT agreed that the higher the health score the more viabile and resilient the shortnose sturgeon inhabiting that river were to withstand stochastic change. Specifically the SRT determined a population health score of 11 or 12 is necessary for a population that is able to withstand stressors; and identified the following thresholds, *in total*, as necessary to consider a population resilent enough to withstand stressors:

- all life stages are present - demographic score must be a 3,
- abundance myst be either stable or increasing (i.e., 2 or 3 points), and
- number of individuals must be high (5).

Notably, the populaton health scores should rely on recent survey data collected every three to five years over, a minimum of 18 to 25 years for northern populations, and 12 to 24 years for southern populations. Longevity of survey periodicity is based on the product of regional age of shortnose sturgeon at maturity (i.e., 12 years in the north; 8 years in the south) times 1.5. For example, an 18 survey period in the north is roughly 1.5 times the number of years it takes for a mature female inhabiting a northern river to spawn (12 x 1.5) and 25 years is roughly twice that amount. The period is shorter in the southern region as females reach maturity at younger ages; for example shortnose sturgeon removed from the Savannah River and held in captivity reached sexual maturity at age 6 (M. Mohead, NMFS, pers. comm. 2009). These long-term surveys to determine relative abundance estimates at a riverine scale should be complimented by a periodic assessment of the distribution of size/age structure occurring every three to five years.

Step 2: Assess Impact of Stressors

Stressors that shortnose sturgeon may encounter were tabulated and organized by river (Table 39). The SNS SRT then ranked the impact of each stressor to a riverine population of shortnose sturgeon using a using a scoring system of 1-5 as listed below:

1 – No or Low Risk
2 – Moderately Low Risk
3 – Moderate Risk
4 – Moderately High Risk
5 – High Risk

Scores for each stresser were first posed by the SNS SRT member with the greatest knowledge of area. Each score was then revisited by the entire SNS SRT to ensure consistently across rivers; the SRT specifically discussed the rationale for all ranks of three and above and also the reasoning for the scoring to ensure consistent assessment across the geographic range of the speices. Notably, only two scores were adjusted: the impact of dams to both the Savannah and St. Johns riverine populations were reduced from a “four” to a “three”.

The SRT then considered simply summing the scrores of each stressor by river for a cumulative score. However, the SRT firmly believed the biological impact of stressors to shortnose sturgeon varied; that is the impacts from some stressors would have greater impacts to the resilence of the shortnose sturgeon than others. For example the SNS SSRT agreed that habitat modification had much greater biological effects to the viability of a shortnose sturgeon riverine population than the adequacy of existing laws and regulations. Likewise condition of habitat quality and quantity has a greater impact on the status of shortnose sturgeon than competition, predation or disease (Factor C).

The SRT acknowledged those stressors receiving the higher scores of 3 or greater were mostly attributed to habitat destruction (e.g., dams and dredging), followed by overutilization, and other natural and manmade factors (Table 39). Effects of competition, predation, and diseases, along with and inadequacy of existing laws and regulations were not ranked as highly hazardous as none received any rank score greater than 2. The SRT decided to address this disparity, and therefore weighted the summed value for each riverine population as described below:

- **Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range (Factor A)** received a weighting of 50% of the total cumulative total as habitat quality and quantity is the overriding factor in the survival and recovery of shortnose sturgeon. This includes effects of dams and degraded water quality, as well as dredging. The SRT members noted that habitat degradation/modification posed the greatest threat to the species.
- **Overutilization for Commercial, Recreational, Scientific, or Educational Purposes (Factor B)** received a weighting of 25% of the total cumulative total as bycatch mortality resulting from fisheries can greatly affect the reproductive capabilities of a population.
- **Disease and Predation (Factor C)** received a weighting of 5% of the total cumulative toal as few data exist describing this factor as a major impact to shortnose sturgeon and there is no reason to conclude it is limiting survival or recovery of shortnose sturgeon.
- **The Inadequacy Existing Regulatory Mechanisms (Factor D)** received a weighting of 5% of the total cumulative total as regulations and permitting afford protection of shortnose sturgeon across their range.
- **Other Natural or Manmade Factors (Factor E)** received a weighting of 15% of the cumulative total given impingement and entrainment pose risks to early life stages of shortnose sturgeon.

Table 39. The matrix of stressors populated with scores determined by the SRT for each river system for the 5 ESA factors (A-E) and by specific stressors identified under each factor. The 5 factors were weighted by the values in the first row to calculate the overall stressor score.

Weighting					0.50			0.25				0.0 5				0.05					0.15	
Riverine Population	Dams	Dredging	Water Quality/Quantity	Energy Other	Factor A Scorea	Commercial and Recreational Bycatch	Scientific Collection	Factor B ScoreFactor B Score	Competition	Predation	Disease	Factor C ScoreScore	International Authorities	Interstate & Fed. Authorities	State Authorities	A Factor D ScoreScore	Impingement & Entrainment	Ship Strikes	Artificial Propagation	Introd. of exotic/invasv spp.	Factor E ScoreScore	Overall Threat Score
Penobscot	3	3	3	1	10	1	1	2	1	1	1	3	1	2	2	5	1	1	1	1	4	6.5
Kennebec Complex	1	3	3	2	9	2	1	3	1	1	1	3	1	2	2	5	1	1	1	1	4	6.25
Piscataqua	1	3	2	2	8	2	1	3	1	1	1	3	1	2	2	5	1	1	1	1	4	5.75
Merrimack	1	1	3	1	6	1	1	2	1	1	1	3	1	2	2	5	1	1	1	1	4	4.5
Connecticut	5	2	3	1	11	2	2	4	1	1	1	3	1	2	2	5	2	1	1	1	5	7.65
Housatonic	4	1	4	1	10	1	1	2	1	1	1	3	1	2	2	5	1	1	1	1	4	6.5
Hudson	1	3	3	2	9	2	1	2	1	1	1	3	1	2	2	5	1	1	1	2	5	6.4
Delaware	1	4	4	3	12	3	1	3	1	2	1	4	1	2	2	5	4	2	1	2	9	8.8
"Chesapeake" & C&D	1	4	4	2	11	3	1	4	1	2	1	4	1	2	2	5	1	1	1	2	5	7.7
Susquehanna	5	1	3	1	10	2	1	2	1	2	1	4	1	2	2	5	3	1	1	2	7	7.25
Potomac	1	3	5	1	10	3	1	5	1	2	1	4	1	2	2	5	3	1	1	3	8	7.65
Roanoke	3	1	3	1	8	3	1	4	1	1	1	3	1	2	2	5	2	1	1	2	6	6.3
Chowan	2	1	3	1	7	3	1	4	1	1	1	3	1	2	2	5	2	1	1	2	6	5.8
Tar/Pamlico	2	1	3	1	7	3	1	4	1	1	1	3	1	2	2	5	1	1	1	2	5	5.65
Neuse	4	1	4	1	10	3	1	4	1	2	1	4	1	2	2	5	1	1	1	2	5	7.2
New	1	1	2	1	5	3	1	4	1	1	1	3	1	2	2	5	1	1	1	2	5	4.65
North	1	1	2	1	5	3	1	4	1	1	1	3	1	2	2	5	1	1	1	2	5	4.65
Cape Fear	5	4	4	2	15	3	1	4	1	2	1	4	1	2	2	5	2	2	1	2	7	10
Winyah Bay Complex	3	3	3	1	10	4	1	5	1	2	1	4	1	2	2	5	2	1	1	2	6	7.6
Santee	5	1	1	1	8	5	1	6	1	2	1	4	1	2	2	5	1	1	1	2	5	6.7
Cooper	5	2	2	1	10	1	1	2	1	2	1	4	1	2	2	5	1	1	1	2	5	6.7
Lakes Marion and Moultire	5	1	1	1	8	2	1	3	1	2	1	4	1	2	2	5	1	1	1	2	5	5.95
ACE Basin	1	1	1	1	4	2	1	3	1	2	1	4	1	2	2	5	1	1	1	2	5	3.95
Savannah	3	5	4	2	14	4	1	5	1	2	1	4	1	2	2	5	3	1	1	2	7	9.75
Ogeechee	1	1	3	1	6	3	1	4	1	1	1	3	1	2	2	5	1	1	2	1	5	5.15
Altamaha	2	2	2	1	7	3	1	4	1	2	1	4	1	2	2	5	2	1	1	2	6	5.85
Satilla	1	1	3	1	6	1	1	2	1	2	1	4	1	2	2	5	1	1	1	2	5	4.7
St. Mary's	1	2	3	1	7	1	1	2	1	1	1	3	1	2	2	5	1	1	1	1	4	5
St. John's	3	2	3	1	9	1	1	2	1	2	1	4	1	2	2	5	1	1	1	1	4	6.05

Step 3: Linking Population Health and Threat Scores

Finally the SRT examined the relationship between population health scores and associated stressors for each shortnose sturgeon riverine population (Fig. 31). Inherent is the negative correlation of stressors and population health: one would expect greater resilence and viability with lesser sterssors. Examining the health score and associated stressors by river, the SNS SRT noted: 1) despite relatively high stressor scores, the Hudson and Kennebec river populations appear relatively healthy; 2) shortnose sturgeon in the Savannah River appear moderately healthy, but their status is perilous; 3) shortnose in the ACE system are of moderate health with low stress and may be most able to recover.

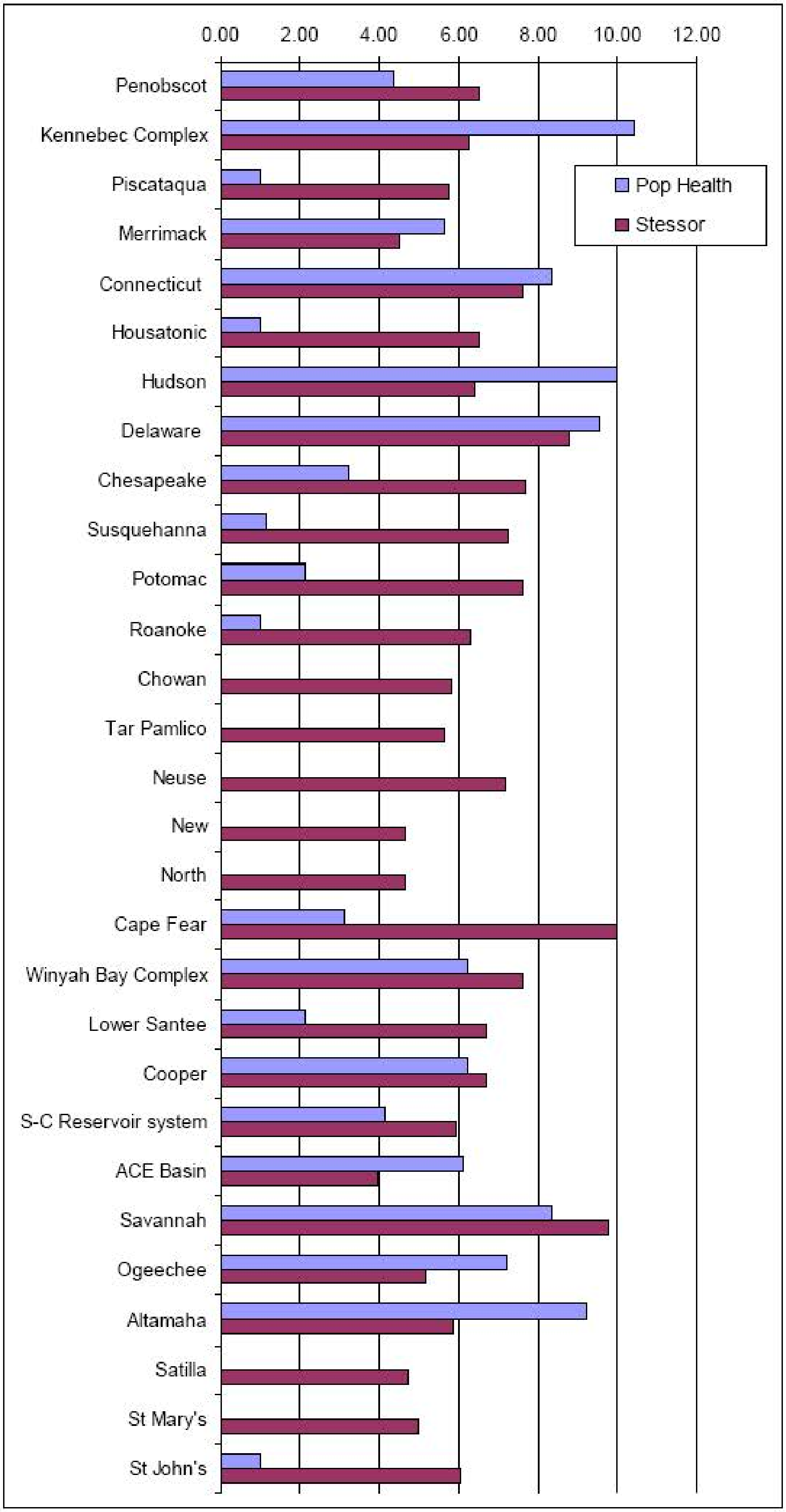


Figure 31. The relationship between population health scores and associated stressors for each shortnose sturgeon riverine population.

RAMAS Extinction Risk Modeling

The SRT asked Dr. Joe Hightower (NCSU) to perform an age-structured population model using the RAMAS software (Akçakaya and Root 2007) to estimate extinction probabilities. Managers responsible for restoring threatened or endangered species can use population models in several ways. Models can aid in identifying which rates are most responsible for the current low abundance (e.g., low recruitment versus poor adult survival) or should be the focus of management efforts intended to restore the population (Crouse et al. 1987, Caswell 1989, Gross et al. 2002). For example, efforts to reduce bycatch might have little effect if adult survival is already high (Gross et al. 2002). Models can also provide guidance about the expected timing of rebuilding or of further declines. The timing of simulated declines can be compared to the timing of planned surveys and status reviews, in order to determine whether monitoring and restoration efforts will be adequate.

It is also helpful to examine the simulated population trajectories in order to determine what level of sampling will detect population changes. For example, Zehfuss (2000) simulated population declines in Gulf sturgeon (*Acipenser oxyrinchus desotoi*) and determined that monitoring for 7-10 years would be required to detect a population decline of 10 percent per year. Population size decreased by 52 to 65 percent before a statistically significant decline was detected. These results were based on annual monitoring with a relatively high capture probability (0.1). No shortnose sturgeon populations are being monitored this intensively, so substantial population changes could occur before being detected.

Appropriate data for the RAMAS model were available for the shortnose sturgeon populations in the Hudson, Cooper and Altamaha Rivers (Cooke et al. 2004, DeVries 2006, Woodland and Secor 2007) and were utilized to populate the model (Table 40). These data allowed comparison of northern (Hudson) and southern (Cooper, Altamaha) populations as well as those with larger number of individuals (Hudson, Altamaha) compared to fewer (Cooper).

Table 40. Parameters used in RAMAS shortnose sturgeon models for the Hudson (Woodland and Secor 2007), Cooper (Cooke et al. 2004), and Altamaha (DeVries 2006) rivers. The coefficient of variation (CV) was used to represent environmental stochasticity (year-to-year variability in rates). Survival from egg to age 1 is included in the estimated fertility.

	Hudson		Cooper		Altamaha	
Parameter	**Value**	**CV**	**Value**	**CV**	**Value**	**CV**
Survival (egg to age 1)	1.83×10^{-4}	-	3.23×10^{-5}	-	2.56×10^{-5}	-
Survival (age 1+)	0.80	0.14	0.86	0.153	0.66	0.17
Fertility (age 6)	0.377	0.66	0.067	0.566	0.893	0.47
Fertility (age 7)	0.433	0.66	0.108	0.566	1.551	0.47
Fertility (age 8)	0.490	0.66	0.155	0.566	2.399	0.47
Fertility (age 9)	0.547	0.66	0.204	0.566	3.421	0.47
Fertility (age 10)	0.605	0.66	0.253	0.566	4.594	0.47
Fertility (age 11)	0.663	0.66	0.300	0.566	5.892	0.47
Fertility (age 12)	0.720	0.66	0.344	0.566	7.287	0.47
Fertility (age 13)	0.776	0.66	0.384	0.566	8.752	0.47
Fertility (age 14)	0.831	0.66	0.420	0.566	10.263	0.47
Fertility (age 15)	0.884	0.66	0.452	0.566	11.797	0.47
Fertility (age 16)	0.936	0.66	0.480	0.566	13.334	0.47
Fertility (age 17)	0.987	0.66	0.504	0.566	14.858	0.47
Fertility (age 18)	1.036	0.66	0.525	0.566	16.355	0.47
Fertility (age 19)	1.082	0.66	0.544	0.566	17.813	0.47
Fertility (age 20)	1.128	0.66	0.559	0.566	19.224	0.47

The survival rate for age-1+ fish from each system (Table 40) was obtained from a published catch curve analysis, using age composition data for fish ages 4 and older (Altamaha: DeVries 2006) or ages 5 and older (Hudson: Woodland and Secor 2007, Cooper: Cooke et al. 2004). Each catch curve estimate was assumed to apply to fish age 1 and older because of the lack of information about age-specific rates.

Each age-specific fertility rate was the product of fecundity, maturity, spawning frequency, sex ratio, and survival from egg to age 1. Fecundity was obtained using river-specific von Bertalanffy age-length and length-weight curves (Dadswell et al. 1984, Cooke et al. 2004, DeVries 2006, Woodland and Secor 2007) and a constant rate of eggs/kg of body weight (Dadswell et al. 1984). Sexual maturity was assumed to occur at age 6 (Dadswell et al. 1984, Kynard 1997). Following Root (2002), a spawning frequency of 4 years was assumed with a 1:1 sex ratio. Following the approach used in previous shortnose sturgeon models (Gross et al. 2002, Root 2002), survival from egg to age 1 was adjusted to produce a population at equilibrium. Notably the model does not include any density dependence in population rates - this is generally considered a reasonable starting point when information is lacking, particularly for depressed populations (Gross et al. 2002).

Next, population size for each system was identified from existing estimates based on capture-recapture; the values were halved to estimate the number of females. The Hudson River total population is thought to be as high as 61,000 fish (Bain 2001, cited in Woodland and Secor 2007); so the modeled female population was set at one-half the total or 30,500. The Cooper River population reportedly contains about 200 adults (or about 100 females). A total modeled population of 200 females (age 1 and older) resulted in about 100 adult females (age 6+). For the Altamaha River (DeVries 2006), the modeled female population was set at one-half the population estimate of 6,320. For each population, the starting population vector was based on the equilibrium age distribution.

Extinction Probabilities

Data then was used in an age-structured population model (RAMAS Metapop version 5.0, Akçakaya and Root 2007) to estimate extinction probabilities. The software uses a Leslie matrix model (Leslie 1945, Donovan and Welden 2002) to project population size and age structure through time. The Leslie matrix (**A**) contains age-specific fertilities (F_i) in the first row and survival rates (S_i) on the subdiagonal. In this example, the matrix represents ages 1-4:

$$A = \begin{bmatrix} F_1 & F_2 & F_3 & F_4 \\ S_1 & 0 & 0 & 0 \\ 0 & S_2 & 0 & 0 \\ 0 & 0 & S_3 & 0 \end{bmatrix}$$

Population size at time t is given by a column vector (n(t)):

$$n(t) = \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix}$$

When the Leslie matrix is multiplied by the population vector, the result is another column vector (n(t+1)), the projected population vector at time t+1:

$$n(t+1) = A \bullet n(t)$$

The standard Leslie matrix model can be modified by including an additional survival parameter in the lower right corner:

$$A = \begin{bmatrix} F_1 & F_2 & F_3 & F_4 \\ S_1 & 0 & 0 & 0 \\ 0 & S_2 & 0 & 0 \\ 0 & 0 & S_3 & S_{4+} \end{bmatrix}$$

By including this survival rate, the last element of the population vector becomes an accumulator, in this case containing fish that are age 4 and older.

The first element of population vector **n**(t+1) is the number of age-1 fish. It is obtained as the product of the first row in **A** (fertilities) multiplied by **n**(t):

$$n(t+1) = \sum_a F_a n_a(t)$$

Because the year-t population vector generates the age-1 fish in year t+1, the fertilities (F_i) must account for survival from egg to age 1, in addition to the age-specific maturity and fecundity rates and the frequency of spawning. The standard practice of modeling only females (Donovan and Welden 2002, Gross et al. 2002, Root 2002) was followed so the fertility term also included 0.5 based on an assumed 1:1 sex ratio.

The model was used to project abundance through time and to record the frequency with which abundance drops to 0 (extinction) or below a specified threshold (quasi-extinction). Following Root and Akçakaya (1997), quasi-extinction of a population was based on 80 females. Akçakaya and Root (2007) recommend use of a threshold greater than 0, as population dynamics are difficult to model when the number of individuals is very low (e.g., Allee effects, inbreeding depression). Based on the Connecticut River population rates, a population of 80 females would be expected to contain about 17 adults.

Environmental stochasticity can be incorporated into the model by estimating the coefficient of variation (CV) for population rates. A CV greater than 0 produces random year-to-year variation about the mean fertility or survival rate. Woodland and Secor (2007) estimated that the year-to-year variability in cohort strength of Hudson River shortnose sturgeon had a CV of 0.66. This estimate was obtained by hindcasting the catches used in fitting the catch curve, assuming a constant rate of mortality across years. Variability in the expected catch at age 1 for each year class was used to estimate the CV. This approach to the Altamaha River age composition and obtained an estimated CV of 0.47; age composition data were not available for the Cooper River so the average of the Hudson and Altamaha CVs was used.

A 100-year horizion was used for each simulation following Root (2002) and the recommendation of the SNS SRT. Root and Akçakaya (1997) recommend choosing a horizon that is intermediate in length and based on the species' life history characteristics. A long horizon may make it difficult to justify model assumptions (e.g., that the vital rates will vary around the current values). A horizon that is too short may yield results that are not informative (e.g., a horizon less than the generation time of the species may be misleading about the longer-term risk of extinction).

For each river, the model assumed equilibrium at the current population size and estimated the probability of quasi-extinction (defined as a population comprised of 80 females) at zero for the Hudson, Altamaha, and Ogeechee river shortnose sturgeon populations even with year-to-year variability in recruitment and survival; while quasi-extinction occurred in year 32 for the Cooper River. Next RAMAS estimated the probability of a 50% decline in population size: the Altamaha population had a 75% probability of a 50% decline in number over the next 100 years (Fig. 32); the Hudson a 65% probability (Fig. 32) and the CooperRiver a 32% probability (Fig. 32). The probability of an 80% decline in number of shortnose sturgeon was relatively low for all three riverine populations: Hudson 9%, Cooper 1%, and Altamaha 23%.

A similar approach was used to estimate variability in survival rates. Rather than assuming constant survival and estimating variable recruitment, constant recruitment from age 1 and estimated variability in survival were assumed. The resulting CVs (Hudson 0.14, Altamaha 0.17) were similar to the assumed values (0.10-0.20) used by Root (2002). These estimated CVs are likely biased because survival estimates will vary less as the number of years since recruitment increases (e.g., a weak year class can be generated with only slightly lower annual survival if the rate is applied over many years). Also note that estimated CVs were obtained assuming that all variability was due to either recruitment or survival. Using both sources of variation in the simulations should be conservative (overstating expected variability in population size).

Results - Extinction

The estimated probability of extinction was zero for all three populations under the default assumptions, despite the long (100-year) horizon and the relatively high year-to-year variability in fertility and survival rates (Figure 32). Expected minimum abundance (based on a probability of 0.5) over the 100-year horizon was 13,429 for the Hudson, 122 for the Cooper, and 1,251 for the Altamaha.

The estimated probability of a 50 percent decline was relatively high (Hudson 0.65, Cooper 0.32, Altamaha 0.73), whereas the probability of an 80 percent decline was low (Hudson 0.09, Cooper 0.01, Altamaha 0.23, Figure 33). The probability of quasi-extinction was 0 for the Hudson and Altamaha populations. For the Cooper River, quasi-extinction first occurred in year 32 and the cumulative probability increased in a linear fashion for the remainder of the simulated 100-year horizon (Figure 34).

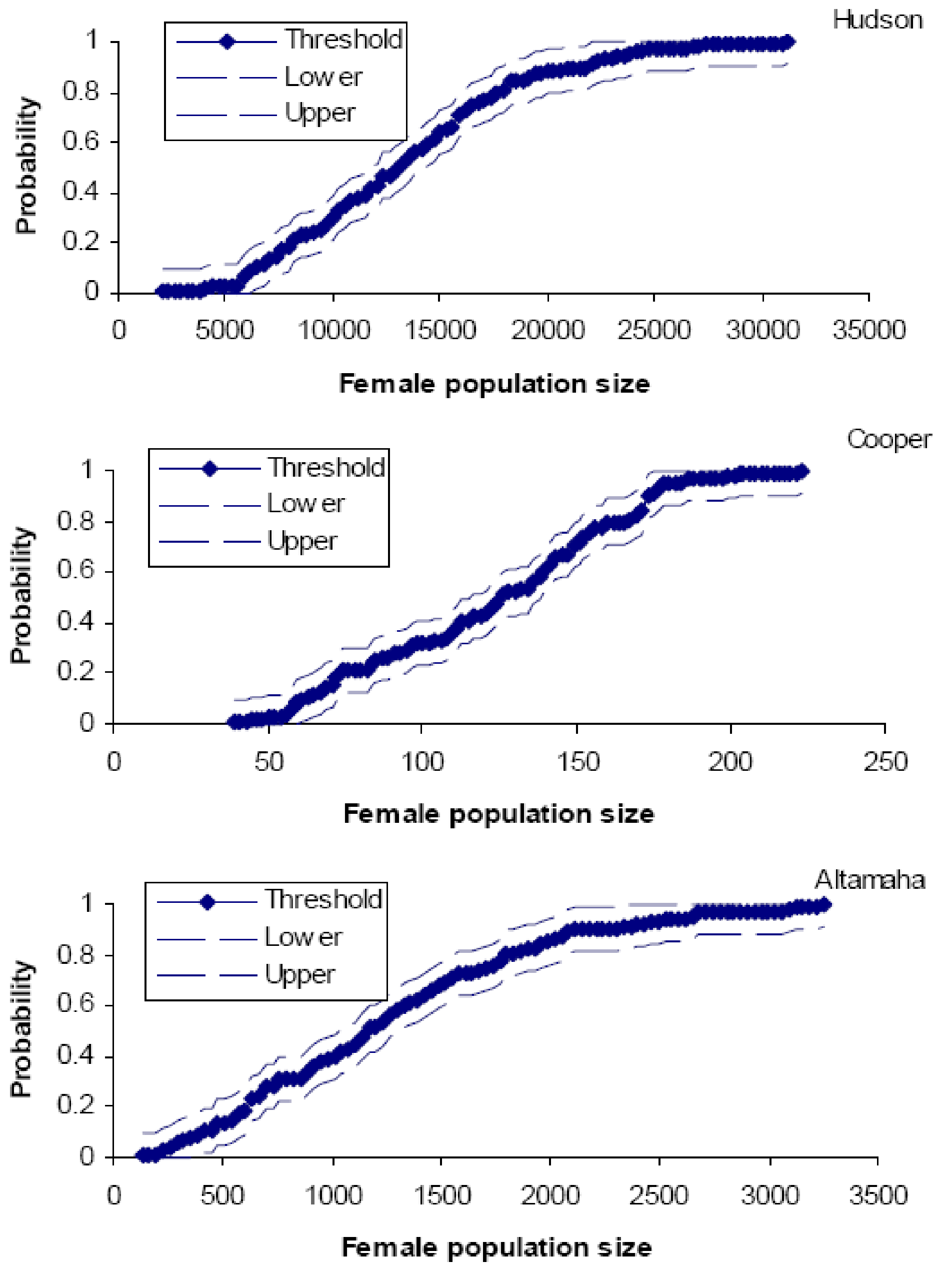


Figure 32. RAMAS estimated probabilities (and 95% confidence intervals) for female population size reaching various levels over a 100-year horizon for the Hudson (top), Cooper (middle), and Altamaha (bottom) river populations of shortnose sturgeon.

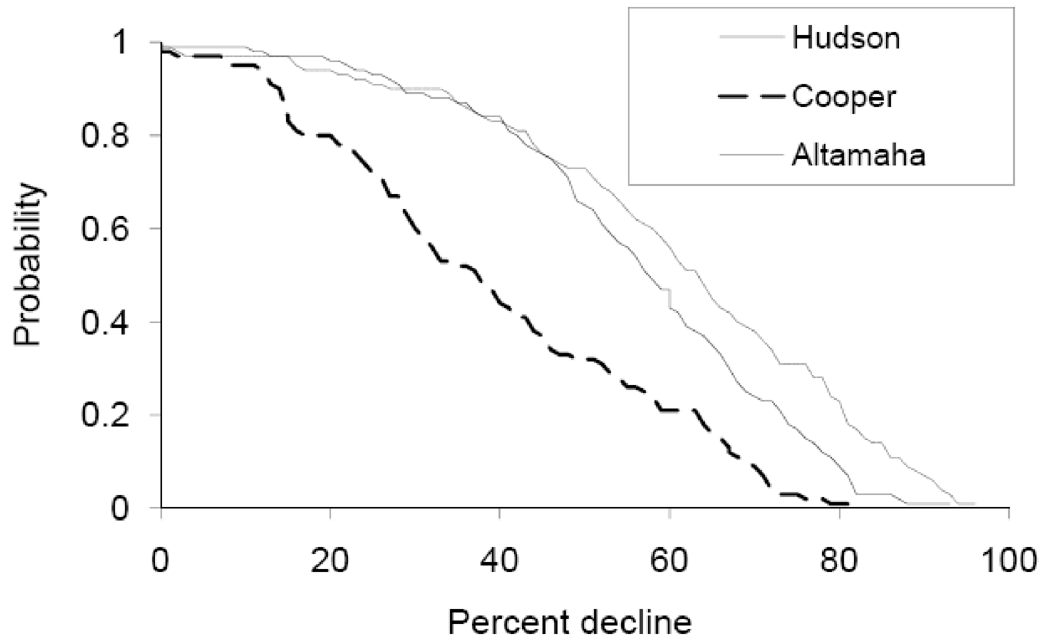


Figure 33. RAMAS estimated probabilities (and 95% confidence intervals) for percent declines in female population size over a 100-year horizon for the Hudson, Cooper, and Altamaha populations of shortnose sturgeon.

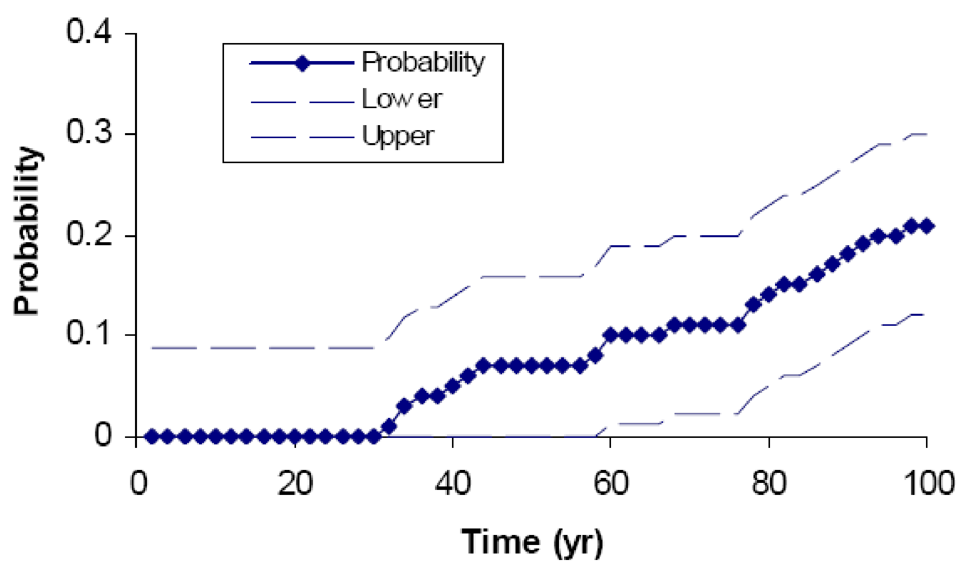


Figure 34. RAMAS estimated cumulative quasi-extinction probabilities (and 95% confidence intervals) for Cooper River shortnose sturgeon, based on a 100-year horizon. The quasi-extinction threshold was defined as a female population size of 80 individuals age-1 and older.

Effects of catastrophic events

The RAMAS software includes the capability of modeling catastrophic events, defined as occasional or rare environmental fluctuations (e.g., drought, fish kill) that are in addition to the default year-to-year fluctuations (stochasticity). The SNS SRT proposed four scenarios to be examined based on their reasonable likelihood to occur coupled with the relative ease in modeling their impact to a specified year class. The four scenarios modeled were:

1) spawning site mortality – mortality of all fish at a spawning site could occur due to a chemical spill or other localized water quality problem. It was assumed to occur with probability 0.1 (i.e. once every ten years on average) and to result in year-class failure and the mortality of spawning fish (25% of mature females, based on a spawning interval of 4 years).
2) drought - drought was assumed to result in year-class failure for two successive years (due to poor conditions for spawning) and was assumed to occur with probability 0.1.
3) year-class failure - based on USGS ichthyoplankton sampling in the Connecticut River to detect spawning (M. Kieffer, USGS, pers. com) this was assumed to result in year-class failure in 50% of years. In this scenario, egg-to-age 1 survival was doubled so that the population would still be at equilibrium, but have greater variability due to year-class failures.
4) bycatch - bycatch was assumed to result in 7% additional mortality each year for ages 6 and older (mature fish, large enough to be vulnerable to netting) due to an increase in gill-netting effort.

Notably, the episodic events considered by the SNS SRT in their extinction risk assessment (Table 39) were different than those in the RAMAS model. This was due to the options available in the RAMAS model wherein a suite of impacts aimed toward identifying effects to a particular age class over time occurred; in comparison the stressors ranked by the SNS SRT (Table 36) were more broad and assessed impact to the populations across many age classes collectively. In particular habitat destruction was found by the SNS SRT to have a high impact to status of the shortnose sturgeon; habitat modification was not an option offered in the RAMAS model due to complexity of potential effects across life stages and habitats.

Results - Catastrophies

These four catastrophic events were simulated to ascertain impact to the three riverine populations (Table 41). Resiliency was always dependent on population abundance; the larger the population the more resilent. In all four catastrophic scenarios (taken separately), the probability of extinction generally remained low after a catastrophic event was added to the model, except that additional bycatch mortality resulted in a 0.72 probability of extinction for the small Cooper River population (Table 41). Of the events, bycatch generally had the greatest effect to a population presumably because it occurred annually while the other events occurred stochastically ranging from 0.10 (spawning site mortality, drought) to 0.5 (year-class failure).

Probabilities of the catastrophic events leading to quasi-extinction of shortnose sturgeon were moderate for the Altamaha River, and high for the Cooper River population. Regardless of the type of catastrophic event, the probability of quasi-extinction was negligible for the Hudson River, due to its great population size. Quasi-extinction in the Altamaha River by these events ranged from 0.08 for year class failure to 0.92 for bycatch. The probability of quasi-extinction was the highest for the smallest population: Cooper River values ranged from 0.40 for year class failure to 1.00 for bycatch. Of the four scenarios examined, bycatch in general had the greatest impact, presumably because it occurred every year, while the other events occurred with a probability ranging from 0.10 (spawning site mortality, drought) to 0.5 (year-class failure).

Table 41. RAMAS estimated probabilities of extinction and quasi-extinction by river for four types of catastrophes: spawning site mortality, drought, year-class failure, and bycatch. Quasi-extinction is defined as a population of less than 80 females.

	Probability of extinction			**Probability of quasi-extinction**		
Catastrophe	**Hudson**	**Cooper**	**Altamaha**	**Hudson**	**Cooper**	**Altamaha**
Spawning site mortality	0.00	0.11	0.01	0.01	0.91[a]	0.36
Drought	0.00	0.00	0.03	0.00	0.94[b]	0.4
Year-class failure	0.00	0.00	0.00	0.00	0.40	0.08
Bycatch	0.00	0.72	0.12	0.04	1.00[c]	0.92[d]

[a]Median time to quasi-extinction = 28.5 years.
[b] Median time to quasi-extinction = 45.0 years.
[c] Median time to quasi-extinction = 16.7 years.
[d] Median time to quasi-extinction = 73.2 years.

Multiple age classes present in a population provided some stability in the face of catastrophic events, so that even the small Cooper River population would require 16 or more years for quasi-extinction to occur (Table 41). Quasi-extinction was least likely for the year-class failure scenario, despite having a 50:50 chance of recruitment failure each year. As noted above, egg to age-1 survival was doubled for this case, in order to retain a population at equilibrium (asymptotic growth rate of 1.0). For the remaining scenarios, the asymptotic growth rate decreased below 1.0 because of the year-class failures or additional mortality.

For the three shortnose sturgeon populations considered here, modeling results suggest that observed variability in shortnose sturgeon recruitment and survival will not drive these populations to extinction, even when abundance is low. This result is based on the assumption that mean population rates do not change, although they can vary considerably from year to year. It is also based on the assumption that these populations are stable (on average) at their current levels of abundance. Root (2002) similarly found the risk of extinction to be 0 for the default case for Connecticut River shortnose sturgeon.

Percent declines due to random variability in recruitment and survival are predicted to be greater for the Altamaha River population than for the Hudson or Cooper. Since all three population models were set up to be stable, the greater percent decline for the Altamaha is likely due to the lower age-1+ survival rate and higher CV. A decline of 80 percent was relatively unlikely for all three populations under the default conditions. Population size would vary much less over a shorter horizon. Reducing the horizon to 25 years results in an interval (+ 1 SD) of 17,928-35,904 for the Hudson, 145-252 for the Cooper, and 1,330-5,160 for the Altamaha.

Extinction risk increases dramatically if catastrophic events alter population rates. The degree to which populations can withstand these events depends on their current abundance. The probability of quasi-extinction is essentially 0 for the large Hudson River population, but ranges from 0.08 to 0.92 for the Altamaha River population, thought to be the fourth largest at present (DeVries 2006). The large current size of the Altamaha population nevertheless provides considerable buffering; the median time to quasi-extinction for the bycatch scenario is 73 years. In contrast, quasi-extinction is likely for the small Cooper River population under either of the three scenarios resulting in negative population growth (spawning site mortality, drought, bycatch).

As in prior studies (Gross et al. 2002, Root 2002), the population models used here were set up to be at equilibrium, without any density-dependence. Given a lack of population data, that is a reasonable starting point for examining short-term population behavior, but that assumption becomes less tenable as the time horizon increases. A better approach for a horizon of 10 or more years would be to build into the model density dependence in either recruitment or age-1+ survival. Density-dependence in fisheries models is typically provided by the spawner-recruit curve, which predicts lower per-capita recruitment as spawning stock increases (compensation, Hilborn and Walters 1992). Possible evidence of a compensatory response in shortnose sturgeon is the lower estimated recruitment in recent years for the Hudson River population, following a period of several strong year classes (Woodland and Secor 2007).

Including density dependence should allow for more realistic modeling of catastrophic events, in that a population could offset decreased recruitment or survival. The best argument for density dependence is that most fish populations can stabilize at multiple equilibrium points; for example, at different sustainable levels of fishing mortality. Getting information about compensatory changes in recruitment or survival is a very difficult task but one advantage of studying shortnose sturgeon is that most populations are starting from low levels. Thus there is potential for a large contrast between current and future population levels, which will be important for detecting changes in population rates. If rebuilding occurs, periodic studies similar to those conducted on the Hudson, Cooper, and Altamaha rivers should result in more realistic population models and a better understanding of the risks of catastrophic events.

The SRT thought RAMAS was a useful tool to estimate extinction risk probabilities for shortnose sturgeon populations that differ in life history parametes and abundance. The results provided insight for potential effects of certain stressors over time. The SRT noted the assumption that each population was currently at equilibrium was most likely violated due to their endangered status.

Summary of the Risk Assessment

As detailed above, the SRT developed cumulative shortnose sturgeon population health scores (Table 38), ranked stressors occurring to shortnose sturgeon within each river (Table 39), and then anticipating a negative relationship, compared population health to stressors (Figure 31). Summarized below by river are the population health and stressor scores; for each score a short explanation is provided to support influential ranks. See the River Summaries section for detailed river accounts; maps of each river are included in Figures 35-38.

Penobscot River

Population health = 4.35

- Likely 1,000 or more adults; no juveniles or larvae observed.

Stressor score = 6.50

- Dams are a modearate threat; efforts ongoing to remove 2 -3 dams.
- Dredging is a moderate threat as it occurs at a suspected over-wintering area.
- Water Quality is a moderate threat:
    - Coal tar deposits are documented around Bangor, ME.
    - At least 10 municipal water treatment plants, fish hatcheries and industrial waste discharge.
    - Several pulp mills in operation.

Kennebec System

Population health score = 10.42

- Popualtion size is large with an estimated 9,488 individuals and appears to be increasing.
- This population appears to be functioning as source of recruits for other nearby rivers in particular the Penobscot River.

Stressor score = 6.25

- Dredging is a moderate threat as maintenance dredging occurs in foraging area.
- Water Quality is a moderate threat:
    - Wood chips cover substrate in the foraging area.
    - Mercury, PCBs, and dioxin levels noted as high.

Piscataqua River

Population health = 1.00

Few historical records; current status unknown.

Stressor score = 5.75

- Dredging is a moderate stressor:
    - Navigation channel is maintained with in-river disposal.
    - Dredging north of the Public Service Company of New Hampshire every 5-6 years.

Merrimack River

Population health score = 5.65

- Populaiton size is les than 100 adults; spawning has been confirmed.

Stressor score = 4.50

- Water quality is a moderate stressor:

- Periodic industrial and sewage releases during flood conditions.
- DO concentrations below minimum thresholds during drought or low flow.

Connecticut River

Population health score = 8.35

- Small (1,242-1,580 adults) but stable population; confirmed spawning and all life stages are present.
- Potential source of recruits to other nearby rivers.

Stressor score = 7.65

- Dams are major stressor on habitat:
  - Sturgeon are separated into upstream and downstream segments by the Holyoke Dam. The dam bisects upstream spawning habitat from downstream feeding habitat in the estuary.
  - Fish passage through the Holyoke Dam and industrial canal system is lethal for many adults.
  - Hydropower operations close to the Montague spawning area, including the artificial manipulation of critical spawning habitat (disruption of natural flows, dewatering, and torrential releases), likely impede spawning and recruitment success.
- Water quality is modearate souce of stress:
  - High levels of mercury and PCBs have been noted in finfish tissues.
  - Coal tar deposits are documented below Holyoke Dam.

Housatonic River

Population health score = 1.00

- Abundance is extremely low or zero; no evidence of a spawning.

Stressor score = 6.50

- Dams received a modearatley high score for stress as historical habitat is no longer accessible.
  - The Derby Dam restricts access to historic habitat.
- Water quality received a moderately high score due to :
  - PCB contamination
  - sewage outflows and resulting fecal coliform levels make the river unsuitable for primary contact (swimming).

Hudson River

Population health score = 10.00

- Very large population at about 30,000 adults; confirmed spawning and all life stages are present.
- No apparent immigration or emigration to other rivers; shortnose sturgeon are isolated and therefore lack source of recruits to recover from catastrophic event
- State and Federal regulations are consistently protective.

Stressor score = 6.40

- Dredging is a moderate threat as maintenance dreding occurs in areas of known spawning and foraging; however dredging occurs when shortnose sturgeon are not present in the area.

- Water quality is considered a moderate threat given:
  - o Temporary sediment loading occurs with the spring runoff.
  - o Contaminants still pose threats as heavy metals were detected in shortnose sturgeon, along with PCBs and dioxins.

Delaware River

Population health score = 9.56

- Estimated abundance of 12,000 adults is stable.
- Likely source of recruits to other nearby rivers.
- Recapture of 168 shortnose sturgeon originally caught and tagged as adults in the 1980s suggests that older individuals comprise a substantial portion of the population.

Stressor score = 8.80

- Dredging was identified as a moderately high threat:
  - o Maintenance dredging occurs in areas of nursery, foraging and wintering areas; restricted to periods to protective anadromous fishes.
- Water quality was identified as a moderately high threat:
  - o Mercury and cadmium have been found in shortnose sturgeon tissue.
  - o Endocrine disrupting chemicals (EDC's) have been found in shortnose sturgeon tissues include PCDD's/TCDF's, DDE, and PCB's. EDC's have been linked to reduced fecundity and egg viability, increased early life stage mortality, anatomical defects in larvae and other conditions.
- Impingement/entrainment were rated as moderately high sources of stressors:
  - o Likely occurring near spawning site and taking early life stages;
  - o Larvae have been reported from intakes at the Mercer Generating Station and a small cogeneration plant in Fairless Hills, PA;
  - o Larvae have also been reported in the vicinity of water treatment plant intakes at Trenton and Morrisville.
- Bycatch was a moderate threat:
  - o Bycatch occurs from both commercial American shad fishery using gillnets as well as from the recreational hook and line fishery.

Chesapeake Bay

Population health score = 3.23

- 78 shortnose sturgeon have been reported; mostly adults.
- Spawning not documented; juveniles believed to be rare.

Stressor score = 7.70

- Dredging ranked as a moderately high stressor:
  - o Maintenance dredging of navigation channel occurs in the upper tidal areas.
- Water quality ranked as a moderately high stressor:
  - o Low DO concentration in the summer may create habitat squeeze.
  - o Metals, PCBs, and kepone present.
    - o Public Health advisories restricting human consumption of at least 10 fish species due to metals, PCBs, and kepone contamination.
- Bycatch is a source of moderate stress and occurs primarily from gillnets, pound nets, and fyke nets.

Susquehanna River

Population health score = 1.12

- While historically abundant, no sturgeon are likely present upriver of the Conowingo Dam.

Stressor score = 7.25

- Dams received are ranked as a source of high stressor:
  - Four dams present on the mainstem:
    - York Haven Dam at rkm 90;
    - Safe Harbor Dam at rkm 52;
    - Holtwood Dam built at rkm 40; and
    - Conowingo Dam at rkm 16.
- Water quality was ranked as a moderate stressor:
  - Nutrient enrichment and habitat alteration.
  - Metals present and low pH levels due to acid mine drainage.
  - Total dissolved solids, PCBs, PAHs, and HOCs.

Potomac River

Population health score = 2.12

- Twelve shortnose sturgeon have been captured since 1996.
- A 2004-2007 tagging study of two female shortnose sturgeon revealed residency in the river and one individual moved upstream in a possible spawning run.

Stressor score = 7.65

- Dredging is a moderate threat as maintenance dredging occurs in suspected foraging and wintering areas.
- Water quality is the greastet threat due to contaminated sediments, PCBs, debris and nitrogen runoff, low DO concentrations, seasonal algae blooms, and fish kills.
- Bycatch is a moderate threat – it occurs via pound nets.
- Impingement/entrainment is a moderate tharea due to significant municipal water witihdrawls and the presence of fossil fuel power plant intakes.

Roanoke River

Population health score = 1.00

- One recent shortnose sturgeon record; many historical accounts.

Stressor score = 6.30

- Dams are a moderate threat given 3 upstream dams on the mainstemdams:
  - John H. Kerr Dam at rkm 287.8;
  - Roanoke Rapids Dam at rkm 221.4; and
  - Gaston Dam at rkm 234.3.
- Bycatch is a moderate threat – it occurs via poundnets.
- Water quality is moderate threat given:
  - low DO concentrations in summer months.
  - bank erosion nearby spawning grounds.
  - Public Health Advisories due to dioxins and mercury.
  - large water withdraws.

Chowan River
Population health score = 0.00

- Shortnose sturgeon recorded in 1881; not noted in historical documents.

Stressor score = 5.80

- Bycatch is a moderate threat that occurs both via poundnets and gillnets.
- Water quality is a moderate threat given:
  - nutrient loading,
  - low DO concentration, and
  - Public Health Advisory due to mercury.

Tar/Pamlico River
Population health score = 0.00

- No recent documented records of shortnose sturgeon.

Stressor score = 5.65

- Bycatch and water quality are sources of moderate threats.
  - Bycatch – many local commercial fisheries.
  - Water quality - Public Health Adsvisory due to mercury, large water withdraws.

Neuse River
Population health score = 0.00

- Anecdotal reports for both historic and current presence; no documented specimens or reports confirmed by experts.

Stressor score = 7.20

- Dams were scored as moderately high stressor:
  - Mainstem dams: Milburnie Dam at rkm 341; and Falls Dam at rkm 378.4.
  - Additional dams upstream.
- Water quality was ranked as a moderately high stressor given:
  - nutrient runoff from hog farms,
  - urban development in Piedmont leading to associated sedimentation,
  - over 157 permitted wastewater discharges and municipal wastewater treatment plants.
  - All waters in the basin are designated "Nutrient Sensitive Waters."
  - Multiple fish kill events have recently occurred (71 events between 1996 and 2000).
  - Public Health Advisory due mercury and PCB contamination.
- Nuese River was rated as one of America's Most Endangered Rivers in 2007.
- Bycatch is a moderate threat due to many commercial fisheries ongoing in the lower river and estuary.

New River
Population health score = 0.00

- Many historic accounts by no specimens or recent records.

Stressor score = 4.65

- Bycatch is a moderate threat due to many commercial fisheries ongoing in the lower river and estuary.
- Water quality was a moderately low stressor;

- recent improvements of upgraded water treatement.
- Public Health Advisory for mercury.

North River

Population health score = 0.00

- Both historical accounts and recent anectdotal reports note occurrence; no documented specimens or reports by experts.

Stressor score was 4.65

- Bycatch was a moderately high stressor due to its potential given ongoning commercial fisheries.

Cape Fear River

Population health score = 3.12

- Population likely about 50; gravid females have been documented.

Stressor score = 10.00

- Dams are a high source of stress as the mainstem has many dams:
  - Lock and Dam # 1 is at rkm 97;
  - Lock and Dam #2 is at rkm 149;
  - Lock and Dam # 3 is at rkm 186;
  - Buckhorn Dam is upstream.
  - The ACOE has committed to provide fish passage at the three Lock and Dams in the lower Cape Fear.
- Dredging is a moderately high source of stress:
  - Extensive dredging for maintence and port expansion has and is occurring.
  - Blasting to expand channel.
- Water quality is a moderately high source of stress:
  - Periodic algal blooms occur in some tributaries below point-source discharges.
  - Nutrient loading occurs.
  - Low DO concentration is a major problem in the lower river, especially during warm summer months that result in algal blooms.
- Bycatch is a moderate source of stress via commercial gill nets set for American shad.

Winyah Bay Complex

Population health score = 6.23

- Number of shortnose sturgeon is unknown; all three life stages (adults, juveniles, and eggs) have been collected.

Stressor score = 7.60

- Dams are a moderate source of stress:
  - Blewett Falls Dam, located at ~ rkm 330 in Great Pee Dee, North Carolina does not appear to block access to historical spawning habitat but does cause interrupted flow regimes.
- Dredging is a modearate source of stress as the shipping channel is maintained.
- Water quality is a moderate source of stress:
  - Mercury, PCBs, and dioxin.
  - Water withdrawal.
  - Paper mill on the Sampit River.

- Bycatch is a moderately high source of stress due to drift and anchored gill nets in the American shad fishery.

Santee River
Population health score = 2.12
- Adults have been collected most recently in 2005.

Stressor score = 6.70
- Dams are a high souce of stress as they bisect sturgeon spawning and foraging habitats:
  - St. Stephen Dam at rkm 92
  - Santee/Wilson Dam at rkm 143
- Commercialy bycatch is a high source of stess via fixed gillnets in the American shad fishery.

Cooper River
Population health score = 6.23
- At least 300 spawning adults in Pinopolis Dam tailrace.
- Adults and eggs have been collected; no juveniles.

Stressor score = 6.70
- Dams are a high source of stress:
  - Flow is regulated and discharged with "peaking."
  - Pinopolis Dam at rkm 77 bisects sturgeon spawning and foraging habitats.

Lakes Marion and Moultrie in Santee-Cooper Reservoir System
Population health score = 4.12
- Adults, juveniles, and eggs have been collected.
- Condition of shortnose sturgeon residing in reservoirs is less robust compared with those below the dams perhaps due to prey availability.

Stressor score = 5.95
- Dams received the highest threat ranking:
  - Three dams (Wilson/Santee, Pinopolis and St. Stephen) located in the lower basin bisect foraging and spawning habitat.
  - Flow is reduced and regulated leading to poor water quality and limited water quantity.
- Bycatch from the commercial shad fishery is a high threat.

ACE Basin
Population health score = 6.12
- No records prior to mid 1990s; recent sighintgs (adults and juveniles) likely result of immigration by fish stocked in Savannah.

Stressor score = 3.95
- No stressor was identified as a moderate to high threat.

Savannah River
Population health score = 8.35.
- Popualtion likely between 1,500 – 2,000 adults; both adults and juveniles have been collected.

Stressor score = 9.75

- Dams were ranked as a moderate stressor:
  - New Savannah Bluff Lock and Dam likely impedes access to upriver spawning habitat.
- Dredging received the highest stressor ranking:
  - Dredging of navigation channel required; occurs in areas of overwintering and foraging.
  - Proposed dredging associated with the Savannah Harbor Expansion project requires extensive dredging.
- Water quality was a moderately high stressor:
  - Water quality is poor due to industry and changes in river morphology due to dredging.
  - Proposed expansion is predicted to shift salt wedge upriver and further exacerbate existing DO issues.
- Bycatch was a moderately high stressor – occurs via gillnets in commercial shad fishery.

Ogeechee River

Population health score = 7.23

- Populaiton estimate between 147-266 individuals; all life stages documented.

Stressor score = 5.15

- Water quality is a moderate stressor:
  - Low DO concentrations are routinely documented.
  - Low groundwater levels degrade summer habitat.
- Bycatch is a moderate stressor:
  - Documented in both the commercial shrimp trawl and shad gillnet fisheries.

Altamaha River

Population health score = 9.22

- Recent population estimate of 6,320 adults; all life stages present.

Stressor score was 5.85

- Bycatch is a moderate stressor:
  - Documented in both the commercial shrimp trawl and shad gillnet fisheries.
  -

Satilla River

Population health score = 0.00

- Present, but likely small, population.
  - Collections were made in the late 1980s and early 1990s.
  - Short directed survey in 1995 failed to capture shortnose sturgeon.
  - Extensive survey ongoing; speciments collected both 2009 and 2010.

Stressor score = 4.70

- Water quality is a moderate stressor:
  - Low DO concentrations suspected.
  - Low groundwater levels degrade summer habitat.

St Marys River

Population health score = 0.00

- Present, but likely small, population.
    - Collections were made in the late 1980s and early 1990s.
    - Directed survey in 1994 and 1995 failed to capture shortnose sturgeon.
    - Extensive survey ongoing; speciments collected both 2009 and 2010.

Stressor score = 5.00

- Water quality is a moderate stressor:
    - Large area of extremely low DO.
    - Low groundwater levels degrade summer habitat.

St. Johns River

Population health score = 1.00

- Likley very small population; single specimen since 2000.

Stressor score = 6.05

- Dams are a moderately high stressor:
    - Rodman Dam about 12.9 km upstream impedes passage to Ocklawaha River.
- Water quality is a moderate stressor:
    - Pollution is abundant.
    - Industial discharge and non-point discharges common.
    - Nutrient loading and high water temperatures create seasonal low DO conditions.

Authorized Research

Wild Populations of Shortnose Sturgeon

NMFS, Office of Protected Resources, has been responsible since 1974 under section 10(a)(1)(A) of the ESA (16 U.S.C. 1531 *et seq*.) for the conservation and recovery of the listed shortnose sturgeon, and has authority, delegated from the Secretary of Commerce, to issue permits for takes related to research and enhancement otherwise prohibited by section 9 of the ESA.

Research permits provide broad guidance to researchers in the form of permit conditions and research protocols, designed to minimize stress and mortality of shortnose sturgeon. Permit conditions are based on the best scientific and commercial information available - gathered from researchers over time, from published scientific sources, and elsewhere - to demonstrate how shortnose sturgeon are likely to respond to particular sampling or research procedures. The anticipated effects of proposed research, in addition to a baseline of all other known stressors faced by the species, are considered cumulatively to ensure that research does not jeopardize shortnose sturgeon, their environment, and/or conservation and recovery efforts.

Research Objectives Identified by the Shortnose Sturgeon Recovery Plan (NMFS 1998):

The Shortnose Sturgeon Recovery Plan (NMFS 1998) identified *Recovery Tasks* for guidance of rangewide and river specific research priorities. The following is a summary of the recovery objectives addressed in the document in terms of single-population segments, several-population segments, or rangewide goals.

- Recovery Task 1.1A – Conduct a rangewide genetic assessment of shortnose sturgeon;

- Recovery Task 1.1B –Determine abundance, age structure, and recruitment of shortnose sturgeon;
- Recovery Task 1.1C – Determine endangered and threatened population size thresholds;
- Recovery Task 1.1D – Conduct a status review for each population segment;
- Recovery Task 1.1E – Develop a standardized sampling protocol and determine minimum sampling required to assess presence of shortnose sturgeon;
- Recovery Task 1.1F – Sample for shortnose sturgeon in rivers where they historically occurred;
- Recovery Task 1.2A – Conduct research (mark-recapture, telemetry, survey sampling, etc.) indicating shortnose sturgeon seasonal distribution and map concentration areas to characterize critical habitat;
- Recovery Task 1.2C – Develop criteria to identify essential habitat;
- Recovery Task 1.3A – Assess mortality factors and define take limits for shortnose sturgeonpopulation segments;
- Recovery Task 2.2A – Assess shortnose sturgeon mortality from incidental capture and document characteristics of fisheries that impact shortnose sturgeon (gear types, fishing season and location, fishing effort, etc.);
- Recovery Task 2.2B – Conduct research to determine sub-lethal effects of incidental capture and provide guidelines to minimize bycatch mortality and sub-lethal effects (i.e. reduce soak times, reduce handling time, gear modification, etc.);
- Recovery Task 2.3A – Identify and, if prudent, designate critical habitat for shortnose sturgeon population segments;
- Recovery Task 2.3B – Conduct field research to document shortnose sturgeon use of any designated critical habitats and to identify changes in habitat use that would affect critical habitat designations;
- Recovery Task 2.4A – Insure that fish passage devices on all proposed and re-licensed structures allow adequate passage of shortnose sturgeon and do not alter migration or spawning behavior;
- Recovery Task 2.4B – Conduct research to assess the direct and indirect effects of blasting, dredging, and in-river disposal on all life stages of shortnose sturgeon;
- Recovery Task 2.4C – Compare impacts of various dredging, blasting, and disposal techniques and equipment on shortnose sturgeon and their habitat to minimize the detrimental effects of these activities;
- Recovery Task 2.4D – Conduct research to assess shortnose sturgeon mortality from entrainment and impingement and maximize efforts to obtain scientific information from dead fish;
- Recovery Task 2.4E – Analyze shortnose sturgeon tissue, food items, and sediment/water samples from shortnose sturgeon habitat to assess the degree of contaminant loading;
- Recovery Task 2.4G – Collect continuous recordings of dissolved oxygen in shortnose sturgeon habitat to identify the extent and duration of hypoxic events;
- Recovery Task 2.4I – Determine the extent of parasitism, disease, competition for resources, and direct mortality to shortnose sturgeon resulting from introduced species and stock transfers;
- Recovery Task 3.1A – In each river, identify natural migration patterns of each life stage and any barriers to movement between habitats. Devise methods to pass shortnose sturgeon above/below existing barriers;
- Recovery Task 3.1B – Examine the relationships between river discharge level (and the correlated bottom water velocity), substrate type, and shortnose sturgeon spawning success;
- Recovery Task 3.1C – Investigate the relationship between spawning substrate characteristics and shortnose sturgeon reproductive success. Conduct field experiments that – 1) evaluate the ability of natural river discharge to remove sediment and debris from spawning substrate; and 2) evaluate the acceptability of artificial substrate to spawning females;
- Recovery Task 3.1E – Investigate satisfactory methods for examining diet;

- Recovery Task 3.1F – Determine rangewide diet, foraging ecology and growth, for each shortnose sturgeon life stage. In populations with poor growth, examine foraging habitat characteristics and conduct experimental manipulations, if appropriate, to restore habitat;
- Recovery Task 3.1G – If contaminants are directly or indirectly responsible for loss of shortnose sturgeon fitness, identify contaminant or oxygen demanding sources and reduce loading;
- Recovery Task 3.3B – Determine minimum population size below which restoration may be considered; and
- Recovery Task 3.4A – Assess the need for augmenting shortnose sturgeon population segments with stocked fish.

Current Permits Authorized for Wild Populations of Shortnose Sturgeon:
There are currently 17 section 10(a)(1)(A) scientific research permits issued to study shortnose sturgeon in rivers of the United States (Table 42). Each permit authorizes sampling of adult/juvenile shortnose sturgeon, and some authorize collection of early life stages (ELS). Individual permits have varying objectives, depending on the research objectives of researchers.

Table 42. Existing shortnose sturgeon research permits authorized for wild populations.

Permit No.	**Location**	***Authorized Take***	***Research Activity***
10115 Expires: 8/3/2013	Saltilla & Saint Marys Rivers, GA & FL	85 adult/juv 20 ELS	Capture, handle, measure, weigh, PIT tag, tissue sample, collect ELS
ENVIRONMENTAL ASSESSMENT ON THE EFFECTS OF THE ISSUANCE OF A SCIENTIFIC RESEARCH PERMIT TO CONDUCT RESEARCH ON SHORTNOSE STURGEON IN THE SAINT MARYS RIVER AND SATILLA RIVERS, GEORGIA AND FLORIDA			
14394 Expires: 9/30/14	Altamaha River and Estuary, GA	500 adult/juv. (1 lethal), 100 ELS	Capture, handle, weigh, measure, PIT tag, transmitter tag, tissue sample, anesthetize, laparoscopy, blood collection, fin ray section, collect ELS
ENVIRONMENTAL ASSESSMENT ON THE EFFECTS OF THE ISSUANCE OF A SCIENTIFIC RESEARCH PERMIT (FILE NO. 14394) TO CONDUCT RESEARCH ON SHORTNOSE STURGEON IN THE ALTAMAHA RIVER, GEORGIA			
10037 Expires: 4/30/2013	Ogeechee River and Estuary, GA	150 adult/juv. (2 lethal), 40 ELS	Capture, handle, measure, weigh, PIT tag, tissue sample, fin-ray section, anesthetize, laparoscopy, blood collection, radio tag, collect ELS
ENVIRONMENTAL ASSESSMENT OF ISSUANCE OF A SCIENTIFIC RESEARCH PERMIT TO DR. DOUGLAS PETERSON, UNIVERSITY OF GEORGIA, (FILE NO.10037) TO CONDUCT RESEARCH ON ENDANGERED SHORTNOSE STURGEON			
15677 Expires:_ 5/31/2016	S. Carolina Rivers and Estuaries	154 adult/juv 100 ELS	Capture with gill & trammel net or trawl, measure, weigh, photograph/video, dart tag, PIT tag, genetic tissue sample, anesthetize, laparoscopy, gonadal biopsy, blood sample; collect ELS
ENVIRONMENTAL ASSESSMENT ON THE EFFECTS OF THE ISSUANCE OF A SCIENTIFIC RESEARCH PERMIT (FILE NO. 15677) TO CONDUCT SCIENTIFIC RESEARCH ON SHORTNOSE STURGEON IN SOUTH CAROLINA RIVERS			
14759 Expires: 8/19/2015	North Carolina Rivers	70 adult/juv.	Capture, handle, weigh measure, Floy tag, PIT tag, genetic tissue sample; anesthetize acoustic tag
ENVIRONMENTAL ASSESSMENT ON THE EFFECTS OF THE ISSUANCE OF A SCIENTIFIC RESEARCH PERMIT (FILE NO. 14759) TO CONDUCT SCIENTIFIC RESEARCH ON SHORTNOSE STURGEON IN NORTH CAROLINA RIVERS			
14176 Expires: 9/30/2015	Potomac River	30 adult/juv. 20 ELS	Capture, handle, weigh, measure, Floy PIT tag, genetic tissue sample; anesthetize w/ electronarcosis; & internal acoustic tag
ENVIRONMENTAL ASSESSMENT ON THE EFFECTS OF THE ISSUANCE OF A SCIENTIFIC RESEARCH PERMIT FILE NO. 14176 TO CONDUCT RESEARCH ON SHORTNOSE STURGEON IN THE POTOMAC RIVER, MARYLAND AND VIRGINIA			
14604 Expires: 4/19/2015	Delaware River and Estuary NJ & DE	1,000 adult/juv. (1 lethal), 300 ELS	Capture, handle, measure, weigh, Floy tag, PIT tag, tissue sample, anesthetize, ultrasonic tag, laparoscopy, blood collection, collect ELS
ENVIRONMENTAL ASSESSMENT ON THE EFFECTS OF THE ISSUANCE OF A SCIENTIFIC RESEARCH PERMIT (File No. 14604) TO CONDUCT SCIENTIFIC RESEARCH ON SHORTNOSE STURGEON IN THE DELAWARE RIVER			
14396 Expires: 12/31/2014	Delaware River and Estuary NJ & DE	100 adult/juv	Capture, handle, measure, weigh, Floy tag, PIT tag, genetic tissue sample, anesthetize, and sonic tag
ENVIRONMENTAL ASSESSMENT ON THE EFFECTS OF THE ISSUANCE OF A SCIENTIFIC RESEARCH PERMIT (FILE NO. 14396) TO CONDUCT SCIENTIFIC RESEARCH ON SHORTNOSE STURGEON IN THE DELAWARE RIVER			
16439 Expires:10/31/2011	Hudson River,	240 and 2,340 shortnose sturgeon in year 1-3 and year 4-5,	Capture, handle, weigh, measure, PIT & Carlin tag, genetic tissue sample, and gastric lavage
ENVIRONMENTAL ASSESSMENT (SEA) OF THE ISSUANCE OF A SCIENTIFIC RESEARCH PERMIT MODIFICATION (FILE NO. 16439) TO NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION (NYSDEC) FOR CONDUCTING RESEARCH ON ENDANGERED SHORTNOSE STRUGEON			
Subject Permit **17095*** Would Expire: 5/31/17	Hudson River and Estuary, NY	82 Shortnose adult/juv; & 40 ELS; 82 Atlantic adult/juv; & 40 ELS	Capture, handle, measure, weigh, PIT tag, Carlin tag, photograph, tissue sample, collect ELS
ENVIRONMENTAL ASSESSMENT Of Issuance of a Scientific Research Permit (File No. 17095) to Entergy nuclear Generation, Inc. to Conduct Research on Endangered Shortnose and Atlantic Sturgeon			
16549 PROPOSED FOR 5/31/2012(	UPPER CONN. RIVER, MERRIMACK RIVER, MA	673 ADULT/JUV. (5 LETHAL), 1,430 ELS FROM EAST COAST RIVERS	CAPTURE, HANDLE, MEASURE, WEIGH, ANESTHETIZE, PIT TAG, TIRIS TAG, RADIO TAG, TEMPERATURE/DEPTH TAG, TISSUE SAMPLE, BORESCOPE, LABORATORY TESTS, PHOTOGRAPHS, COLLECT ELS

ON THE ISSUANCE OF A MODIFICATION TO SCIENTIFIC RESEARCH PERMIT NO. 1549 [BOYD KYNARD, S.O. CONTE ANADROMOUS FISH RESEARCH CENTER] TO CONDUCT RESEARCH ACTIVITIES ON ENDANGERED SHORTNOSE STRUGEON			
15614 EXPIRES: 5/23/2016	LOWER CONN. RIVER & ESTUARY., CT	500 ADULT/JUV (2 LETHAL); 300 ELS	CAPTURE, HANDLE, MEASURE, WEIGH, PIT & FLOY TAG ACOUSTIC TAG, GASTRIC LAVAGE, FIN RAY SECTION, COLLECT ELS
ENVIRONMENTAL ASSESSMENT ON THE EFFECTS OF THE ISSUANCE OF SCIENTIFIC RESEARCH PERMIT FILE NO. 15614 TO CONDUCT RESEARCH ON SHORTNOSE STURGEON IN CONNECTICUT WATERS			
	KENNEBEC COMPLEX AND ESTUARY, ME	500 ADULT/JUV.; 30 ELS	CAPTURE, HANDLE, MEASURE, WEIGH, TISSUE SAMPLE, PIT TAG, ACOUSTIC TAG, LAVAGE, ANESTHETIZE, COLLECT ELS
ENVIRONMENTAL ASSESSMENT FOR ISSUANCE OF SCIENTIFIC RESEARCH PERMITS NOS. 16306 TO CONDUCT SCIENTIFIC RESEARCH ON PROTECTED SHORTNOSE STURGEON IN THE GULF OF MAINE			

During the 2007 sampling season, 5,926 adults and/or juvenile shortnose sturgeon were authorized for takes in 18 rivers throughout the shortnose sturgeon's range. Interestingly, take averaged 20%percent of that authorized previously; over the last few years there have been few research mortalities or harmful injuries reported by researchers, and none were reported in 2007. The existing research permits generally cover the following types of studies.

1. Presence/absence surverys include research to document shortnose sturgeon usage in areas within the historic range of the species, but have not been adequately sampled in recent history (e.g., Permit Nos. 1542 and 1543); or in rivers where shortnose sturgeon are thought to have been extirpated (e.g., Permit No. 10113).

2. River surveys are permitted in rivers where sturgeon populations are known to occur but are typically widespread and few in numbers (e.g., Permit Nos. 1447 and 1505). Valuable information is often sought on their stock status by sampling and tracking tagged animals, identifying spawning sites, and determining life history information such as food habits and specific habitat requirements of the various life stages of sturgeon.

3. Researchers assessing population dynamics commonly propose more detailed stock assessments including population estimates and studies of life history, distribution, juvenile recruitment, and survival rates, as well as specific habitat requirements for each life stage. In the Altamaha River (Permit No. 1420), for example, major research objectives include: 1) assessing the current spawning stock of shortnose sturgeon; 2) providing a population estimate with an analysis of the age-structure of the current population to identify potential survival "bottlenecks"; and 3) identifying, quantifying and defining critical habitats of shortnose sturgeon life stages.

Other research objectives within current permits:

1. Genetic Tissue Collection - documenting genetic evidence for the uniqueness of populations.
2. Diet - examining preferred diets of sturgeon through non-lethal gastric lavage.
3. Spawning - documenting spawning periodicity and demographic health of populations.
4. Dam Passage - improving technology to better pass sturgeon.
5. Contaminant - studying adverse effects of estrogenic compounds on sex ratio and health.
6. Movement - documenting temporal and spatial movements.

Future Research Objectives for Shortnose Sturgeon Throughout Their Range:

While much has been accomplished in terms of meeting various recovery objectives identified in the Shortnose Sturgeon Recovery Plan (NMFS 1998), many goals and tasks have not been achieved. Currently, comprehensive information is not available for population dynamics, distribution, juvenile movement and behavior, and factors leading to reproductive success, even for well-studied populations. New and more reliable estimates of population size, age structure, and recruitment are needed in the future in order to adequately assess the status of each of riverine population. Other research areas identified by the Status Review Team include:

- Genetic Assessments: Rangewide genetic assessments have been made by various researchers (King et al. upubl. data, Wirgin et al. 2009, Wirgin et al. 2005, Walsh et al. 2001, Grunwald et al. 2002, Quattro et al. 2002). Although further research and discussion is warranted on descriptive genetic differences between shortnose sturgeon populations, the SRT recommends that future genetic assessments also focus on management guidelines using genetic differences between populations. Research should be carried out to determine whether observed genetic differences between populations are indicative of adaptive significance or are simply due to isolation and random genetic drift. One example is to examine differences in growth rate with maximum age and size to determine if these differences are purely genotypic, purely phenotypic, or a combination of the two. Results could identify resisilence or sensitivity and assist in identifying benefits or risks of stocking across regions.

- Surveys and Presence/Absence Studies: In many river systems (e.g., within the state of South Carolina) there are long standing records of shortnose sturgeon occurrence, but incomplete information exists on their current distribution or abundance. Likewise, there are sizable information gaps on the subsistence of shortnose sturgeon in several rivers with historical populations (e.g., within the state of North Carolina). Currently managed as extirpated rivers, several of these rivers have potential for populations of shortnose sturgeon, and, accordingly, more research emphasis should be placed on presence/absence exploration in these rivers.

- Distribution and Abundance: Information on the distribution, abundance, and movements of all life stages of shortnose sturgeon is outstanding for many riverine populations, particularly for young-of-the year and juveniles stages.

- Designating Critical Habitat: Critical habitat has not been designated for shortnose sturgeon. All areas essential to the conservation of the species will soon need to be recognized to ensure adequate protection of each life stage. One area of research crucial to discovering and designating critical habitat for shortnose sturgeon will be the study of foraging ecology and growth of the various life stages, as well as defining the benthic habitats that support preferred prey. Research has recently definee diets of shortnose sturgeon both in a northern and southeastern river system (Savoy and Benway 2004, and Collins et al. 2008). To enhance this understanding, however, results on the mapping of the benthic organisms will be needed to better define both the available and preferred diets of sturgeon. Probabilistic/generalized linear models or similar approaches used to map benthic habitat should be constructed to help identify the distribution of shortnose sturgeon through space and time.

  Although there has been great progress in identifying spawning habitat and overwintering sites, this information is still missing for some river systems where they are known to occur. Additionally, these areas where shortnose sturgeon aggregate (i.e., spawning, overwintering) are small relative to their distribution during the remainder of the year and will therefore make the fish extremely vulnerable to disturbance. Finally, obtainting information on nursery areas and characterization of nursery habitat is a priority.

- Coastal Movement and the Potential for Colonization: We summarized the recent information on shortnose sturgeon movement to both saltwater environs around their natal rivers, as well as between rivers. Recent advances in technology allow better data collection on these movements. Directed research to evaluate coastal migrations and interbasin movements of shortnose sturgeon, including the occasional use of smaller rivers near known spawning populations, is essential in order to explore the potential for recolonization to aid in restoration of depleted or extirpated populations.

- Long-term Population Monitoring Programs: There are relatively few long-term monitoring programs for shortnose sturgeon. New and more reliable estimates of population size, age structure, survival and recruitment are needed to monitor population health and abuandance trends over time. New directed or ship-of-opportunity monitoring programs should be established for shortnose sturgeon populations that appear to have strong populations and may be recovering such those in the Kennebec, Delaware, and Altamaha rivers. Such monitoring programs are critical in evaluating recovery, but will also afford important opportunities to better evaluate population health through more rigorous demographic analyses.

- Improve Quality of Data for Population Estimates: Develop techniques to validate shortnose sturgeon ageing procedures and improve estimates of size and age at maturity and spawning periodicity (reproductive schedule) through use of modern histological techniques, specimens in hatcheries, and electronic tagging methods. Verify if fin spine removal is non-deleterious; determine effects of pectoral fin spine clipping for ageing on long-term sturgeon health.

    - Modeling: Apply extinction risk modeling such as RAMAS to project impact of threats to population survival.
    - Further investigate the relationship between river attributes (i.e., river size, summer foraging range, kms of undammed habitat, freshwater discharge and other measures) and population size to identify factors restricting abundance. Rivers with strong populations could aid in setting conservation targets by river.

- Competition: There is a general lack of understanding of resource partitioning between shortnose and Atlantic sturgeon. Research is needed to examine within and among species dominance hierarchies and possible density-dependent effects.

- Adverse Effects of Research and Fisheries: Assessement of commercial and recreational fisheries on bycatch of shortnose sturgeon would assist in determining extent and level of impact. The RAMAS model concluded even moderate mortality to adult sturgeon can dramatically reduce recruitment and significantly reducing the long-term persistence of a riverine population.

- Dam Passage: The impact of dams was consistently ranked as a high source of stress to shortno sturgeon populations by the SNS SRT. Dams impede upstream and downstream migration, regulate flow and contain turbines that injure or kill downstream migrants.

Ongoing research to improve fish passage for safe and effective voliational passage of sturgeon is needed.

- Contaminant Research: Contaminants and nutrients resulting from human activity are common in rivers. Therefore, identifying contaminants and oxygen demanding sources are viewed as primary research priorities by the SNS SRT. Contaminant studies should include a long-term, range-wide analysis of contaminants taken from sturgeon tissue. Over time, a baseline should be developed to detect causal relationships and trends related to specific contaminant levels. Likewise, existing and past research identifying oxygen demanding sources should be expanded to categorize and map causal relationships of high biological oxygen demand in sturgeon waters and to suggest remedial action and improve water qualities where practicable.

- Impacts of Dredging: Dredging and disposal is required to maintain and support commercial shipping and recreational boating, construction of infrastructure, and marine mining. Dredging itself can pose significant impacts to aquatic ecosystems by removing, disturbing, disposing, and resuspending bottom sediments, modifying substrate and impacting the community structure of benthic macrofauna. Additionally, direct impacts have been documented from dredging through river courses having known nursery areas of juvenile shortnose sturgeon and mortality of fish via the dredge. In-water work restricitions are often employed during sensitive time periods (spawning, migration, feeding) when anadromous fish are present. While research to assess the direct and indirect effects of blasting, dredging and in-river disposal on sturgeon species is ongoing, additional information is required to understand both direct and indirect effects and identify measures to best protect sturgeon.

Summary of Permitted Research:
Research permits through ESA section 10 are designed to gather information on wild shortnose sturgeon in their natal rivers. Permits contain conditions that must be strictly followed by researchers in order to reduce potential adverse impacts to sturgeon and their environment. Moreover, permits require researchers to exercise care when handling animals to minimize any possible injury. If these research protocols are followed closely, the research activities should not result in significant injury or mortality of shortnose sturgeon, are expected to be no more than short-term in nature (e.g., including the temporary handling discomfort experienced by the sampled individual), and the information gained will outweight the effects.

The SNS SRT therefore believes that research is a beneficial tradeoff to enhance the survival and recovery of shortnose sturgeon. As a vital agent for developing management information and conservation measures, research is designed to do no more harm to the species than is caused by the existing level of stressors faced by the species.

Captive Shortnose Sturgeon

NMFS is responsible for the conservation and recovery of endangered shortnose sturgeon (*Acipenser brevirostrum*) pursuant to the ESA. Enhancement and scientific research involving captive, or cultured, sturgeon has been identified in the Recovery Plan (NMFS 1998) as important means of gathering both valuable information about shortnose sturgeon and increasing the public's awareness.

Expressly, the Recovery Plan (NMFS 1998) highlights the following uses of listed cultured sturgeon to address recovery objectives:

- Recovery Task No. 1.2B - Conduct laboratory experiments with c*ultured* fish to study behavior patterns, habitat/food preferences and physiological tolerances;
- Recovery Task No. 2.2D - Use *cultured* fish to develop genetic markers to identify illegally-marketed shortnose sturgeon products;
- Recovery Task No. 2.4B - Conduct research to assess direct and indirect effects of blasting, dredging, and in-river disposal on all life stages of shortnose sturgeon;
- Recovery Task No. 2.4C - Compare impacts of dredging, blasting and disposal techniques and equipment on shortnose sturgeon and their habitat to minimize the detrimental effects of these activities;
- Recovery Task No. 2.4D - Conduct research to assess shortnose sturgeon mortality from entrainment and impingement, and maximize efforts to obtain scientific information from dead fish;
- Recovery Task No. 2.4F - Determine the effects of contaminants on shortnose sturgeon growth, survival, and reproduction using *cultured f*ish;
- Recovery Task No. 2.4H - Use *cultured* shortnose sturgeon to determine the species' tolerance for low dissolved oxygen levels under a variety of temperature and salinity conditions and assess the sub-lethal effects of hypoxia;
- Recovery Task No. 2.5A - Educate the public and heighten awareness of shortnose sturgeon issues by printing and distributing articles, posters; and pamphlets. Make *cultured* shortnose sturgeon available to aquaria and zoos;
- Recovery Task No. 3.2A - Develop a Shortnose Sturgeon Breeding and Stocking Protocol; and
- Recovery Task No. 3.3 & 3.4 - Reintroduce shortnose sturgeon into river ecosystems where they have been extirpated, or have been determined to need augmentation.

Current Inventory of Shortnose Sturgeon at Research Facilities:
Through issuance of ESA Section 10(a)(1)(A) permits, scientific and enhancement studies are conducted by researchers on captive shortnose sturgeon maintained at various research facilities. Researchers employed by the USFWS, USGS, the University of Florida, University of Georgia, and one private facility, are currently authorized to study captive shortnose sturgeon. Some of these captive individuals are periodically conditioned and spawned and the resulting gametes and progeny are used for scientific studies, such as cryogenics, disease transmission, nutrition, genetics, toxicology, fish passage, and fish culture techniques. Table 43 summarizes authorized permits for captive shortnose sturgeon populations, highlighting the research location, river origin, and research objectives and inventory.

Originally developed from either wild Connecticut and Savannah River parents, first generation (F-1) stocks of sturgeon maintained at these facilities range in age from "age 0" (YOY) to 23 years. Additionally, second and third generation stocks (F-2 and F-3) are also produced as progeny. Although these captive shortnose sturgeon are not releasable to the wild, except under prescribed conditions, shortnose sturgeon can be transferred under separate permits to other facilities for further scientific research, enforcement forensics, or other educational purposes. Upon expiration of these permits, or at the cessation of research, the permit holders can apply for a new permit, transfer individuals to another permitted facility, or euthanize those not required for further study. Commercial culture, sale or transfer of these individuals to a non-permitted facility is prohibited under the ESA.

Current Inventory of Shortnose Sturgeon at Educational Display Facilities:
Educational display of cultured shortnose sturgeon at public aquaria and zoos was identified in the Recovery Plan (Task No. 2.5A) as an essential and effective use of captive shortnose sturgeon. A total of 22 shortnose sturgeon are currently displayed at seven regional aquaria and zoos. An estimated 4.4 million visitors attend these educational facilities each year where visitors are introduced to shortnose sturgeon and learn about its history, threats, and survival in the wild. Table 44 summarizes the current educational display facilities maintaining shortnose sturgeon at zoos and aquariums located throughout the shortnose sturgeon's geographic range.

These permits require that shortnose sturgeon displayed at these facilities are not released, displayed with other sturgeon species or with shortnose sturgeon from other managed watersheds. If the display is closed shortnose sturgeon must be sacrificed, transferred to another facility, or be disposed of in an acceptable manner. Although it is highly unlikely that display individuals could become reproductively active in the controlled environment of these facilities, the permits require that any progeny resulting be sacrificed to prevent an accidental release into the environment. Additionally, commercial culture or sale of these display shortnose sturgeon is prohibited.

Table 43. Current inventory of shortnose sturgeon held in captivity at research facilities.

Permit	Research Facility	River of Origin	Research & Enhancement Activity Authorized	Inventory
1549 Expires 1/31/12	Conte Research Center, (USGS)Turner Falls, MA	Conn. R.	Fish passage technology; conditioning & propagation, behavior, and tagging studies	F-1 Adult----22 F-1 Juv ------92 F-1 YOY----12
		Savannah R.		F-2 Juv------110
1574 Expires 8/31/11	University of Florida, Gainesville, FL	Savannah R.	Embryonic & reproductive biology	F-1 Adult------9 F-2 Adult---113 F-3 Juv-------65
1579 Expires 8/1/11	Alden Research Lab Holden, MA	Savannah R.	Fish passage technology	F-2 YOY---216 F-2 Juv-------41
		Conn. R		F-1 Juv-------27
1604* Expires 5/31/12	Warm Springs Fish Technology Center (USFWS) Warm Springs, GA; Charleston, SC; and Orangeburg, SC	Savannah R.	Refugia, conditioning, propagation, nutrition, embryonic, fish health, behavioral, tagging, genetics, & fish culture genetic sampling, and gamete bank	F-1 Adult --25 F-2 Adult---37

* Propagation of shortnose sturgeon by the USFWS ended in the spring of 2008 but a subset of the broodstock and offspring are still maintained at Warm Springs and Orangeburg.

Table 44. Inventory of shortnose sturgeon maintained in educational display facilities.

Permit	Display Facility	River of Origin	Annual Visitors	Authorized No. & Inventory No.
1472 Expires 07/31/09	Maritime Aquarium Norwalk, CT	Connecticut River (Conn. DEP)	500,000	50 / 2
1473 Expires 07/31/09	Virginia Museum Newport New, VA	Connecticut River (USGS--S.O. Conte Center)	300,000	50 / 10
1273 In process	North Carolina Aquarium Wilmington, NC	Savannah River (USFWS Bears Bluff NFH)	300,000	17 / 6
1510 Expires 03/31/10	Liberty Science Jersey City, NJ	Connecticut River (USGS--S.O. Conte Center)	1,200,000	5 / 0
1545 Expires 07/31/11	North Carolina Zoo Asheboro, NC	Savannah River (USFWS Bears Bluff NFH)	700,000	12 / 1
1555 Expires 07/31/11	Springfield Museum Springfield, MA	Connecticut River (USGS--S.O. Conte Center)	500,000	5 / 0
1589 Expires 03/31/12	Riverbanks Zoo Columbia, SC	Savannah River (USFWS Bears Bluff NFH)	900,000	8 / 3

Current Status of Captive Shortnose Sturgeon:
As part of the recovery plan for shortnose sturgeon, research facilities culturing shortnose sturgeon aim to identify the physical, chemical and biological parameters necessary for the optimal growth, survival, and reproduction of shortnose sturgeon in the wild. Likewise, the recovery objective of an educational display is to permanently maintain and display captive shortnose sturgeon to enhance the public's awareness of the plight of the species.

Negative impacts of maintaining cultured shortnose sturgeon at research and educational facilities are typically limited to the facilities; there is little impact to native populations as these captive shortnose sturgeons for display are managed, to a large degree, as research or display animals and are usually the result of captive brooding.

However NMFS authorizes and encourages some lethal testing of hatchery raised individuals to gain information otherwise unobtainable that can directly benefit this endangered species in the wild. Captive stocks of shortnose sturgeon serve as surrogates for wild stocks. Utilizing captive fish for experimental activities, researchers eliminate the need for specimen collection from the wild. All activities that occur at these facilities are consistent with on-going, standard husbandry care that routinely occurs at such facilities in voluntary compliance with the Animal Welfare Act (7 U.S.C. 2131 *et. seq.*). Sturgeon are fed and maintained properly, given daily care, treated humanely, and are provided medical care as necessary.

The SNS SRT also recognizes that similar genetic, physical, physiological, ecological, and behavioral characteristics can be shared by shortnose sturgeon produced in a hatchery and the natural populations from which they are derived. As a result, all components of the shortnose sturgeon, including populations of natural individuals and hatchery stocks derived from similar populations, are included in the ESA listing of the species.

Important to the above discussion, under certain circumstances, defined by the shortnose sturgeon recovery plan (NMFS 1998), captive bred shortnose sturgeon may also be used to restore or supplement a natural population. If sampling indicates that sturgeon have been either extirpated from a river or watershed where they have historically occurred, or if there is evidence that supplementation of an existing population is the only reasonable manipulation that could prevent the loss of a population in imminent danger of extirpation, then captive individuals could be used to restore or supplement the population if the habitat and environment is judged suitable for survival of all of the life stages.

Therefore, NMFS recognizes the importance of maintaining sound cultural practices and establishing effective breeding protocols for research, but especially if cultured fish are produced with the intent for restoration purposes. The effectiveness of these practices developed by hatchery managers is considered essential by NMFS to avoid such errors as excessive inbreeding, loss of genetic diversity, increased disease potential, or diminished survival fitness in the wild. For that reason, permit holders maintaining captive shortnose sturgeon facilities are encouraged to report annually to NMFS regarding their fish cultural practices, emphasizing proper protocols for fish health, selection criteria, level of inbreeding, effective population sizes, and sex ratios maintained for breeding (ASMFC 1996). Progeny or stocks not meeting such standards, or are not needed for reasonably anticipated research, are routinely euthanized in consultation with NMFS.

Accomplishments and Future Research Objectives for Shortnose Sturgeon Throughout Their Range:
Cultured shortnose sturgeon have been used in achieving a number of recovery goals identified by the recovery plan. A standard, effective spawning protocol has been developed which has eliminated much trial and error in producing a genetically varied progeny closely related to the natural population from which they were derived. Furthermore, significant research effort has been spent investigating cryo-preservation techniques, genetic tissue analyses, culture techniques, behavior, nutrition, fish health, and tagging and marking methods of shortnose sturgeon. Also, much more is now known about species tolerances for low dissolved oxygen concentrations, temperature, salinity and other water quality parameters that impact sturgeon survival in the wild. Lastly, the educational goal of the recovery plan to increase the shortnose sturgeon's visibility in public zoos and aquaria has been successful. An estimated 4.4 million visitors annually to these facilities, has increased the awareness of shortnose sturgeon and their endangered status while garnering some needed support for their protection and conservation.

The SNS SRT recognizes several remaining goals within the recovery plan which make use of captive shortnose sturgeon for research and display purposes. Such objectives include: 1) studying the ecotoxicology and ecophysiology of shortnose sturgeon and their habitats including contaminants and toxins, and the potential effects of estrogenic compounds through ontogeny; 2) investigating genetic markers which identify individuals and groups of animals; 3) studying the pathology of diseases in shortnose sturgeon; 4) providing for upstream and downstream passage of shortnose sturgeon beyond man-made barriers; 5) maintaining refugia for hatchery stocks closely related to the natural population from which they were derived; 6) developing a gene-bank for sturgeon gametes to maximize genetic resources and to provide an appropriate genetic match for future work within population segments; 7) providing display animals for educational facilities; and 8) developing a non-invasive method to sample for gender in both mature and immature shortnose sturgeon in the wild.

Non-regulatory conservation measures

Since shortnose sturgeon have been endangered since 1967, much of the conservation and recovery measures are supported at Federal and state levels. There are several partnership programs with non-profit organizations that bring additional funds and resources to shortnose sturgeon protection, recovery, and outreach and education efforts. There are numerous initiatives to restore river systems and watersheds that will ultimately benefit shortnose surgeon. These partnerships and restoration initiatives are summarized below.

Partnerships
The Seaboard Fisheries Institute (SBFI) is a nonprofit organization focusing on Atlantic sturgeon other anadromous fishes of the Delaware River and Estuary. The Institute is located in Penns Grove, NJ, once the site of the largest sturgeon landings in the United States (Saffron 2004). The Seaboard Fisheries Institute promotes research, education, and outreach endeavors to build a base of knowledge and a constituency for the Atlantic sturgeon and as its habitats (SBFI 2008). SBFI is funding ERC, Inc. through a Section 22 grant from ACOE to conduct an acoustic

telemetry study of juvenile shortnose and Atlantic sturgeon in the Delaware Estuary, with particular reference to the oligohaline reach of the river.

The Nature Conservancy (TNC) has taken an active role in shortnose sturgeon research and restoration in the south. In the Savannah River, TNC is working with ACOE to identify effects of water release on sturgeon spawning habitat; shortnose sturgeon implanted with ultrasonic transmitters are being tracked to assess impacts of flow and identify spawning areas.

In 1993 the National Paddlefish and Sturgeon Steering Committee drafted “The Framework for the Management and Conservation of Paddlefish and Sturgeon Species in the United States.” This document proposed a framework for the conservation of eight species of paddlefish and sturgeon including shortnose sturgeon. The document carries no regulatory force but is intended to foster partnerships among agencies and organizations with an interest in the conservation of sturgeon species. Strategies include research on life history, population characteristics, and habitat requirements; development and coordination of culture and stocking protocols; habitat protection; mitigation of stressors from over-harvest; public information and education; and national coordination of conservation efforts.

River & watershed restoration programs

The Penobscot River Restoration Project is an unprecedented collaborative effort involving a hydropower company (PPL Corporation), the Penobscot Indian Nation, six conservation groups, and state and federal agencies to restore 11 species of sea-run fishes to the Penobscot River, while maintaining energy production (PRRT 2008). Core aspects of the restoration effort include: 1) the purchase and removal of the two lowermost dams on the Penobscot River and, 2) the purchase and decommissioning of a third dam (PRRT 2008).

The Hudson River Estuary Program heads a unique regional partnership (government, non-profit and business sectors, and concerned citizens) to restore the Hudson River to its former grandeur. The program goals include conservation of natural resources that benefit both shortnose and Atlantic sturgeon (NYS DEC 2008). Education and outreach is one key component and the symbol for the program is a sturgeon which has been made into numerous signs that were strategically placed at river and stream crossings of the Hudson River watershed promoting both the program and the protection of sturgeon.

The Hudson River Foundation (HRF), established in 1981, is a partnership among environmental groups, government regulatory agencies, and utility companies seeking the constructive resolution of a long series of legal controversies concerning the environmental impacts of power plants on the Hudson River (HRF 2009). The HRF supports scientific research, communication, enhanced management and education about the River. The HRF has made large non-government investments towards shortnose sturgeon restoration through strategic research efforts over the past two decades.

The Chesapeake Bay Foundation (CBF) is an independent non-profit organization dedicated solely to restoring and protecting the Chesapeake Bay and its tributary rivers. It was founded 40 years ago with the goal of improving water quality by reducing pollution. The CBF strategic plan include continuing to build a broad constituency, achieving measurable water quality goals such as the reduction of nutrients, increase production of oyster, blue crab and shad, and reduce the rate of loss of forests, farms, and wetlands (CBF 2008). The activities of the CBF have helped to improve both shortnose and Atlantic sturgeon habitat in the Bay.

Conclusion

The Shortnose Sturgeon Recovery Plan (NMFS 1998) identified 19 populations based on the fish's strong fidelity to natal rivers and the premise that populations in adjacent river systems did not interbreed with any regularity. The Plan recommended that each population be managed separately until further evidence and information allowed for the consideration of potential DPS delineations for shortnose sturgeon. Since the Plan was published in 1998, additional information on straying rates and genetic analysis is available; both mtDNA and nDNA indicate effective (with spawning) coastal migrations are occurring between adjacent rivers in some areas, particularly within the Gulf of Maine and the southeast. This new information was used by the SNS SRT to investigate shortnose sturgeon population structure.

The best data available suggest that shortnose sturgeon can be separated into smaller groupings across their geographic range. These genetically obvious groups form regional clusters. To conserve this genetic diversity and preserve the recruitment opportunity, the SNS SRT recommends approaching shortnose sturgeon conservation and recovery at both the riverine population scale and regionally depending on the action/ activity. Differences in life history and ecology support these genetic groupings.

This biological assessment is organized at a riverine scale: the status of shortnose sturgeon within each river was summarized by reviewing published information regarding abundance and distribution (both historic and current), river-specific natural history, and habitat information. The SNS SRT next identified and ranked stressors to each riverine population; the stressors were organized by factors in the ESA. The SNS SRT identified emerging threats and recommended research priorities. Based on this holistic approach the SRT concluded shortnose sturgeon across their geographic include 5 genetically distinct groupings (Figs. 35-38) each of which have geographic ecological adaptiations. These groups are: 1) Gulf of Maine; 2) Connecticut and Housatonic Rivers; 3) Hudson River; 4) Delaware River and Chesapeake Bay; and 5) Southeast. Three of these regional groups appear to be functioning as a metapopulation: Gulf of Maine, Delaware/Chesapeake Bay, and Southeast. The other two groups (Connecticut/Housatonic and the Hudson River) are thought to be evolutionarily significant. The SNS SRT notes that these grouping are based on currently available data; additional data may suggest additional population structure; in particular within the southeast. Further the SNS SRT recommends that each riverine population be considered as a separate management/recovery unit.

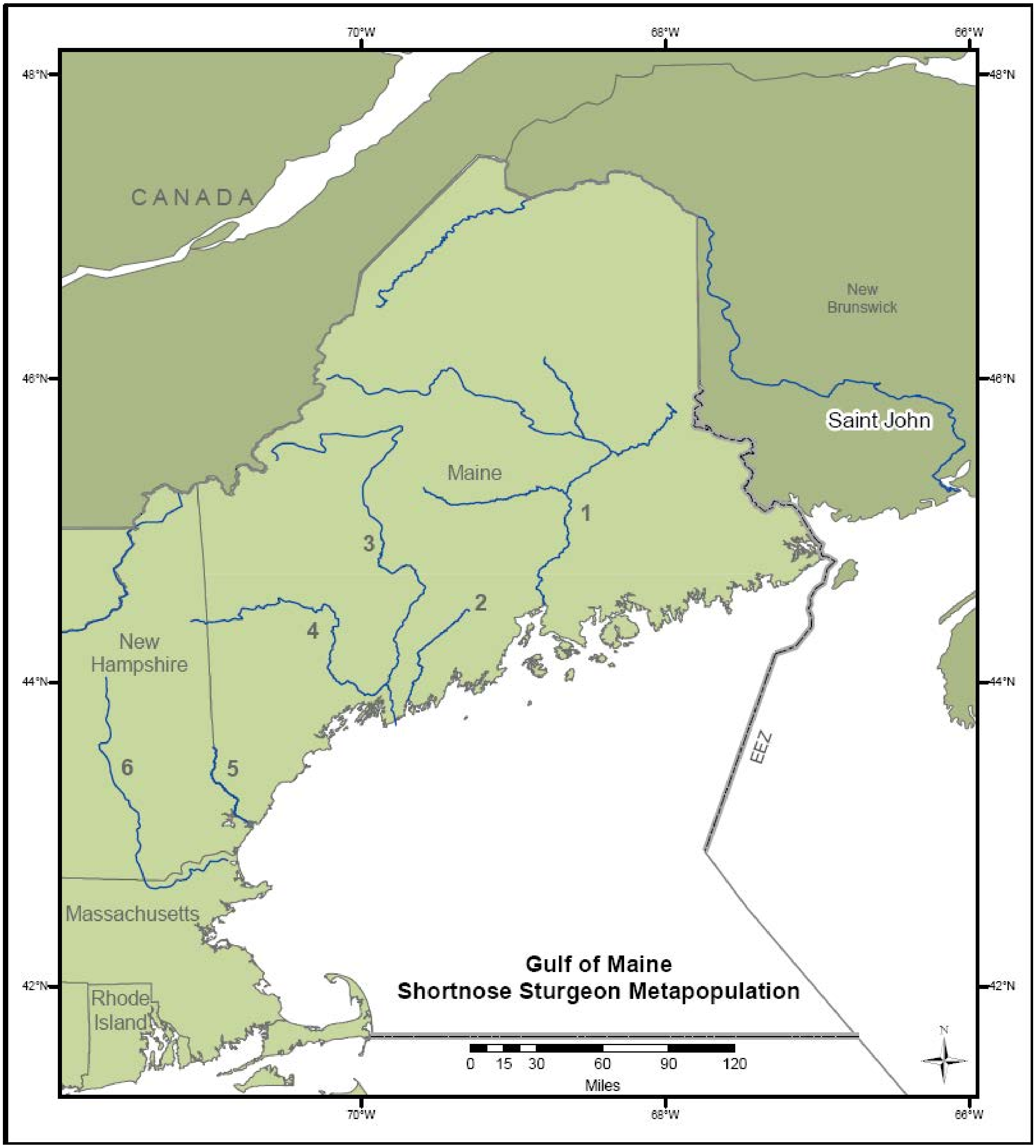


Figure 35. Map depicting Gulf of Maine shortnose sturgeon population cluster from the US/Canada border on the Saint Croix River through Chatham Light, Cape Cod, MA.

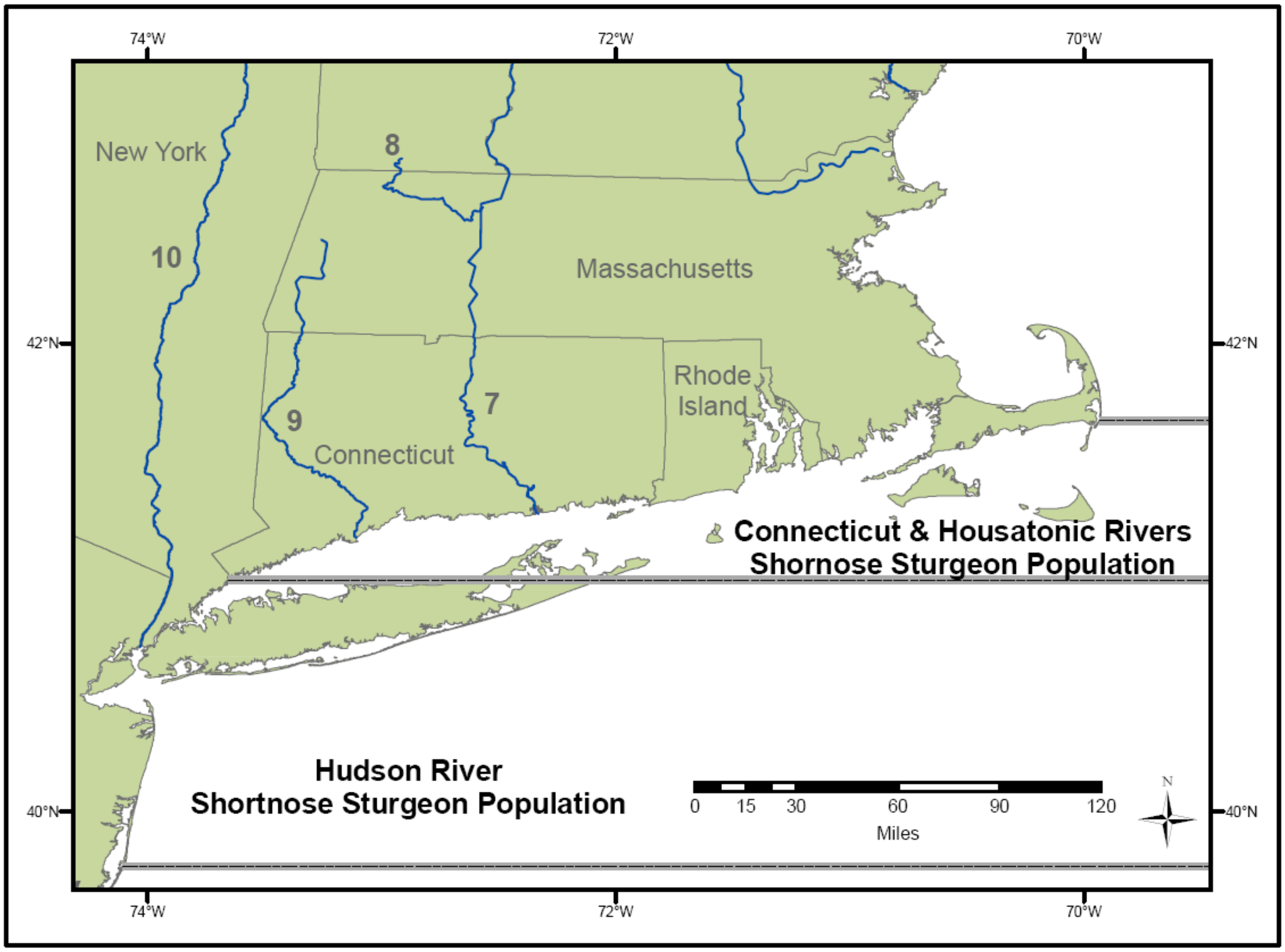


Figure 36. Map depicting geographic range of two shortnose sturgeon population clusters: the Connecticut/Housatonic and the Hudson. The Conneticut/Housatonic population cluster is bounded by Chatham Light, Cape Cod, MA in the north and the CT/NY state border to the south. The Hudson population cluster includes fish betweenthe CT/NY state border in the north to the Barnegat Light, NJ in the south.

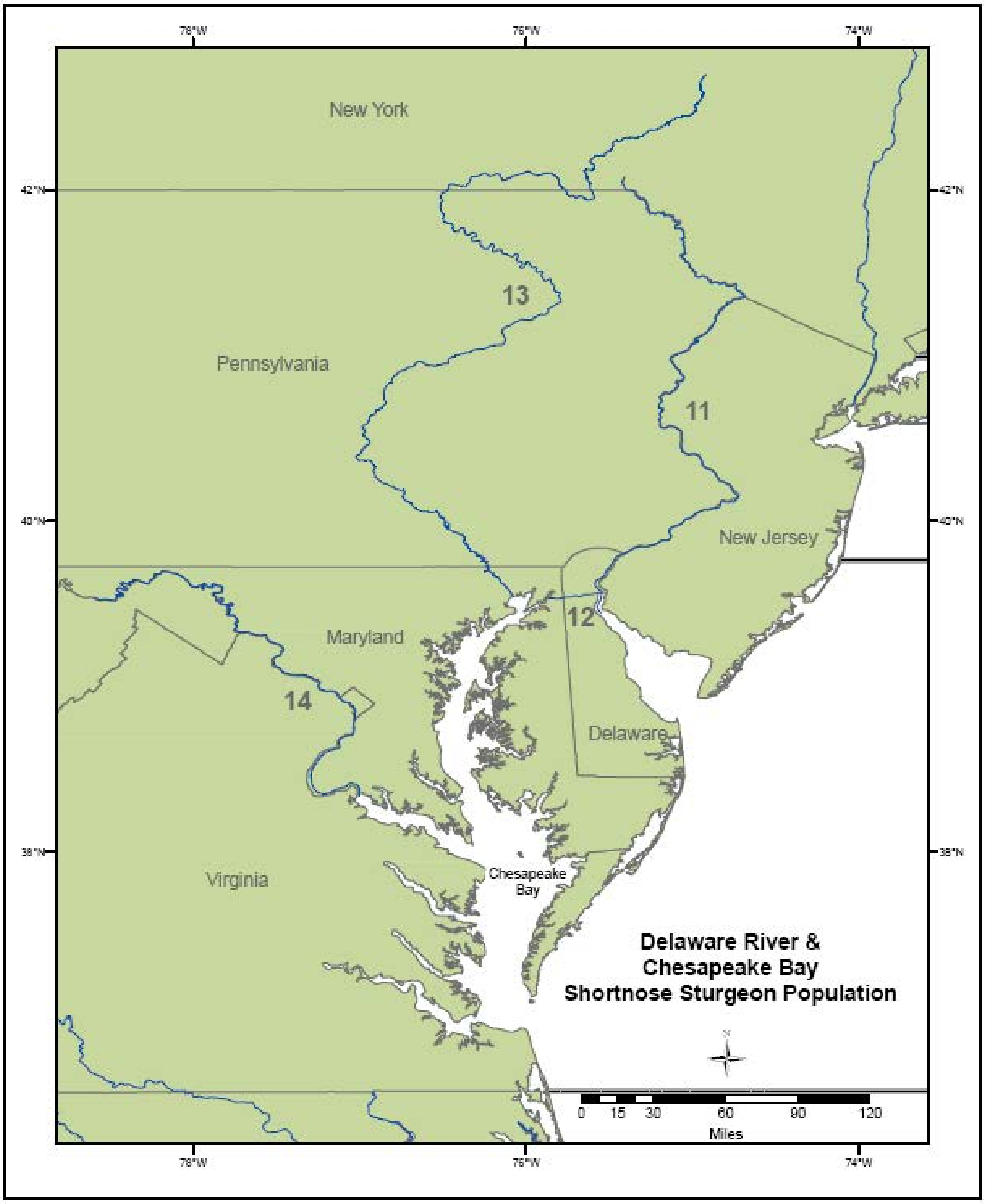


Figure 37. Map depicting the geographic range of the Delaware/Chesapeake Bay population cluster of shortnose sturgeon: boundaries are Barnegat Light, NJ in the north and the VA/NC state border in the south.

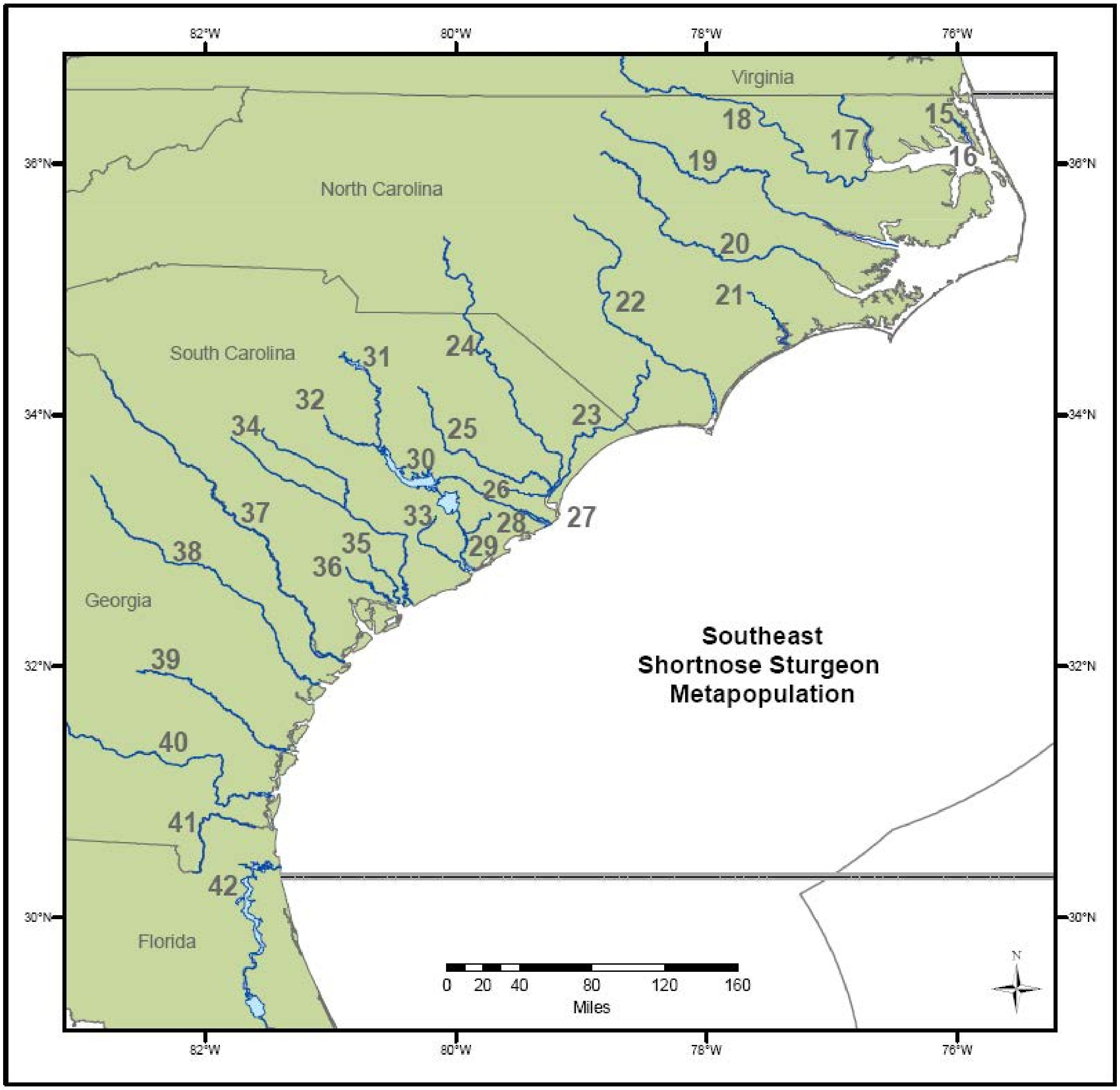


Figure 38. Map depicting the geographic range of the southeast shortnose sturgeon population cluster bounded in the north by the VA/NC state border through Atlantic Beach, FL in the south.

References

ABRT (*Acropora* Biological Review Team). 2005. Atlantic *Acropora* Status Review Document. Report to National Marine Fisheries Service, Southeast Regional Office. March 3, 2005. 152 p + App.

ACOE (U.S. Army Corps of Engineers). 2005. Final Environmental Impact Statement for a Proposed Water Treatment Residuals Management Process for the Washington Aqueduct, Washington D.C.

ACOE (U.S. Army Corps of Engineers). 2008a. Philadelphia District. Dredging http://www.nap.usace.army.mil/dredge/d2.htm (accessed May 2007).

ACOE (U.S. Army Corps of Engineers). 2008b. Norfolk District Chowan River Basin Comprehensive Watershed Study http://www.nao.usace.army.mil/Projects/Civil%20Works%20projects/Chowan%20River/homepage.asp.

Akçakaya, H. R. and W. Root. 2007. RAMAS Metapop: Viability Analysis for Stage-structured Metapopulations (version 5). Applied Biomathematics, Setauket, New York.

Alam S. K., M. S. Brim, G. A. Carmody, and F. M. Parauka. 2000. Concentrations of heavy and trace metals in muscle and blood of juvenile Gulf sturgeon (*Acipenser oxyrinchus desotoi*) from the Suwannee River, Florida. Journal Environmental Science and Health A35: 645-660.

Allendorf, F. W. and G. Luikart. 2007. Conservation and the Genetics of Populations. Blackwell Publishing, Malden, MA. 608 pp.

American Rivers. 2002. *The Ecology of Dam Removal – A Summary of Benefits and Impacts*, February, 2002 http://www.americanrivers.org/site/PageServer

Amlacher, E. 1970. Textbook of Fish Diseases. TFH Publications Inc., Jersey City, 1970.

Anders, P. J., C. R. Gelok, and M. S. Powell. 2001. Population structure and mitochondrial DNA (mtDNA) diversity in North American white sturgeon (*Acipenser transmontanus*). Proceedings of the Fourth International Sturgeon Symposium, 8–13 July 2001. Oshkosh, Wisconsin.

Angelo, W. J. 2005. East River's strong tides power submerged turbines. Engineering News-Record. January 24, 2005. http://www.enr.com/news/powerIndus/archives/050124.asp

Anonymous. 1888. Message on Fishery Treaty. American Fishery Interests. 50th Congress, 1st Session, Senate, Ex. Doc. No. 113. Pg 887.

Anonymous. 1938. *40,000 tons of coal dredged in Susquehanna Bar: Upwards of 40 people given employment through river operations*. The Morning Press. February 22, 1938.

Anonymous. 1998. *Power company, hatchery charged up about flounder farming partnership.* Gulf of Maine Times. Gulf of Maine Council on the Marine Environment.

Anonymous. 2000. *Piscataqua River dredging planned*. http://www.sandandgravel.com/news/article.asp?v1=7810

Anonymous. 2003.

Appalachian Power Company. 2008. Appalachian Power Company Smith Mountain Project FERC Project No. 2210. Application for New License for Major Project–Existing Dam. Volume 1. Appalachian Power Company, Roanoke, Virginia.

Appy, R. G., and M. J. Dadswell. 1978. Parasites of *Acipenser brevirostrum* LeSueur and *Acipenser oxyrhynchus* Mitchill (Osteichthyes: Acipenseridae) in the Saint John River Estuary, N.B., with a description of *Caballeronema pseudoargumentosus* (Nematoda: Spirurida). Canadian Journal of Zoology 56: 1382-1391.

Armstrong, J.L. 1999. Movement, habitat selection and growth of early-juvenile Atlantic sturgeon in Albemarle Sound, North Carolina. M.S. Thesis, North Carolina State University, Raleigh. 87 pp.

Armstrong, J.L., and J.E. Hightower. 1999. Movement, habitat selection and growth of early-juvenile Atlantic sturgeon in Albemarle Sound, North Carolina. Final Report to the U.S. Fish and Wildlife Service and Virginia Power. U.S. Geological Survey, North Carolina Cooperative Fish and Wildlife Research Unit, North Carolina State University, Raleigh. 78 pp.

Armstrong, J.L., and J.E. Hightower. 2002. Potential for restoration of the Roanoke River population of Atlantic sturgeon. Applied Ichthyology 18:475-480.

Arndt, G. M., J. Gessner, E. Anders, S. Spratte, J. Filipiak, L. Debus, and K. Skora. 2000. Predominance of exotic and introduced species among sturgeons captured from the Baltic and North Seas and their watersheds, 1981-1999. Boletin Instituto Espanol De Oceanografia 16: 29-36.

Arndt, G. M., J. Gessner, and C. Raymakers. 2002. Trends in farming, trade and occurrence of native and exotic sturgeons in natural habitats in Central and Western Europe. Journal of Applied Ichthyology 18: 444-448.

ASA (Analysis and Communication). 2007. 2006 year class report for the Hudson River Estuary Program prepared for Dynegy Roseton LLC, on behalf of Dynegy Roseton LLC Entergy Nuclear Indian Point 2 LLC, Entergy Nuclear Indian Point 3 LLC, and Mirant Bowline LLC. Washingtonville NY.

ASMFC (Atlantic States Marine Fisheries Commission). 1996. Breeding and Stocking Protocol for Cultured Atlantic Sturgeon. Fishery Management Report No. 68, 16 pp.

ASMFC (Atlantic States Marine Fisheries Commission). 1998. Amendment 1 to the interstate fishery management plan for Atlantic sturgeon. Fishery Management Report No. 31, 43 pp.

ASSRT (Atlantic Sturgeon Status Review Team). 2007. Status Review of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). Report to National Marine Fisheries Service, Northeast Regional Office. February 23, 2007. 174 pp.

Atkins, C. G. 1887. The river fisheries of Maine. In: The Fisheries and Fishery Industries of the United States. G. B. Goode and Associates, Section V, Vol. 1.

Atz, J. W., and C. L. Smith. 1977. Hermaphroditism and gonadal teratoma-like growths in sturgeon (Acipenser). Bulletin of the Southern California Academy of Sciences 75:119–126.

Auer, N. A. 1996a. Importance of habitat and migration to sturgeons with emphasis on Lake sturgeon. Canadian Journal of Fisheries and Aquatic Science 53:152-160.

Auer, N. A. 1996b. Response of spawning lake sturgeons to change in hydroelectric facility operation. Transactions of the American Fisheries Society 125:66–77.

Auer, N.A. 2004. Conservation. Pages 257-276 *in:* LeBreton, G.T.O.; Beamish F.W.H; McKinley R.S. (eds.) Sturgeons and paddlefish of North America. Kluwer Academic Publishers, Dordrecht.

Avise, J. C. 2000. Phylogeography: The History and Formation of Species. Harvard University Press, Cambridge, MA. 447 pp.

Avise, J.C. 2004. Molecular markers, natural history, and evolution. Second edition. Sinauer Associates, Sunderland, Massachusetts.

Bahn, R.A., J. Fleming, D. Harrison, and D.L. Peterson. 2010. The anchored gill net shad fishery of the Altamaha River, Georgia. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies. 63: 183-187.

Bahn, R.A., J.E. Fleming, and D.L. Peterson. 2012. Bychatch of shortnose sturgeon in the commercial American shad fishery of the Altamaha River, Georgia. North Americal Jouirnal of Fisheriies Management. 32: 557-562.

Bain, M. B. 1997. Atlantic and shortnose sturgeons of the Hudson River: Common and Divergent Life History Attributes. Environmental Biology of Fishes 48: 347-358.

Bain, M. B. 2001. Sturgeon of the Hudson River: ecology of juveniles. Report to the Hudson River Foundation, New York.

Bain, M., K. Arend, N. Haley, S. Hayes, J. Knight, S. Nack, D. Peterson, and M. Walsh. 1998a. Sturgeon of the Hudson River: Final Report on 1993-1996 Research. Prepared for The Hudson River Foundation by the Department of Natural Resources, Cornell University, Ithaca, New York.

Bain, M. B., D.L. Peterson, and K. K. Arend. 1998b. Population status of shortnose sturgeon in the Hudson River: Final Report. Prepared for Habitat and Protected Resources Division National Marine Fisheries Service by New York Cooperative Fish and Wildlife Research Unit, Department of Natural Resources, Cornell University, Ithaca, NY.

Bain, M. B., N. Haley, D. L. Peterson, K. K. Arend, K. E. Mills, and P. J. Sullivan. 2000. Shortnose sturgeon of the Hudson River: an endangered species recovery success. Annual meeting of American fisheries Society. EPRI-AFS Symposium: Biology, Management and Protection of Sturgeon. St. Louis, MO. 23-24 August 2000.

Bain, M. B., N. Haley, D. L. Peterson, K. K Arend, K. E. Mills, and P. J. Sullivan. 2007. Recovery of a US Endangered Fish. PLoS ONE 2(1): e168. doi:10.1371/journal.pone.0000168

Basinwide Planning Section. 2002. Neuse River Basinwide Water Quality Plan. North Carolina Department of Environment and Natural Resources, Division of Water Quality, Raleigh.

Basinwide Planning Section. 2004. Tar-Pamlico River Basinwide Water Quality Plan. North Carolina Department of Environment and Natural Resources, Division of Water Quality, Raleigh.

Basinwide Planning Section. 2005. Cape Fear River Basinwide Water Quality Plan. North Carolina Department of Environment and Natural Resources, Division of Water Quality, Raleigh.

Basinwide Planning Section. 2006. Roanoke River Basinwide Water Quality Plan. North Carolina Department of Environment and Natural Resources, Division of Water Quality, Raleigh.

Basinwide Planning Section. 2007a. Chowan River Basinwide Water Quality Plan. North Carolina Department of Environment and Natural Resources, Division of Water Quality, Raleigh. 160 pp.

Basinwide Planning Section. 2007b. Pasquotank River Basinwide Water Quality Plan. North Carolina Department of Environment and Natural Resources, Division of Water Quality, Raleigh.

Basinwide Planning Section. 2007c. White Oak River Basinwide Water Quality Plan. North Carolina Department of Environment and Natural Resources, Division of Water Quality, Raleigh.

Bateman, D. H. and M. S. Brim. 1994. Environmental contaminants in Gulf sturgeon of Northwest Florida 1985-1991. USFWS Publication Number PCFO-EC 94-09. Panama City, Florida. 23pp.

Bath, D.W., J.M. O'Conner, J.B. Albert, and L.G. Arvidson. 1981. Development and identification of larval Atlantic sturgeon (*Acipenser oxyrinchus*) and shortnose sturgeon (*A. brevirostrum*) from the Hudson River estuary, New York. Copeia 1981:711-717.

Baxter, R.M. 1977. Environmental effects of dams and impoundments. Annual Review of Ecology and Systematics 8:255-283.

Beacham, T.D. 1993. Competition between juvenile pink (*Oncorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta*) and its effect on growth and survival. Canadian Journal of Zoology 71: 1270-1274.

Bean, T.H. 1893. The fishes of Pennsylvania, with descriptions of the species and notes on their common names, distribution, habits, reproduction, rate of growth, and mode of capture. E.K. Meyers Printing House, Harrisburg, PA.

Beauvais, S. L., S. B. Jones, S. K. Brewer, and E. E. Little. 2000. Physiological measures of neurotoxicity of diazinon and malathion to larval rainbow trout (*Oncorhynchus mykiss*) and their correlation with behavioral measures. Environmental Toxicology and Chemistry 19: 1875-1880.

Bemis, W.E., and E.K. Findeis. 1994. The sturgeons' plight. Nature 370: 602.

Bemis,W.E., E.K. Findeis, and L. Grande. 1994. An Overview of Acipenseriformes. International Conference on Sturgeon Biodiversity and Conservation. The American Museum of Natural History July 28 – 30.

Bemis, W. E., E. K. Findeis, and L. Grand. 1997. An overview of Acipenseriformes. Environmental Biology of Fishes 48: 25-71.

Bemis, W.E., and L. Grande. 1992. Early development of the actinopterygian head. I. External development and staging of the paddlefish *Polyodon spathula*. Journal of Morphology 213: 47-83.

Bemis, W. E. and B. Kynard. 1997. Sturgeon rivers: an introduction to Acipenseriform biogeography and life history. Environmental Biology of Fishes 48: 167-183.

Benke, A.C. and C.E. Cushing (Eds.). 2005. Rivers of North America. Elsevier Academic Press. 49-57 pp.

Berlin, W. H., R. J. Hesselberg, and M. J. Mac. 1981. Chlorinated hydrocarbons as a factor in the reproduction and survival of Lake Trout (*Salvelinus namaycush*) in Lake Michigan. USFWS Technical Paper 105 42 pp.

Billard, R., and G. Lecointre. 2001. Biology and conservation of sturgeon and paddlefish. *Review of Fish Biology and Fisheries* 10: 355-392.

Billsson, K., L. Westerlund, M. Tysklind, and P. Olsson. 1998. Developmental disturbances caused by polychlorinated biphenyls in zebrafish (*Brachydanio rerio*). Marine Environmental Research 46: 461-464.

Birstein, V. J. 1993. Sturgeons and paddlefishes: threatened fishes in need of conservation. Conservation Biology 7: 773–787.

Birstein, V. J. 1999. Effect of ecosystem degradation on anadromous sturgeons. Pages 19-37 *in:* Proceedings of the CMS Symposium on Animal Migration. Gland, Switzerland). CMS Technical Series Publication Bonn-the Hague.

Birstein VJ, L. Betts, and R. DeSalle. 1998. Molecular identification of *Acipenser sturio* specimens: a warning note for recovery plans. Biological Conservation 84: 97-101.

Birstein, V. J., and R. DeSalle. 1998. Molecular phylogeny of Acipenserinae. Molecular Phylogenetics and Evolution 9: 141–155.

Birstein, V. J., P. Doukakis, and R. DeSalle. 2002. Molecular phylogeny of Acipenseridae: nonmonophyly of Scaphirhynchidae. Copeia 2: 287–301.

Birstein VJ, R. Hanner, and R. DeSalle. 1997. Phylogeny of the Acipenseriformes: cytogenetic andmolecular approaches. Environmental Biology of Fishes 48: 127-155.

Blacklidge, K. H. and C.A. Bidwell. 1993. Three ploidy levels indicated by genome quantification in Acipenseriformes of North America. Journal of Heredity 84: 427–430.

Blankenship, K. 1996. From shipping lanes to shorelines: 'beneficial use' projects give new life to dredged materials. Bay Journal 6(7), October 1996.

Boesch, D. F., R. B. Brinsfield,and R. E. Magnien. 2001. Chesapeake Bay eutrophication: scientific understanding, ecosystem restoration, and challenges for agriculture. Journal Environmental Quality 30: 303-320.

Boreman, J. 1997. Sensitivity of North American sturgeons and paddlefish to fishing mortality. Environmental Biology of Fishes 48:399-405.

Bowden, W.B., and J.E. Hobbie. 1977. Nutrients in Albemarle Sound, North Carolina. University of North Carolina, Sea Grant College Program, Raleigh. Report 75-25:1-187.

Bowman M.B. 2002. Legal perspectives on dam removal. BioScience 52: 739-747.

Brennan, J.S. and G.M. Cailliet. 1989. Comparative age determination techniques for white sturgeon in California. American Fisheries Society 118:296-310.

Brickell, J. 1737. The natural history of North Carolina. With an account of the trade, manners and customs of the Christian and Indian inhabitants, illustrated with copper-plates, whereon are curiously engraved the map of the country, several strange beasts, birds, fishes, snakes, insects, trees, and plants, &c. Dublin, Ireland.
[available online at http://www.ncpublications.com/colonial/Bookshelf/Natural/Fish.htm?]

Bricker, S.B., C.G. Clement, D.E. Pirhalla, S.P. Orlando, and D.F.G. Farrow. 1999. National estuarine eutrophication assessment: effects of nutrient enrichment in the nation's estuaries. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Science, Silver Spring, Maryland. 71 pp.

Bricker, S., B. Longstaff, W. Dennison, A. Jones, K. Boicourt, C. Wicks, and J. Woerner. 2007. Effects of Nutrient Enrichment In the Nation's Estuaries: A Decade of Change. NOAA Coastal Ocean Program Decision Analysis Series No. 26. National Centers for Coastal Ocean Science, Silver Spring, MD. 328 pp.

Bringolf, R.B., T.J. Kwak, W.G. Cope, and M.S. Larimore. 2005. Salinity tolerance of flathead catfish: implications for dispersal of introduced populations. Transactions of the American Fisheries Society 134:927-936.

Brown, J. J., J. Perillo, T. J. Kwak, and R. J. Horwitz. 2005. Implications of *Plyodictis olivaris* (Flathead Catfish) introduction into the Delaware and Susquehanna drainages. Northeastern Naturalist 12: 473-484.

Browne, R.M. 2004. Reproduction of the shortnose and Atlantic sturgeons in the Saint John River. M.S. Thesis, University of New Brunswick, 94 pp.

Bruch, R. M., and F. P. Binkowski. 2002. Spawning behavior of lake sturgeon (*Acipenser fulvescens*). Journal of Applied Ichthyology 18:570–575.

Brundage, H. 1986. Radio tracking studies of shortnose sturgeon in the Delaware River for the Merrill Creek Reservoir Project, 1985 Progress Report. V.J. Schuler Associates, Inc.

Brundage, H.M. 2003. Contaminant Analysis of Tissues from a Shortnose Sturgeon (*Acipenser brevirostrum*) from the Kennebec River, Maine. Report to the National Marine Fisheries Service, Protected Resources Division, Gloucester, MA from Environmental Research and Consulting, Inc. 34 pp.

Brundage, H. M., and R. E. Meadows. 1982a. The Atlantic sturgeon in the Delaware River estuary. Fisheries Bulletin 80: 337-343.

Brundage, H.M., and R.E. Meadows. 1982b. Occurrence of the endangered shortnose sturgeon, *Acipenser brevirostrum*, in the Delaware River estuary. Estuaries 5(3):203-208.

Buck, E.H. 1995. Summaries of major laws implemented by the National Marine

Fisheries Service. CRS Report for Congress. Congressional Research Service, Library of Congress, March 24, 1995.

Buckley, J.H. 1982. Seasonal movement, reproduction, and artificial spawning of shortnose sturgeon (*Acipenser brevirostrum*) from the Connecticut River. M.S. Thesis. University of Massachusetts, Amherst. 64 pp.

Buckley, J., and B. Kynard. 1981. Spawning and rearing of shortnose sturgeon from the Connecticut River. Progressive Fish Culturist 43:74-76.

Buckley, J. and B. Kynard. 1983. Studies on shortnose sturgeon. Report. Massachusetts Cooperative Fishery Research Unit.

Buckley, J., and B. Kynard. 1985a. Yearly movements of shortnose sturgeon in the Connecticut River. Transactions of the American Fisheries Society 114:813-820.

Buckley, J., and B. Kynard. 1985b. Habitat use and behavior of prespawning and spawning shortnose sturgeon, *Acipenser brevirostrum*, in the Connecticut River. Pages 111-117 *in:* F.P. Binkowski and S.I. Doroshov, eds. North American sturgeons: biology and aquaculture potential. Developments in Environmental Biology of Fishes 6. Dr. W. Junk Publishers, Dordrecht, Netherlands. 163pp.

Buigues, G. I. Zamora, A.J. Mazon, V. Valverde, and F.J. Perez. 2008. Sea energy conversion: problems and possibilities. The International Conference on Renewable Energies and Power Quality (ICREPQ ’06). 8pp.

Burkholder, J., D. Eggleston, H. Glasgow, C. Brownie, R. Reed, G. Janowitz, M. Posey, G. Melia, C. Kinder, R. Corbett, D. Toms, T. Alphin, N. Deamer, and J. Springer. 2004. Comparative impacts of two major hurricane seasons on the Neuse River and western Pamlico Sound ecosystems. Proceedings of the National Academy of Sciences 101(25):9291-9296.

Bushnoe, T. M., J. A. Musick, and D. S. Ha. 2005. Essential spawning and nursery habitat of Atlantic sturgeon (*Acipenser oxyrinchus*) in Virginia. Virginia Institute of Marine Science, Gloucester Point, and Virginia.

Cameron, P., J. Berg, V. Dethlefsen, and H. Von Westernhagen. 1992. Developmental defects in pelagic embryos of several flatfish species in the southern north-sea. Netherlands Journal of Sea Research 29: 239-256.

Campana, S. E. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. Journal of Fish Biology 59: 197-242.

Campbell, J. G., and L. R. Goodman. 2004. Acute sensitivity of juvenile shortnose sturgeon to low dissolved oxygen concentrations. Transactions of the American Fisheries Society 133:772-776.

Canada DFO. 2008a. The Saint John River Basin and its Fishery Resources. Accessed November/10/2008. http://www.mar.dfo-mpo.gc.ca/science/mactaquac/stjohn.html

Canada DFO. 2008b. Aquatic Species at Risk – Shortnose Sturgeon. Accessed November/19/2008. http://www.dfo-mpo.gc.ca/species-especes/species-especes/shortnosesturgeon-esturgeonamuseaucourt-eng.htm

Caraco N. F. and J.J. Cole. 2002. Contrasting impacts of a native and alien macrophyte on dissolved oxygen in a large river. Ecological Applications 12:1496-1509.

Caraco, N.F., J.J. Cole, P.A. Raymond, D. L Strayer, M.L. Pace, S.E.G. Findlay, and D.T. Fischer. 1997. Zebra mussel invasion in a large turbid river: phytoplankton response to increased grazing. Ecology 78:588-602.

Carlson, D.M., and K.W. Simpson. 1987. Gut contents of juvenile shortnose sturgeon in the upper Hudson estuary. Copeia 1987:796-802

Carnes, W. C. 1965. Appendices to the survey and classification of the Roanoke River and tributaries, North Carolina. North Carolina Wildlife Resource Commission Final Report Federal Aid in Fish Restoration, Job I-Q, Proj. F-14-R.

Carr, J. W. and L. E. Kennedy. 2007. Housatonic River Watershed 2002 Water Quality Assessment Report (21wqar07.doc DWM CN 141.5). Massachusetts Division of Environmental Protection, Division of Watershed Management. 112 pp.

Carr, J. W. and L. E. Kennedy. 2008. Connecticut River Watershed 2003 Water Quality Assessment Report (34wqar07.doc DWM CN 105.5). Massachusetts Division of Environmental Protection, Division of Watershed Management. 156 pp.

Caswell, H. 1989. Matrix population models: construction, analysis, and interpretation. Sinauer, Sunderland, Massachusetts.

CBF (Chesapeake Bay Foundation). 2008. Saving a National Treasure. Accessed 12/12/2008. http://www.cbf.org/site/PageServer?pagename=about_sub_mission_plan

CBP (Chesapeake Bay Program). 1994. Chesapeake Bay Basinwide Toxins Reduction Strategy Re-evaluation Report. CBP/TRS 117/94, September 1994. 192pp.

CBS News. 2006. *A rising wave of tidal power: young ocean energy companies stake claims on the coast for a bottomless energy source*. November 4, 2006. http://www.cbsnews.com/stories/2006/11/04/business/main2153298.shtml

Cheuvront, B. 2003. A social and economic analysis of commercial fisheries in North Carolina: Beaufort Inlet to the South Carolina state line. North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries, Morehead City. A report for the NC Technical

Assistance to the South Atlantic Fishery Management Council, Task 5: NEPA related activities, Contract No. SA-03-03-NC. 51pp.

CHGE (Central Hudson Gas and Electric Corporation). 1999. Draft environmental impact statement for State pollution discharge elimination system permits for Bowline Point1&2, Indian Point 1&2, and Roseton 1&2 Steam electric generating stations.

Choudhury, A., and T.A. Dick. 1998. The historical biogeography of sturgeons (Osteichthyes: Acipenseridae): A synthesis of phylogenetics, paleontology, and palaeogeography. Journal of Biogeography. 25(4): 623-640.

Chytalo, K. 1996. Summary of Long Island Sound dredging windows strategy workshop. In: Management of Atlantic Coastal Marine Fish Habitat: Proceedings of a Workshop for Habitat Managers. ASMFC Habitat Management Series #2.

Clarke, K.R. 1993. Non-parametric multivariate analysis of changes in community structure. Australian Journal of Ecology 18:117-143.

Clement M, Posada D, Crandall KA. 2000. tcs: a computer program to estimate gene genealogies. Molecular Ecology, 9, 1657-1660.

CLF (Conservation Law Foundation). 2008. Portsmouth Sewage Treatment Plant: Fighting for More Stringent Protections for the Piscataqua River and Great Bay Estuary. (http://www.clf.org/programs/cases.asp?id=683)

Cobb, S.N. 1900. The sturgeon fishery of the Delaware River and Bay. Rept. U.S. Comm. Fish. 1899:369-380.

Coffin, C., C. 1947. Ancient fish weirs along the Housatonic River. Archeological Society of Connecticut, Bulletin 21:35–38.

Cohen, A. 1997. Sturgeon poaching and black market caviar: a case study. Env. Biol. Fish. 48: 423-426.

Collins, M.R., D. Cooke, B. Post, J. Crane, J. Bulak, T.I.J. Smith, T.W. Greig, and J.M. Quattro. 2003b. Shortnose sturgeon in the Santee-Cooper Reservoir System, South Carolina. Transactions of the American Fisheries Society. 132: 1244-1250.

Collins, M.R., C. Norwood, B. Post and A. Hazel. 2006. Diets of Shortnose and Atlantic Sturgeon in South Carolina: Results of Research conducted 2004-2006 Final Report to National Fish and Wildlife Foundation. South Carolina Department of Natural Resources. 38 pp.

Collins, M.R., C. Norwood, and A. Rourk. 2008. Final report to NFWF: Shortnose and Atlantic sturgeon age-growth, status, diet, and genetics. Project 2006-0087-009.

Collins M.R., W.C. Post, and D.C. Russ. 2001. Distribution of shortnose sturgeon in the Lower Savannah River. Final Report to the Georgia Ports Authority. 21pp.

Collins, M.R., W.C. Post, D.C. Russ, and T.I.J. Smith. 2002. Habitat use and movements of juvenile shortnose sturgeon in the Savannah River, Georgia-South Carolina. Transactions of the American Fisheries Society 131:975-979.

Collins, M.R., W.C. Post, D.C. Walling, C.A. Way, A.A. Avildsen, A.R. Rourk, aned C.A. Kalinowsky. 2003a. Shortnose sturgeon in the Winyah Bay System, South Carolina. Report to National Marine Fisheries Service. Marine Resources Research Institute, South Carolina Department of Natural Resources Project #NA17FL1541.

Collins, M. R., S. G. Rogers, and T. I. J. Smith. 1996. Bycatch of sturgeons along the Southern Atlantic Coast of the USA. North American Journal of Fisheries Management 16: 24-29.

Collins, M.R., S.G. Rogers, T.I.J. Smith and M.L. Moser. 2000a. Primary factors affecting sturgeon populations in the southeastern United States: fishing mortality and degradation of essential habitats. Bulletin of Marine Science 66(3):917-928.

Collins, M.R., T.I.J. Smith., W.C. Post and O. Pashuk . 2000b. Habitat Utilization and Biological Characteristics of Adult Atlantic sturgeon in two South Carolina rivers. Transactions of the American Fisheries Society 129**:** 982-988.

Collins, M.R., and T.I.J. Smith. 1993. Characteristics of the adult segment of the Savannah River population of shortnose sturgeon. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 47:485-491.

Collins, M.R., and T.I.J. Smith. 1997. Distribution of shortnose and Atlantic sturgeons in South Carolina. North American Journal of Fisheries Management 17:995-1000.

Cooke, D. W., J. P. Kirk, J. V. Morrow, Jr., and S. D. Leach. 2004. Population dynamics of a migration limited shortnose sturgeon population. Proceedings of the Annual Conference, Southeastern Association of Fish and Wildlife Agencies 58:82-91.

Cooke, D. W., and S. D. Leach 1999. Santee Cooper blueback herring studies. South Carolina Department of Natural Resources, Annual Progress Report SCR 1-22, Columbia.

Cooke, D.W., and Leach, S. D. 2004. Implications of a migration impediment on shortnose sturgeon spawning. *North American Journal of Fisheries Management* 24, 1460–1468. doi:10.1577/M03-141.1

Cooke D.W., Leach S.D., and J.J. Isely. 2002. Behavior and lack of upstream passage of shortnose sturgeon at a hydroelectric facility and navigation lock complex. Pp 101–110 *In* Van Winkle W., Anders P.J., Secor D.H., Dixon D.A. (Eds.) *American Fisheries Society Symposium 28*. Oshkosh, WI.

Cooper, S. and D. Lipton. 1994. Mid-Atlantic research plan. Mid-Atlantic Regional Marine Research Program, College Park, Maryland. 163 pp.

Cope, E.D. 1883. The fisheries of Pennsylvania. Rept. State Comm. Fish. 1881 and 1882:103-183.

Copeland, B.J., R.G. Hodson and S.R. Riggs. 1984. The ecology of the Pamlico River, North Carolina: an estuarine profile. U.S. Fish and Wildlife Service, Division of Biological Services, Washington, D.C. FWS/OBS-82/06. 83 pp.

Copeland, B.J., R.G. Hodson, S.R. Riggs and J.E. Easley, Jr. 1983. The ecology of Albemarle Sound, North Carolina: an estuarine profile. U.S. Fish and Wildlife Service, Division of Biological Services, Washington, D.C. FWS/OBS-83/01. 68 pp.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2005. Assessment and update status report on the shortnose sturgeon *Acipenser brevirostrum* in Canada, Ottawa. Vi: 27 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

Cox, D.T., and H.L. Moody. 1981. St. Johns River Fisheries Resources. Completion Report, Study I, Ecological Aspects of the Fishery. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida. USA.

Craft, C., J. Clough, J. Ehmna, S. Joye, R. Park, S. Pennings, H. Guo, and M. Machmuller. 2009. Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services. Frontiers in Ecology and the Environment.

Crance, J.H. 1986. Habitat suitability index models and instream flow suitability curves: shortnose sturgeon. U.S. Fish and Wildlife Service, Division of Wildlife and Contaminant Research, National Ecology Center, Ft. Collins, Colorado. Biological Report 82(10.129). 31 pp.

Crouse, D. T., L. B. Crowder, and H. Caswell. 1987. A stage-based population model for loggerhead sea turtles and implications for conservation. Ecology 68:1412-1423.

Cuerrier, J. P. 1951. The use of pectoral fin rays for determining the age of sturgeon and other species of fish. Canadian Fish Culturist 11:10–18

Culbertson, J.B., M. Crawford, E. Brinker, M.H. Posey, L.L. Leonard, T. Alphin, G.B. Avery, Jr., D.M. DuMond and C.T. Hackney. 2008. Monitoring Effects of a Potential Increased Tidal Range in the Cape Fear River Ecosystem Due to Deepening Wilmington Harbor, North Carolina Year 8: June 1, 2007 – May 31, 2008. Unpublished report prepared for the U. S. Army Corps of Engineers, Wilmington District. University of North Carolina at Wilmington Department of Biological Sciences, Wilmington, NC.

Cunjak, R. A., and R.W. Newbury. 2005. St. John River. In : Rivers of North America, A.C. Benke, and C.E. Cushing (Editors). Elsevier Academic Press, Burlington, Massachusetts, pp. 953-958.

Curry, R.A., C. A. Doherty, T. D. Jardine, and S. L. Currie. 2007. Using movements and diet analyses to assess effects of introduced muskellunge (*Esox masquinongy*) on Atlantic salmon (*Salmo salar*) in the Saint John River, New Brunswick. Environmental Biology of Fishes 79:49–60.

Cutts, C.J., N.B. Metcalfe, and A.C. Taylor. 1998. Aggression and growth depression injuvenile Atlantic salmon: the consequences of individual variation in standard metabolic rate. Journal of Fish Biology 52: 1026-1037.

CZR Incorporated. 2001. Monitor Potential Effects of Increased Tidal Range on the Cape Fear River Ecosystem Due to Deepening Wilmington Harbor, North Carolina. Part B. Initial Baseline Monitoring. Prepared for U. S. Army Corps of Engineers, Wilmington District, Wilmington, NC.

CZR Incorporated. 2002. Monitor Potential Effects of Increased Tidal Range on the Cape Fear River Ecosystem Due to Deepening Wilmington Harbor, North Carolina. Part B. Initial Baseline Monitoring. Prepared for U. S. Army Corps of Engineers, Wilmington District, Wilmington, NC.

Dadswell, M.J. 1975. Mercury, DDT and PCB content of certain fishes from the Saint John River estuary, New Brunswick. Transactions of the Atlantic Chapter, Canadian Society of Environmental Biologists Annual Meeting. Fredericton, NB, November 1975.

Dadswell, M.J. 1979. Biology and population characteristics of the shortnose sturgeon, Acipenser brevirostrum LeSueur 1818 (Osteichthyes: Acipenseridae), in the Saint John River estuary, New Brunswick, Canada. Canadian Journal of Zoology 57:2186-2210.

Dadswell. M.J. 1984. Status of the shortnose sturgeon, *Acipenser brevirostrum*, in Canada. Canadian Field-Naturalist 98:75-79.

Dadswell, M. J. and R. A. Rulifson. 1994. Macrotidal estuaries: a region of collision between migratory marine animals and tidal power development. Biological Journal of the Linnean Society 51: 93-113.

Dadswell, M. J., B. D. Taubert, T. S. Squiers, D. Marchette, and J. Buckley. 1984. Synopsis of biological data on shortnose sturgeon, *Acipenser brevirostrum* LeSueur 1818. NOAA Technical Report NMFS 14 and FAO (Food and Agriculture Organization of the United Nations) Fisheries Synopsis 140.

Dame, R., M. Alber, D. Allen, M. Mallin, C. Montague, A. Lewitus. A. Chalmers, R. Gardner, C. Gilman, B. Kjerfve, J. Pinckney and N. Smith. 2000. Estuaries of the south Atlantic coast of North America: their geographical signatures. Estuaries 23:793-819.

Damon-Randall, K., R. Bohl, S. Bolden, D. Fox, C. Hager, B. Hickson, E. Hilton, J. Mohler, E. Robbins, T. Savoy and A. Spells. 2010. Atlantic Sturgeon Research Techniques. NOAA Technical Memorandum NMFS-NE-215. 64pp.

Daniels, R. A., Limburg, K. E., Schmidt, R. E., Strayer, D. L., and Chambers, R. C. 2005. Changes in Fish Assemblages in the Tidal Hudson River, New York. *American Fisheries Society Symposium* 45:471-503.

DEHNR. 1990a. North Carolina coastal marinas: water quality assessment. Raleigh, NC. Report 90-01:1-69.

DEHNR (North Carolina Department of Environment, Health, and Natural Resources) 1990b. Chowan River Water Quality Management Plan - 1990 Update. 16 pp. + appendices.

DeVries, R.J. 2006. Population Dynamics, Movements, and Spawning Habitat of the Shortnose Sturgeon, *Acipenser brevirostrum*, in the Altamaha River System, Georgia. M.S. Thesis, University of Georgia, Athens, Georgia. 103 pp.

Diaby, S. 2000. An Economic Analysis of Commercial Fisheries in the Albemarle Sound Management Area, North Carolina. NC Department of Environment and Natural Resources, Division of Marine Fisheries, Morehead City, NC. Atlantic Coastal Fisheries Cooperative Management Act, National Oceanic and Atmospheric Administration Award No. NA87FG0367-1.

Diamond, G. 1986. Rare endangered fish caught in the Susquehanna River. The Record. June 18, 1986.

Diaz, R.J. and R. Rosenberg. 2008. Spreading dead zones and consequences for marine ecosystems. Science 321:926-929.

Dickerson, D. 2006. Observed takes of sturgeon and turtles from dredging operations along the Atlantic Coast. Supplemental data provided by U.S. Army Engineer R&D Center Environmental Laboratory, Vicksburg, Mississippi.

Dilauro, M.N., W.S. Kaboord, and R.A. Walsh. 1999. Sperm-Cell Ultrastructure of North American Sturgeons. Ii. The Shortnose Sturgeon (*Acipenser brevirostrum*, LeSueur, 1818). Canadian Journal of Zoology 77: 321-330.

Dilauro, M.N., W.S. Kaboord and R.A. Walsh. 2000. Sperm-Cell Ultrastructure of North American Sturgeons. Iii. The Lake Sturgeon (*Acipenser fulvescens* Rafinesque, 1817). Canadian Journal of Zoology 78: 438-447.

Disler, N. N. 1960. Lateral line sense organs and their importance in fish behavior. U.S.S.R. Academy of Science, Publication TT 70-54021 (1971 translation), Nat. Tech. Info. Serv. Springfield, VA.

Donovan, T. M., and C. W. Welden. 2002. Spreadsheet exercises in conservation biology and landscape ecology. Sinauer Associates, Sunderland, Massachusetts.

Dornin, C. 2007. Tidal power from Piscataqua River? (http://www.seacoastonline.com/apps/pbcs.dll/article?AID=/20070519/NEWS/705190344)

Dovel, W.L. 1979. The biology and management of shortnose and Atlantic sturgeon of the Hudson River. New York State Department of Environmental Conservation, AFS9-R, Albany.

Dovel, W.L. 1981. The Endangered shortnose sturgeon of the Hudson Estuary: Its life history and vulnerability to the activities of man. The Oceanic Society. FERC Contract No. DE-AC 39-79 RC-10074.

Dovel, W. L., and T. J. Berggren. 1983. Atlantic sturgeon of the Hudson Estuary, New York. NY Fish and Game J. 30:140-172.

Dovel, W.L., A.W. Pekovitch and T.J. Berggren. 1992. Biology of the shortnose sturgeon (*Acipenser brevirostrum* Lesueur, 1818) in the Hudson River estuary, New York. Pages 187-216 in C.L. Smith, editor, Estuarine Research in the 1980s. State University of New York Press, Albany, New York.

Downeast LNG. 2009. FERC Issues Favorable Draft Environmental Impact Statement For Downeast LNG. Press release May 15, 2009. http://www.downeastlng.com/pressrelease.php?id=37

DRBC (Delaware River Basin Commission). 2007. The Delaware River Basin. Website article: http://www.state.nj.us/drbc/thedrb.htm.

DRBC (Delaware River Basin Commission). 2012. Basin Information. Website article: http://www.state.nj.us/drbc/basin/

Ducheney, P., R. F. Murray, Jr., J. E. Waldrip, and C. A. Tomichek. 2006. Fish passage at Hadley Falls: past, present, and future. HydroVision 2006 Proceedings, HCI Publications.

Dudley, R. W. and G. A. Hodgkins. 2002. Trends in Streamflow, River Ice, and Snowpack for Coastal River Basins in Maine During the 20th Century. Water Resources Investigations Report 02-4245. USGS. Augusta, ME. 26 pp.

Dulvy, N.K., Ellis, J.R., Goodwin, N.B., Grant, A., Reynolds, J.D. and Jennings, S. 2004. Methods of assessing extinction risk in marine fishes. Fish and Fisheries 5, 255–276.

Duncan M.S., J.J. Isely, and D.W. Cooke. 2004. Evaluation of shortnose sturgeon spawning in the Pinopolis Dam Tailrace, South Carolina. *North American Journal of Fisheries Management*. 24: 932–938

Dunn, W. 2001. Merrimack River: A comprehensive watershed assessment report. Massachusetts Executive Office of Environmental Affairs, Devens, Massachusetts.

Dwyer, F.J., D.K. Hardesty, C.E. Henke, C.G. Ingersoll, D.W. Whites, T. Augspurger, T.J. Canfield, D.R. Mount, and F.L. Mayer. 2005. Assessing contaminant sensitivity of endangered and threatened aquatic species. Part III. Effluent toxicity tests: Archives of Environmental Contamination and Toxicology, 48:174-183 (91371).

Dwyer, F.J., D. K. Hardesty, C. G. Ingersoll, J. L. Kunz, and D.W. Whites. 2000. Assessing contaminant sensitivity of American Shad, Atlantic sturgeon and shortnose sturgeon. Final Report prepared for the New York State Dept. of Environmental Conservation.

Earll, R.E. 1884. North Carolina and its fisheries. Pp. 475-497 in G.B. Goode (ed.) The fisheries and fishery industries of the United States, Section II, Part VII. U.S. Commission on Fish and Fisheries, Washington, D.C. [online at http://www.nefsc.noaa.gov/nefsc/publications/classics/goode1884/goode1884.htm]

Eastman., S. E. 1912. In Old South Hadley (MA). Blakely Printing Company, Chicago, Illinois.

Edwards, R.E., and T.W. Stoe. 1998. Nutrient Reduction Cost Effectiveness Analysis, 1996 Update, Susquehanna River Basin Commission Publication No. 195., Harrisburg, PA.

Ehrlich, D. 2007. Cleantech Group, LLC. Nova Scotia Looks at Tidal Power. Accessed November/19/2008. http://cleantech.com/news/1675/nova-scotia-looks-at-tidal-power).

Elofsson, H., Van Look, K., Borg, B. & Mayer, I. 2003. Influence of salinity and ovarian fluid on sperm motility in the fifteen-spined stickleback. *Journal of Fish Biology* 63**,** 1429-1438.

EPA (Environmental Protection Agency). 1994. Biological assessment for the shortnose sturgeon (*Acipenser brevirostrum*) in the lower Penobscot River. Prepared for U.S. EPA by Metcalf & Eddy, Wakefield, MA.

EPA (Environmental Protection Agency). 2003. Ambient water quality criteria for dissolved oxygen, water clarity and chlorophyll-a for the Chesapeake Bay and its tributaries. pp. 343, U.S. Environmental Protection Agency, Washington, DC (USA). http://www.epa.gov/Region3/chesapeake/baycriteria.htm

EPA (Environmental Protection Agency). 2004. National Coastal Condition Report II, EPA-620/R-03/002. U.S. Environmental Protection Agency, Offices of Water and Research and Development, Washington, DC. http://www.epa.gov/owow/oceans/nccr2/.

EPA (Environmental Protection Agency). 2006. Watershed assessment tracking and environmental results: lower Connecticut River.

Epperly, S.P. and S.W. Ross. 1986. Characterization of the North Carolina Pamlico-Albemarle estuarine complex. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Center, Beaufort Laboratoy, Beaufort, NC. NOAA Technical Memorandum NMFS-SEFC-175:1-55.

EPRI. 2006. Evaluation of an Angled Louver Facility for Guiding Sturgeon to a Downstream Bypass. Electric Power Research Institute (EPRI), Palo Alto, CA, Holyoke Gas & Electric Company, Holyoke, MA, and WE-Energies Inc., Milwaukee, WI: 2006. 1011786.

ERC, Inc. (Environmental Research and Consulting, Inc.). 2002. Contaminant analysis of tissues from two shortnose sturgeon (Acipenser brevirostrum) collected in the Delaware River. Prepared for National Marine Fisheries Service. 16 pp. + appendices.

ERC, Inc. (Environmental Research and Consulting, Inc.). 2003. Contaminant analysis of tissues from a shortnose sturgeon (Acipenser brevirostrum) from the Kennebec River, Maine. Report submitted to National Marine Fisheries Service, Protected Resources Division, Gloucester, MA. 5 pp.

ERC, Inc. (Environmental Research and Consulting, Inc.). 2006a. Acoustic telemetry study of the movements of shortnose sturgeon in the Delaware River and bay progress report for 2003-2004. Prepared for NOAA Fisheries. 11 pp.

ERC, Inc. (Environmental Research and Consulting, Inc.). 2006b. Final report of shortnose sturgeon population studies in the Delaware River, January 1999 through March 2003. Prepared for NOAA Fisheries and NJ Division of Fish and Wildlife. 11 pp.

ERC, Inc. (Environmental Research and Consulting, Inc.). 2007a. Investigations of shortnose sturgeon early life stages in the Delaware River. Progress report for the period May-June 2007. Prepared for the NJ Division of Fish and Wildlife. 4 pp.

ERC, Inc. (Environmental Research and Consulting, Inc.). 2007b. Preliminary acoustic tracking study of juvenile shortnose sturgeon and Atlantic sturgeon in the Delaware River. May 2006 through March 2007. Prepared for NOAA Fisheries. 9 pp.

ERC, Inc. (Environmental Research and Consulting, Inc.). 2008. Final report of investigations of shortnose sturgeon early life stages in the Delaware River, spring 2007 and 2008. Prepared for the NJ Division of Fish and Wildlife. 24 pp.

ERM (Environmental Resources Management, Inc). 1980. Oxygen dynamics study: Susquehanna River below Conowingo Dam, Maryland. Interim Report.

Esch, G.W. and T.C. Hazen. 1980. The ecology of Aeromonas hydrophila in Albemarle Sound, North Carolina. University of North Carolina, Water Resources Research Institute, Raleigh. WRRI Report 153:1-116.

Evermann, B.W. and B.A. Bean. 1898. Indian River and its fishes. Report U.S. Comm. Fish and Fisheries for 1896.

Eyler, S.M., E.S. Jorgen, M. F. Mangold and S.A. Welsh. 2000. Distribution of sturgeons in candidate open water dredged material placement sites in the Potomac River (1998-2000). U.S. Fish and Wildlife Service, Annapolis, Maryland. 26 pp.

Fay, C., M. Barton, S. Craig, A. Hecht, J. Pruden, R. Saunders, T. Sheehan, and J. Trial. 2006. Status review for anadromous Atlantic salmon (Salmo salar) in the United States. Report to the National Marine Fisheries Service and U.S. Fish and Wildlife Service. 283 pp.

Feist, G. W., M. A. H. Webb, D. T. Gundersen, E. P. Foster, C. B. Schreck, Al. G. Maule, and M. S. Fitzpatrick. 2005. Evidence of detrimental effects of environmental contaminants on growth and reproductive physiology of white sturgeon in impounded areas of the Columbia River. Environmental Health Perspectives 113: 1675-1682.

FERC (Federal Energy Regulatory Commission). 2008a. Hydrokinetic Projects. Accessed 12/10/2008. http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics.asp#skipnavsub

FERC (Federal Energy Regulatory Commission). 2008b. Liquid Natural Gas Projects. Accessed 12/10/2008. http://www.ferc.gov/industries/lng.asp#skipnavsub

Fernandes, S.J. 2008. Population demography, distribution, and movement patterns of Atlantic and shortnose sturgeons in the Penobscot River estuary, Maine. University of Maine. Masters thesis. 88 pp.

Fernandes, S. J.; Zydlewski, G. B.; Kinnison, M. T.; Zydlewski, J. D.; Wippelhauser, G. S., 2010: Seasonal distribution and movements of Atlantic and shortnose sturgeon in the Penobscot River estuary, Maine. Trans. Am. Fish.Soc. 139, 1436–1449.

Flagg, L.N. 1974. Striped Bass and Smelt Survey, Completion Report. AFS-4, 1974.

Fleming, J.E., T.D. Bryce, and J.P. Kirk. 2003. Age, growth, and status of shortnose sturgeon in the lower Ogeechee River, Georgia. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 57:80-91.

FL FWC (Florida Fish and Wildlife Conservation Commission). Shortnose sturgeon population evaluation in the St. Johns River, Florida.

Flournoy, P.H., S.G. Rogers, and P.S. Crawford. 1992. Restoration of shortnose sturgeon in the Altamaha River, Georgia. Final Report to the U.S. Fish and Wildlife Service, Atlanta, Georgia.

Fontana, F., L. Congiu, V.A. Mudrak, J.M. Quattro, T.I.J. Smith, K. Ware, and S.I. Doroshov. 2008. Evidence of hexaploid karyotype in shortnose sturgeon. Genome 51:113-119.

Fowler, H.W. 1910. Notes on chimaeroid and ganoid fishes. Proc. Acad. Nat. Sci. Philadelphia 62:603-612.

Fowler, H.W. 1912. Records of fishes for the middle Atlantic states and Virginia. Proc. Acad. Nat. Sci. Philadelphia 64:34-59.

Fowler, H.W. 1945. A study of the fishes of the southern Piedmont and Coastal Plain. Academy of Natural Sciences of Philadelphia. Monograph 7.

Frank, K. T., B. Petrie, J. S. Choi, and W. C. Leggett. 2005. Trophic cascades in a formerly cod-dominated ecosystem. Science 308: 1621-1623.

Fried, S.M. and J.D. McCleave. 1973. Occurrence of shortnose sturgeon (*Acipenser brevirostrum*) an endangered species, in Montsweag Bay, Maine. Journal of the Fisheries Board of Canada 30: 563-564.

Fuller, P.L. 2008a. *Ictalurus furcatus*. U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida. http://nas.er.usgs.gov/queries/FactSheet.asp?speciesID=740, Revision Date: 10/25/2007.

Fuller, P.L. 2008b. *Pylodictis olivaris*. U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida. http://nas.er.usgs.gov/queries/FactSheet.asp?speciesID=750, Revision Date: 4/21/2006.

Fuller, P.L., and A.J. Benson. 2008. *Channa argus*. U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida. http://nas.er.usgs.gov/queries/FactSheet.asp?speciesID=2265, Revision Date:8/22/2007

Gadomski , D. M. and M. J. Parsley. 2005. Laboratory studies on the vulnerability of young white sturgeon to predation. North American Journal of Fisheries Management 25: 667-674.

Galbraith, K. 2008. Power from the restless sea stirs the imagination. The New York Times. September 22, 2008. http://www.nytimes.com/2008/09/23/business/23tidal.html?_r=0

Geoghegan, P., M.T. Mattson and R.G Keppel. 1992. Distribution of shortnose sturgeon in the Hudson River Estuary, 1984-1988. IN Estuarine Research in the 1980s, C. Lavett Smith, Editor. Hudson River Environmental Society, Seventh symposium on Hudson River ecology. State University of New York Press, Albany NY, USA.

Gephard, S. and J. McMenemy. 2004. An overview of the program to restore Atlantic salmon and other diadromous fishes to the Connecticut River with notes on the current status of these species in the river. American Fisheries Society Monograph 9: 287-317.

Giberson, A.V. 1999. Flow preference as a mechanism for resource partitioning in shortnose sturgeon (*Acipenser brevirostrum*) and Atlantic sturgeon (*Acipenser* *oxyrhynchus*) populations. Honours thesis. University of New Brunswick. 30 pp.

Giberson, A.V. 2004. Social behaviour, competition and interactions of juvenile shortnose sturgeon (*Acipenser brevirostrum*) and Atlantic sturgeon (*A. oxyrhynchus*). M.Sc. Thesis UNB. 78 pp.

Giese, G.L., H.B. Wilder and G.G. Parker, Jr. 1979. Hydrology of major estuaries and sounds in North Carolina. U.S. Geological Survey, Water Resources Investigation 79-46. 175 pp.

Giesy, J. P., J. Newsted, and D. L. Garling. 1986. Relationships between chlorinated hydrocarbon concentrations and rearing mortality of Chinook salmon (*Oncorhynchus tshawytscha*) eggs from Lake Michigan. Journal of Great Lakes Research 12: 82-98.

Gilbert, C.R. 1989. Atlantic and shortnose sturgeons. United States Department of Interior Biological Report 82, 28 pages.

Gorham S.W. and D.E. McAllister. 1974. The shortnose sturgeon, Acipenser brevirostrum, in the Saint John River, New Brunswick, Canada, a rare and possibly endangered species. Syllogeus 5:17-18.

Gowan, D. 2008. Moving mud threatens to bury port. Telegraph-Journal. Nov. 3, 2008. http://nbbusinessjournal.canadaeast.com/front/article/468569

Greeley, J. R. 1937. Section II. Fishes of the areas with an annotated list. In A biological survey of the lower Hudson watershed. Supplement to the 26th annual report. New York State Conservation Department, Albany NY, USA.

Greene, C. H. and A. J. Pershing. 2007. Climate drives sea change. Science 315: 1084-1085.

Greene, C. H., A. J. Pershing, T. M. Cronin, and N. Ceci. 2008. Arctic climate change and its impacts on the ecology of the North Atlantic. Ecology 89(11): S24-S38.

Gross, M. R., J. Repka, C. T. Robertson, D. H. Secor, and W. V. Winkle. 2002. Sturgeon conservation: insights from elasticity analysis. Pages 13-30 in W. van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society, Symposium 28, Bethesda, Maryland.

Gruchy, C. G. and B. Parker. 1980. *Acipenser brevirostrum* LeSueur, shortnose sturgeon. Page 38 in D. S. Lee, C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, J. R. Stauffer, editors, Atlas of North American Freshwater Fishes. North Carolina State Museum of Natural History, Raleigh, North Carolina. North Carolina Biological Survey, Publication 1980-12:1-867.

Grunwald, C., L. Maceda, J. Waldman, J. Stabile, and I. Wirgin. 2007. Conservation of Atlantic sturgeon *Acipenser oxyrinchus oxyrinchus*: delineation of stock structure and distinct population segments. Conservation Genetics DOI 10.1007/s10592-007-9420-1

Grunwald, C., J. Stabile, J.R. Waldman, R. Gross, and I.I. Wirgin. 2002. Population genetics of shortnose sturgeon *Acipenser brevirostrum* based on mitochondrial DNA control region sequences. Molecular Ecology 11:1885-1898.

Hackney, C. T., M.H. Posey, L.L. Leonard, T Alphin, and G.B. Avery Jr. 2002. Monitoring Effects of a Potential Increased Tidal Range in the Cape Fear River Ecosystem Due to Deepening Wilmington Harbor, North Carolina Year 1: August 1, 2000 – July 31, 2001. Unpublished report prepared for the U. S. Army Corps of Engineers, Wilmington District. University of North Carolina at Wilmington Department of Biological Sciences, Wilmington, NC.

Hackney, C. T., M. Posey, L.L. Leonard, T Alphin, G.B. Avery Jr., and others. 2003. Monitoring Effects of a Potential Increased Tidal Range in the Cape Fear River Ecosystem Due to Deepening Wilmington Harbor, North Carolina Year 2: June 1, 2001 – May 31, 2002. Unpublished report prepared for the U. S. Army Corps of Engineers, Wilmington District. University of North Carolina at Wilmington Department of Biological Sciences, Wilmington, NC.

Hackney, C. T., M. Posey, L.L. Leonard, T Alphin, G.B. Avery Jr., and others. 2004. Monitoring Effects of a Potential Increased Tidal Range in the Cape Fear River Ecosystem Due to Deepening Wilmington Harbor, North Carolina Year 3: June 1, 2002 – May 31, 2003. Unpublished report prepared for the U. S. Army Corps of Engineers, Wilmington District. University of North Carolina at Wilmington Department of Biological Sciences, Wilmington, NC.

Hackney, C. T., M. Posey, L.L. Leonard, T Alphin, G.B. Avery Jr., D.M. DuMond, and others. 2005. Monitoring Effects of a Potential Increased Tidal Range in the Cape Fear River Ecosystem Due to Deepening Wilmington Harbor, North Carolina Year 4: June 1, 2003 – May 31, 2004. Unpublished report prepared for the U. S. Army Corps of Engineers, Wilmington District. University of North Carolina at Wilmington Department of Biological Sciences, Wilmington, NC.

Hackney, C. T., Posey, L.L. Leonard, T Alphin, G.B. Avery Jr., D.M. DuMond, and others. 2006. Monitoring Effects of a Potential Increased Tidal Range in the Cape Fear River Ecosystem Due to Deepening Wilmington Harbor, North Carolina Year 5: June 1, 2004 – May 31, 2005. Unpublished report prepared for the U. S. Army Corps of Engineers, Wilmington District. University of North Carolina at Wilmington Department of Biological Sciences, Wilmington, NC.

Hackney, C. T., Posey, L.L. Leonard, T Alphin, G.B. Avery Jr., D.M. DuMond, and others. 2007. Monitoring Effects of a Potential Increased Tidal Range in the Cape Fear River Ecosystem Due to Deepening Wilmington Harbor, North Carolina Year 6: June 1, 2005 – May 31, 2006. Unpublished report prepared for the U. S. Army Corps of Engineers, Wilmington District. University of North Carolina at Wilmington Department of Biological Sciences, Wilmington, NC.

Hackney, C. T., Posey, L.L. Leonard, T Alphin, G.B. Avery Jr., D.M. DuMond, and others. 2008. Monitoring Effects of a Potential Increased Tidal Range in the Cape Fear River Ecosystem Due to Deepening Wilmington Harbor, North Carolina Year 7: June 1, 2006 – May 31, 2007. Unpublished report prepared for the U. S. Army Corps of Engineers, Wilmington District. University of North Carolina at Wilmington Department of Biological Sciences, Wilmington, NC.

Hackney, C.T., M.H. Posey, S.W. Ross and A.R. Norris. 1996. A review and synthesis of data on surf zone fishes and invertebrates in the South Atlantic Bight and the potential impacts from beach renourishment. Report to Wilmington District, U.S. Army Corps of Engineers. University of North Carolina-Wilmington. 111 pp.

Haley, N. 1996. Juvenile sturgeon use in the Hudson River. Master's thesis. University of Massachusetts, Amhearst, MA, USA.

Haley, N. J. 1999. Habitat Characteristics and resource Use patterns of Sympatric Sturgeons in the Hudson River Estuary. M.S., University of Massachusetts Amherst.

Haley, N., J. Boreman, and M. Bain. 1996. Juvenile sturgeon habitat use in the Hudson River. Section VIII: 36 pages in J.R. Waldman, W.C. Nieder, E.A. Blair, editors, Final Reports of the Tibor T. Polgar Fellowship Program 1995, Hudson River Foundation, New York.

Hall, W.J., T.I.J. Smith, and S.D. Lamprecht. 1991. Movements and habitats of shortnose sturgeon, *Acipenser brevirostrum* in the Savannah River. Copeia (3):695-702.

Hammer Ø., D.A.T. Harper, and P.D. Ryan. 2007. PAST: palaeontological statistics software package for education and data analysis. Palaeontologia Electronica (2001) 4(1):9. Download from http://folk.uio.no/ohammer/past.

Hammerschmidt, C. R., M. B. Sandheinrich, J. G. Weiner, and R. G. Rada. 2002. Effects of dietary methylmercury on reproduction of fathead minnows. Environmental Science and Technology 36: 877-883.

Hardy, R., and M.K. Litvak. 2004. Effects of temperature on the early development, growth, and survival of shortnose sturgeon, *Acipenser brevirostrum*, and Atlantic sturgeon, *Acipenser oxyrhynchus*, yolk-sac larvae. Environmental Biology of Fishes. 70: 145-154.

Hastings, R.W., J.C. O'Herron II, K. Schick, and M.A. Lazzari. 1987. Occurrence and distribution of shortnose sturgeon, Acipenser brevirostrum, in the upper tidal Delaware River. Estuaries 10:337-341.

Hatch, R. H. 1971. Hydrographic data, 1966-1970, Penobscot River, Maine. A compilation of results of surveys of the cooperative fishery unit, University of Maine. Information Memorandum, June, 1971. 19 pp.

Hatchery International Magazine. 2006. Supplier Profile, Acadian Sturgeon and Caviar Inc. Saint John, New Brunswick, Canada. Accessed November/19/2008. http://www.hatcheryinternational.com/profiles/pr-acadian.html

Hatin, D., S. Lachance, and D. Fournier. 2007. Effect of dredged sediment deposition on use by Atlantic sturgeon and lake sturgeon at an open-water disposal site in the St. Lawrence estuarine transition zone. Pages 235-256 *in:* J. Munro, D. Hatin, J.E. Hightower, K. McKown, K.J. Sulak, A.W. Kahnle and F. Caron, editors. Anadromous sturgeons: habitats, threats and management. American Fisheries Society, Symposium 56, Bethesda, Maryland.

Hatin, D. R., S. Lachance, and D. Fournier. In Press. Effect of annual sediment deposition at Madame Island open-water disposal site on the use by Atlantic sturgeon (*Acipenser oxyrinchus*) and lake sturgeon (*Acipenser fulvescens*) in the Saint Lawrence River middle estuary. *In:* J. Munro, D. Hatin, K. McKown, J. Hightower, K. Sulak, A. Kahnle, and F. Caron (eds) Proceedings of the Symposium on anadromous sturgeon: Status and trend, anthropogenic impact and essential habitat. American Fisheries Society, Bethesda, Maryland.

Haywood, H. C. and C. Buchanan. 2007. Total maximum daily loads of polychlorinated biphenyls (PCBs) for tidal portions of the Potomac and Anacostia rivers in the District of Columbia, Maryland, and Virginia. Interstate Commission on the Potomac River Basin. ICPRB Report 07–7. Rockville, MD.

Hazen, T.C. 1979. Ecology of Aeromonas hydrophila in a South Carolina reservoir. Microbial Ecology 5:179-195.

Heath, R.C. 1975. Hydrology of the Albemarle-Pamlico region. North Carolina: a preliminary report on the impact of agricultural developments. U.S. Geological Survey, Water Resources Investigation 9-75:1-98.

Hedrick, R.P., Groff, J.M., McDowell, T.S., Wingfield, W.H. 1990. An iridovirus from the integument of white sturgeon. Dis. Aquat. Org. 8:39–44.

Hedrick, R.P., McDowell, T.S., Groff, J.M., Yun, S., Wingfield, W.H. 1992. Isolation and some properties of an iridovirus-like agent from white sturgeon *Acipenser transmontanus*. Dis. Aquat. Org. 12:75–81

Heidt, A.R., and R.J. Gilbert. 1978. The shortnose sturgeon in the Altamaha River drainage, Georgia. Pages 54-60 in R.R. Odum and L. Landers, editors. Proceedings of the rare and endangered wildlife symposium. Georgia Department of Natural Resources, Game and Fish Division, Technical Bulletin WL 4, Athens, Georgia.

Hellyer, G. 2000. Connecticut River fish tissue contaminant study –Ecological and human health risk screening. Environmental Protection Agency, New England Regional Laboratory, Chelmsford, Massachusetts.

Henne, J. P., K. M. Ware, W. R. Wayman, R. S. Bakal, and A. Horvath. 2006. Synchronous Hermaphroditism and Self-Fertilization in a Captive Shortnose Sturgeon. Transactions of the American Fisheries Society 135:55–60.

Hett, A. K. and A. Ludwig. 2005. SRY-related (Sox) genes in the genome of European Atlantic sturgeon (*Acipenser sturio*). Genome 48: 181–186.

Hewitt, D.A. 2003. Abundance and migratory patterns of anadromous fish spawning runs in the Roanoke River, North Carolina. M.S. Thesis, Fisheries and Wildlife Sciences, North Carolina State University, Raleigh. 125 pp.

Higgins, C.B. 2006. Invasion genetics of the blue catfish (*Ictalurus furcatus*) range expansion into large river ecosystems of the Chesapeake Bay watershed. M. S. Thesis, Virginia Commonwealth University, Richmond. 43 pp.

Hightower, J.E., A.M. Wicker, and K.M. Endres. 1996. Historical trends in abundance of American shad and river herring in Albemarle Sound, North Carolina. North American Journal of Fisheries Management 16:257-271.

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York.

Hildebrand, S.F. and Schroeder,W.C. 1928. Fishes of Chesapeake Bay. U.C. Bur. Fish. Bill. 53.

Hill, J. 1996. Environmental considerations in licensing hydropower projects: policies and practices at the Federal Energy Regulatory Commission. American Fisheries Society Symposium 16: 190-199.

Hilton, E. J. and L Grande. 2006. Review of The Fossil Record Of Sturgeons, Family Acipenseridae (Actinopterygii: Acipenseriformes), from North America. *J. Paleont.*, 80(4), pp. 672–683.

Hindar, K., N. Ryman, and F. Utter. 1991. Genetic effects of cultured fish on natural fish populations. Can. J. Fish. Aquat. Sci. 48: 945-957.

Hobbie, J.E., B.J. Copeland and W.G. Harrison. 1975. Sources and fates of nutrients in the Pamlico River estuary of North Carolina. In L.E. Cronin (ed.), Estuarine Research. Vol. 1. Academic Press, New York. Pp. 287-302.

Hocutt, C. H. and E.O. Wiley. 1986. The zoogeography of North American freshwater fishes. John Wiley and Sons, New York, NY

Holland, B.F., Jr. and G.F. Yelverton. 1973. Distribution and biological studies of anadromous fishes offshore North Carolina. North Carolina Department of Natural and Economic Resources, Division of Commercial and Sports Fisheries, Morehead City. Special Scientific Report 24:1-132.

HRF (Hudson River Foundation). 2009. http://www.hudsonriver.org/ Accessed in 2009.

Hulme, P.E. 2005. Adapting to climate change: is there scope for ecological management in the face of global threat? Journal of Applied Ecology 43: 617-627.

Hurley, K. L., R. S. Sheehan, and R. C. Heidinger. 2004. Accuracy and Precision of Age Estimates for Pallid Sturgeon from Pectoral Fin Rays. North American Journal of Fisheries Management 24:715–718.

IPCC (Intergovernmental Panel on Climate Change). 2007. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.). IPCC, Geneva, Switzerland. pp 104.

Jaccard, P. 1901. Etude comparative de la distribution florale dans une portio ´ n des Alpes et des Jura. Bull. Soc. Vaudoise Sci. Nat 37, 547–579.

Jackson, J.K., A.D. Huryn, D.L. Strayer, D.L. Courtemanch, and B.W. Sweeney. 2005. Atlantic coast rivers of the northeastern United States. Pages 21-61 *in:* A.C. Benke and C.E. Cushing (eds.). Rivers of North America. Elsevier Academic Press.

Jager, H. I. 2001. Individual variation in life history characteristics can influence extinction risk. Ecological Modeling 144:61–76.

Jager H.I., J.A. Chandler, K.B. Lepla, and W. Van Winkle. 2001. A theoretical study of river fragmentation by dams and its effects on white sturgeon populations. Enviromental Biology of Fishes 60:347–361

Jamieson, B. G. M. 1991. Fish evolution and systematics: evidence from spermatozoa. Cambridge:Cambridge University Press.

Jarvis, P.L., J.S. Ballantyne, and W.E. Hogans, 2001. The influence of salinity on the growth of juvenile shortnose sturgeon. North American Journal of Aquaculture 63, 272– 276.

Jelks, H.L., S.J. Walsh, N.M. Burkhead, S. Contreras-Balderas, E. Diaz-Pardo, D.A. Hendrickson, J. Lyons, N.E. Mandrak, F. McCormick, J.S. Nelson, S.P. Platania, B.A. Porter, C.B. Renaud, J.J. Schmitter-Soto, E.B. Taylor, and M.L. Warren, Jr. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33(8):372-407.

Jenkins, W.E., T.I.J. Smith, L.D. Heyward, and D.M. Knott. 1993. Tolerance of shortnose sturgeon, *Acipenser brevirostrum*, juveniles to different salinity and dissolved oxygen concentrations. Proceedings of the Southeast Association of Fish and Wildlife Agencies, Atlanta, Georgia.

Jerome, W. C. Jr., A.P. Chesmore, C. O. Anderson, Jr., and F. Grice. 1965. A Study of the marine resources of the Merrimack River estuary. Massachusetts Division of Marine Fisheries Monograph Series 1: 90 pp.

Jha, A. 2008. First tidal power turbine gets plugged in. guardian.co.uk, Thursday July 17, 2008. Accessed 12/09/2008.
http://www.guardian.co.uk/environment/2008/jul/17/waveandtidalpower.renewableenergy/print

Johnson, H. 1982. Fisheries production in Albemarle Sound. Page 55 in Albemarle Sound trends and management. University of North Carolina, Sea Grant College Program, Raleigh. UNC-SG 82-02.

Johnston, R.K., W.R. Munns, P.L. Tyler, P. Marajh-Whittemore, K. Finkelstein, K. Munney, F.T. Short, A. Mellville, and S.P. Hahn. 2002. Weighing the evidence of ecological risk from chemical contamination in the estuarine environment adjacent to the Portsmouth Naval Shipyard, Kittery, Maine, USA. Environmental Toxicology and Chemistry 21:182-194.

Jones, K.B., K.H. Riiters, J.D. Wickham, R.D.Tankersley, Jr., R.V. O'Neill, D.J. Chaloud, E.R. Smith, and A.C. Neale. 1997. An ecological assessment of the United States Mid-Atlantic Region. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C. EPA/600/R-97/130. 104 pp.

Jordan, D.S. 1886. Notes on fishes collected at Beaufort, North Carolina with a revised list of the species known from that locality. Proceedings of the U.S. National Museum 9:25-30.

JØrgensen, E. H., O. Aas-Hansen, Al G. Maule, J. E. T. Strand, M. M. Vijayan. 2004. PCB impairs smoltification and seawater performance in anadromous Arctic char (*Salvelinus alpinus*). Comparative Biochemsitry and Physiology, Part C 138: 203-212.

Kahnle, A., and K. Hattala. 1988. Bottom trawl survey of juvenile fishes in the Hudson River estuary. Summary Report for 1981-1986. New York State Department of Environmental Conservation. Albany, NY, USA.

Kahnle, A.W., K. A. Hattala and K. McKown. 2007. Status of Atlantic sturgeon in the Hudson River Estuary, New York USA .IN Anadromous sturgeon habitats, threats and management, J. Munro, editor, AFS Symposium 56, Washington DC USA.

Kahnle, A.W., R.W. Laney and B.J. Spear. 2005. Proceedings of the workshop on status and management of Atlantic Sturgeon, Raleigh, NC 3-4 November 2003. Special Report No. 84 for the Atlantic States Marine Fisheries Commission.

Keleher, C. J. and F. J. Rahel. 1996. Thermal limits to salmonid distributions in the Rocky Mountain region and potential habitat loss due to global warming: A geographic information system (GIS) approach. Transactions of the American Fisheries Society 125(1): 1-13.

Kiddon, J., J. Paul, C. Strobel, B. Brown, H. Buffum and J. Copeland. 2002. Mid-Atlantic integrated assessment (MAIA) estuaries 1997-98. Summary Report. Environmental conditions in the Mid-Atlantic estuaries. U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, Narragansett, RI, and Region III, Philadelphia, PA. EPA/620/R-02/003. 11 pp.

Kieffer, M. C. 1991. Annual movements of shortnose and Atlantic sturgeons in the lower Merrimack River. M.S. Thesis. University of Massachusetts, Amherst.

Kieffer, M. C., and B. Kynard. 1993. Annual Movements of shortnose and Atlantic sturgeons in the Merrimack River, Massachusetts. Transactions of the American Fisheries Society 122:1088–1103.

Kieffer, M., and B. Kynard. 1996. Spawning of shortnose sturgeon in the Merrimack River, Massachusetts. Transactions of the American Fisheries Society 125:179-186.

Kim, D.S., Y.K. Nam, J.K. Noh, C.H. Park, and F.A. Chapman, F.A. 2005. Karyotype of North American shortnose sturgeon *Acipenser brevirostrum* with the highest chromosome number in the Acipenseriformes. Ichthyological Research 52: 94–97.

King, T.L., A.P Henderson, B.E. Kynard, M.C. Kieffer, and D.L. Peterson. 2013. A nuclear DNA perspective on delineating fundamental units of management and evolutionary significant lineages in the endangered shortnose sturgeon. Final Report to the National Capital Region, U.S. National Park Service and Eastern Region, USGS. 67pp.

King, T. L., B. A. Lubinski, A. P. Spidle. 2001. Microsatellite DNA variation in Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) and cross species amplification in the Acipenseridae. Conservation Genetics 2(2): 103-119.

Kleinschmidt. 2006. Entrainment Report prepared for Connecticut Resources Recovery Authority Mid-Connecticut Resource Recovery Facility, Hartford, CT, Permit No. CT0003875. November 2006. 26 pp and appendices.

Kleinschmidt. 2007. Annual Progress Report prepared for Consolidated Edison Energy of Massachusetts, Inc. West Springfield Station, NPDES Permit No. MA0004707. February 2007. 23 pp and appendices.

Klyashtorin, L.B. 1976. The sensitivity of young sturgeons to oxygen deficiency. J. Icthyol. 16: 677-681.

Knight, J.A. 1985. Differential preservation of calcined bone at the Hirundo site, Alton, Maine. Master's Thesis, Institute for Quaternary Studies, University of Maine, Orono, Maine.

Knowles L.L. and B.C. Carstens. 2007. Delimiting species without monophyletic gene trees. Systematic Biology 56: 887-895.

Ko, F. and J.E. Baker. 2004. Seasonal and annual loads of hydrophobic organic contaminants from the Susquehanna River basin to the Chesapeake Bay. Marine Pollution Bulletin. 48: 840-851.

Kocan, R. M., M. B. Matta, and S. Salazar. 1993. A laboratory evaluation of Connecticut River coal tar toxicity to shortnose sturgeon (*Acipenser brevirostrum*) embryos and larvae. Final Report to the National Oceanic and Atmospheric Administration, Seattle, Washington.

Kocan, R., M., M., B., Matta, and S., M., Salazar. 1996. Toxicity of weathered coal tar for shortnose sturgeon (*Acipenser brevirostrum*) embryos and larvae. Archives of environmental contamination and toxicology 31:161–165.

Kornegay, J.W. 2005. Juvenile Atlantic sturgeon catches increase in North Carolina rivers. Tidewater Press, Newsletter of the Tidewater Chapter of the American Fisheries Society 20(2):7-8.

Krause, R.E., and R.B. Randolph. 1989. Hydrology of the Floridan aquifer system in Southeast Georgia and adjacent parts of Florida and South Carolina. U.S.Geological Survey Professional Paper 1403-D, 65 pp.

Krieger J. and P. A. Fuerst. 2002. Evidence for a slowed rate of molecular evolution in the order Acipenseriformes. Molecular Biology and Evolution 19:891-897.

Krieger, J., P. A. Fuerst, and T. M. Cavender. 2000. Phylogenetic relationships of the North American sturgeons (order Acipenseriformes) based on mitochondrial DNA sequences. Mol. Phylogenet. Evol. 16, 64–72.

Krieger J, A.K. Hett, P.A. Fuerst, E. Artyukhin, and A. Ludwig. 2008. The molecular phylogeny of the order Acipenseriformes revisited. Journal of Applied Ichthyology 24: 36-45.

Kruse, G. O. and D. L. Scarnecchia. 2002a. Assessment of bioaccumulated metal and organochlorine compounds in relation to physiological biomarkers in Kootenai River white sturgeon. Journal of Applied Ichthyology 18: 430-438.

Kruse, G. O. and D. L. Scarnecchia. 2002b. Contaminant uptake and survival of white sturgeon embryos. American Fisheries Society Symposium 28: 151-160.

Kwak, T.J., W.E. Pine, III, D.S. Waters, J.A. Rice, J.E. Hightower, and R.L. Noble. 2004. Population dynamics and ecology of introduced flathead catfish. Division of Inland Fisheries, North Carolina Wildlife Resources Commission, Raleigh. Federal Aid in Sport Fish Restoration, Project F-68, Study 1, Final Report.

Kynard, B. 1996. Twenty-one years of passing shortnose sturgeon in fish lifts on the

Connecticut River: what has been learned? Draft report by National Biological Service, Conte Anadromous Fish Research Center, Turners Falls, MA. 19 pp.

Kynard, B. 1997. Life history, latitudinal patterns, and status of the shortnose sturgeon, *Acipenser brevirostrum*. Environmental Biology of Fishes 48:319–334.

Kynard, B. 1998. Twenty-two years of passing shortnose sturgeon in fish lifts on the Connecticut River: What has been learned? Pages 255–264. *In:* M. Jungwirth, S. Schmutz, and S. Weiss, editors. Fish migration and fish bypasses. Fishing News Books, London.

Kynard, B., M. Breece, M. Atcheson, M. Kieffer, and M. Mangold. 2007. Status of Shortnose Sturgeon in the Potomac River. Final Report to the National Park Service, National Capital Region, Washington, D.C.

Kynard, B., and M. Horgan. 2001. Guidance of yearling shortnose and pallid sturgeon using vertical bar rack and louver arrays. North American Journal of Fisheries Management 21:561–570.

Kynard, B. and M. Horgan. 2002. Ontogenetic behavior and migration of Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus*, and shortnose sturgeon, *A. brevirostrum*, with notes on social behavior. Environmental Biology of Fishes 63: 137-150.

Kynard, B., M. Horgan, M. Kieffer, and D. Seibel. 2000. Habitats used by shortnose sturgeon in two Massachusetts rivers, with notes on estuarine Atlantic sturgeon: a hierarchical approach. Transactions of the American Fisheries Society 129: 487- 503.

Kynard, B., Breece, M., Atcheson, M., Kieffer, M. and Mangold, M. 2009. Life history and status of shortnose sturgeon (Acipenser brevirostrum) in the Potomac River. Journal of Applied Ichthyology 25: 34–38.

Kynard, B., P. Bronzi, H. Rosenthal. 2012. Life History and Behavior of Connecticut River Shortnose and other Sturgeons. World Sturgeon Conservtion Society: Special Publication 4(2012).

Lahnsteiner, F., B. Berger, T. Weismann, and R.A. Patzner. 1997. Sperm structure and motility of the freshwater teleost *Cottus gobio*. Journal of Fish Biology 50: 564-574.

Langland, M.J. 1998. Changes in sediment and nutrient storage in three reservoirs in the lower Susquehanna River Basin and implications for the Chesapeake Bay: importance of the Susquehanna River and its reservoir system to the Chesapeake Bay. USGS.

LaPatra, S.E., J.M. Groff, G.R. Jones, B. Munn, T.L. Patterson, R.A. Holt, A.K. Hauck, and R. P. Hedrick. 1994. Occurrence of white sturgeon iridovirus infections among cultured white sturgeon in the Pacific Northwest. Aquaculture 126: 201-210.

LaPatra, S.E., G.R. Jones, W.D. Shewmaker, K.A. Lauda, and R. Schneider. 1995. Immunological Response of White Sturgeon to a Rhabdovirus of Salmonid Fish. In: Vadim Birstein and William Bemis, editors, pages 8-9. The Sturgeon Quarterly 3.

Lawson, J. 1709. A new voyage to Carolina; containing the exact description and natural history of that country: together with the present state thereof. And a journal of a thousand miles, travel'd thro' several nations of indians. Giving a particular account of their customs, manners, etc. London. The University of North Carolina, Chapel Hill. 1967 edition edited with an Introduction and notes by Hugh Talmage Lefler. 305 pp.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister and J.R. Stauffer, Jr. 1980. Atlas of North American freshwater fishes. North Carolina State Museum of Natural History, Raleigh. North Carolina Biological Survey, Publication 1980-12:1-867.

Lenihan, H.S. 1999. Physical-biological coupling on oyster reefs: how habitat structure influences individual performance. Ecological Monographs 69:251-275.

Lenihan, H.S., and C.H. Peterson. 1998. How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. Ecological Applications 8:128-140.

Leslie, P. H. 1945. On the use of matrices in certain population mathematics. Biometrika 33:183-212.

LeSueur, C.A. 1818. Description of several species of Chondropterygious fishes of North America, with their varieties. Transactions of the American Philosophical Society 1:383-395.

Leung, K.M.Y., J.R. Wheeler, D. Morritt, and M. Crane. 2002. Endocrine disruption in fishes and invertebrates: Issues for saltwater ecological risk assessment. Pages 189-215 *In:* M.C. Newman, M.H. Roberts, and R.C. Hale. Eds. Coastal and Estuarine Risk Assessment. Lewis Publishers, Boca Raton.

Lewis, J. A. 1996. Effects of underwater explosions on life in the sea. DSTO-GD-0080. Melbourne, Australia.

Li, X.,M.K. Litvak, and J.E.H. Clark. 2007. Overwintering habitat use of shortnose sturgeon (*Acipenser brevirostrum*): defining critical habitat using a novel underwater video survey and modeling approach.

Liem, A.H. and L.R. Day. 1959. Records of uncommon and unusual fishes from eastern Canadian waters. 1950-1958. J. Fish. Res. Board. Can. 16:503-574.

Linsley, J. H. 1844. Catalogue of the fishes of Connecticut, arranged according to their natural families. American Journal of Science and Arts 47:55–80.

Lippson, A. J. 1979. Environmental Atlas of the Potomac Estuary. Williams & Heintz.

Litwiler, T.L. 2001. Conservation plan for sea turtles, marine mammals, and the shortnose sturgeon in Maryland, Maryland Department of Natural Resources Technical Report FS-SCOL-01-2, Oxford, Maryland 134pp.

LMS. 1984. Albany Steam Generating Station SPDES Aquatic Monitoring Program. October 1982-September 1983. Revised 1984. Prepared for Niagara Mohawk Power Corporation. LMSE-83/0451&191/070.

LMS. 1985. Albany Steam Generating Station SPDES Aquatic Monitoring Program. April 1984-April 1985. July 1985, Revised December 1985. Prepared for Niagara Mohawk Power Corporation. LMSE-85/0301&191/073.

Loftfield, T.C. 1987. Excavations at 31On305, the Flynt Site at Sneads Ferry, North Carolina. North Carolina Division of Archives and History, State Historic Preservation Office, Office of State Archaeology, Raleigh. OSA #2190.

Longwell, A. C., S. Chang, A. Hebert, J. Hughes, and D. Perry. 1992. Pollution and developmental abnormalities of Atlantic fishes. Environmental Biology of Fishes 35:1-21.

Luczkovich, J., L. Ausley, C. Pullinger, G. Ward, and K. West. 2001. The effects of the flood on the water quality and the fishes of the Pamlico River Estuary. Pages 235-245 *in*: J.R. Maiolo, J.C. Whitehead, M. McGee, L. King, J. Johnson and H. Stone (eds.) Facing Our Future: Hurricane Floyd and Recovery in the Coastal Plain. Coastal Carolina Press, Wilmington, North Carolina. 312pp.

Ludwig, A. 2006. A sturgeon view on conservation genetics. European Journal of Wildlife Research 52: 3–8.

Mac, M. J., and C. C. Edsall. 1991. Environmental contaminants and the reproductive success of Lake Trout in the Great Lakes: an epidemiological approach. Journal of Toxicology and Environmental Health 33: 375-394.

MacConnell, E., Hedrick, R.P., Hudson, C. and C.A. Speer. 2001. Identification of an iridovirus in cultured pallid (Scaphirhynhcus albus) and shovelnose sturgeon (S. platorynchus). Fish Health Newsletter 29(1): 1-3.

MacNeill, D., and W.D. Busch. 1994. The Biology, History and Management of the Lake Sturgeon in the Lower Great Lakes. *Sea Grant*, Cornell Cooperative Extension, State University of New York, Sportfishing Fact Sheet, January 1994.

MacPherson, T.A., L.B. Cahoon, and M.A. Mallin. 2007. Water column oxygen demand and sediment oxygen flux: Patterns of oxygen depletion in tidal creeks. Hydrobiologia 586:235-248.

Magnin, E. 1963. Rechèrches sur la systématique et la biologie des Acipenséridae *Acipenser sturio* L., *Acipenser oxyrhynchus* Mitchill, et *Acipenser fulvescens* Rafinesque. Ann Stat Centre Hydrobiol Appl 9:7–244

Mallin, M.A., M.R. McIver, H.A. Wells, M.S. Williams, T.E. Lankford, and J.F. Merritt. 2003. Environmental assessment of the lower Cape Fear River system, 2002-2003. University of North Carolina-Wilmington, Center for Marine Science. CMS Report No. 03-03. 169pp. [http://www.uncwil.edu/cmsr/aquaticecology/LCFRP/WQ%20Reports/02-03/Report.htm]

Mallin, M.A., M.H. Posey, G.C. Shank, M.R. McIver, S.H. Ensign, and T.D. Alphin. 1999. Hurricane effects on water quality and benthos in the Cape Fear watershed: natural and anthropogenic impacts. Ecological Applications 9:350-362.

Malone, T.C., W. Boynton, T. Horton, and C. Stevenson. 1993. Nutrient loading to surface waters: Chesapeake case study. Pages 8-38 *in:* M. F. Uman (ed.) Keeping pace with science and engineering. National Academy Press, Washington, D.C.

Mal'tsev, A. G. and Ya. G. Merkulov. 2006. A biometric method for determining the sex of acipenserids, including the Russian sturgeon *Acipenser gueldenstaedtii* (Acipenseridae) of the Azov Population. Journal of Ichthyology 46(6): 460-464.

Marchette, D.E., and R. Smiley. 1982. Biology and life history of incidentally captured shortnose sturgeon, *Acipenser brevirostrum*, in South Carolina. Report of South Carolina Wildlife and Marine Resources 57pp.

Martin, D. M., T. Morton, T. Dobrzynski, and B. Valentine. 1996. *Estuaries on the Edge: the Vital Link Between Land and Sea.* Washington , D.C.: the American Oceans Campaign 297pp.

Mason W.T, and J.P. Clugston. 1993. Foods of the Gulf Sturgeon in the Suwannee River, Florida. *Transactions of the American Fisheries Society.* 122: 378–385.

Matta, M. B., C. Cairncross, R. M. Kocan. 1997. Effect of a polychlorinated biphenyl metabolite on early life stage survival of two species of trout. Bulletin of Environmental Contamination and Toxicology 59: 146-151.

MBI (Midwest Biodiversity Institute). 2009. Fish assemblage and habitat assessment of the Presumpscot River. 124 pp. MBI/2008-12-6.

McAtee, W.L., and A.C. Weed. 1915. First list of the fishes of the vicinity of Plummers Island, Maryland. Proceedings of the Biological Society of Washington 18:1–14.

McCabe, B.C. 1942. The distribution of fishes in the streams of western Massachusetts. Doctoral dissertation, Cornell University, Ithaca, New York.

McCabe, D.J., M.A. Beckey, A. Mazloff, A., J.E. Marsden. 2006. Negative effect of zebra mussels on foraging and habitat use by lake sturgeon (Acipenser fulvescens). Aquatic Conservation 16(5):493-500.

McCarthy, I.D. 2001. Competitive ability is related to metabolic asymmetry in juvenile rainbow trout. J. Fish. Biol. 59: 1002-1014.

McCarthy, I. D. and D. F. Houlihan. 1997. The effect of temperature on protein metabolism in fish: The possible consequences for wild Atlantic salmon (*Salmo salar* L.) stocks in Europe as a result of global warming. Pp. 57-77 In Global Warming: Implications for freshwater and marine fish. C. M. Wood and D. G. McDonald, eds. Cambridge University Press, Cambridge, United Kingdom.

McCleave, J.D., S.M. Fried and A.K. Towt. 1977. Daily movements of shortnose sturgeon, Acipenser brevirostrum, in a Maine estuary. Copeia 1977:149-157.

McCormick, S. D., J. M. Shrimpton, and J. D. Zydlewski. 1997. Temperature effects on osmoregulatory physiology of juvenile anadromous fish. Pages 279-301 in C. M. Wood and D. G. McDonald, eds. Cambridge University Press, Cambridge, United Kingdom.

McDonald, M. 1887. The rivers and sounds of North Carolina. Pages 625-637 in G.B. Goode, editor. The fisheries and fishery industries of the United States, Section V, Volume 1. U.S. Commission on Fish and Fisheries, Washington, D.C.

McLean, R.I., J.K. Summers, C.R. Olsen, S.L. Domotor, I.L. Larsen, and H. Wilson. 1991. Sediment accumulation rates in Conowingo Reservoir as determined by man-made and natural radionuclides. Estuaries. 14:2 148-156.

McQuinn, I.H. and P. Nellis. 2007. An acoustic-trawl survey of middle St. Lawrence estuary demersal fishes to investigate the effects of dredged sediment disposal on Atlantic sturgeon and lake sturgeon distribution. Pages 257-272 in J. Munro, D. Hatin, J.E. Hightower, K. McKown, K.J. Sulak, A.W. Kahnle and F. Caron, editors. Anadromous sturgeons: habitats, threats and management. American Fisheries Society, Symposium 56, Bethesda, Maryland.

McQuinn, I. H. and P. Nellis. In Press. An acoustic-trawl survey of middle St. Lawrence estuary demersal fisheries to investigate the effects of dredged sediment disposal on Atlantic and lake sturgeon distribution. In J. Munro, D. Hatin, K. McKown, J. Hightower, K. Sulak, A. Kahnle, And F. Caron (eds.). Proceedings of the Symposium on anadromous sturgeon: status and trend, anthropogenic impact and essential habitat. American Fisheries Society, Bethesda, Maryland.

ME DEP (Maine Department of Environmental Protection). 2005. Dioxin monitoring program – 2004 final report. DEPLW0703-2005. MEDEP. Augusta, ME.

ME DEP. 2006. Holtra-Chem: Phases of site cleanup. http://www.maine.gov/dep/rwm /holtrachem/updatephases.htm

Meehan, W.E. 1910. Experiments in sturgeon culture. Trans. Am. Fish. Soc. 39:85-91.

Meek, J. and L. Kennedy. 2010. Merrimack River Watershed 2004-2009 Water Quality Assessment Report (84wqar09.doc DWM CN179.5). Massachusetts Department of Environmental Protection, Division of Watershed Management. 125 pp.

Menhinick, E.F. 1991. The freshwater fishes of North Carolina. North Carolina Wildlife Resources Commission, Raleigh. 227 pp.

Metcalf and Eddy. 1994. Biological assessment for the shortnose sturgeon (*Acipenser brevirostrum*) in the lower Penobscot River. Submitted to U.S. EPA Region 1, Boston, Massachusetts. 88 pp.

Miller, A.I. and L.G. Beckman. 1996. First record of predation on white sturgeon eggs by sympatric fishes. Transactions of the American Fisheries Society 125: 338-340.

Miller, D. and J. Ladd. 2004. Channel morphology in the Hudson River Estuary: past changes and opportunity for restoration. IN Currents – newsletter of the Hudson River Environmental Society, Vol. XXXIV, No. 1.

Monosson, E. 1997. Reproductive and developmental effects of contaminants in fish populations: establishing cause and effect. Pages 177-194 In R.M. Rolland, M.Gilbertson, and R.E. Peterson. Eds. Chemically Induced Alterations in Functional Development and Reproduction in Fishes: Proceedings from a Session at the Wingspread Conference Center, 21-23 July 1995, Racine, WI. SETAC Press, Pennsacola, FL.

Moore A. and C. P. Waring. 2001. The effects of a synthetic pyrethroid pesticide on some aspects of reproduction in Atlantic salmon (*Salmo salar* L.). Aquatic Toxicology 52:1-12.

Moorhead, K.K., and M.M. Brinson. 1995. Response of wetlands to rising sea level in the lower coast plain of North Carolina. Ecological Applications. 5: 261-271.

Moser, M. 1999. Cape Fear River Blast Mitigation Tests: Results of Caged Fish Necropsies. Final Report to CZR, Inc. under Contract to U.S. Army Corps of Engineers, Wilmington District.

Moser, M.L., M. Bain, M.R. Collins, N. Haley, B. Kynard, J.C. O'Herron, II, G. Rogers and T.S. Squires. 2000a. A protocol for use of shortnose and Atlantic sturgeons. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Protected Resources, Silver Spring, Maryland. NOAA Technical Memorandum NMFS-OPR-18. 18 pp.

Moser, M.L., J.B. Bichy and S.B. Roberts. 1998. Sturgeon distribution in North Carolina. Center for Marine Science Research, Wilmington, North Carolina. Final Report to U.S. Army Corps of Engineers, Wilmington District. 89 pp.

Moser, M.L., J. Conway, T. Thorpe and R. Hall. 2000b. Effects of recreational electrofishing on sturgeon habitat in the Cape Fear River drainage. University of North Carolina, Sea Grant Program, Raleigh. Final report. 16 pp.

Moser, M.L. and S.W. Ross. 1989. A preliminary survey of the distribution of the endangered shortnose sturgeon, *Acipenser brevirostrum*, in the upper Cape Fear River estuary, North Carolina. North Carolina Wildlife Resources Commission, Raleigh. Final Report.

Moser, M.L. and S.W. Ross. 1993. Distribution and movements of shortnose sturgeon (*Acipenser brevirostrum*) and other anadromous fishes of the lower Cape Fear River, North Carolina. U.S. Army Corps of Engineers, Wilmington District, Wilmington, North Carolina. Final Report.

Moser, M.L. and S.W. Ross. 1995. Habitat use and movements of shortnose and Atlantic sturgeons in the lower Cape Fear River, North Carolina. Transactions of the American Fisheries Society 124:225-234.

Murawski, S. A. and A. L. Pacheco. 1977. Biological and fisheries data on Atlantic Sturgeon, *Acipenser oxyrhynchus* (Mitchill). National Marine Fisheries Service Technical Series Report 10: 1-69.

Murdoch, P.S., J.S. Baron, and T.L. Miller. 2000. Potential effects of climate change on surface water quality in North America. Journal of the American Water Resources Association, 36, 347–366.

Murphy, G. 2005. State of Delaware annual compliance report for Atlantic sturgeon. Submitted to the Atlantic States Marine Fisheries Commission Atlantic Sturgeon Plan Review Team, September 2005, Washington, D.C.

Murphy, G. 2006. State of Delaware summary of Atlantic sturgeon by-catch. Summary Report Prepared for Atlantic States Marine Fisheries Commission Atlantic Sturgeon Technical Committee – Bycatch Workshop, February 1-3, 2006, Norfolk, VA.

Musick JA, Jenkins RE, Burkhead NM. 1994. Sturgeons, family Acipenseridae. Pages 183-190 *In*: R.E. Jenkins and N.M. Burkhead (eds.) Freshwater Fishes of Virginia. American Fisheries Society, Bethesda, MD.

NAST (National Assessment Synthesis Team). 2000. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change, US Global Change Research Program, Washington DC, 2000 http://www.usgcrp.gov/usgcrp/Library/nationalassessment/1IntroA.pdf

NB Canada Nat. Res. 2008 (New Brunswick Canada Natural Resources). 2008. Saint John-Lower Sturgeon Fishing. Accessed November/19/2008. http://www.gnb.ca/0254/StJohnLower-Sturgeon-e.asp

NC DEM (North Carolina Division of Environmental Management). 1979. Chowan River Restoration Project (CHORE). North Carolina Department of Natural Resources and Community Development, Raleigh. Draft Report.

NC DEM (North Carolina Division of Environmental Management). 1982. Chowan River Water Quality Management Plan. North Carolina Department of Natural Resources and Community Development Raleigh. Draft Report.

NC DMF (North Carolina Division of Marine Fisheries). 2008. North Carolina License and Statistics Section Summary Statistics of License and Permit Program, Commercial Trip Ticket Program, Marine Recreational Fishery Statistics Survey, Recreational Commercial Gear Survey, and Striped Bass Creel Survey in the Central and Southern Management Area. North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries, License and Statistics Section, Morehead City, North Carolina.

NC DWR (North Carolina Division of Water Resources). 2001. North Carolina State Water Supply Plan. North Carolina Department of Environment and Natural Resources, Division of Water Resources, Raleigh. [available on the Division of Water Resources web site at: www.ncwater.org]

NC DWR (North Carolina Division of Water Resources). 2006. Water Resources Development Plan Fiscal Years 2007-2012. North Carolina Department of Environment and Natural Resources, Division of Water Resources, Raleigh. 94 pp. [available on the Division of Water Resources web site at: www.ncwater.org]

NCSU (North Carolina State University). 2008. NCSU Water Quality Programs, River Basin Characteristics. College of Agriculture and Life Sciences, North Carolina Extension Water Quality Information System. http://www.water.ncsu.edu/chowan.html

NC WRC (North Carolina Wildlife Resources Commission). 2005. North Carolina Wildlife Action Plan. Raleigh, NC. 498 pp. + appendices.

Neale, R. 1986. Rare shortnose sturgeon spotted in Susquehanna near Conowingo. Record/Democrat. June 4, 1986.

Nellis, P., S. Senneville, J. Munro, G. Drapeau, D. Hatin, G. Desrosiers and F.J. Saucier. 2007. Tracking the dumping and bed load transport of dredged sediment in the St. Lawrence estuarine transition zone and assessing their impacts on macrobenthos in Atlantic sturgeon habitat. Pages 215-234 *In:* J. Munro, D. Hatin, J.E. Hightower, K. McKown, K.J. Sulak, A.W. Kahnle and F. Caron (eds.) Anadromous sturgeons: habitats, threats and management. American Fisheries Society, Symposium 56, Bethesda, Maryland.

NIDIS (National Integrated Drought Information System). 2008. Current Drought Conditions for the State of Georgia, November 4, 2008. http://www.drought.gov/portal/server.pt?uuID=%7B950C0A74-978E-47AF-2FF0-9159361A2000%7D&mode=2&in_hi_userid=2&state=GA

Niklitschek, J. E. 2001. Bioenergetics modeling and assessment of suitable habitat for juvenile Atlantic and shortnose sturgeons (Acipenser oxyrinchus and A. brevirostrum) in the Chesapeake Bay. Dissertation. University of Maryland at College Park, College Park.

Niklitschek, E. J. and D. H. Secor. 2005. Modeling spatial and temporal variation of suitable nursery habitats for Atlantic sturgeon in the Chesapeake Bay. Estuarine, Coastal and Shelf Science 64: 135-148.

NJ COA. 2006. NJ Division of Fish and Wildlife Conservation Officer *NJ Division of Fish and Wildlife, Monthly Highlights, Bureau of Law Enforcement*, March 21-April 20, 2006. http://www.njcoa.com/highlights/H_06_04.html

NMFS (National Marine Fisheries Service). 1987. (Draft) Status Review of Shortnose Sturgeon (*Acipenser* brevirostrum LeSueur 1818) Listed under the Endangered Species Act of 1973.

NMFS (National Marine Fisheries Service). 1996. Status Review of Shortnose Sturgeon in the Androscoggin and Kennebec Rivers. Northeast Regional Office. National Marine Fisheries Service. June, 1996. 26 pp.

NMFS (National Marine Fisheries Service). 1998. Recovery plan for the shortnose sturgeon (*Acipenser brevirostrum*). Prepared by the Shortnose Sturgeon Recovery Team for the National Marine Fisheries Service, Silver Spring, Maryland 104 pp.

NMFS (National Marine Fisheries Service). 1999. 1999 Amendment to Incidental Take Statement from 1993 Biological opinion on the Salem and Hope Creek Nuclear Generating Stations in Lower Alloways Creek Township, Salem County, New Jersey. 32 pp.

NMFS (National Marine Fisheries Service). 2001. Biological opinion on the impacts of Delaware River Main Channel Blasting Project F/NER/2001/00047. 103 pp.

NMFS (National Marine Fisheries Service). 2003. Biological opinion on NPDES Permit for the Washington Aqueduct. F/NER/2003/00600. http://www.nero.noaa.gov/prot_res/section7/EPA-signedBOs/WashingtonAqueduct2003-signedBO.pdf

NMFS (National Marine Fisheries Service). 2004. Biological Opinion on Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries F/NER/2003/00961. 65pp.

NMFS (National Marine Fisheries Service). 2009. Biological opinion on the Deepening of the Delaware River Federal Navigation Channel F/NER/2009/00615. 137 pp.

NMFS and USFWS (National Marine Fisheries Service and United States Fish and Wildlife Service). 1998. Status review of Atlantic sturgeon (Acipenser oxyrinchus oxyrinchus). U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service and United States Fish and Wildlife Service. 126 pp.

Normandeau Associates. 1998. A Biological Assessment prepared for bath Iron Works for submittal to the Army Corps of Engineers, New England Division, for the Bath Iron Works Proposed Modernization. 33 pp and appendices.

NY DOS (NY Dept. of State). 1990. Hudson River Significant Tidal habitats: a guide to the functions, values and protection of the river's natural resources. Prepared by Division of Coastal Resources and Waterfront revitalization and The Nature Conservancy. NYDOS , Albany NY,USA.

NYHS (New York Historical Society as cited by Dovel as Mitchell. S. 1811). 1809. Volume1. Collections of the New-York Historical Society for the year 1809.

NYS DEC New York State Department of Environmental Conservation. Hudson River Estuary Program. Accessed 12/2/2008. http://www.dec.ny.gov/lands/4920.html

Oakley, N. C. 2005. Status of shortnose sturgeon, *Acipenser brevirostrum*, in the Neuse River, North Carolina. Thesis. Department of Fisheries and Wildlife Science, North Carolina State University, Raleigh, NC.

Oakley, N.C. and J.E. Hightower. 2007. Status of shortnose sturgeon in the Neuse River, North Carolina. American Fisheries Society Symposium 56:273-284.

Officer, C. B., B. B. Biggs, J. L. Taft, L. E. Cronin, M. A. Tyler and W. R. Boynton. 1984. Chesapeake Bay anoxia: origin, development, and significance. Science 223: 22-27.

O'Herron, J. C., II, K. W. Able, and R. W. Hastings. 1993. Movements of shortnose sturgeon (Acipenser brevirostrum) in the Delaware River. Estuaries 16:235–240.

Omoto, N.; Maebayashi, M.; Mitsuhashi, E.; Yoshitomi, K.; Adachi, S.; Yamauchi, K., 2002: Effects of estradiol-17beta and 17alfa-methyltestosterone on gonadal sex differentiation in the F_2 hybrid sturgeon, the bester. *Fish. Sci.* **68**, 1047–1054.

Paerl, H.W. 1982. Environmental factors causing blue-green algal blooms in the Chowan. Pages 51- 53 in Albemarle Sound trends and management. University of North Carolina, Sea Grant College Program, Raleigh. UNC-SG 82-02:

Paerl, H.W., J.D. Bales, L.W. Ausley, C.P. Buzzelli, L.B. Crowder, L.A. Eby, M. Go, B.L. Peierls, T.L. Richardson and J.S. Ramus. 2000. Hurricane's hydrological, ecological effects linger in major US estuary. Eos, Transactions of the American Geophysical Union 81:457-462.

Paerl, H.W., C.P. Buzzelli, M. Go, B.L. Peierls, R.A. Luettich, T.L. Richardson, J.S. Ramus, L.A. Eby, L.B. Crowder, L.W. Ausley, J. Overton and J.D. Bales. 2001. Water quality and fisheries habitat changes in the Pamlico Sound after three hurricanes: a short-term and long-term perspective. Pages 255-263 in J.R. Maiolo, J.C. Whitehead, M. McGee, L. King, J. Johnson and H. Stone, editors. Facing Our Future: Hurricane Floyd and Recovery in the Coastal Plain. Coastal Carolina Press, Wilmington, North Carolina. 312 pp.

Paerl, H.W., J.L. Pinckney, J.M. Fear and B.L. Peierls. 1998. Ecosystem responses to internal and watershed organic matter loading: consequences for hypoxia in the eutrophying Neuse River Estuary, North Carolina, USA. Marine Ecology Progress Series 166:17-25.

Paerl, H.W., J.L. Pinckney and S.A. Kucera. 1995. Clarification of the structural and functional roles of heterocysts and anoxic microzones in the control of pelagic nitrogen fixation. Limnology and Oceanography 40:634-638.

Palmer, A.G. 2001. Seasonal, diel, and tidal movements of shortnose sturgeon, Acipenser brevirostrum, in the Cooper River, South Carolina. Master's Thesis. University of Charleston, Charleston, South Carolina.

Palmer, M.A., C.A. Reidy Liermann, C. Nilsson, M. Florke, J. Alcama, P.S. Lake and N. bond. 2008. Climate change and the world's river basins: anticipating management options. Frontiers in Ecology and the Environment 6: 81-89.

Paragamian, R.C. ,and P. Beamesderfer. 2003. Growth estimates from tagged white sturgeon suggest that ages from fin rays underestimate true age in the Kootenai River, USA and Canada. Transactions of the American Fisheries Society 132:895–903, 2003.

Park, R.A., J.K. Lee, P.W. Mausel, and R.C. Howe. 1991. The effects of sea level rise on US coastal wetlands. In: J.B. Smith and D.A. Tirpak (eds), The potential effects of global climate change on the United States. Appendix B – sea-level rise. Washington DC: US Environmental Protection Agency.

Parker E. 2007. Ontogeny and life history of shortnose sturgeon (*Acipenser brevirostrum* lesueur 1818): effects of latitudinal variation and water temperature. Ph.D. Dissertation. University of Massachusetts, Amherst. 62 pp.

Parker E. and B. Kynard. 1995. Latitudinal differences in ontogenetic behavior between two populations of shortnose sturgeon (*Acipenser brevirostrum*): A laboratory study. Final Report to National Marine Fisheries Service, Charlestown, SC. January 25, 2005. 19 pp.

Parsley,M.J. and Beckman,L.G. 1994. White sturgeon spawning and rearing habitat in the Lower Columbia River. North American Journal of Fisheries Management 14:812-827.

Parsons, D.S. and J.F. Payne. 2002. A bacteriological investigation of selected flounder, crab and lobster collected from St. John's Harbour, June 2001. (Unpublished report prepared for DFO, Newfoundland Region and St. John's Harbour ACAP).

Patel, T.R. and J. Payne. 2004. Microbiological Analysis of Sediment and Water–Column Samples from St. John's Harbour and Antibiotic Resistance of the Isolates. Prepared For St. John's Harbour ACAP, Inc. 46 pp.

Patrick, W.S. and K. Damon Randall 2008. Using a five-factored structured decision analysis to evaluate the extinction risk of Atlantic sturgeon (Acipenser oxyrinchus

5 oxyrinchus). Biological Conservation. 6 pp.

Paul, J.F., B.Melzian, B.S. Brown, C. Strobel, J. Kiddon, J. Latimer,D. Campbell and D. Cobb. 1998. Condition of the Mid-Atlantic estuaries. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C. EPA 600-R-98-147. 50 pp.

Peakall, R. and P.E. Smouse. 2007. GENALEX 6: genetic analysis in Excel. Population genetic software for teaching and research. Molecular Ecology Notes 6, 288-295. http://www.anu.edu.au/BoZo/GenAlEx/

Pease Development Authority. 2006. Pease Development Authority Division of Ports and Harbors Annual Dredge Report. Portsmouth, NH.

Pekovitch, A.W. 1979. Distribution and some life history aspects of shortnose sturgeon (*Acipenser brevirostrum)* in the upper Hudson River Estuary. Hazleton Environmental Sciences Corporation. 67 pp.

Pershing, A. J., C. H. Greene, J. W. Jossi, L. O'Brien, J. K. T. Brodziak, and B. A. Bailey. 2005. Interdecadal variability in the Gulf of Maine zooplankton community, with potential impacts on fish recruitment. ICES Journal of Marine Science 62: 1511-1523.

Petersen, J.B., and D. Sanger. 1986. Archeological Phase II Testing at the Eddington Bend site (74-8), Penobscot County, Maine. Final Report to Bangor Hydro-Electric Company, University of Maine, Orono, Maine.

Peterson, C.H., H.C. Summerson, E. Thompson, H.S. Lenihan, J. Grabowski, L. Manning, F. Micheli and G. Johnson. 2000. Synthesis of linkages between benthic and fish communities as a key to protecting essential fish habitat. Bulletin of Marine Science 66(3):759-774.

Petrie, B. 2007. Does the North Atlantic Oscillation Affect Hydrographic Properties on the Canadian Atlantic Continental Shelf? Atmosphere and Ocean 45(3): 141-151.

Pine, W.E., III. 2003. Population ecology of introduced flathead catfish. Doctoral dissertation. North Carolina State University, Raleigh.

Piotrowski, T. 2002. The Northeast. Pages 1–19 in T. Piotrowski, editor. The Indian heritage of New Hampshire and northern New England. McFarland and Company Inc., Jefferson, North Carolina.

Posey, M.H., T.D. Alphin, L. Cahoon, D. Lindquist and M.E. Becker. 1999. Interactive effects of nutrient additions and predation on infaunal communities. Estuaries 22:785-792.

Pottle, R., and M.J. Dadswell. 1979. Studies on larval and juvenile shortnose (*Acipenser brevirostrum*). Report to the Northeast Utilities Service Company, Hartford, Connecticut.

Power Engineering. 2004. Innovative intake screen protects fish at Newington Energy. PennWell Corporation. http://pepei.pennnet.com/display_article/216713/6/ARTCL/none/none/1/Innovative-Intake-Screen-Protects-Fish-at-Newington-Energy/

PRRT (Penobscot River Restoration Trust). 2008. Project details. Accessed 12/12/2008. http://www.penobscotriver.org/content/4003/The_Project/

PSEG Nuclear LLC. 2007. Notification of Shortnose Sturgeon Incidental Take.

Quattro, J.M., T.W.Greig, D.K. Coykendall, B.W. Bowen, and J.D. Baldwin. 2002. Genetic issues in aquatic species management: the shortnose sturgeon (Acipenser brevirostrum) in the southeastern United States. Conservation Genetics 3: 155–166, 2002.

Rehwoldt, R. E., W. Mastrianni, E. Kelley, and J. Stall. 1978. Historical and current heavymetal residues in Hudson River fish. Bulletin of Environmental Toxicology 19: 335-339.

Reilly, F.J., Jr. and B.J. Bellis. 1983. The ecological impact of beach nourishment with dredged materials on the intertidal zone at Bogue Banks, North Carolina. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Virginia.

Reyff, J.A. 2008. Underwater sound pressure levels associated with marine pile driving assessment of impacts and evaluation of control measures. Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 481–490.

Rice, T.M. and H.F. Hall. 2000. Wilmington Harbor, North Carolina, 96 Act, New Hanover and Brunswick Counties, North Carolina. Supplement to the Final Fish and Wildlife Coordination Act Report. U.S. Fish and Wildlife Service, Division of Ecological Services, Raleigh, North Carolina. 74 pp. + appendices.
[available on the web at http://www.fws.gov/nc-es/pubs/wilmington/WH_FWCA.pdf]

Richardson, B., C. Stence, and S. Minkkinen. 2007. Experimental Atlantic sturgeon Acipenser oxyrinchus spawning and stocking in Maryland. 1-8 pp.

Richmond, A., and B. Kynard. 1995. Ontogenic behavior of shortnose sturgeon. Copeia 1995:172-182.

Rien, T.A., and R.C. Beamesderfer. 1994. Accuracy and precision of white sturgeon age estimates from pectoral fin rays. Transactions of the American Fisheries Society 123:255-265.

Riggs, S.R. 1996. Sediment evolution and habitat function of organic-rich muds within the Albemarle estuarine system, North Carolina. Estuaries 19:169-185.

Risser, D. W., and S. F. Siwiec. 1996. Water-Quality Assessment of the Lower Susquehanna River Basin, Pennsylvania and Maryland: Environmental Setting: U.S. Geological Survey Water Resources Investigations Report 94-4245. 70 pp.

Roble, S.M. 2006. Natural heritage resources of Virginia: rare animal species. Virginia Department of Conservation and Recreation, Division of Natural Heritage, Richmond. 46 pp. [online at: http://www.dcr.virginia.gov/natural_heritage/documents/anlist06.pdf]

Rodzen, J.A. and B. May. 2002. Inheritance of microsatellite loci in the white sturgeon (*Acipenser transmontanus*). Genome 45:1064-1076.

Rogers, S. G., and W. Weber. 1994a. Occurrence of shortnose sturgeon (Acipenser brevirostrum) in the Ogeechee-Canoochee river system, Georgia during the summer of 1993. Final Report of the United States Army to the Nature Conservancy of Georgia.

Rogers, S.G., and W. Weber. 1994b. Movements of shortnose sturgeon in the Altamaha River System, Georgia. Contributions Series No. 57. Coastal Resources Division, Georgia Department of Natural Resources, Brunswick, Georgia.

Rogers, S.G., and W. Weber. 1995a. Movements of shortnose sturgeon in the Altamaha River system, Georgia. Contributions Series #57. Coastal Resources Division, Georgia Department of Natural Resources, Brunswick, Georgia.

Rogers, S.G., and W. Weber. 1995b. Status and restoration of Atlantic and shortnose sturgeons in Georgia. Final Report to the National Marine Fisheries Service, Southeast Regional Office, St. Petersburg, Florida.

Root, K.V. 2002. Evaluating risks for threatened aquatic species: the shortnose sturgeon in the Connecticut River. Pages 45-54 in W. van Winkle, P.J. Anders, D.H. Secor, and D.A. Dixon, eds. Biology, management, and protection of North American sturgeon. American Fisheries Society, Symposium 28, Bethesda, Maryland.

Root, K.V., and H.R. Akçakaya. 1997. Ecological risk analysis for the shortnose sturgeon populations in the Connecticut River. Report to Northeast Utilities and Electric Power Research Institute. Applied Biomathematics, Setauket, New York.

Rose, G. A., B. deYoung, D. W. Kulka, S. V. Goddard, and G. L. Fletcher. 2000. Distribution shifts and overfishing the northern cod (*Gadus morhua*): a view from the ocean. Canadian Journal of Fisheries and Aquatic Sciences 57: 644-663.

Rosenthal, H. and D. F. Alderdice. 1976. Sublethal effects of environmental stressors, natural and pollutional, on marine fish eggs and larvae. Journal of the Fisheries Research Board of Canada 33: 2047-2065.

Ross, S.W. and J.E. Lancaster. 1996. Movements of juvenile fishes using surf zone nursery habitats and the relationship of movements to beach nourishment along a North Carolina beach: pilot project. North Carolina National Estuarine Research Reserve, Wilmington, NC, Final report submitted to NOAA Office of Coastal Resource Management and the U.S. Army Corps of Engineers. 31 pp.

Ross, S.W., F.C. Rohde and D.G. Lindquist. 1988. Endangered, threatened and rare fauna of North Carolina, part 2. A re-evaluation of the marine and estuarine fishes. North Carolina State Museum of Natural Sciences, Raleigh. North Carolina Biological Survey, Occasional Papers 1988-7. 20 pp.

Rossiter, A., D.L.G. Noakes, and E.W.H. Beamish. 1995. Validation of age estimation for the lake sturgeon. Transactions of the American Fisheries Society 124:777-781.

Ruelle, R. and C. Henry. 1992. Organochlorine compounds in pallid sturgeon. Contaminant Information Bulletin, June, 1992.

Ruelle, R. and K. D. Keenlyne. 1993. Contaminants in Missouri River pallid sturgeon. Bulletin of Environmental Contamination and Toxicology 50: 898-906.

Rulifson, R.A., M.T. Huish and R.W. Thoesen. 1982a. Anadromous fish in the southeastern United States and recommendations for development of a management plan. U.S. Fish and Wildlife Service, Southeast Region, Fisheries Program, Atlanta, Georgia. 525 pp.

Rulifson, R.A., M.T. Huish and R.W. Thoesen. 1982b. Status of anadromous fishes in southeastern U.S. estuaries. Pages 413-425 in V.S. Kennedy, editor. Estuarine Comparisons: Proceedings of the Sixth Biennial International Estuarine Research Conference, Gleneden Beach, Oregon, November 1-6, 1981. Academic Press, New York. 709 pp.

Ryder, R.A. 1890. The sturgeons and sturgeon industries of the eastern coast of the United States, with an account of experiments bearing upon sturgeon culture. Bull. U.S. Fish. Comm. 8:231-328.

Saffron, I. 2004. Introduction: the Decline of the North American Species In Sturgeons and Paddlefish of North America. LeBreton, G.T.O., F.W.H. Beamish and R.S. McKinley, eds. Fish and Fish Series, Vol. 27. Springer Netherlands. 323 pp.

Saitou, N. and Nei, M. 1987. The neighbor-joining method: A new method for reconstructing phylogenetic trees. Molecular Biology and Evolution 4:406-425.

Sanger, D.M., M.D. Arendt, Y. Chen, E.L. Wenner, A.F. Holland, D. Edwards, J. Caffrey. 2002. A synthesis of water quality data: National Estuarine Research Reserve System-wide monitoring program (1995-2000). National Estuarine Research Reserve Technical Report Series 2002:3. South Carolina Department of Natural Resources, Marine Resources Division Contribution No. 500. 135 p.

Saravanabhavan, G. 2003. Analysis of steroid hormones as endocrine disruptors in sewage, seawater and mussels using GC-MS techniques. M.Sc. thesis, Memorial U., Newfoundland and Labrador Canada.

Sauer, M.M. and E.J. Kuenzler. 1981. Algal assay studies of the Chowan River, North Carolina. University of North Carolina, Water Resources Research Institute, Raleigh. WRRI Report 161:1-78.

Savoy, T. 1991a. Anadromous fish studies in Connecticut waters. Final Report for Connecticut Department of Environmental Protection, Project AFC-25, Old Lyme, Connecticut.

Savoy, T. 1991b. Sturgeon status in Connecticut waters. Final Report to the National Marine Fisheries Service, Gloucester, Massachusetts.

Savoy, T. 2004. Population estimate and utilization of the lower Connecticut River by shortnose sturgeon. American Fisheries Society Monograph 9:345–352.

Savoy, T. F., and J. Benway. 2004. Food habits of shortnose sturgeon collected in the lower Connecticut River from 2000 through 2002. American Fisheries Society Monograph 9:353–360.

Savoy, T., and J. Benway. 2006. Connecticut anadromous fish investigations. Final Report to the National Marine Fisheries Service, Gloucester, Massachusetts.

SBFI (Seaboard Fisheries Institute) 2008. Promoting sustainability of diadromous fishes in the Delaware River and Estuary, through research, education, and public outreach programs. Accessed 12/12/2008. http://www.seaboardfisheries.org/

Scarnecchia, D. L. 2000. The Importance of Ecosystem Effects in Sturgeon Introduction and Culture in Florida. In Proceedings of the Florida Sturgeon Culture Risk Assessment Workshop. 39-48.

Scarry, J.F. and C.M. Scarry. 1997. Subsistence remains from prehistoric North Carolina archaeological sites. North Carolina Division of Archives and History, State Historic Preservation Office, Office of State Archaeology, Raleigh. Published online at: http://www.arch.dcr.state.nc.us/subsist/subsis.htm

SCDNR (South Carolina Department of Natural Resources). 2005. Comprehensive Wildlife Conservation Strategy.

SCDNR (South Carolina Department of Natural Resources). 2006. South Carolina rare, threatened, & endangered species inventory. [online at https://www.dnr.sc.gov/pls/heritage/county_species.list?pcounty=all]

Schaefer, R.H. 1967. Species composition, size, and seasonal abundance of fish in the surf waters of Long Island. New York Fish and Game Journal 14:1-46.

Schindler, D. W. 2001. The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium. Canadian Journal of Fisheries and Aquatic Sciences 58: 18-29.

Schlosser, I. J. and P. L. Angermeier. 1995. Spatial Variation in Demographic Processes of Lotic Fishes: Conceptual Models, Empirical Evidence, and Implications for Conservation. American Fisheries Society Symposium 17: 392-401.

Scholz N. L., N. K. Truelove, B. L. French, B. A. Berejikian, T. P. Quinn, E. Casillas and T. K. Collier. 2000. Diazinon disrupts antipredator and homing behaviors in Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 57: 1911-1918.

Schubel, J.R. 1968. Suspended sediment discharge of the Susquehanna River at Havre de Grace, Maryland, during the period 1 April 1966 through 31 March 1967. Chesapeake Science. 9:131-135.

Schubel, J.R. and D.W. Pritchard. 1986. Responses of Upper Chesapeake Bay to variations in discharge of the Susquehanna River. Estuaries. 9(4A): 236-249.

Schultz R.J. 1980. Role of polyploidy in the evolution of fishes. In: *Polyploidy: Biological Relevance* (ed**.** Lewis WH), pp. 313-340. Plenum Press. New York.

Schwartz, F. J. and M. D. Dahlberg. 1978. Biology and ecology of the Atlantic stingray, *Dasyatis sabina* (Pisces: Dasyatidae), in North Carolina and Georgia. Northeast Gulf Sci. 2:1-23.

Schwartz, F. J., W. W. Hassler, J. W. Reintjes and M. W. Street. 1977. Marine fishes. Pp. 250-264 In Endangered and Threatened Plants and animals of North Carolina. J.E. Cooper, S.S. Robinson and J.B. Funderburg, editors. North Carolina State Museum of Natural History, Raleigh.

Schwartz, F. J., W. T. Hogarth, And M. P. Weinstein. 1981. Marine and freshwater fishes of the Cape Fear Estuary, North Carolina, and their distribution in relation to environmental factors. Brimleyana 7:17-37.

Schwartz, F.J. and G.W. Link, Jr. 1976. Status of Atlantic, Acipenser oxyrhynchus, and shortnose, A. brevirostrum, sturgeons in North Carolina (Pisces, Acipenseridae). Association of Southeast Biologists Bulletin 23(2):94.

Scott W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Ottawa. Bulletin 184. 966 pp.

Scott, W.B. and M.G. Scott. 1988. Atlantic fishes of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences No. 219.

Secor, D. H. 1995. Chesapeake Bay Atlantic sturgeon: current status and future recovery. Summary of Findings and Recommendations from a Workshop convened 8 November 1994 at Chesapeake Biological Laboratory. Chesapeake Biological Laboratory, Center for Estuarine and Environmental Studies, University of Maryland System, Solomons, Maryland.

Secor, D. H. 2002. Atlantic sturgeon fisheries and stock abundances during the late nineteenth century. Am. Fish. Soc. Sympos. 28: 89-98.

Secor, D.H., P.J. Anders, W. Van Winkel and D. Dixon. 2002. Can we study sturgeons to extinction? What we do and don't know about the conservation of North American sturgeons. Am. Fish. Soc. Symp. 28: 3-10.

Secor, D.H. and T.E. Gunderson. 1998. Effects of hypoxia and temperature on survival, growth, and respiration of juvenile Atlantic sturgeon, Acipenser oxyrinchus. Fishery Bulletin 96: 603-613.

Secor, D.H., and E.J. Nickltschek. 2001. Hypoxia and Sturgeons. Report to the Chesapeake Bay Program. Technical Report Series No. TS-314-01-CBL.

Secor, D.J. and E.J. Niklitschek. 2002. Sensitivity of sturgeons to environmental hypoxia: A review of physiological and ecological evidence, p. 61-78 In: R.V. Thurston (Ed.) Fish Physiology, Toxicology, and Water Quality. Proceedings of the Sixth International Symposium, La Paz, MX, 22-26 Jan. 2001. U.S. Environmental Protection Agency Office of Research and Development, Ecosystems Research Division, Athens, GA. EPA/600/R-02/097. 372 pp.

Secor, D.H., E. Niklitschek, J.T. Stevenson, T.E. Gunderson, S.P. Minkkinen, B. Richardson, B. Florence, M. Mangold, J. Skjeveland, and A. Henderson-Arzapalo., 2000. Dispersal and growth of yearling Atlantic sturgeon, Acipenser oxyrhynchus, released into Chesapeake Bay. Fish. Bull. 98: 800-810.

Seibel, D. and B. Kynard. 1992. Habitat selection, movements, and response to illumination of shortnose sturgeons in the Connecticut River. Masters Thesis, University of Massachusetts, Amherst, Massachusetts.

Shin, R. K. 2007. A Costly Standoff. The Hart and Miller Islands Controversy. Certification Paper, U of MD School of Law. 42pp.

Simpson, P.C. 2008. Movements and habitat use of Delaware River Atlantic Sturgeon. Masters Thesis. Delaware State University, Dover, Delaware. 137pp.

Skjeveland, J. A., S.A. Welsh, M.F. Mangold, S.M. Eyler, and S. Nachbar. 2000. A report of investigations and research on Atlantic and shortnose sturgeon in Maryland waters of the Chesapeake Bay (1996-2000). U.S. Fish & Wildlife Service, Maryland Fisheries Resource Office, Annapolis, MD.

Smith, H.M. 1893. Report on a collection of fishes from the Albemarle region of North Carolina. Bulletin of the U.S. Fish Commission 11:185-200.

Smith, H.M. 1907. The fishes of North Carolina. North Carolina Geological and Economic Survey 2:1-453.

Smith, H. M., and B. A. Bean. 1898. List of fishes known to inhabit the waters of the District of Columbia and vicinity. Bulletin of the U.S. Fish Commission for 1898 18:179–187.

Smith, T. I. J. 1985. The fishery, biology, and management of Atlantic sturgeon, Acipenser oxyrhynchus, in North America. Environmental Biology of Fishes 14: 61-72.

Smith, T. I. J. and J. P. Clugston. 1997. Status and management of Atlantic sturgeon, Acipenser oxyrinchus, in North America. Environmental Biology of Fishes 48:335-346.

Smith, T.I.J., J.W. McCord, M.R. Collins, and W.C. Post. 2002a. Occurrence of stocked shortnose sturgeon *Acipenser brevirostrum* in non-target rivers. Journal of Applied Ichthyology. 18:470-474.

Smith, T.I.J., M.C. Collins, W.C. Post, and J.W. McCord. 2002b. Stock enhancement of shortnose sturgeon: a case study. American Fisheries Society Monograph. 28:31-44.

Snyder, D.E. 1988. Description and identification of shortnose and Atlantic sturgeon larvae. American Fisheries Society Symposium 5:7-30.

South Carolina State Climatology Office. 2008. South Carolina Current Drought Status. September 16, 2008.
http://www.dnr.sc.gov/climate/sco/Drought/Drought_press/release_Aug29_2008.php

Speer, L., L. Lauck, E. Pikitch, S. Boa, L. Dropkin and V. Spruill. 2000. Roe to ruin: the decline of sturgeon in the Caspian Sea and the road to recovery. Natural Resources Defense Council, Wildlife Conservation Society, and Sea Web, 26 pp.

Speir, H. and T.O. O'Connell. 1996. Status of Atlantic sturgeon in Maryland's Chesapeake Bay. MD DNR Tidal Fisheries Technical Report Series, Number 17.

Spells, A. 1998. Atlantic sturgeon population evaluation utilizing a fishery dependent reward program in Virginia's major western shore tributaries to the Chesapeake Bay. U.S. Fish and Wildlife Service, Charles City, Virginia.

Sprunt, J. 1914. Chronicles of the Cape Fear River: Being some account of historic events on the Cape Fear River. Edwards and Broughton Printing Company, Raleigh, North Carolina. 594 pp.

Sprunt, J. 1916. Chronicles of the Cape Fear River 1660-1916. Second Edition. Edwards and Broughton Printing Company, Raleigh, North Carolina. 732 pp.

Squiers, T. S. 1982. Evaluation of the 1982 spawning run of shortnose sturgeon (Acipenser brevirostrum) in the Androscoggin River, Maine. Maine Department of Marine Resources Final Report to Central Maine Power Company, Augusta.

Squiers, T. 1988. Anadromous Fisheries of the Kennebec River. Maine Department of Marine Resources. 44 pp.

Squiers, T.S. 2000. Kennebec River shortnose sturgeon population study: August, 1998 - December 1999. Maine Department of Marine Resources.

Squiers, T.S. 2003. State of Maine 2003 Atlantic sturgeon compliance report to the Atlantic States Marine Fisheries Commission. Report submitted to Atlantic States Marine Fisheries Commission, October 31, 2003, Washington, D.C.

Squiers, T.S., L. Flagg, M. Smith, K. Sherman, and D. Ricker. 1981. American shad enhancement and status of sturgeon stocks in selected Maine waters. Final Report to the National Marine Fisheries Service, Gloucester, Massachusetts.

Squiers, T.S., M. Robillard, and N.Gray. 1993. Assessment of potential shortnose sturgeon spawning sites in the upper tidal reach of the Androscoggin River. Final Report to the National Marine Fisheries Service, Gloucester, Massachusetts.

Squiers, T.S., and M. Smith. 1979. Distribution and abundance of shortnose sturgeon in the Kennebec River estuary. Completion Report Project AFC-19 to the National Marine Fisheries Service, Gloucester, Massachusetts.

Squiers, T.S., M. Smith, and L. Flagg. 1982. American Shad Enhancement and Status of Sturgeon Stocks in Selected Maine Waters. Completion Report Project AFC-20, Department of Marine Resources, Maine. 71 pp.

SRBC (Susquehanna River Basin Commission). 2006. Conowingo Pond Management Plan. Publication No. 242. 1-159 pp.

Stanley, D.W. 1992. Historical trends: water quality and fisheries, Albemarle-Pamlico Sounds, with emphasis on the Pamlico River Estuary. University of North Carolina Sea Grant College Publication UNC-SG-92-04. Institute for Coastal and Marine Resources, East Carolina University, Greenville, NC. 215 pp.

Stanley, D.W. and J.E. Hobbie. 1977. Nitrogen recycling in the Chowan River, N.C. University of North Carolina, Water Resources Research Institute, Raleigh. WRRI Report 121:1-127.

Stanley, D.W. and S.W. Nixon. 1992. Stratification and bottom-water hypoxia in the Pamlico River Estuary. Estuaries 15:270-281.

State of South Carolina versus State of North Carolina-Water Wars. http://www.scattorneygeneral.org/currentcases/waterwar.html

Stevenson JC and Kearney MS. Impacts of global climate change and sea level rise on tidal wetlands. In: Silliman BR, Bertness MD, and Strong D (Eds). Anthropogenic modification of North American salt marshes. Berkeley, CA: University of California Press. In press.

St. Johns River Water Management District. 2010. St. Marys River Basin. http://www.sjrwmd.com/stmarysriver/

Strauss. 1994. Study advises against raising Enfield Dam. Hartford Courant. August 6, 1994. http://articles.courant.com/1994-08-06/news/9408060408_1_study-boating-restoring

Strayer, D.L., K.A. Hattala and A.W. Kahnle. 2004. Effects of an invasive bivalve (Dreissena polymorpha) on fish in the Hudson River estuary. Can J. Fish. Aquat. Sci. 61:924-941.

Street, M.W. 1982. Fisheries resources and trends of the Albemarle Sound area. Pages 57-60 in Albemarle Sound trends and management. University of North Carolina, Sea Grant College Program, Raleigh. UNC-SG 82-02.

Street, M.W., A.S. Deaton, W.S. Chappel and P.D. Mooreside. 2005. North Carolina Coastal Habitat Protection Plan. North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries, Morehead City. 630 pp.

Summers, K. 2001. National coastal condition report. U.S. Environmental Protection Agency, Office of Research and Development, Office of Water, Washington, D.C. EPA-620/R-01/005. 204 pp. www.epa.gov/owow/oceans/NCCR/index

Summers, K. 2004. National coastal condition report II. U.S. Environmental Protection Agency, Office of Research and Development, Office of Water, Washington, D.C. EPA-620/R-03/002. 286 pp. http://www.epa.gov/owow/oceans/nccr2/

Taft, J. L., W. R. Taylor, E. O. Hartwig, and R. Loftus. 1980. Seasonal oxygen depletion in Chesapeake Bay. Estuaries 3: 242-247.

Tamura K, Dudley J, Nei M & Kumar S. 2007. MEGA4: Molecular Evolutionary Genetics Analysis (MEGA) software version 4.0. *Molecular Biology and Evolution* 24:1596-1599.

Taubert, B. D. 1980a. Biology of shortnose sturgeon, *Acipenser brevirostrum*, in the Holyoke Pool, Connecticut River, Massachusetts. Doctoral dissertation. University of Massachusetts, Amherst, MA, USA.

Taubert, B.D. 1980b. Reproduction of shortnose sturgeon, *Acipenser brevirostrum*, in the Holyoke Pool, Connecticut River, Massachusetts. Copeia 1980:114-117.

Taubert, B.D., and M.J. Dadswell. 1980. Description of some larval shortnose sturgeon (Acipenser brevirostrum) from the Holyoke Pool, Connecticut River, Massachusetts, USA, and the Saint John River, New Brunswick, Canada. Canadian Journal of Zoology 58:1125-1128.

Tenore, K.R. 1972. Macrobenthos of the Pamlico River estuary, North Carolina. Ecological Monographs 42:51-69.

TNC (The Nature Conservancy) and SARP (Southeast Aquatic Resources Partnership). 2005. Conserving the Roanoke River. Conservation Action Plan. The Nature Conservancy, North Carolina Chapter, Durham, North Carolina. 61 pp.

Trested, D.G., J.J. Isley, R. Bakal and K.M. Ware. 2003. A behavioral comparison of hatchery-reared and wild shortnose sturgeon in the Savannah River, South Carolina-Georgia. Draft Report. Clemson University. 39 pp.

Turner, E. & Montgomerie, R. 2002. Ovarian fluid enhances sperm movement in Arctic charr. *Journal of Fish Biology* 60**,** 1570-1579.

Udall, S.L. 1967. Native fish and wildlife endangered species. Federal Register 32 (48): 4001.

Uhler, P.R., and O. Lugger. 1876. A list of fishes of Maryland. Report of the Commissioner of Fisheries of Maryland 1876:67–176.

UNB Litvak Lab. 2008. NSERC Discovery Grant-- Ecology and behaviour during early life stages of fishes: theory and application (2008-13). https://sites.google.com/site/litvaklabsite/research

U.S. Department of Energy. 2009. Report to Congress on the Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies: Prepared in Response to the Energy Independence and Security Act of 2007, Section 633(B). Wind and Hydropower Technologies Program, Energy Efficiency and Renewable Energ y, U.S. Department of Energy. December, 2009.

US DOI (United States Department of Interior). 1973. Threatened wildlife of the United States. Shortnose sturgeon. Office of Endangered Species and International Activities, Bureau of Sport Fisheries and Wildlife, Washington, D.C. Resource Publication 114 (Revised Resource Publication 34).

USFWS (U.S. Fish and Wildlife Service). 1996. Endangered shortnose sturgeon caught in the northern bay. News Media Alert.

USFWS (U.S. Fish and Wildlife Service). 2005. Comprehensive Conservation Plan and Final Environmental Impact Statement. Roanoke River National Wildlife Refuge. U.S. Department of the Interior, Fish and Wildlife Service, Southeast Regional Office, Atlanta, Georgia. 257 pp.

USFWS (U.S. Fish and Wildlife Service). 2007. 2007 Connecticut River Migratory Fish Counts. http://www.fws.gov/r5crc/Fish/old07.html

VA DGIF (Virginia Department of Game and Inland Fisheries). 2002. Buggs Island Lake. [http://www.dgif.virginia.gov/fishing/waterbodies/reports/2002%20Kerr%20Reservoir.pdf]

VA DGIF (Virginia Department of Game and Inland Fisheries). 2005. Virginia's comprehensive wildlife conservation strategy. Virginia Department of Game and Inland

Fisheries, Richmond. 900 pp. + appendices. [online at http://bewildvirginia.org/wildlifeplan /virginia-wildlife-action-plan.pdf]

VA DGIF (Virginia Department of Game and Inland Fisheries). 2008. Special status faunal species in Virginia. Wildlife Diversity Division, Richmond. 14 pp.
[online at http://www.dgif.virginia.gov/wildlife/virginiascspecies.pdf]

Van Den Avyle, M. J. 1984. Species profile: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic) - Atlantic   sturgeon. USFWS. FWS/OBS-82/11.25. U.S. Army Corps of Engineers, TR EL-82-4. 17 pp.

Van Der Kraak, G. and N. W. Pankhurst. 1997. Temperature effects on the reproductive performance of fish. Pp 159-176 In C. M. Wood and D. G. McDonald, eds. Cambridge University Press, Cambridge, United Kingdom.

VanDerwarker, A. 2001a. An archaeological assessment of pre-Columbian fauna in the Roanoke River Basin. University of North Carolina at Chapel Hill, Research Laboratories of Archaeology, Research Report No. 21:1-43.

VanDerwarker, A. 2001b. An archaeological study of Late Woodland fauna in the Roanoke River Basin. North Carolina Archaeology 50:1-46.

VanDerwarker, A. 2002. Swimming upriver: changes in subsistence and biogeography in the Roanoke River Valley. Pp. 59-64 In The Archaeology of Native North Carolina: Papers in honor of H. Trawick Ward, edited by Jane M. Eastman, Christopher B. Rodning, and Edmond A. Boudreaux III. Southeastern Archaeological Conference Special Publication 7. Mobile, AL.

Van Eenennaam, J.P., S.I. Doroshov, G.P. Moberg, J.G. Watson, D.S. Moore and J Linares. 1996. Reproductive conditions of the Atlantic sturgeon *Acipenser oxyrhyncus* in the Hudson River. Estauries 19(4):769-777.

Vecsei, P. J. and D. L. Peterson. 2004. Sturgeon Ecomorphology: a descriptive approach. In: Sturgeons and Paddlefish of North America. (Eds) S. McKinley, W.B.H Beamish, and G.S. Lebreton. Kluwer Academic Press.

Vera, J. C., C. W. Wheat, H. W. Fescemyer, M. J. Frilander, D. L. Crawford, I. Hanski, J. H. Marden. 2008. Rapid transcriptome characterization for a nonmodel organism using 454 pyrosequencing, Molecular Ecology 17:1636-1647.

Vladykov, V.D. and J.R. Greeley. 1963. Order Acipenseroidei. Pages 24-60 in Fishes of the Western North Atlantic. Memoir Sears Foundation for Marine Research 1(Part III). xxi + 630 pp.

Waite, R., J. Giordano, M. Scully, K. Rowles, J. Steel, M.W. Rumley, T. Stroud, G. Stefanski, A. Coburn, L. Everett, L. Webb-Margeson, J. Chazal, L. Peck and N. Petrovich. 1994. Comprehensive Conservation and Management Plan, Technical Document, Albemarle-Pamlico

Estuarine Study. North Carolina Department of Health and Natural Resources, Albemarle-Pamlico Estuary Study, Raleigh, and U.S. Environmental Protection Agency, Washington, D.C. 179 pp. + appendices.

Waldman, J. 1995. Sturgeons and paddlefishes: a convergence of biology, politics, and greed. Fisheries 20: 20–21, 49.

Waldman, J. R., Doukakis, P. and I. Wirgin. 2008. Molecular analysis as a conservation tool for monitoring the trade of North American sturgeons and paddlefish. Journal of Applied Ichthyology. Volume 24 Issue s1, Pages 20 – 28.

Waldman J.R.,C. Grunwald, J. Stabile, and I. Wirgin. 2002. Impacts of life history and biogeography on genetic stock structure in Atlantic Sturgeon, *Acipenser oxyrinchus oxyrinchus*, Gulf sturgeon *A. oxyrinchus desotoi*, and shortnose sturgeon, *A.brevirostrum.* J Appl Ichthyol 18:509-518.

Walsh, M.G., M.B. Bain, T. Squires, J.R. Walman, and Isaac Wirgin. 2001. Morphological and genetic variation among shortnose sturgeon Acipenser brevirostrum from adjacent and distant rivers. Estuaries Vol. 24, No. 1, p. 41-48. February 2001.

Walters, D.A. 1997. Estimated water use, by county, in North Carolina. U.S. Geological Survey, North Carolina Water Science Center, Raleigh, North Carolina. Open-File Report 97-599. 102 pp.

Wang, Y. L., F.P. Binkowski, and S.I. Doroshov. 1985: Effect of temperature on early development of white and lake sturgeon, *Acipenser transmontanus* and *A. fulvescens*. *Env. Biol. Fish.* **14**, 43–50.

Waring C. P. and A. Moore. 2004. The effect of atrazine on Atlantic salmon (*Salmo salar*) smolts in fresh water and after sea water transfer. Aquatic Toxicology 66:93-104.
Washburn and Gillis Associates, LTD. n.d. Studies of the early life history of the shortnose sturgeon (Acipenser brevirostrum). Final Report submitted to the Northeast Utilities Service Company, Hartford, Connecticut. 120 pp.

Webb, M. A. H., G. W. Fiest, M. S. Fitzpatrick, E. P. Foster, C. B. Shreck, M. Plumlee, C. Wong, and D. T. Gunderson. 2006. Mercury concentrations in gonad, liver, and muscle of white sturgeon *Acipenser transmontanus* in the lower Columbia River. Archives of Environmental Contamination 50: 443-451.

Weber, W. 1996. Population size and habitat use of shortnose sturgeon, Acipenser brevirostrum, in the Ogeechee River sytem, Georgia. Masters Thesis, University of Georgia, Athens, Georgia.

Weber, W., C.A. Jennings, and S.G. Rogers. 1998. Population size and movement patterns of shortnose sturgeon in the Ogeechee River system, Georgia. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 52: 18-28.

Wei, Qiwei. 2003. Studies on Chinese sturgeon (Acipenser sinensis Gray): spawning ecology and adult and yearling abundance. Doctoral Dissertation, Institute of Hydrobiology, *Wuhan*, China.

Welch, D. W., Y. Ishida, and K. Nagasawa. 1998. Thermal limits and ocean migrations of sockeye salmon (*Oncorhynchus nerka*): Long-term consequences of global warming. Canadian Journal of Fisheries and Aquatic Sciences 55(4): 937-948.

Welsh, S.A., M.F. Mangold, J.E. Skjeveland, and A.J. Spells. 2002. Distribution and Movement of Shortnose Sturgeon (Acipenser brevirostrum) in the Chesapeake Bay. Estuaries Vol. 25 No. 1: 101-104.

White, R.R. and J.L. Armstrong. 2000. Survival of Atlantic sturgeon captured by flounder gillnets in Albemarle Sound. Final Report to the North Carolina Division of Marine Fisheries, Morehead City. Fishery Resources Grant Program, 98FEG-39.

White, G. C., K. P. Burnham, D. L. Otis, and D. R. Anderson. 1978. CAPTURE: Software that Computes Estimates of Capture Probability and Population Size for Closed Population Capture-recapture Data. USGS.

White, M. G. III and S. D. Lamprecht. 1991. Investigations of the June 5 and June 7, 1991 in the rediversion canal and Santee River. S. Car. Wildl. Mar. Res. Dep.

Whitehead, J. 2001. Geology of the Fredericton-Mactaquac Dam area. In: Pickerill, R.K. and Lentz, D.L. (eds), Geology of New Brunswick, New England Intercollegiate Geological Conference, Guidebook, 83, p.A1-1 - A1-12

Whiteman, K. W., V. H. Travnichek, M. L. Wildhaber, A. DeLonay, D. Papoulias, and D. Tillett. 2004. Age estimation for shovelnose sturgeon: a cautionary note based on annulus formation in pectoral fin rays. N. Am. J. Fish. Manage. 24:731–734.

Whitworth, W. 1996. Freshwater fishes of Connecticut. State Geological and Natural History Survey of Connecticut, Connecticut Department Bulletin 114, 243 pp.

Wilk, S. J., and M. J. Silverman. 1976. Summer benthic fish fauna of Sandy Hook Bay, New Jersey. NOAA Technical Report SSRF-698. National Marine Fisheries Science Center, Woods Hole, Massachusetts

Williams, J. E, J. E. Johnson, D. A. Hendrickson, S. Contreras-Balderas, J. D. Williams, M. Navarro-Mendoza, D. E. McAllister, and J. E. Deacon. 1989. Fishes of North America Endangered, Threatened, or of Special Concern. Fisheries 14: 2-20.

Winger, P. V., P. J. Lasier, D. H. White, J. T. Seginak. 2000. Effects of contaminants in dredge material from the lower Savannah River. Archives of Environmental Contamination and Toxicology 38: 128-136.

Wippelhauser, G. 2003. Rept 03/09 Striped Bass and American Shad Restoration and Monitoring – Annual Report. January 1, 2003 – December 31, 2003

Wirgin, I., C. Grunwald, E. Carlson, J. Stabile, D.L. Peterson, and J. Waldman. 2005. Range-wide population structure of shortnose sturgeon *Acipenser brevirostrum* based on sequence analysis of mitochondrial DNA control region. Estuaries 28:406-21.

Wirgin, I., C. Grunwald, J. Stabile, and J.R. Waldman. 2009. Delineation of discrete population segments of shortnose sturgeon *Acipenser brevirostrum* based on mitochondrial DNA control region sequence analysis. Conservation Genetics DOI 10.1007/s10592-009-9840-1.

Wirgin, I., Maceda L, Stabile J, Mesing C. 1997. An evaluation of introgression of Atlantic coast striped bass mitchondrial DNA in a Gulf of Mexico population using formalin-preserved museum collections. *Molecular Ecology*, **6**, 907 916.

Wirgin, I., J. R. Waldman, J. Rosko, R. Gross, M. R. Collins, S. G. Rogers, and J. Stabile. 2000. Genetic Structure of Atlantic Sturgeon Populations Based on Mitochondria1 DNA Control Region Sequences. Transactions of the American Fisheries Society 123:47&486.

Wirgin, I., J. R. Waldman, J. Stabile, B. Lubinski, and T. King. 2002. Comparison of mitochondria1 DNA control region sequence and microsatellite DNA analyses in estimating population structure and gene flow rates in Atlantic sturgeon *Acipenser oxyrinchus.* J. Appl. Ichthyol. 18:313-319.

Witherspoon, A.M., C. Baldwin, O.C. Boody and J. Overton. 1979. Response of phytoplankton to water quality in the Chowan River system. University of North Carolina, Water Resources Research Institute, Raleigh. WRRI Report 129:1-204.

Woodland, R. J. 2005. Age, growth, and recruitment of Hudson River shortnose sturgeon (Acipenser brevirostrum). Master's thesis. University of Maryland, College Park.

Woodland, R.J. and D. H. Secor. 2007. Year-class strength and recovery of endangered shortnose sturgeon in the Hudson River, New York. Transaction of the American Fisheries Society 136:72-81.

Worth, S.G. 1904. Report on operations with the striped bass at the Weldon North Carolina substation in May 1904. U.S. Department of Commerce and Labor, Bureau of Fisheries, Beaufort, NC.

Wurfel, B. and G. Norman. 2006. Oregon and Washington to expand sea lion control efforts in the Columbia River. Oregon Department of Fish and Wildlife News Release March 17, 2006. http://www.dfw.state.or.us/news/2006/march/018.asp

Yarrow, H.C. 1874. Report of a reconnaissance of the shad-rivers south of the Potomac. Report of the Commissioner for 1872 and 1873, Part II. U.S. Commissioner of Fish and Fisheries, Washington, D.C. Pp. 396-402.

Yarrow, H.C. 1877. Notes on the natural history of Fort Macon, N.C., and vicinity. (No. 3) Fishes. Proceedings of the Academy of Natural Sciences, Philadelphia 29:203-218.

Zehfuss, K. P. 2000. The status, movement, habitat preference, and monitoring of Gulf sturgeon in several Florida rivers. Ph.D dissertation, North Carolina State University, Raleigh.

Zhang, S., D. Wang, and Y. Zhang. 2000. Mitochondrial DNA variation, effective female population size and population history of the endangered Chinese sturgeon, *Acipenser sinensis*. Pages 673-683 In Conservation Genetics 4(6).

Zhang S., Q. Wu, and Y. Zhang. 2001. On the taxonomic status of the Yangtze sturgeon, Asian and American green sturgeon based on mitochondrial control region sequences. Acta Zoologica Sinica. 47(6): 632 – 639.

Ziegeweid, J.R., C.A. Jennings, D.L. Peterson and M.C. Black. 2008. Effects of salinity, temperature, and weight on the survival of young-of-year shortnose sturgeon. Transactions of the American Fisheries Society 137:1490-1499.

Zydlewski, G. B., Kinnison, M. T., Dionne, P. E., Zydlewski, J. and Wippelhauser, G. S. (2011), Shortnose sturgeon use small coastal rivers: the importance of habitat connectivity. Journal of Applied Ichthyology, 27: 41–44.