Northeast Fisheries Science Center Reference Document 13-06

An Atlantic Sturgeon Population Index for ESA Management Analysis

by John Kocik, Christine Lipsky, Tim Miller,
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ABSTRACT

The listing in 2012 of Atlantic sturgeon (*Acipenser oxyrinchus*) under the Endangered Species Act identified four Distinct Population Segments (DPSs) as endangered and one as threatened. We developed an index of population abundance for Atlantic sturgeon in the Northeast to aid managers to evaluate potential threats to these stocks. The index uses fishery bycatch estimates, data from the USFWS Atlantic Coast Sturgeon Tagging Database, and published values of Atlantic sturgeon life history parameters. Estimates of total Atlantic sturgeon bycatch were derived from data collected on observed commercial fishing trips monitored by the Northeast Fisheries Observer Program (NEFOP). We evaluated uncertainty in the index input data with a risk analysis model that used a parametric bootstrapping approach. Based on our index, the mean abundance of Atlantic sturgeon in oceanic waters off the Northeast coast of the US during 2006-2011 was 417,934 fish, with a 95% confidence interval of 165,381 to 744,597 fish. This estimate does not include Atlantic sturgeon that may reside year-round in rivers and estuaries. Our abundance estimates are consistent with annual swept area abundance estimates of Atlantic sturgeon in nearshore areas derived from Northeast Area Monitoring and Assessment Program surveys conducted during 2007-2012.

INTRODUCTION

Problem and Scope

To evaluate impacts of human activities on threatened and endangered Atlantic sturgeon Distinct Population Segments (DPSs), an index of population abundance is desirable. This index can then be used to evaluate the impact of projected or actual Atlantic sturgeon fisheries-related incidental mortality (*i.e.,* unintended bycatch). This paper describes the development of an Atlantic Sturgeon Population Index (ASPI). The ASPI was derived from a conceptual model that interprets annual bycatch in terms of Atlantic sturgeon population dynamics and the probability of encountering sturgeon in commercial fisheries. The ASPI provides an annual estimate of the abundance of Atlantic sturgeon in the areas where sturgeon bycatch estimates are available. Atlantic sturgeon that occur in estuaries or rivers—and also north of the Gulf of Maine or south of Cape Hatteras—are not included in the ASPI. Uncertainty in the bycatch data and in the other input parameters was evaluated using a parametric bootstrap approach. The ASPI population estimates were then partitioned across five DPSs and Canada based on genetic assignment analysis of fishery-sampled individuals. The resulting DPS abundance estimates and their confidence intervals provide baseline data to evaluate risk thresholds for expected bycatches of Atlantic sturgeon.

Background

In 2010, NOAA's National Marine Fisheries Service was petitioned to list Atlantic sturgeon under the Endangered Species Act (ESA). In 2012, five distinct population segments (DPSs) were listed; four DPSs were listed as Endangered (New York Bight, Chesapeake Bay, Carolina, and South Atlantic) and one as Threatened (Gulf of Maine). At the time of listing, however, only limited analyses had been conducted of (a) tag-return information in a long-term USFWS Atlantic sturgeon tagging database; (b) recent commercial fishery Atlantic sturgeon bycatch estimates; and (c) abundance indices of Atlantic sturgeon in the Northeast Area Monitoring and Assessment Program (NEAMAP) inshore surveys.

This report summarizes work that the Northeast Fisheries Science Center has conducted to develop abundance estimates consistent with the new data. The approaches described in the work introduce a new method for population estimation, an instantaneous rates model for tagging data, an improved model-based estimator of bycatch, methods for characterizing the uncertainty of population estimates, and comparisons with swept area estimates. We recognize that efforts are underway by the Atlantic States Marine Fisheries Commission to formally assess Atlantic sturgeon populations. The analyses and results presented in this paper should be useful in the ASMFC assessments.

METHODS

Conceptual Bycatch Model

Our Atlantic sturgeon population estimates are based on a conceptual model that interprets a series of annual bycatch estimates in terms of recruitment, capture mortality, inter-annual natural mortality, and the probability of incidentally capturing sturgeon in various commercial fisheries. Our conceptual model was constructed as follows:

Consider a series of total bycatch estimates by year (c_t). If we assume that every sturgeon incidentally captured (a) survives the capture process (no bycatch mortality); (b) does not suffer any other source of mortality; and (c) is never seen again, the total minimum population size of Atlantic sturgeon off the Northeast coast of the US would be the sum of the discards between 2006 and 2010. A simple mass balance approach that relaxes these assumptions can be used to describe the observed catches. The minimum population size in year t can then be defined as

$$n_t = c_t(1-\theta)\, e^{-M} \qquad (1)$$

where n_t is the minimum number of fish at the end of year t, c_t is the number of fish bycaught alive during year t, θ is the fraction of fish that die during capture, and M is the natural mortality rate from all other causes. This approach assumes that the magnitude of natural mortality that occurs in the capture period is negligible such that fishing mortality and natural mortality can be approximated. If M and θ equal 0, then n_t is equal to c_t as noted above.

The bycatches that occur in year t+1 represent both new fish never seen before R_{t+1}, and recaptures of the surviving fish from previous years $n_t\mu_{t+1}$ where μ_{t+1} is the encounter rate in year $t+1$. Given the total incidental captures during year $t+1$, the new captures are $R_{t+1} = c_{t+1} - n_t\mu_{t+1}$. The minimum population alive at the end of year t+1 can be written as a function of those fish that were alive at the end of year t but not seen in year t+1 and those that were seen in year t+1 as bycatch c_{t+1}. We define μ_{t+1} as the fraction of fish alive in year t observed in year t+1 as bycatch. The observed bycatch in year t+1 therefore consists of fish not observed before plus some fraction observed as bycatch before and alive at the end of year t. These concepts can be expressed as

$$n_{t+1} = \{(1-\mu_{t+1})n_t + (c_{t+1} - \mu_{t+1}n_t)(1-\theta)\}e^{-M} \qquad (2)$$

The first term within brackets on the right hand side of Eq. 2 [i.e., (1- u_{t+1}) n_t] is the population not observed in year t+1. The second term within brackets expresses the new captures in year t+1 (R_{t+1}) surviving the capture process (i.e., 1-θ). The number of new and previously observed fish is then reduced by the probability of survival (non-capture effects) [i.e., e^{-M}] outside of the brackets.

The population model makes no explicit assumption about recruitment of new individuals to the population. Thus, minimum population size is defined by a recursive equation that converges to a long-term-value defined by (a) the encounter probability μ; (b) the probability of surviving capture (1-θ); (c) the natural mortality rate M; and (d) the number of fish observed as bycatch in year t. If the parameters μ, θ, and M are constant, the minimum population converges to an equilibrium value defined by the average rate of observed bycatch. Note that the population will increase only when there are new captures ($c_{t+1} - \mu_{t+1}n_t$ is greater than zero). In practical terms, the population estimates derived using Eq. 2 will not decrease with additional years of data unless the natural mortality or encounter probabilities have been underestimated. Conversely, if the fraction of fish that die after capture is actually greater than observed, the population estimates will increase. This occurs because a greater number of new fish enter the population each year.

Recursive application of Eq. 2 defines a minimum population of sturgeon observed as bycatch in previous years. However, total population size is estimated using the estimated probability of incidentally capturing sturgeon in the fisheries. This quantity is defined by the fishing mortality rate and the interplay with non-fishing mortality. Using the Baranov catch equation, the probability of encountering a sturgeon is the exploitation rate μ, which is a function of the instantaneous rates of fishing mortality *F* and non-fishing mortality *M*, viz.

$$\mu_t = \frac{F_t}{F_t+M}\left(1-e^{-(F_t+M)}\right) \qquad (3)$$

The exploitation rate μ is equal to the tag recovery probability (when accounting for non-reporting of tags and also for tags loss). Thus tag-recovery data—and the model described in the next section— can be used to obtain estimates of the encounter probability.

The total population size, denoted as N_t, is minimum population size n_t, raised by the encounter probability. This minimal estimate is the Atlantic Sturgeon Population Index (ASPI):

$$N_t = \frac{n_t}{\mu} \qquad (4)$$

The data to estimate the parameters in Eq. 1 to 4 were derived from various sources. Because data were available by type of fishing gear and by size of sturgeon, we modeled the population component-wise by gear type and size group. The gear and size-specific bycatch model (Eq. 2) can be written as

$$n_{g,s,t+1} = \left\{\left(1-\mu_{s,t+1}\right)n_{g,s,t} + \left(c_{g,s,t+1} - \mu_{s,t+1}n_{g,s,t}\right)\left(1-\theta_g\right)\right\}e^{-M_s} \qquad (5)$$

Gear type, denoted by the subscript *g*, refers to gillnets and otter trawls. Sturgeon size classes, denoted by the subscript s, are defined as subadults (< 150 cm) and adults (≥150 cm). The total population size can then be estimated from Eq. 4 as

$$N_t = \sum_s \sum_g \frac{n_{g,s,t}}{\mu_{s,t}}. \qquad (6)$$

Model for Exploitation and Survival Rates from Tag-recovery Data

The USFWS sturgeon tagging database (USFWS 2012) includes releases and recaptures of Atlantic sturgeon since 1989. Tag release information is submitted by state and federal researchers. Recoveries are from three sources: commercial fishermen handling their own tagged fish; independent researchers (including researchers operating independently or contracted commercial fishing vessels targeting sturgeon for researchers); and commercial vessels operating in their specific fisheries and where the tagged fish are handled by researchers or fishery observers (termed "report," "independent," and "dependent," respectively). For our analysis work, we were provided with a subset of the database by the USFWS (S. Eyler, USFWS, pers. comm.). From this subset, we excluded "independent" recoveries because research-based encounter rates are unlikely to be the same as commercial encounter rates. We also excluded recoveries of sturgeons other than Atlantic sturgeon, and excluded recoveries that were either re-released or recaptured fish possessing no external tags. To make these results applicable to the areas where discard estimates were available, we further excluded releases from the Southeast region (south of Cape Hatteras) and Canada, and any releases prior to 1993. Finally, the releases and recoveries were separated into two size groups: (1) fish less than 150 cm (subadults); and (2) fish greater than 150 cm (adults) (Tables 2 to 6).

The "dependent" recoveries were far more numerous than the number of sturgeon recorded by observers as bycatch associated with commercial fishing activities. Therefore, we used the ratio of the total number of tag recoveries by observers between 1993 and 2011 (n=15) to the total "dependent" recoveries (n=267) to scale down the matrix of "dependent" recoveries (Tables 5 and 6). No multiple recaptures occurred in the "dependent" or "report" categories of recoveries.

A model parameterized with instantaneous rates of mortality and tag shedding was used to derive estimates of exploitation rates for the ASPI model (previous section). The expected number of recoveries from Y_r releases in group r (defined by size class of releases s, a and year of release t_r) in fisheries with a researcher during time $t = t_r, \ldots, 2011$ is

$$E\left(R_{r,1,t}\right) = Y_r \pi_{r,1,t} = Y_r e^{-\sum_{i=t_r-1}^{t-1} Z_{r,i}} \frac{\rho F_t}{Z_{r,t}} \left(1 - e^{-Z_{r,t}}\right)$$

where ρ is the fraction of recoveries from effort with researchers. The expected number of recoveries in fisheries without a researcher during time t is

$$E\left(R_{r,2,t}\right) = Y_r \pi_{r,2,t} = Y_r e^{-\sum_{i=t_r-1}^{t-1} Z_{r,i}} \frac{\lambda(1-\rho) F_t}{Z_{r,t}} \left(1 - e^{-Z_{r,t}}\right)$$

where λ is the probability of reporting tags. The expected number of unrecovered tags is

$$E\left(U_{r,u}\right) = \left[Y_r - \sum_{t=t_r}^{T} \left(R_{r,1,t} + R_{r,2,t}\right)\right] \left[1 - \sum_{t=t_r}^{T} \left(\pi_{r,1,t} + \pi_{r,2,t}\right)\right].$$

We accounted for shedding of tags (L) by comparing recoveries of sturgeon that were doubled-tagged with a conventional and a PIT tag. Shedding rate was greater in the first year after release than later, so we used different values for these two intervals (Figure 2). Given a 0.7 probability of retention one year after release and a 0.5 probability of retention five years after release, the shedding rate for the first year was calculated as $L_1 = -\log(0.7) \approx 0.357$. The shedding rate in the second and all subsequent years after release was calculated as $L_2 = -\log(0.5/0.7)/4 \approx 0.084$. We assumed $M_s = 0.125$ for fish less than 150 cm and $M_a = 0.07$ for all fish greater than 150 cm (Kahnle et al. 2007). Thus for tag-recoveries, $Z_{r,t} = F_t + M_r + L$ for $t \geq t_r$ and $Z_{r,t_r-1} = 0$.

We used annual values of ρ, calculated as the ratio of observer trips to those in the Vessel Trip Report (VTR) database from years 1994 to 2011 (Table 7). The criteria for including trips from the Northeast Fisheries Observer Program (NEFOP) and VTR databases were identical to those used to estimate discards for 2006-2011. For 1993, we used the same ratio as for 1994.

The parameters to be estimated were annual fishing mortality rates (1993-2011) and the reporting rate of tags in the unobserved component of the fishery. We assumed that the number of recoveries in each component of the fishery during each interval in a given release group (by size class and year) were multinomial distributed. We then fit the model using an AD Model

Builder (Fournier et al. 2012) program that provided estimates and standard errors of the logit of the annual exploitation rates

$$\mu_{r,t} = \frac{F_t}{F_t + M_r}\left(1 - e^{-(F_t + M_r}\right)$$

and also the annual survival rates

$$S_{r,t} = e^{-(F_t + M_r)}.$$

We calculated approximate standard errors using the delta method and 95% confidence intervals as

$$CI\left(\frac{1}{1 + e^{-X}}\right) = \frac{1}{1 + e^{-X \pm Z_{0.975} SE(X)}}$$

where X is the logit of survival or exploitation rate and $Z_{0.975}$ is the quantile of the standard normal distribution associated with 0.975 cumulative probability.

Exploitation and survival rate estimates

Estimated exploitation rates were generally higher prior to 2001 (0.05 to 0.12) than afterward (0.002 to 0.05), and were similar between the two size classes of released sturgeon (Figure 3 and Table 8). For releases less than 150 cm in length, annual probabilities of survival exceeded 0.75 and exceeded 0.8 after 1998 (Figure 4 and Table 9). For releases greater than 150 cm, survival was slightly higher due to the lower natural mortality rate. The reporting rate for recoveries from unobserved fishing trips was estimated to be 0.295 (SE = 0.076).

The Risk Analysis Framework in @RISK

The overall uncertainty in the Atlantic sturgeon population estimates are a function of the uncertainty in the estimates from the discard and tagging data, and the uncertainty in the natural mortality and post-capture mortality rates. The joint effects of uncertainty in the estimates from the ASPI model were calculated in a Microsoft Excel workbook using the @RISK software package (Palisade Corporation, 2012). Probability density functions were assumed for each of the ASPI inputs and parameterized by the estimated means and variances.

The @RISK software creates multiple realizations of a stochastic process using parametric Monte Carlo simulations. Each realization of the stochastic process is created by randomly sampling from the corresponding assumed probability distribution of each ASPI model input. Sampling distributions of model outputs were based on 22,500 iterations. The number of stochastic realizations was based on convergence criteria that required less than a 1% change in the mean between successive realizations, and a confidence level of 95% (the mean of each output simulated had to be accurate 95% of the time)

The ASPI estimate (N_t) was then partitioned across the Distinct Population Segments using a Mixed Stock Analysis (MSA; Wirgin, personal communication 12 June 2012). This analysis was based on genetic data from 173 Atlantic sturgeon taken as bycatch in US Atlantic coast commercial fisheries, and sampled as part of the NEFOP. The MSA results, depicted as DPS point estimates in Figure 3 of Damon-Randall et al. (2012), were given as: 2% Canada, 11% Gulf of Maine, 49% New York Bight, 14% Chesapeake Bay, 4% Carolina, and 20% South

Atlantic[1]. Because the MSA sample size is a small, albeit spatially diverse sample, the partitioning of the ASPI estimate was done solely using point estimates without taking account of any variance associated with the genetic assignments (Figure 1). To illustrate the variance around the samples, the Carolina DPS point estimate of 0.04 has a mean of 0.042 with a 95% confidence limit of (0.008 - 0.092). Future ASPI estimates and stock assessments could include these variances in the DPS partitioning exercise, but it would be prudent to wait until samples sizes increase. The population estimates for each DPS were then used to derive the ratio of bycatch mortalities in 2011 to the estimated abundance of sub-adult and adult sturgeon.

Distributions for ASPI model inputs

The key model inputs and assumed distributions used for the Monte Carlo simulation are provided in Table 10.

We assumed normal distributions for the logit annual encounter rates, with mean and standard deviations provided by the estimates and standard error from the tag-recovery model (e.g., Figure 5). We assembled the 10,000 simulations in each year 2006-2009 (corresponding to the bycatch estimates) into one data field (40,000 in total) and transformed them using the inverse of the logit. By doing so, we obtained values on the probability scale for the distribution of average exploitation (or encounter) rates during 2006 to 2009.

Means and standard errors for adult and subadult natural mortality were provided by Kahnle *et al*. (2007). For subadult mortality, M ranged from 0.09 to 0.16 for fish aged 2-10 (<150 cm). This variability in subadult M was best described using a mean of 0.125 and a standard deviation of 0.024 (Figure 6a). For adult mortality, Kahnle *et al*. (2007) reported an M of 0.07. We added a minimal standard deviation of 0.001 (Figure 6b) to provide some variance, and also incorporated a variance threshold as a placeholder so that information of adult M from future studies could be included. We further assumed that a negligible fraction of the sturgeon in the sub-adult group grow into the adult group.

We used bycatch estimates and standard errors for 2006 to 2010 provided in Miller and Shepherd (2011, see also Appendix A). These represent dead encounters and apply only to the Fishery Management Plans (FMPs) that will be included in the Northeast Regional Office (NERO)'s batched consultation (Table 1a). We used a left-truncated normal distribution with mean and standard deviations provided by the annual bycatch estimates and their standard errors (Table 1). The values used for the left-truncation were the annual minima determined from the actual numbers of sturgeon in the Northeast Fisheries Observer Program (NEFOP) database by year and gear type. We partitioned the total estimated bycatch into subadult and adult components by applying the annual proportion of measured lengths less or greater than 150 cm. In Figure 7, an example is given of the distribution of estimated gillnet bycatches of Atlantic sturgeon in 2006 The NEFOP reports the fraction of sturgeon dead at the time of capture. The average survival rate for 2006-2010 was used to estimate θ. Based on Miller and Shepherd (2011), we assumed an observed average bycatch mortality of 5% for trawl-caught sturgeon and 20% for sturgeon taken in gillnets.

[1] In the final stages of this report these percentages were modified slightly (T. King, USFWS, pers. comm.) The new percentages are: Canada, 1%; Gulf of Maine, 11%; New York Bight, 51%; Chesapeake Bay, 13%; Carolina, 2%, and South Atlantic (SA) 22%. The revised estimates were not used in this report. See Damon-Randall, K, Colligan, M, and Crocker, J 2013. Composition of Atlantic sturgeon in rivers, estuaries, and in marine waters (White paper). NOAA/NMFS, Gloucester, MA: Protected Resources Division.

RESULTS

ASPI Model Results

Based on the ASPI index, the mean abundance of Atlantic sturgeon in oceanic waters off the Northeast coast of the US and Canada during 2006-2011 was 417,934 fish, with a 95% confidence interval of 165,381 to 744,597 fish (Figure 8; Table 11). The values pertaining to the five USA DPSs represent 98% of the total (i.e., 409,575 fish with a 95% confidence interval of 162,074 to 729,705 fish). There is less than a 1% probability that the abundance of sturgeon is lower than 118,393 fish (Table 12). The relative impact of recent annual bycatches of Atlantic sturgeon in US fisheries was examined by allocating the average bycatch mortality during 2006-2010 (314.8 individuals) to each DPS using the genetic assignment ratios. The average bycatch to population ratio across DPSs was 0.09% (Table 11).

Sensitivity Analyses

We also explored the sensitivity of the model to directional changes in key parameters by varying each parameter one at a time about the mean estimate (Table 13). Changes to the exploitation rate had the greatest affect on abundance, as this parameter appears in the denominator of the abundance equation (Eq. 6). Percentage changes in the total discard estimates, natural mortality rates, and the discard mortality rates all generated proportional changes in total abundance. Increases in natural mortality rates and discard mortality rates resulted in reduced population sizes. Changes to sub adult natural mortality (M) were about five times as important as changes in adult M. Changes in the discard mortality rate of sturgeons caught in gillnets had about four times the influence of changes in the discard mortality rates in trawls. Increases in the numbers of discards of adult and sub adult sturgeons in gillnets and trawls resulted in increased estimates of population size. Population size increased about 1.4% for a 10% change in discards of adult sturgeon in gillnets; for subadults, the comparable change was 3.2%. For adult sturgeon caught in trawls, abundance increased by 1.2% for a 10% change in the discard mortality rate and increased by 4.1% for sub adults. The functional responses of abundance to changes in the parameter values are characteristic of the model (Eq. 1-6), but the magnitude of these changes depends upon the relative values of other parameters and data in the model. For example, the percentage rate of change in population size as a function of the percentage rate of change in natural mortality is expected to be linear - but the magnitude of the slope depends upon the overall level of exploitation, total discards, and other model parameters.

The conceptual model (Eq. 1-6) assumes that not all sturgeon die after incidental capture. The estimate of bycatch mortality is based on reports by observers of the number of sturgeon dead at capture. Additional mortality after capture is assumed to be zero. As an exploratory exercise, we used the bycatch estimates to derive annual population abundance estimates by dividing the bycatch by the exploitation rate (Table 14). This variation in model formulation is less realistic than the ASPI approach because it fails to account for the accumulation of fish implied by the survival of fish after capture.

In Table 14, the variability (CV = 124%) associated with the mean abundance estimate in the first scenario (i.e., annual discards/annual exploitation rate during 2006-2009) is greater than expected given biologically feasible recruitment, growth, and migration dynamics of Atlantic sturgeon. However, under all three scenarios, the abundance estimates from annual discards suggest oceanic population sizes in excess of 100,000 sturgeon.

NEAMAP Alternative for Tuning

We conducted one final analysis to determine how our average estimated population size compared to a population estimate derived from the Northeast Area Monitoring and Assessment Program (NEAMAP). The NEAMAP surveys are conducted from Cape Cod, Massachusetts to Cape Hatteras, North Carolina in nearshore waters at depths to 18.3 m. The surveys, conducted during the fall since 2007 and during the spring since 2008, use a spatially stratified random design with a total of 35 strata and 150 stations per survey. The calculation method used to determine the swept area of the survey is provided in Appendix B.

Atlantic sturgeon are frequently sampled during the NEAMAP survey. Minimum swept area population estimates of Atlantic sturgeon from the fall survey range from 6,980 to 42,160 fish with CVs between 0.02 and 0.57. Minimum swept area abundance estimates from the spring surveys range from 25,540 to 52,990 fish with CVs between 0.27 and 0.65 (Table 15). The survey estimates are considered minimum values because these they are based on the unlikely assumptions that (a) the survey gear captures 100% of the sturgeon that occur within the path of the survey tows, and (b) all of the sturgeon in the population exist in the areas sampled by the survey. We define catchability as the product of the probability of capture given encounter (i.e. net efficiency) and the fraction of the population within the sampling domain (availability). Catchabilities less than 100% result in population size estimates greater than the minimum swept area abundance. The true catchability depends on many things including the availability of the species to the survey and the behavior of the species with respect to the gear. True efficiencies less than 100% are common for most species. The average ASPI estimate of 417,934 fish implies a catchability of between 6 and 13% for the spring NEAMAP survey, and a catchability of between 2 and 10% for the fall NEAMAP survey. If the availability of Atlantic sturgeon in the areas sampled by the spring NEAMAP survey were say 50%, then the implied range of net efficiencies for this survey would double to 12 and 26%. The ratio of total sturgeon habitat to area sampled by the NEAMAP survey is unknown, but is certainly greater than one. Abundance estimates derived from the 2007-2012 NEAMAP surveys, by season and year, are presented in Table 16 for survey catchabilities from 5 to 100%.

DISCUSSION

The population abundance estimates developed using the ASPI model are based on estimated discards in coastal commercial fisheries between North Carolina and the U.S.-Canada border. However, since Atlantic sturgeon are anadromous, a part of their life history also involves a residency period in rivers and estuaries, beyond the area of inference of the coastal discard estimates. Mature sturgeon move into rivers during spring for spawning, although not necessarily on an annual basis. Females return to coastal waters following spawning while male sturgeon may remain in the estuaries until fall. Juveniles inhabit estuaries for several years before moving to the marine environment where they participate in extensive coastal migrations (Atlantic Sturgeon Status Review Team, 2007). Although the fishery encounter rates used in the ASPI model encompass both coastal and estuarine areas, the discard estimates do not account for the seasonal availability of sturgeon to the coastal fisheries and thus the resulting ASPI abundance estimates are biased low.

Under the assumption that tags were removed from all recovered sturgeon, annual exploitation rates from the tag-recovery model are approximately analogous to the encounter rates used in the ASPI model when population size is large or encounter rates are low. Estimates of the annual probability of survival derived from the tag-recovery model include fishing mortality, and therefore represent the lower bound on the true survival rate because there is a high probability of surviving the capture process. The currently available tagging data are insufficient to detect fine-scale movement patterns, but other data from acoustic tags may be sufficient to discern relationships between inshore and ocean abundance estimates. The discrete time instantaneous rates model used in our analyses is more realistic than a Brownie-type band recovery model because it incorporates tag shedding and external estimates of natural mortality. However, like the Brownie model, our model does not account for recoveries that are not terminal encounters. Although a cursory examination of the tagging data suggests that multiple recaptures are uncommon, this may reflect a high tag shedding rate and the removal of tags from captured fish.

The abundance estimates from the ASPI model are sensitive to the encounter rates and also to the natural mortality rates. The estimates of bycatch for each gear type and year have less impact because each is part of a cumulative sum (Eq. 2). Although the scaled recoveries in the "dependent" category are non-integer values and therefore not ideal for the multinomial model (which, in theory, is based on counts of discrete outcomes), we could not use the tag-recoveries in the NEFOP database directly because the release year in which they originated was unknown.

Pollock et al. (2002) used a similar approach in modeling recoveries in observed and unobserved components of fisheries. They used binomial models for the number of fish caught in each component, conditioned on the total number caught. In our study, we did not know the total numbers of fish caught in either component. Rather than include further binomial likelihood components we used the proportions of observed trips directly (i.e., the binomial MLEs) which excluded some uncertainty in the estimated quantities. However, the number of trips observed annually was extremely large (1,075-2,716) implying that our proportion estimates were extremely precise using the binomial model (SEs between 0.0006 and 0.0013).

The range of estimated catchabilities for Atlantic sturgeon in the NEAMAP survey is highly plausible given that significant portions of the population are unavailable to the survey because these components reside in unsampled estuaries, freshwater areas, and to some extent, marine depths greater than 18.3m. Therefore, the NEAMAP survey estimates appear to corroborate the ASPI estimates.

The goal of our analyses was to develop an Atlantic sturgeon abundance index for use by managers prior to completion of comprehensive stock assessments. The ASPI is intended to represent abundance in the geographic area where Atlantic sturgeon are caught in sink gill nets and trawls and monitored by NEFSC fishery observers. The ASPI model was designed to: (1) use previous estimates of sturgeon captured in commercial fisheries; (2) capture heterogeneity of rates over time; (3) use an appropriate range of variability associated with key parameters; and (4) produce a population index that adequately reflected the considerable uncertainty in several of the model parameters. Our analyses are intended to abet more thorough stock assessments of Atlantic sturgeon. A more complete examination of the tagging data and further work on the model-based estimates of discards should lead to improved inferences about Atlantic sturgeon abundance.

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REFERENCES CITED

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. 175 pp.

Fournier, D. A., Skaug, H. J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M. N., Nielsen, A., and Sibert, J. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods & Software 27(2): 233-249.

Kahnle, A. W., Hattala, K.A., and McKown, K.A. 2007. Status of Atlantic sturgeon of the Hudson River estuary, New York, USA. Pages *347-363, IN:* J. Munro, D. Hatin, J. E. Hightower, K. A. McKown, K. J. Sulak, A. Kahnle, and F. Caron, editors. Proceedings of the symposium on anadromous sturgeon: Status and trend, anthropogenic impact, and essential habitat. American Fisheries Society Symposium 56, Bethesda, Maryland.

Miller, T. J., and Shepherd, G.R. 2011. Summary of discard estimates for Atlantic sturgeon (White paper). NOAA/NMFS, Woods Hole, MA: Population Dynamics Branch. http://www.nefmc.org/monk/cte mtg docs/120403/Summary of Discard Estimates for Atlantic Sturgeon-v3.pdf

Palisade Corporation. 2012. @*RISK* (Version 6) [Computer program]. Ithaca, NY: Palisade Corporation.

Pollock, K. H., Hoenig, J. M., Hearn, W. S., and Calingaert, B. 2002. Tag reporting rate estimation: 2. Use of high-reward tagging and observers in multiple-component fisheries. North American Journal of Fisheries Management 22: 727-736.

Damon-Randall, K, Colligan, M, and Crocker, J 2012. Composition of Atlantic sturgeon in rivers, estuaries, and in marine waters (White paper). NOAA/NMFS, Gloucester, MA: Protected Resources Division.

United States Fish and Wildlife Service (USFWS) 2012. Atlantic Coast Sturgeon Tagging Database. Maryland Fishery Resources Office, Annapolis, MD. August 2012.

Table 1. (A) Estimated dead encounters by gear and year, based on Miller and Shepherd (2011), only for FMPs that will be included in NERO's batched consultation; (B) Bycatch estimates, standard errors, and minimum bycatch. Bycatch estimates are normally distributed, with the lower bound truncated by the observed number of discards, labeled as Minimum. Note that Minimum is not a whole number because of partitioning a whole number by the proportion of adults and subadults in each fishery.

A

	Estimated Dead Encounters	
Year	Sink Gillnet	Otter Trawl
2006	234.4	76.5
2007	344.8	70.7
2008	137.3	60.8
2009	319.9	57.9
2010	191.0	69.4
average	247.7	67.1

B

	Adults				Sub Adults		
Gear/Year	Mean	Standard Error	Minimum		Mean	Standard Error	Minimum
Gillnet							
2006	446.0	170.6	33.5		1,166.0	104.8	87.5
2007	613.2	234.6	30.2		1,602.9	144.9	78.8
2008	237.5	90.8	11.9		620.7	87.7	31.1
2009	568.2	217.4	27.9		1,485.2	131.2	73.1
2010	306.6	117.3	13.8		801.4	99.6	36.2
Trawl							
2006	368.4	95.2	5.8		1,425.3	181.4	22.2
2007	338.1	87.4	11.9		1,307.8	162.0	46.1
2008	285.9	73.9	5.8		1,106.1	135.9	22.2
2009	274.9	71.0	9.9		1,063.3	128.5	38.1
2010	322.5	83.4	21.6		1,247.8	161.3	83.4

Table 2. Annual releases of tags on sturgeon less than (N_s) or greater than (N_l) 150 cm.

	N_s	N_l
1993	460	16
1994	286	45
1995	171	34
1996	1099	30
1997	285	38
1998	390	75
1999	256	7
2000	295	3
2001	267	15
2002	92	12
2003	152	12
2004	353	7
2005	585	13
2006	1171	74
2007	951	80
2008	763	70
2009	535	98
2010	375	143
2011	652	327

Table 3. Recoveries of releases less than 150 cm in size from unobserved fishing effort ("report" category).

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1993	9	10	7	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994		5	5	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1995			0	4	3	2	0	0	0	0	0	0	0	1	0	0	0	0	0
1996				9	24	6	3	4	0	0	0	0	0	0	0	0	0	0	0
1997					6	9	3	0	0	1	0	0	0	0	0	0	1	0	0
1998						15	10	4	2	0	0	0	0	0	0	0	0	0	0
1999							4	12	1	0	1	0	0	0	0	0	0	0	0
2000								5	8	0	0	1	0	1	0	0	0	0	0
2001									9	4	1	0	0	1	0	0	0	0	0
2002										1	1	0	0	0	0	0	0	0	0
2003											2	3	0	0	0	0	0	0	0
2004												2	2	0	1	0	0	0	0
2005													4	4	1	0	0	0	1
2006														21	10	3	1	0	1
2007															2	3	1	0	3
2008																6	9	2	1
2009																	2	0	1
2010																		0	1
2011																			5

Table 4. Recoveries of releases greater than 150 cm in size from unobserved fishing effort ("report" category).

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1993	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994		1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995			1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996				1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997					1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998						1	0	0	0	0	0	0	0	0	0	0	0	0	0
1999							0	0	0	0	0	0	0	0	0	0	0	0	0
2000								0	0	0	0	0	1	0	0	0	0	0	0
2001									0	0	0	0	0	0	0	0	0	0	0
2002										0	0	0	0	1	0	0	0	0	0
2003											1	0	0	0	0	0	0	0	0
2004												0	0	0	0	0	0	0	0
2005													0	0	0	0	0	0	0
2006														1	0	0	0	0	0
2007															0	0	0	0	0
2008																0	0	0	0
2009																	0	0	0
2010																		0	0
2011																			0

Table 5. Unscaled recoveries of releases less than 150 cm in size from fishing effort categorized as "dependent."

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1993	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996				6	98	15	0	1	0	0	0	0	0	0	0	0	0	0	0
1997					8	3	2	0	0	0	0	0	0	0	0	0	0	0	0
1998						11	3	0	0	0	0	0	0	0	0	0	0	0	0
1999							7	0	0	0	0	0	0	0	0	0	0	0	0
2000								1	1	0	0	0	0	0	0	0	0	0	0
2001									4	0	0	0	0	0	0	0	0	0	0
2002										1	0	0	0	0	0	0	0	0	0
2003											1	0	2	0	0	0	0	0	0
2004												0	1	0	0	0	0	0	0
2005													10	4	0	0	0	0	0
2006														24	8	4	0	0	0
2007															17	7	0	0	0
2008																18	1	0	0
2009																	0	0	0
2010																		0	0
2011																			0

Table 6. Unscaled recoveries of releases greater than 150 cm in size from fishing effort categorized as "dependent."

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998						0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999							0	0	0	0	0	0	0	0	0	0	0	0	0
2000								0	0	0	0	0	0	0	0	0	0	0	0
2001									0	0	0	0	0	0	0	0	0	0	0
2002										0	0	0	0	0	0	0	0	0	0
2003											0	0	0	0	0	0	0	0	0
2004												0	0	0	0	0	0	0	0
2005													0	0	0	0	0	0	0
2006														0	0	0	0	0	0
2007															1	0	0	0	0
2008																0	0	0	0
2009																	0	0	0
2010																		0	0
2011																			0

Table 7. Annual proportion of observed commercial fishing effort, ρ, calculated as the ratio of observed trips to VTR trips in the same areas and gear types used for the bycatch estimates in Miller and Shepherd (2011).

	ρ
1993	0.042
1994	0.042
1995	0.033
1996	0.027
1997	0.028
1998	0.031
1999	0.028
2000	0.030
2001	0.027
2002	0.023
2003	0.031
2004	0.056
2005	0.057
2006	0.037
2007	0.043
2008	0.035
2009	0.047
2010	0.049
2011	0.047

Table 8. Estimated annual exploitation rates and standard errors for fish less than ($\hat{\mu}_{s,t}$) and greater than ($\hat{\mu}_{l,t}$) 150 cm.

	$\hat{\mu}_{s,t}$	$\widehat{SE}(\hat{\mu}_{s,t})$	$\hat{\mu}_{l,t}$	$\widehat{SE}(\hat{\mu}_{l,t})$
1993	0.073	0.030	0.075	0.03
1994	0.109	0.038	0.111	0.039
1995	0.092	0.036	0.094	0.037
1996	0.045	0.017	0.046	0.017
1997	0.119	0.039	0.122	0.040
1998	0.099	0.034	0.102	0.035
1999	0.065	0.025	0.067	0.026
2000	0.081	0.030	0.083	0.031
2001	0.068	0.027	0.070	0.027
2002	0.025	0.013	0.026	0.014
2003	0.026	0.013	0.026	0.014
2004	0.021	0.010	0.021	0.011
2005	0.020	0.009	0.021	0.009
2006	0.051	0.016	0.052	0.016
2007	0.021	0.008	0.022	0.008
2008	0.018	0.007	0.018	0.007
2009	0.018	0.006	0.018	0.007
2010	0.003	0.002	0.003	0.002
2011	0.015	0.005	0.015	0.006

Table 9. Estimated annual survival rates and standard errors for fish less than ($\hat{S}_{s,t}$) and greater than ($\hat{S}_{a,t}$) 150 cm.

	$\hat{S}_{s,t}$	$\widehat{SE}(\hat{S}_{s,t})$	$\hat{S}_{a,t}$	$\widehat{SE}(\hat{S}_{a,t})$
1993	0.814	0.028	0.855	0.029
1994	0.781	0.036	0.821	0.037
1995	0.797	0.034	0.837	0.035
1996	0.840	0.016	0.883	0.016
1997	0.771	0.037	0.810	0.039
1998	0.789	0.032	0.830	0.034
1999	0.821	0.024	0.863	0.025
2000	0.807	0.028	0.848	0.030
2001	0.818	0.025	0.860	0.026
2002	0.859	0.013	0.903	0.013
2003	0.858	0.013	0.902	0.013
2004	0.863	0.010	0.907	0.010
2005	0.864	0.008	0.908	0.009
2006	0.835	0.015	0.877	0.016
2007	0.862	0.007	0.907	0.008
2008	0.866	0.006	0.910	0.006
2009	0.866	0.006	0.910	0.006
2010	0.880	0.002	0.925	0.002
2011	0.868	0.005	0.913	0.005

Table 10. Values for ASPI model inputs.

Input	Description		Distribution	Mean	Standard Deviation
θ_g	capture mortality	gillnets		0.20	-
θ_t	capture mortality	trawl		0.05	-
M_s	other mortality	subadults	normal distribution	0.125	0.024
M_a	other mortality	adults	normal distribution	0.070	0.001
$c_{s,g}$	subadult bycatch	gillnets	normal distribution	See Table 1	See Table 1
$c_{s,t}$	subadult bycatch	trawl	normal distribution	See Table 1	See Table 1
$c_{a,g}$	adult bycatch	gillnets	normal distribution	See Table 1	See Table 1
$c_{a,t}$	adult bycatch	trawl	normal distribution	See Table 1	See Table 1
$\text{logit}(\mu_{s,2006})$	logit of encounter rate	subadults	normal distribution	-2.9217	0.32534
$\text{logit}(\mu_{a,2006})$	logit of encounter rate	adults	normal distribution	-2.8961	0.32569
$\text{logit}(\mu_{s,2007})$	logit of encounter rate	subadults	normal distribution	-3.8272	0.36501
$\text{logit}(\mu_{a,2007})$	logit of encounter rate	adults	normal distribution	-3.8022	0.36517
$\text{logit}(\mu_{s,2008})$	logit of encounter rate	subadults	normal distribution	-4.0164	0.37575
$\text{logit}(\mu_{a,2008})$	logit of encounter rate	adults	normal distribution	-3.9914	0.37589
$\text{logit}(\mu_{s,2009})$	logit of encounter rate	subadults	normal distribution	-3.9997	0.36716
$\text{logit}(\mu_{a,2009})$	logit of encounter rate	adults	normal distribution	-3.9747	0.36729

Table 11. Estimated ASPI ocean populations (numbers of fish) with 95% lower and upper bounds for five Atlantic sturgeon DPSs and Canada based on Monte Carlo simulations of a conceptual bycatch with a comparison to observed averaged batched ocean mortalities (2006-2010).

DPS	Proportion of Total Ocean Population	Estimated Ocean Population (95% lower)	Estimated Ocean Population (Mean)	Estimated Ocean Population (95% upper)	Batched Ocean Mortalities	Average Batch/Population Ratio
GOM	11%	18,192	45,973	81,906	34.6	
NYB	49%	81,037	204,788	364,853	154.3	
CB	14%	23,153	58,511	104,244	44.1	
Carolina	4%	6,615	16,717	29,784	12.6	
SA	20%	33,076	83,587	148,920	63.0	
Canada	2%	3,308	8,359	14,892	6.3	
US Totals	98%	162,074	409,575	729,705	314.8	0.09%
Totals	100%	165,381	417,934	744,597		

Table 12. Quantiles of the distribution of ASPI in Figure 8.

Probability	Quantile of ASPI
0.01	118,393
0.05	165,442
0.10	201,538
0.15	230,603
0.20	257,065
0.25	282,611
0.30	307,566
0.35	330,820
0.40	352,980
0.45	376,188
0.50	398,346
0.55	421,252
0.60	445,377
0.65	470,015
0.70	497,026
0.75	525,548
0.80	558,552
0.85	600,233
0.90	654,272
0.95	742,954
0.99	940,575

Table 13. Summary of sensitivity analyses applied to model parameters and input data. Entries in columns 2 and 3 represent the ratio of predicted population size to the mean estimate when the model inputs are multiplied by 0.25 (i.e., 75% decline) and 1.75 (i.e., 75% increase). The slope estimate gives the percentage change in population abundance per percentage change in the model inputs.

	Adjustment Factor Applied			
Parameter	0.25	1.75	Slope	Response
Probability of Encounter	4.333	0.528	negative	Power function: Pop=0.988 Prob Encounter^-1.083
Natural Mortality of Sub Adults	1.224	0.839	-0.2463	Linear
Natural Mortality of Adults	1.044	0.963	-0.0541	Linear
Discards of Adult sturgeon in gill nets	0.892	1.108	0.1439	Linear
Discards of Sub Adult sturgeon in gill nets	0.761	1.239	0.3192	Linear
Discards of adult sturgeon in trawls	0.907	1.093	0.1242	Linear
Discards of Sub Adult sturgeon in trawls	0.691	1.309	0.4126	Linear
Discard mortality in gill nets	1.082	0.916	-0.1104	Linear
Discard mortality in trawls	1.020	0.980	-0.0268	Linear

Table 14. Estimated mean sturgeon abundance (number of fish) based on dividing observed total discards by the exploitation rate derived from the tagging model. The coefficient of variation (CV) is based on the variance of estimates across years.

Scenario	Mean Abundance	CV Abundance
Annual discards/annual exploitation rate (2006-9)	312,562	124%
Annual discards/3-yr moving average of exploitation	139,051	39%
Annual discards/5 year average exploitation	139,935	21%

Table 15. Annual minimum swept area abundance estimates (number of fish) and CVs for Atlantic sturgeon during the spring and fall from the Northeast Area Monitoring and Assessment Program survey. Estimates provided by Dr. Chris Bonzek, Virginia Institute of Marine Science.

	Fall		Spring	
Year	Number	CV	Number	CV
2007	6,981	0.015		
2008	33,949	0.322	25,541	0.391
2009	32,227	0.316	41,196	0.353
2010	42,164	0.566	52,992	0.265
2011	22,932	0.399	52,840	0.48
2012			28,060	0.652

Table 16. Summary of estimated sturgeon abundance based on alternative estimates of catchability. Catchability is defined as the product of gear efficiency and availability.

	Fall Survey					Spring Survey					Statistics of Annual Estimates		
Catchability	2007	2008	2009	2010	2011	2008	2009	2010	2011	2012	Min	Mean	Max
0.05	139,620	678,980	644,540	843,280	458,640	510,820	823,920	1,059,840	1,056,800	561,200	139,620	677,764	1,059,840
0.10	69,810	339,490	322,270	421,640	229,320	255,410	411,960	529,920	528,400	280,600	69,810	338,882	529,920
0.15	46,540	226,327	214,847	281,093	152,880	170,273	274,640	353,280	352,267	187,067	46,540	225,921	353,280
0.20	34,905	169,745	161,135	210,820	114,660	127,705	205,980	264,960	264,200	140,300	34,905	169,441	264,960
0.25	27,924	135,796	128,908	168,656	91,728	102,164	164,784	211,968	211,360	112,240	27,924	135,553	211,968
0.30	23,270	113,163	107,423	140,547	76,440	85,137	137,320	176,640	176,133	93,533	23,270	112,961	176,640
0.35	19,946	96,997	92,077	120,469	65,520	72,974	117,703	151,406	150,971	80,171	19,946	96,823	151,406
0.40	17,453	84,873	80,568	105,410	57,330	63,853	102,990	132,480	132,100	70,150	17,453	84,721	132,480
0.45	15,513	75,442	71,616	93,698	50,960	56,758	91,547	117,760	117,422	62,356	15,513	75,307	117,760
0.50	13,962	67,898	64,454	84,328	45,864	51,082	82,392	105,984	105,680	56,120	13,962	67,776	105,984
0.55	12,693	61,725	58,595	76,662	41,695	46,438	74,902	96,349	96,073	51,018	12,693	61,615	96,349
0.60	11,635	56,582	53,712	70,273	38,220	42,568	68,660	88,320	88,067	46,767	11,635	56,480	88,320
0.65	10,740	52,229	49,580	64,868	35,280	39,294	63,378	81,526	81,292	43,169	10,740	52,136	81,526
0.70	9,973	48,499	46,039	60,234	32,760	36,487	58,851	75,703	75,486	40,086	9,973	48,412	75,703
0.75	9,308	45,265	42,969	56,219	30,576	34,055	54,928	70,656	70,453	37,413	9,308	45,184	70,656
0.80	8,726	42,436	40,284	52,705	28,665	31,926	51,495	66,240	66,050	35,075	8,726	42,360	66,240
0.85	8,213	39,940	37,914	49,605	26,979	30,048	48,466	62,344	62,165	33,012	8,213	39,868	62,344
0.90	7,757	37,721	35,808	46,849	25,480	28,379	45,773	58,880	58,711	31,178	7,757	37,654	58,880
0.95	7,348	35,736	33,923	44,383	24,139	26,885	43,364	55,781	55,621	29,537	7,348	35,672	55,781
1.00	6,981	33,949	32,227	42,164	22,932	25,541	41,196	52,992	52,840	28,060	6,981	33,888	52,992

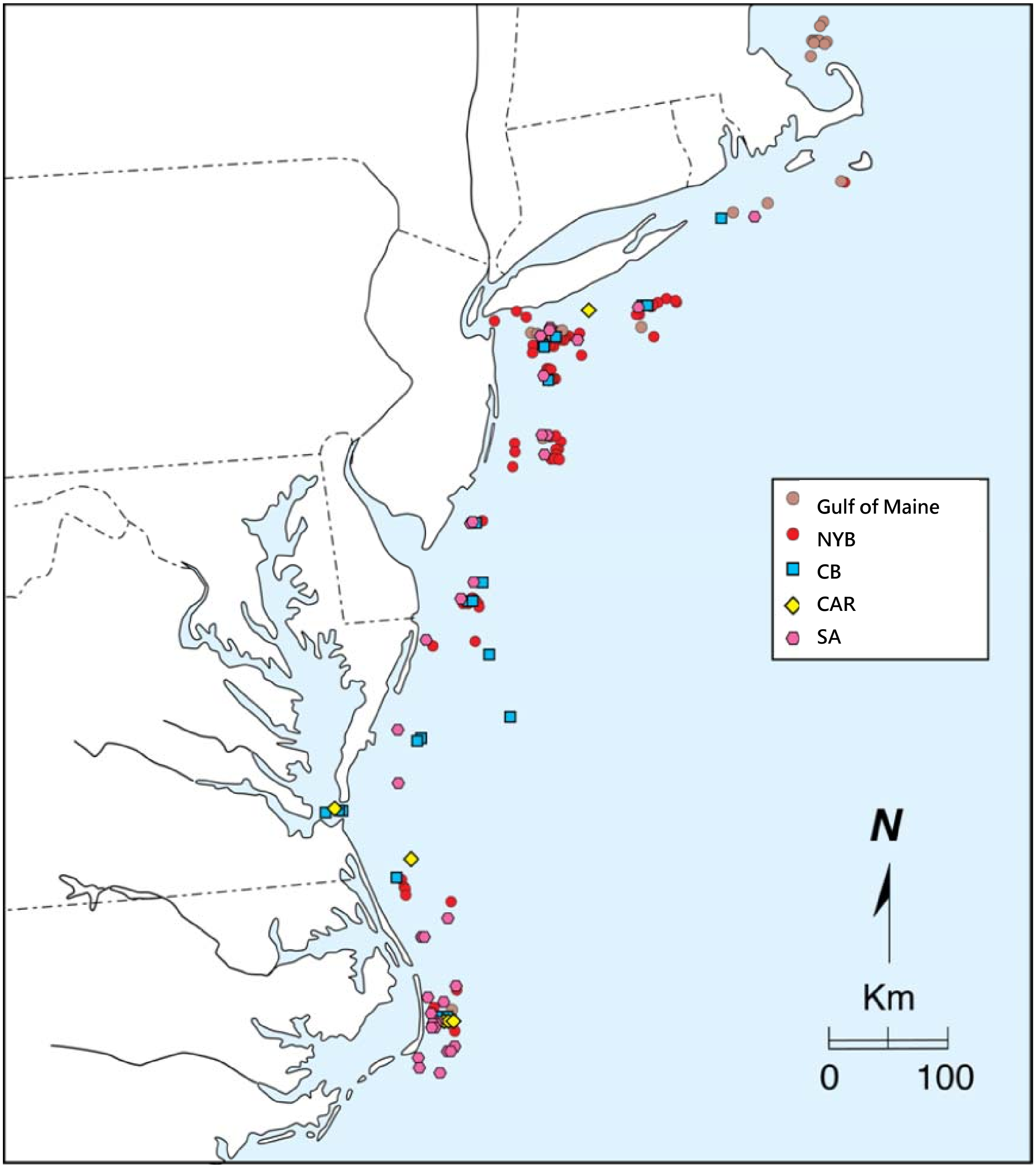


Figure 1. Capture locations and DPS of origin assignments from genetic analysis of NEFOP Atlantic sturgeon specimens (n=173); DPSs are Gulf of Maine, New York Bight (NYB), Chesapeake Bay (CB), Carolina (CAR), and South Atlantic (SA). Map provided by Dr. Isaac Wirgin (New York University).

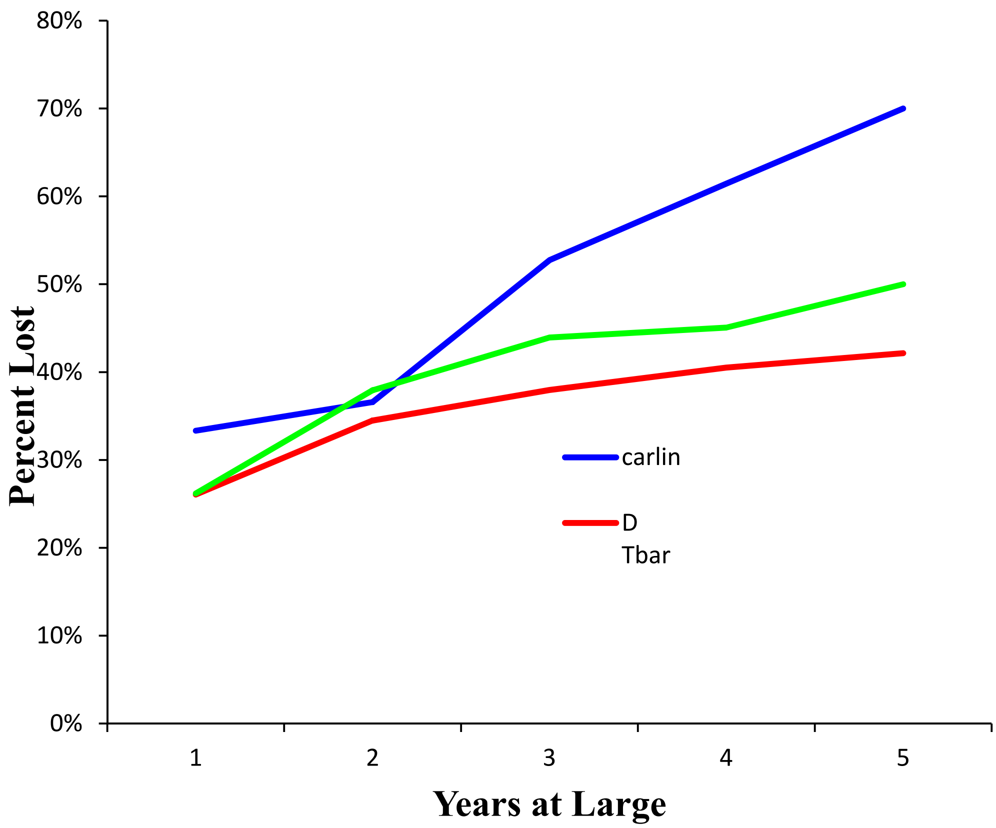


Figure 2. Proportion of Atlantic sturgeon tags shed, by tag type.

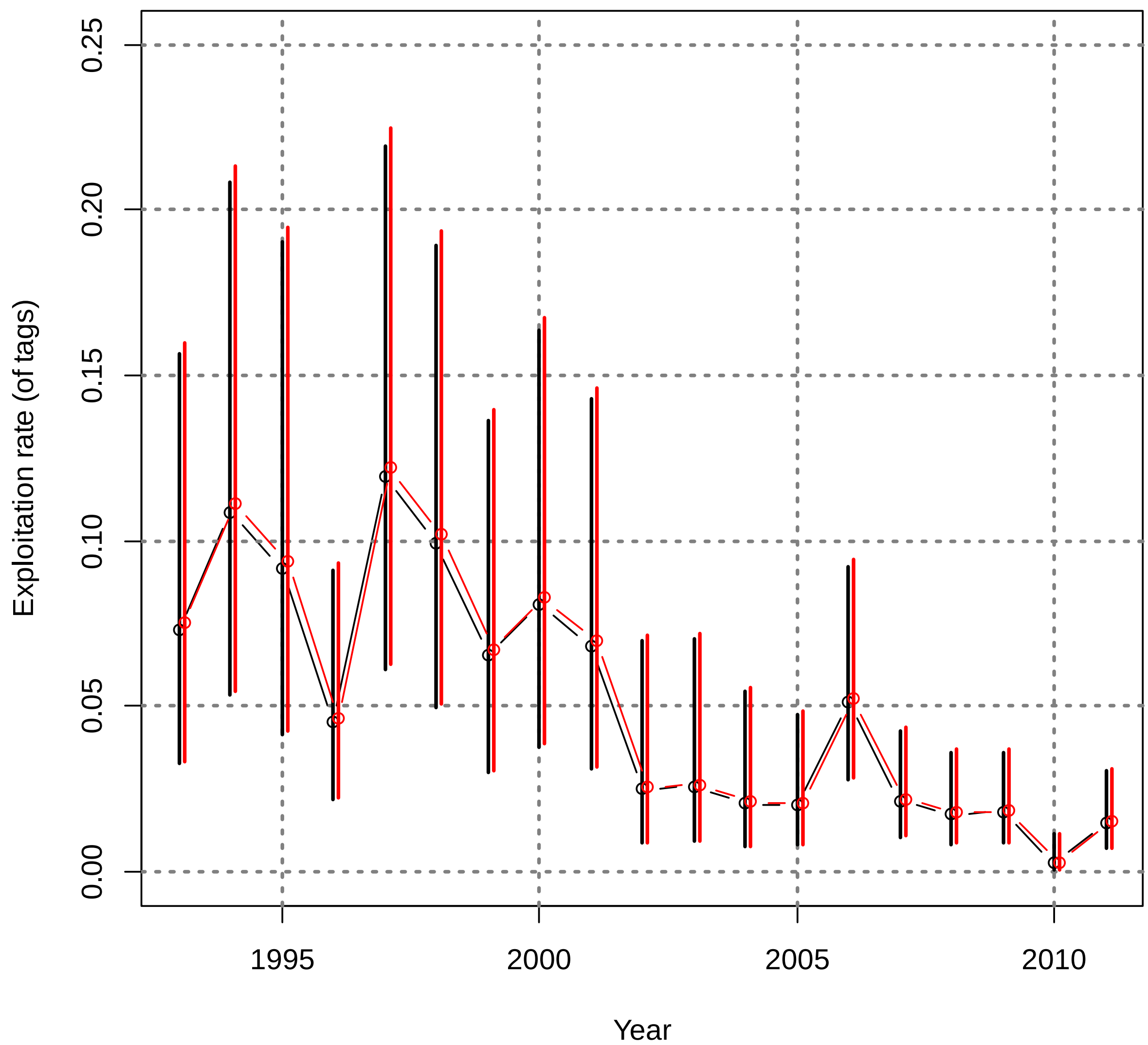


Figure 3. Estimates of annual exploitation rates of Atlantic sturgeon from tag-recovery data for releases of sturgeon less than 150 cm (black) and greater than 150 cm (red). Vertical lines are 95% confidence intervals.

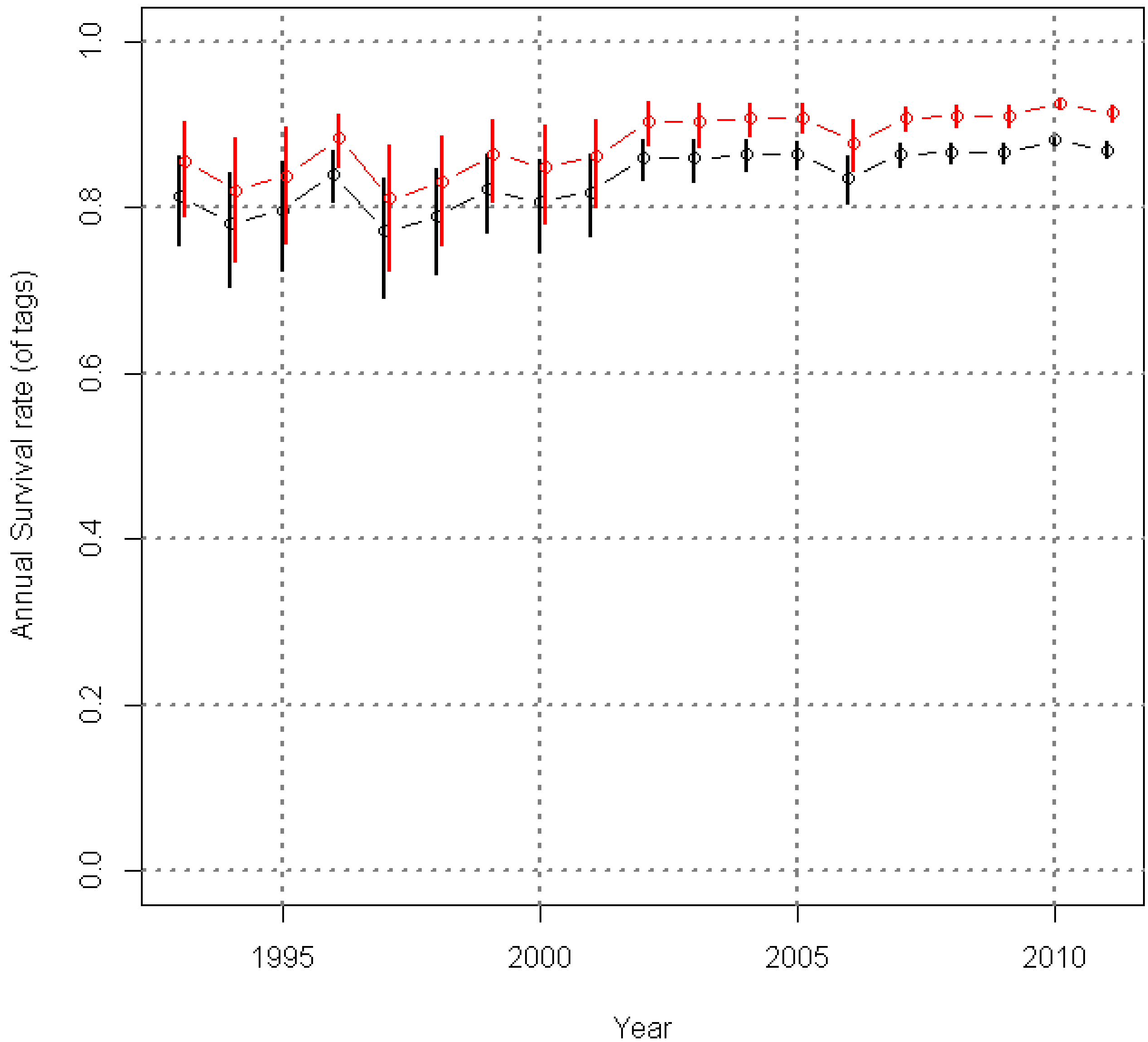


Figure 4. Estimates of annual survival rates of Atlantic sturgeon from tag-recovery data for releases of sturgeon less than 150 cm (black) and greater than 150cm (red). Vertical lines are 95% confidence intervals.

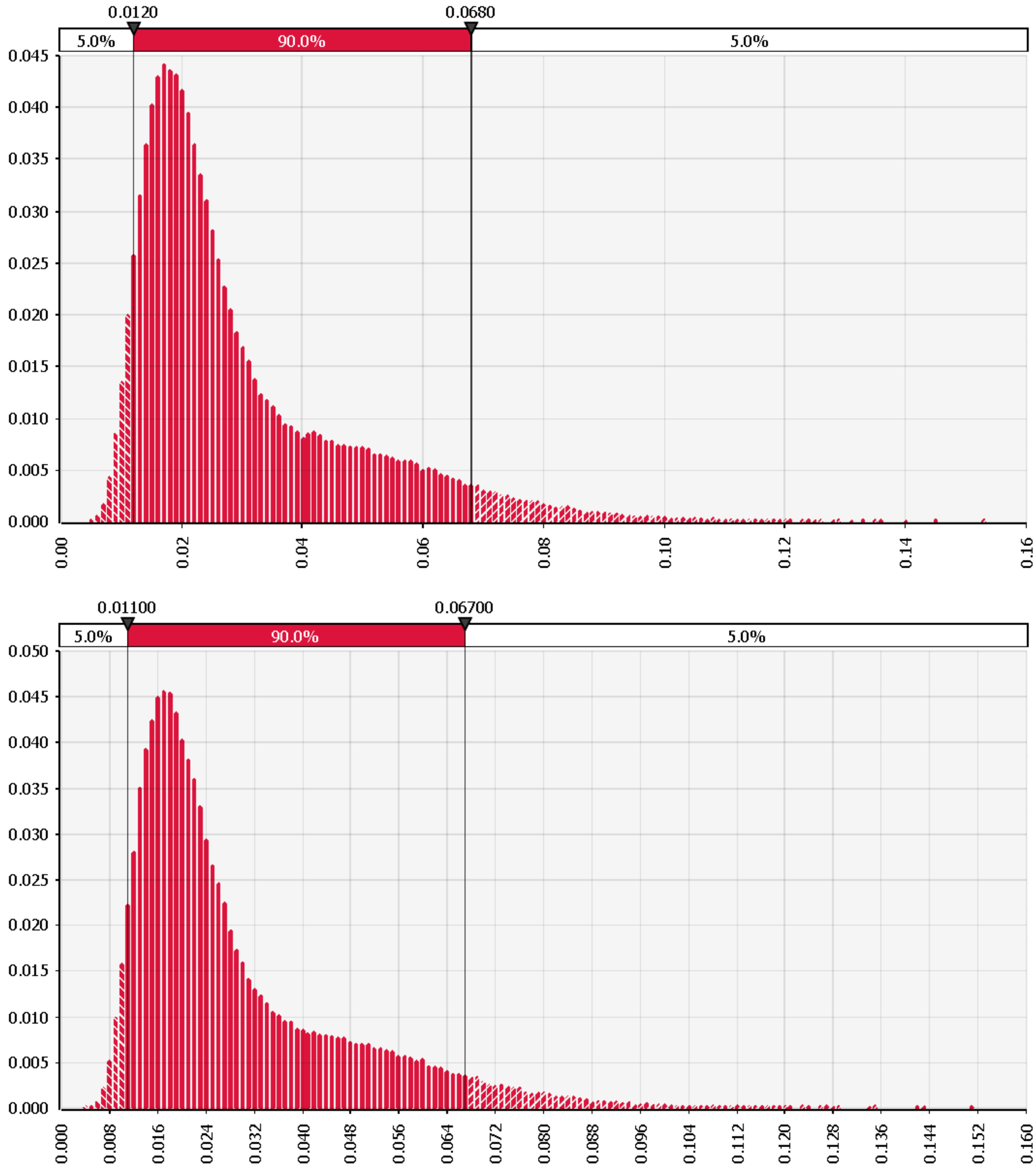
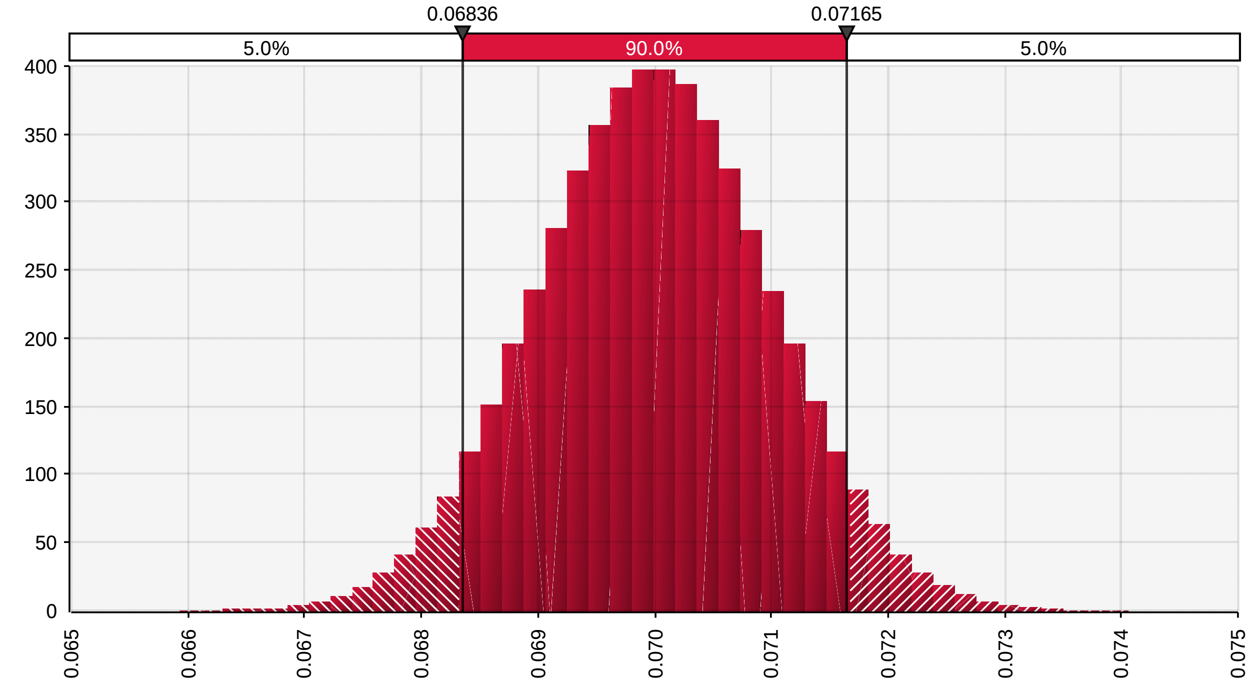


Figure 5. The output distribution of exploitation rates for subadult (sm) and adult (lg) Atlantic sturgeon, with means and standard deviation provided by the estimates and standard errors from the tag-recovery model.

A



B

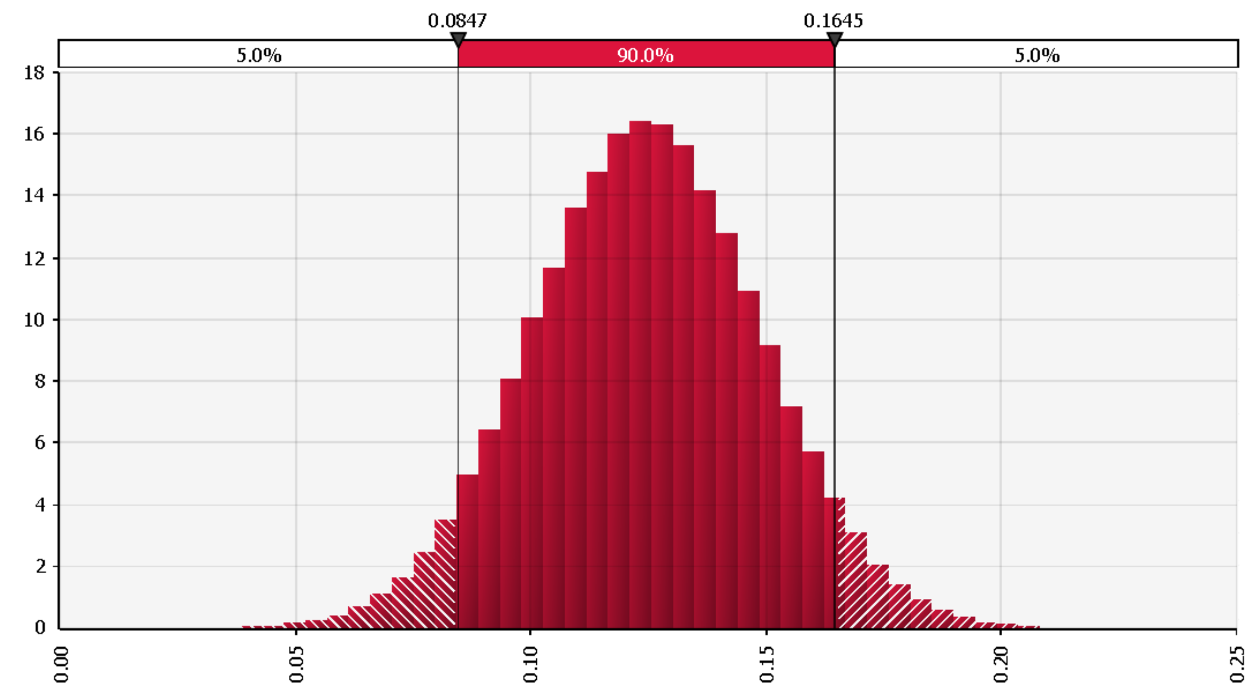


Figure 6. Input distribution for (A) subadult and (B) adult Atlantic sturgeon natural mortality rates (Kahnle *et al*. 2007).

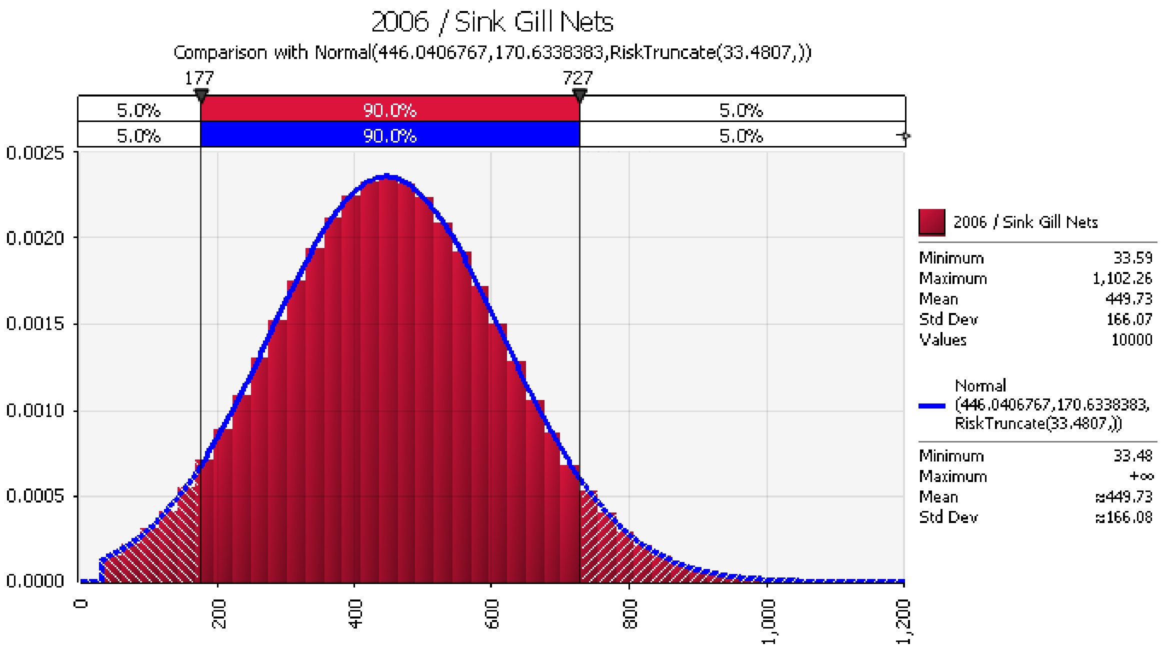


Figure 7. Example uncertainty analyses for estimates of gillnet bycatch of Atlantic sturgeon in 2006. The blue line represents the target distribution which, in this example, is RiskNormal (mean, SD, RiskTruncate(min)) where the mean (446.0) and SD (95.2) are values from Miller and Shepherd (2011) and Table 1. The minimum is truncated (33.6) by observed bycatch as a lower bound.

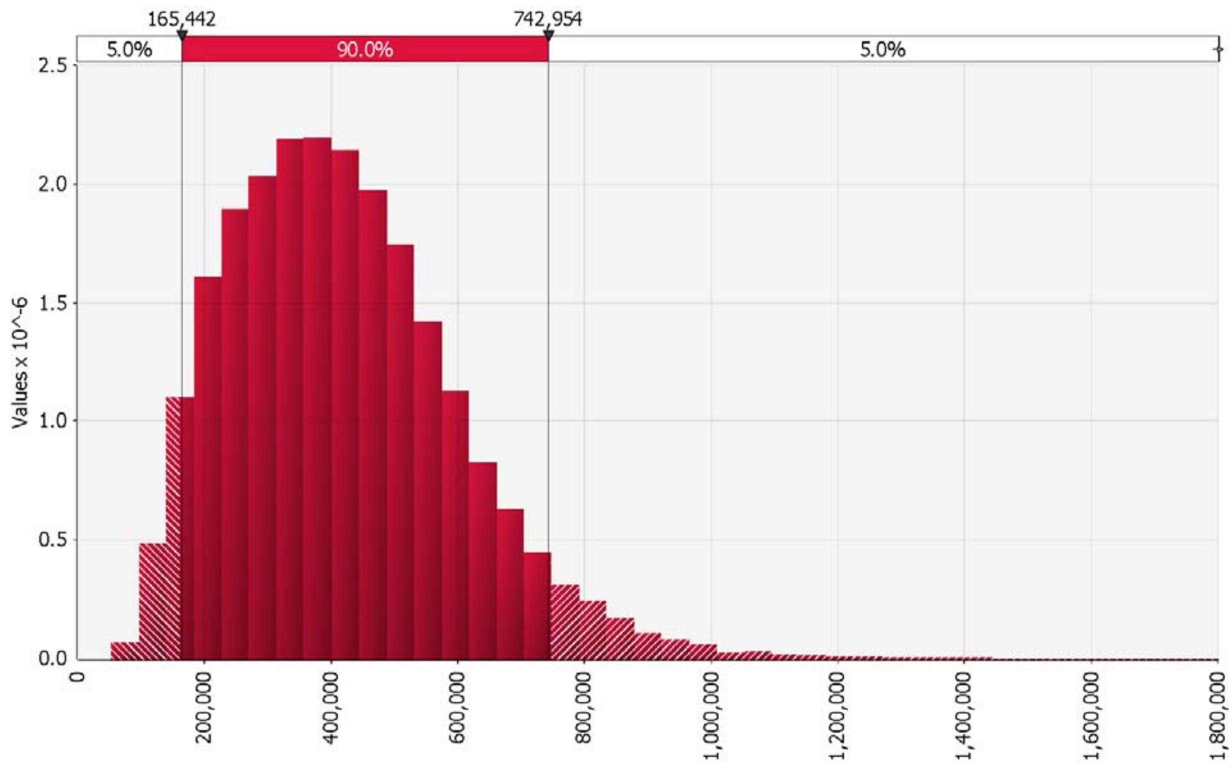


Figure 8. Frequency distribution of the ASPI ocean population of Atlantic sturgeon based on 10,000 simulations of the ASPI model.

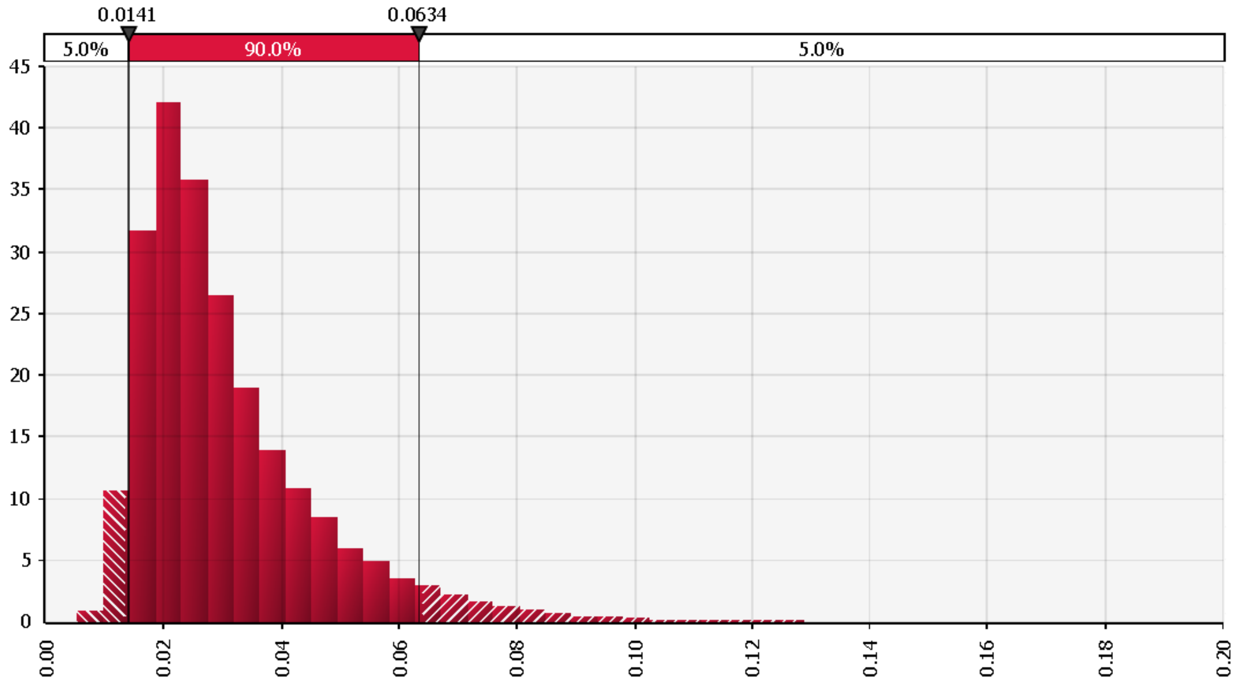


Figure 9. Frequency distribution of ratio of the average batched ocean mortalities (2006-2010) of Atlantic sturgeon to the ASPI ocean population estimate from 10,000 simulations.

APPENDIX A. MODEL-BASED ESTIMATION OF ATLANTIC STURGEON BYCATCH

Here we have provided a portion of the report by Miller and Shepherd (2011) that pertains to estimation of the total discards by trawl and gillnet gear for 2006 – 2009.

Miller and Shepherd (2011) fit a set of quasi-Poisson generalized linear models to observer trip data with number of sturgeon takes as the response and where an FMP was retained, year and quarter were potential explanatory factors. Separate sets of models were fit to trips using gillnet and otter trawl gear. The general model for the log-mean take on trip i is

$$\ln\left(\hat{T}_i\right) = \hat{\beta}_0 + \hat{\beta}_1 X_{1i} + \cdots + \hat{\beta}_p X_{pi}$$

where $\hat{\beta}$ are the estimated coefficients and $X_{1i}, \ldots, X_{pi}$ are the covariates that represent FMP, year, quarter and any interactions. For gillnet gear, the best performing model of those fitted to the trip specific data based on $\mathrm{QAIC_c}$ was a model that allowed yearly effects of the FMPs on sturgeon take. For other trawl gear, the best performing model of those fitted to the trip specific data based on $\mathrm{QAIC_c}$ was a model that allowed quarterly effects of the FMPs on sturgeon take.

To predict sturgeon take for all landings, the same covariates on VTR trips were used to make predictions for all VTR trips in a given subset of effort (e.g., year, quarter, gear type). The predictions are made using the anti-log of the same equation above, but where the covariates are for VTR trip i. The total discard estimates are the sum of all the model predictions in year y

$$\hat{T}_y = \sum_{i=1}^{N_y} \hat{T}_{y,i} \ .$$

Variance estimation for total discards

Let $\hat{\boldsymbol{\beta}}$ be the $p \times 1$ vector of coefficients estimated from the best fitted model (trawl or gillnet) and $\hat{\mathbf{V}}$ ($p \times p$) be the estimated covariance matrix of the estimated coefficients (p is the number of estimated coefficients). Also, let $\mathbf{X}_y$ be the $n_y \times p$ matrix of covariates for the VTR trips in year y where n_y is the number of trips. Then the log estimated predictions for the n_y VTR trips is $\log\left(\hat{\mathbf{T}}_y\right) = \mathbf{X}_y \hat{\boldsymbol{\beta}}$ and the estimated takes are $\hat{\mathbf{T}}_y = e^{\mathbf{X}_y \hat{\boldsymbol{\beta}}}$. The $n_y \times n_y$ covariance matrix for the log predictions is

$$\hat{\mathbf{V}}_{\log\left(\hat{\mathbf{T}}_y\right)} = \mathbf{X}_y \hat{\mathbf{V}} \mathbf{X}'_y$$

and the approximate (delta method) covariance matrix for the estimated takes is

$$\hat{\mathbf{V}}_{\hat{\mathbf{T}}_y} = \hat{\mathbf{T}}_y \hat{\mathbf{T}}'_y \circ \hat{\mathbf{V}}_{\log\left(\hat{\mathbf{T}}_y\right)}$$

where $\mathbf{X} \circ \mathbf{Y}$ is the Hadamard (element-wise) product of matrices $\mathbf{X}$ and $\mathbf{Y}$. The variance of the total take estimate for year y is just the sum of all n_y^2 elements of $\hat{\mathbf{V}}_{\hat{\mathbf{T}}_y}$:

$$\hat{V}\left(\hat{T}_y\right) = \mathbf{1}'_y \hat{\mathbf{V}}_{\hat{\mathbf{T}}_y} \mathbf{1}_y \ .$$

where $\mathbf{1}_y$ is a $n_y \times 1$ vector of ones. Confidence intervals are based on standard errors (square root of variance) and approximate normality of the point estimates.

APPENDIX B. SWEPT AREA CALCULATION METHOD

(*Information provided by Dr. Chris Bonzek, Virginia Institute of Marine Science).*

The NEAMAP survey uses tow-by-tow net measurements to calculate catch per square meter as the base metric in the calculation. That is, the (tow distance) x(wingspread) measurement on tow X is the denominator for number per unit area on tow X. Tow distance is calculated as a sum from moment-by-moment recordings of location (i.e. not straight-line distance from beginning and ending coordinates). For those tows where either a sensor malfunction or GPS malfunction results in missing data, average figures for the particular cruise are substituted. Swept area abundance is calculated as the sum of abundances in each stratum. Tow and net measurement stats are in the table below. These figures are summarized from 1,520 tows to date. Net height does not (currently) enter into swept-area calculations but is included here to help demonstrate the consistent way in which the net fishes. The total survey area is 12,135.27 square km.

	Tow Distance (m)	Wingspread (m)	Net Height (m)
Mean	1856.1	13.52	5.4
Min	1098.2	11.2	3.2
Max	2585.3	15.24	6.75
Std. Dev.	139.3	0.46	0.26

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