NATIONAL MARINE FISHERIES SERVICE
ENDANGERED SPECIES ACT SECTION 7
BIOLOGICAL OPINION

Title:	Biological Opinion on the Environmental Protection Agency's Approval of Georgia's proposed water quality criteria for Cadmium
Consultation Conducted By:	Endangered Species Act Interagency Cooperation Division, Office of Protected Resources, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce
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1 INTRODUCTION

The Endangered Species Act of 1973, as amended (ESA; 16 U.S.C. 1531 et seq.) establishes a national program for conserving threatened and endangered species of fish, wildlife, plants, and the habitat they depend on. Section 7(a)(2) of the ESA requires Federal agencies to insure that their actions are not likely to jeopardize the continued existence of endangered or threatened species or adversely modify or destroy their designated critical habitat. Federal agencies must do so in consultation with National Marine Fisheries Service (NMFS) for threatened or endangered species (ESA-listed), or designated critical habitat that may be affected by the action that are under NMFS' jurisdiction (50 C.F.R. §402.14(a)). If a Federal action agency determines that an action "may affect, but is not likely to adversely affect" endangered species, threatened species, or designated critical habitat (a not likely to adversely affect determination - NLAA) and NMFS concurs with that determination for species under NMFS' jurisdiction, consultation concludes informally (50 C.F.R. §402.14(b)).

When consultation is not concluded informally, section 7(b)(3) of the ESA requires that, at the conclusion of consultation, NMFS provide an opinion stating whether the Federal agency's action is likely to *jeopardize the continued existence* of an ESA-listed species or result in *destruction or adverse modification* of designated critical habitat. Specifically:

"Jeopardize the continued existence" means to engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of an ESA-listed species in the wild by reducing the reproduction, numbers, or distribution of that species." 50 CFR 402.02.

"Destruction or adverse modification" Destruction or adverse modification means a direct or indirect alteration that appreciably diminishes the value of critical habitat as a whole for the conservation of a listed species (84 FR 44976).

If NMFS determines that the action is likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of designated critical habitat, NMFS provides a reasonable and prudent alternative that allows the action to proceed in compliance with section 7(a)(2) of the ESA. If incidental take is expected, with or without RPAs, ESA section 7(b)(4) requires NMFS to provide an incidental take statement that specifies the impact of any incidental taking and includes reasonable and prudent measures (RPMs) to minimize such impacts and terms and conditions to implement the RPMs.

Updates to the regulations governing interagency consultation (50 CFR part 402) were effective on October 28, 2019 [84 FR 44976]. This consultation was pending at that time, and we are applying the updated regulations to the consultation. As the preamble to the final rule adopting the regulations noted, "[t]his final rule does not lower or raise the bar on section 7 consultations, and it does not alter what is required or analyzed during a consultation. Instead, it improves clarity and consistency, streamlines consultations, and codifies existing practice." We have reviewed the information and analyses relied upon to complete this biological opinion in light of the updated regulations and conclude the opinion is fully consistent with the updated regulations.

The action agency for this consultation is the United States Environmental Protection Agency (EPA). The EPA's action under consideration is to approve water quality criteria for cadmium proposed by the Georgia Department of Natural Resource, Environmental Protection Division (Georgia EPD), pursuant to Section 303(c) of the Clean Water Act, 33 U.S.C. §1313(c).

This biological opinion, and accompanying incidental take statement, was prepared by the NMFS Office of Protected Resources Endangered Species Act Interagency Cooperation Division ("We") in accordance with ESA section 7(a)(2) (16 U.S.C. 1536(a)(2)), associated implementing regulations (50 C.F.R. Part 402), and agency policy and guidance.

During consultation we considered the effects of EPA's approval of Georgia EPD's revision of ambient water quality criteria for cadmium on the following ESA-listed species and designated critical habitat; green; hawksbill; Kemp's ridley; leatherback; and loggerhead sea turtles; North Atlantic right whale; oceanic white tip shark; giant manta ray; smalltooth sawfish; shortnose and Southeast Atlantic DPS of the Atlantic sturgeon (hereafter Atlantic sturgeon in this opinion), and the designated critical habitat for Atlantic sturgeon, loggerhead sea turtle, and North Atlantic right whale.

NMFS concluded that the proposed action is NLAA green, hawksbill, Kemp's ridley, leatherback, and loggerhead sea turtles; North Atlantic right whale; oceanic white tip shark; giant manta ray; or smalltooth sawfish. The action is also not expected to adversely modify critical habitat designated for loggerhead sea turtle, North Atlantic right whale, or Atlantic sturgeon. Incidental take of shortnose and Atlantic sturgeon is anticipated. We include an incidental take statement (ITS) that specifies the impact of the take, RPMs to minimize the impact of the take, and terms and conditions to implement the RPMs. A complete record of this consultation is on file at the NMFS' Office of Protected Resources in Silver Spring, Maryland.

1.1 Background

EPA's authorities regarding water quality standards are contained in sections 303(c) and 304(a) of the Clean Water Act. Water quality standards consist of three components: (1) the designated uses of waters, which can include use for public water supplies, propagation of fish and wildlife, recreational, agricultural, industrial and other uses; (2) water quality criteria, expressed in numeric or narrative form, reflecting the condition of the water body that is necessary to protect its designated use, and (3) an antidegradation policy that protects existing uses and provides a mechanism for maintaining high water quality.

Under section 303(c) of the Clean Water Act, the development of water quality standards is primarily the responsibility of States and Tribes, with EPA exercising an oversight role. States and Tribes are required to review their standards every three years and any revisions or new standards must be submitted to EPA for approval. EPA approvals of these standards are Federal actions subject to consultation under section 7 of the ESA. Section 7 consultation is required if EPA determines that its approval of any of the standards may affect ESA-listed species or designated critical habitat.

Under section 304(a) of the Clean Water Act, EPA has published recommended water quality guidelines that serve as scientific guidance for use by States or Tribes in establishing and revising water quality criteria. These guidelines are not enforceable requirements, but are recommended pollutant concentration limits that States or Tribes may adopt as part of their legally enforceable water quality standards. States or Tribes may propose to adopt alternative scientifically defensible criteria instead of EPA's recommended water quality guidelines (see 40 CFR 131.11(b)). The state must obtain approval of these alternative criteria from EPA before they can be adopted for use.

Section 303(c) of the Clean Water Act contains time frames for EPA to review and either approve or disapprove water quality criteria submitted by a State or Tribe. Once EPA receives the criteria proposed by a state, the agency is required, under the Clean Water Act, to review and approve the criteria within 60 days or disapprove them within 90 days. If disapproved, EPA is required to promulgate the water quality criteria developed under 304(a) to supersede the disapproved State or Tribal criteria. In addition, section 303(c) authorizes EPA to promulgate Federal criteria whenever the Administrator determines that such criteria are necessary to meet the requirements of the Clean Water Act. Regulations implementing section 303(c) are codified at 40 CFR part 131.

1.2 Consultation History

On April 6, 2018, the Georgia EPD announced for public review and comment its proposed amendments to its cadmium aquatic life water quality criteria. The comment period ended May 28, 2018. Georgia EPD adopted the revised cadmium aquatic life water quality criteria on June 27, 2018.

On August 29, 2018, the NMFS received a letter from EPA Region 4 requesting Endangered Species Act section 7 technical assistance for the list of species and designated critical habitat within Georgia state-wide waters for the 2016 - 2018 water quality standards triennial review. NMFS responded via-e-mail on August 30, 2018 with the requested information and additional resources and advice. On October 10, 2018, NMFS transmitted data on cadmium toxicity that was extracted from EPA's ECOTOXicology database (ECOTOX) for use in EPA's biological evaluation (BE) assessment.

On December 21, 2019 NMFS received a request for concurrence and BE on EPA's approval of Georgia EPD's proposed cadmium criteria for marine waters only. The United States (U.S.) Government shut down on December 22, 2018 due to a lack of appropriations and remained closed until January 25, 2019. On February 4, 2019 NMFS acknowledged receipt of the request and on February 28, 2019, NMFS requested that EPA provide a BE for cadmium effects on sturgeon in freshwaters because NMFS, not the U.S. Fish and Wildlife Service, has jurisdiction over shortnose and Atlantic sturgeon in freshwaters. On May 3, 2019 NMFS contacted EPA to determine whether the agency wanted to withdraw the consultation request. EPA responded that Georgia's package was still under review and updates to the BE were underway. NMFS received an updated BE on June 17, 2019.

Two issues were identified by NMFS after review of the BE: Standard method analytical limits were potentially too high to quantify cadmium at the proposed criteria in soft waters and Georgia EPD's proposed criteria applied the National Guideline criterion concentrations differently than recommended in the guidelines and as assessed in the BE. Requests for additional information and clarification over a series of e-mails did not adequately resolve the matter. This is summarized below:

EPA reported that Georgia EPD includes the following as boilerplate language in all permits: "All analytical methods, sample containers, sample preservation techniques, sample holding times must be consistent with the techniques and methods listed on 40 CFR Part 136. The analytical method used shall be sufficiently sensitive. EPA-approved methods must be applicable to the concentration ranges of the National Pollutant Discharge Elimination System (NPDES) permit samples." However, there are no EPA-approved methods that have method analytical limits that are low enough to quantify cadmium at criteria applicable to soft waters. This means compliance beyond a mixing zone cannot be reliably confirmed and cadmium impairments of soft receiving waters cannot be detected.

EPA also recommended the NMFS review online information to clarify why Georgia's application of the criteria is considered equivalent to the national guidelines. However, this resource indicated that 65 percent of rivers would exceed the criteria more frequently than recommended under the National Guidelines if the criteria were applied in the manner Georgia proposed.

On August 9, 2019, NMFS informed EPA by letter that a formal consultation was required for EPA's approval of Georgia EPD's proposed cadmium criteria, requesting that EPA provide a determination based on the criteria as applied by Georgia and that EPA provide its perspective on the problem posed by analytical limits that are not sufficiently sensitive to evaluate monitoring data against hardness-based criteria for soft waters. EPA responded on September 17, 2019 with a letter restating that NPDES implementation was not within EPA's discretion. A conference call on Monday September 23, 2019 provided information on how Georgia determined whether NPDES permits require cadmium limits from a representative of EPA's NPDES program. NMFS again requested information on how cadmium is regulated in soft waters when EPA standard methods cannot quantify cadmium at the criterion. NMFS also requested EPA either re-assert their NLAA conclusion or come to a "may affect, likely to adversely affect." These requests were repeated in an e-mail sent to EPA after the call indicating that consultation could not initiate until these two requests were fulfilled.

On October 9, 2019, EPA sent an email indicating that if an NPDES application contained non-detects using 40 CFR 136 methods, then the permitting authority would presume reasonable potential to exceed criteria does not exist, and there would be no monitoring and reporting or limits. If detected and > 50 percent of instream calculated criteria, then Georgia EPD would implement its state rule requiring 10 additional monthly samples to confirm reasonable potential and then limit if appropriate. The message also stated that it is the EPA's position that the updates to Georgia's cadmium chronic and acute criteria are identical to the nationally recommended criteria and EPA's review only covers the numeric equation change.

2 THE ASSESSMENT FRAMEWORK

Section 7(a)(2) of the ESA requires Federal agencies, in consultation with NMFS, to ensure that their actions are not likely to jeopardize the continued existence of endangered or threatened species; or adversely modify or destroy their designated critical habitat. Accordingly, the analysis in this opinion evaluates whether the proposed action would directly, or indirectly, adversely affect individual survival or fitness such that the continued existence of ESA-listed populations or species would be jeopardized, or that designated critical habitat necessary for the conservation of ESA-listed species would be adversely modified or destroyed.

This opinion is structured as follows:

Description of the Proposed Action (Section 3): We describe the proposed action and those aspects (or stressors) of the proposed action that may have direct or indirect effects on the physical, chemical, and biotic environment. This includes subsections on the ***Stressors of the Proposed Action*** (Section 3.1) and ***Conservation Measures to Minimize or Avoid Exposure*** (Section 3.2).

Action Area (Section 4): Action area means all areas to be affected directly or indirectly by the Federal action and not merely the immediate area involved in the action. (50 CFR 402.02). In this section we describe the action area with the spatial extent of those stressors that may have effects on the physical, chemical, and biotic environment.

Species with Ranges and Designated Critical Habitat that Overlap the Action Area (Section 5): Lists the ESA-protected species and designated critical habitat potentially affected by stressors of the action in the action area.

Shared Jurisdiction with the U.S. Fish and Wildlife Service (Section 5.1): Identifies those species that overlap with the action area, but are not subject to this consultation due to NMFS' partial jurisdiction (e.g., sea turtle effects occurring in nesting areas, Gulf sturgeon in freshwater habitat).

Species and Designated Critical Habitat that are Not Likely to be Adversely Affected (Section 5.2): We use two criteria to identify the ESA-listed species or designated critical habitat that are not likely to be adversely affected by the proposed action: exposure to stressors of the action and the probability of response given an exposure. If we conclude that an ESA-listed species or designated critical habitat is not likely to be exposed to the stressors of the action, or, if exposed, is not likely to respond, we must also conclude that the species or designated critical habitat is not likely to be adversely affected by those activities and will make an NLAA determination.

Subsections identify the ***Exposure and Response Considerations*** used to identify those species that do not require further analysis in the opinion. The following sections apply these considerations to identify ***Species that are Not Likely to be Exposed to Waters Affected by the Action*** and ***Species and Essential Elements of Critical Habitat that are Not Likely to Respond to Stressors of the Proposed Action***.

Status of Species and Designated Critical Habitat Addressed in this Opinion (Section 5.3): Applies the risk hypotheses to evaluate the adverse effects of the action on ESA-listed species and designated critical habitat under NMFS' jurisdiction that are likely to respond to cadmium at the criteria. If adverse effects are indicated for individuals or the essential features, we evaluate whether those responses would affect populations or subpopulations of species or the designated critical habitat (Risk Analysis, Section 7.3).

Environmental Baseline (Section 6): We describe the environmental baseline in the action area where potentially adversely affected species occur. The baseline refers to the condition of the listed species or its designated critical habitat in the action area, without the consequences to the listed species or designated critical habitat caused by the proposed action. The environmental baseline includes the past and present impacts of all Federal, State, or private actions and other human activities in the action area, the anticipated impacts of all proposed Federal projects in the action area that have already undergone formal or early section 7 consultation, and the impact of State or private actions which are contemporaneous with the consultation in process. The consequences to listed species or designated critical habitat from ongoing agency activities or existing agency facilities that are not within the agency's discretion to modify are part of the environmental baseline.

Effects of the Action (Section 7): The effects of the action are all consequences to listed species or critical habitat that are caused by the proposed action, including the consequences of other activities that are caused by the proposed action. A consequence is caused by the proposed action if it would not occur but for the proposed action and it is reasonably certain to occur. Effects of the action may occur later in time and may include consequences occurring outside the immediate area involved in the action.

Cumulative Effects *(*Section 8): Cumulative effects are the effects to ESA-listed species and designated critical habitat of future state or private activities that are reasonably certain to occur within the action area. 50 CFR 402.02. Effects from future Federal actions that are unrelated to the proposed action are not considered because they require separate ESA section 7 compliance.

Integration and Synthesis *(*Section 9): In this section, we add the effects of the action and cumulative effects to the environmental baseline and in light of the status of the species and critical habitat, formulate the Service's opinion as to whether the action is likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of critical habitat.

Conclusion *(*Section 10): With full consideration of the status of the species and the designated critical habitat, we consider the effects of the action within the action area on populations or subpopulations and on essential habitat features when added to the environmental baseline and the cumulative effects to determine whether the action could reasonably be expected to:

1) Reduce appreciably the likelihood of survival and recovery of ESA-listed species in the wild by reducing its numbers, reproduction, or distribution, and state our conclusion as to whether the action is likely to jeopardize the continued existence of such species; or
2) Appreciably diminish the value of designated critical habitat for the conservation of an ESA-listed species, and state our conclusion as to whether the action is likely to destroy or adversely modify designated critical habitat.

If, in completing the last step in the analysis, we determine that the action under consultation is likely to jeopardize the continued existence of ESA-listed species or destroy or adversely modify designated critical habitat, then we must identify Reasonable and Prudent Alternatives (RPAs) to the action or indicate that to the best of our knowledge there are no RPAs. See 50 C.F.R. § 402.14.

Incidental Take Statement (Section 11); An incidental take statement is provided that specifies the amount or extent of take and proposes either RPAs to the action that will avoid take or RPMs to minimize the impact of the take. Implementation of the RPMs is specified in the ***Terms and Conditions*** (ESA section 7(b)(4); 50 CFR 402.14 (i)). We also provide discretionary ***Conservation Recommendations*** that may be implemented by EPA (50 CFR 402.14 (j)). Finally, in the ***Reinitiation Notice*** (Section 11.6) we identify the circumstances in which reinitiation of consultation is required (50 CFR 402.16).

2.1 Information Used in this Assessment

To comply with our obligation to use the best scientific and commercial data available, we collected information identified through searches of Web of Science, scientific publisher databases (e.g., Elsevier), government databases (e.g., EPA's National Service Center for Environmental Publications), and literature cited sections of peer reviewed articles, species listing documentation, and reports published by government and private entities. This opinion is based on our review and analysis of various information sources, including:

- EPA's BEs for Georgia EPD's proposed cadmium criteria
- data from Georgia's Online Monitoring and Assessment database (GOMAS) database, the National Water Quality Monitoring Councils' Water Quality Portal, and EPA's ECOTOX database

- government scientific publications, including status reviews, recovery plans, and listing notices for ESA-listed species and designated critical habitat
- reports on the status and trends of water quality, and
- the best available commercial and scientific information, including peer reviewed research.

These resources were used to identify information relevant to the potential stressors and responses of ESA-listed species and designated critical habitat under NMFS' jurisdiction that may be affected by the proposed action to draw conclusions on risks the action may pose to the continued existence of these species and the value of designated critical habitat for the conservation of ESA-listed species.

Data Collection and Screening

The ECOTOX data search targeted cadmium exposures expressed in units of mg/L, for fish, aquatic invertebrates, and aquatic plants and algae. Data for species that do not have reproducing populations in the United States were included in this analysis. This is consistent with the Stephen et al. (1985) Guidelines for Deriving Numerical National Water Quality Criteria. The guidelines indicate that data obtained with non-resident species may be used to provide auxiliary information but should not be used to develop a criterion. Our purpose is not to derive criteria but to determine whether ESA-listed species are likely to respond to cadmium exposures at the proposed criteria concentrations or at concentrations resulting from Georgia EPD's application of those criteria.

Not all cadmium data obtained from ECOTOX were used in the analysis. Data reported only as labile cadmium (i.e., free ion) were excluded because a conversion factor for converting labile cadmium to dissolved cadmium criterion is not available. The data used in this analysis includes studies reporting cadmium exposure concentrations confirmed through chemical analysis and studies reporting nominal concentrations calculated from the amount of cadmium added to the stock solution used to make exposure solutions. Studies reporting nominal concentrations were included to retain data for exposures of smaller organisms where the exposure volumes can be too small for analysis. Entries for freshwater exposures that did not include data on hardness were not included because the applicable cadmium criterion for those exposure conditions could not be calculated. Studies that did not include a control exposure or for which control data were unacceptable were excluded, as were studies where test organisms were pre-exposed to cadmium (i.e., acclimation studies), were collected from cadmium-polluted waters, studies in which only one cadmium concentration was used and those studies where the exposure concentrations or durations were expressed as broad ranges, with the maximum in the range more than three-fold the minimum value.

Interpreting the Data

Interpreting toxicity test data is made challenging by the tremendous amount of diversity in the screened ECOTOX data used in this assessment. For example, the dataset for fish includes 71 species, 20 different life stages, over 60 types of effects tested in more than 100 different water hardness values over more than 100 exposure durations. The dataset is not "balanced" such that each species has been tested at each life stage for each response under each specific exposure scenario (e.g., duration, hardness, etc.). The most abundant data are for mortality in standard laboratory species, specifically the concentration killing half of exposed organisms or LC50s, for the four day tests used in deriving acute criteria. None of these data are for exposures of shortnose or Atlantic sturgeon. More than half of the screened ECOTOX data for cadmium effects in fish are for rainbow trout (N=574) and fathead minnow (N=214). In addition, saltwater exposures are particularly sparse, among the 1,348 screened ECOTOX data entries for fish, only 186 are for saltwater exposures. Limiting the data to a narrow set of toxicity test types to simplify the analysis would only result in lost information.

Using the available data to assess the implications of exposures under the chronic and acute criteria, as applied by Georgia EPD, will not mirror how data are used for deriving the criteria. Deriving criteria is a very different goal from evaluating criteria for protectiveness of imperiled species. Since exposure at the acute criterion concentrations is not expected to extend beyond one day (acute low flow conditions), the acute criterion concentration is assessed using toxicity data for exposures of one day or less. Similarly, the chronic criterion concentration is assessed using data for exposures lasting up to seven days (chronic low flow conditions). Data reported for exposures greater than seven days do not inform an evaluation of the criteria as they are applied by Georgia EPD, but do provide additional information on whether effects may occur at the criterion concentrations.

Endpoints

The database identifies endpoints for the concentration killing or affecting a proportion, typically 50 percent, of exposed organisms. Data identified as an EC50 or LC50 is the concentration affecting or lethal to half of the exposed organisms, respectively. However, an exposure in which half of exposed organisms die or are otherwise affected is clearly not an acceptable outcome and is not suitable for evaluating the protectiveness of criteria. The EPA BE used a rule of thumb that one half an LC50 is an exposure concentration expected to kill few, if any individuals. However, a more common pattern with the metals data was that an LC50/2 concentration would probably result in about a 5 percent death rate (NMFS 2012). This is an unacceptable outcome for imperiled species. The EPA Office of Pesticide Programs uses a risk quotient approach when using LC50s to assess the ecological risk of estimated pesticide exposures (EPA 2004). A risk quotient is the estimated pesticide exposure divided by the LC50. For nontarget aquatic animals, a risk quotient greater than 0.5 warrants concern. For threatened and endangered animals, a risk quotient of greater than 0.05 is of concern. For vetting a criterion, the criterion concentration can be substituted the estimated pesticide exposure. This "bright line" approach has limited use in making a determining of whether a criterion is protective because it doesn't capture the variation around that LC50 estimate, the depth and quality of the data available to assess the criterion, or the implications on survival rates for exposures that occur at the criterion. Risk quotients are used as screening references to draw attention to observations that suggest whether adverse effects may occur at or below exposures that are compliant with proposed criteria.

Effects are also reported in ECOTOX as other fractional response (e.g., EC10, LC20) and in terms of the lethal threshold at which would mortality first occur (LETC), the highest exposure concentration that did not differ significantly from controls, the no observed effects concentration (NOEC), and the lowest concentration that differed significantly from controls, the lowest observed effect concentration (LOEC). The NOECs and LOECs are not ideal measures of effects because they are influenced by study design (e.g., distribution and number of concentrations tested). Depending on exposures tested and underlying variability in responses, the LOEC may actually result in a 30 percent difference in response from controls. Data are not equally available for all types of endpoints or responses and can vary widely due to differences in the life stages of the organisms used and the study design (e.g., exposure duration, flow through versus static exposures). In addition, the same exposure concentration may be reported as the NOEC for one type of response, such as growth, and as the LOEC for another, such as reproduction. This analysis considered these factors when using LOEC and NOEC data. In cases where the lowest reported NOEC is greater than the criterion and indicates a response magnitude that is considered biologically insignificant, we expect that responses in ESA-listed species exposed at or below criterion will be insignificant or are unlikely to occur. Where NOECs are not available, the magnitude of effect at the LOEC is taken into consideration similarly to the evaluation of the criterion using NOECs.

Data indicating responses occurring at or below the criterion concentration, or NOEC data for which the magnitude of response is not reported, may yet suggest insignificant effects, taking into consideration the type of response, abundance of data indicating effects would not occur, diversity of the species represented in the dataset, study quality, and the speed at which a toxicant is expected exert effects relative to the averaging time for the criterion (i.e., 1 hour for the EPA acute guideline, 1 day for 1Q10). For example, some chemicals act rapidly and responses to exposures happen within a matter of a few hours, but only in those individuals susceptible to the chemical, thereafter the exposure-response relationship plateaus. In such cases, the LC50 concentration at 6 hours exposure could be the same as the LC50 at 96 hours exposure. EPA specified averaging times for its national water quality guidelines that are shorter than the exposure durations used in the toxicity tests used to derive the guidelines in order to restrict allowable fluctuations in the concentration of the pollutant in the receiving water and to restrict the length of time that the concentration in the receiving water can be continuously above the guideline (Stephen et al. 1985).

Normalizing Responses in Freshwater Exposures to a Standard Water Hardness

For the analysis of the freshwater criteria, toxicity data from ECOTOX were normalized to the hardness at which EPA method 200.8 would be able to detect cadmium at the chronic guideline concentration. Waters with a hardness of 18 mg/L $CaCO_3$ require a chronic cadmium criterion of 0.2 µg/L, which is equivalent to the method detection limit for EPA standard method 200.8. This allows ready identification of responses occurring at exposures that would not be identified in regulatory practice. The equations for adjusting freshwater response data to water hardness are a rearrangement of the equations used to calculate the freshwater hardness-based criteria (EPA 2019). They are:

$$\text{Acute}= e^{(\text{Log(response concentration) - (0.9789*(LogN(reported hardness) - LogN(target hardness))))}}$$

$$\text{Chronic}=e^{(\text{LogN(response concentration) - (0.7977*(LogN(reported hardness) - LogN(target hardness))))}}$$

This analysis compares freshwater hardness-adjusted response data to the corresponding hardness-adjusted chronic and acute criteria concentrations and salt water response data to the corresponding chronic and acute criteria concentrations. Finally, both salt water and fresh water exposure data were converted to dissolved cadmium if reported as total cadmium in ECOTOX.

Extrapolating Data from Other Species to Shortnose and Atlantic Sturgeon

Ideally quantitative exposure-response data for shortnose and Atlantic sturgeon or taxonomically-related surrogates would be available for one day (sensu acute 1Q10) exposures and seven day (sensu chronic 7Q10) exposures at the applicable cadmium criterion concentrations. Such data are not available. The following discussion describes evidence from toxicity tests using other substances that, for sturgeon, taxonomic relatedness is not always a good predictor for toxicity and that rainbow trout, which have abundant data in the screened ECOTOX set for this opinion, are not "excessively sensitive" to toxicants relative to shortnose and Atlantic sturgeon.

Dwyer et al. (2005) compared the relative toxicity of five chemicals to 18 fish species, including shortnose sturgeon, Atlantic sturgeon, and rainbow trout. Copper was among the chemicals tested. Like cadmium, the toxicity of copper is related to its interactions with the gills of fish. A copper LC50 of 0.08 mg/L was reported for both shortnose sturgeon and rainbow trout while the LC50 for Atlantic sturgeon was only slightly lower, at 0.06 mg/L. For organic chemicals, sturgeon were slightly more sensitive than rainbow trout. Shortnose sturgeon, Atlantic sturgeon and rainbow 4-nonylphenol LC50s were 0.08, 0.05, and 0.19 mg/L respectively. The pentachlorophenol LC50 was less than 0.04 mg/L for Atlantic sturgeon and the LC50 for shortnose sturgeon was 0.07 mg/L while the rainbow trout LC50 was more than twice that, at 0.16 mg/L. Finally, the permethrin LC50s for both shortnose and Atlantic sturgeon were less than 1.2 µg/L while the LC50 for rainbow trout was 3.31 µg/L. Chambers et al. (2012) reported a four-fold difference in sensitivity for early life stage effects of PCB126 in shortnose and Atlantic sturgeon. The shortnose sturgeon LC50 for carbaryl was comparable to that of rainbow trout, at

1.81 and 1.88 mg/L, respectively and the carbaryl LC50 for Atlantic sturgeon was less than 0.8 mg/L.

Addressing Gaps

The absence of cadmium data for shortnose and Atlantic sturgeon and sparseness of cadmium data for taxonomically related species, the differences reported among sturgeon sensitivities to other toxicants, taken with the need to be protective of the ESA-listed sturgeon occurring in Georgia, requires a comprehensive perspective that considers all data. This perspective is based on the expectation that mechanisms of effect in tested species are generally similar to effects in the ESA-listed species based on fundamental physiological functions (e.g., ionic homeostasis, antioxidant defense, nerve function, and calcification). The implications of these effects for their imperiled populations is addressed in the risk analysis that follows the effects analysis. The goal is to determine whether any adverse effects can occur in aquatic life under the proposed criteria.

This approach addresses any data available for sturgeon, then uses a high level review, including of box and whisker plots of the distribution of ECOTOX data relative to the criteria concentrations where appropriate. The widths of the boxes in some of these plots are scaled to reflect the relative abundance of data. Narrow boxes indicate fewer data that wide boxes. In some cases data are presented in paired figures, separating LOEC and NOEC data from endpoints identifying response thresholds and magnitude (e.g., LETC, LC50, EC20) in order to present the data as clearly as possible and re-enforce the distinction between the two types of endpoint data. A summary of the data used to generate the plots is provided in Appendix A.

Observations suggesting adverse effects could occur under the proposed criteria are reviewed more closely, taking into consideration dataset characteristics, such as the diversity of species represented among, species' mean responses, outliers, life stage effects, allometric influences, how responses were documented by researchers, the number and quality of the available toxicity studies, and the magnitude and types of effects reported.

3 Description of the Proposed Action

The purpose of water quality criteria is to maintain or restore water quality conditions that support aquatic life. The Georgia EPD's proposed cadmium criteria apply to all state jurisdictional waters and is stated in Georgia EPD's Water Quality Control Rule 391-3-6(5)(e)(ii) as:

> *"Instream concentrations ...shall not exceed, the acute criteria indicated below under 1-day, 10-year minimum flow (1Q10) or higher stream flow conditions and shall not exceed the chronic criteria indicated below under 7-day, 10-year minimum flow (7Q10) or higher stream flow conditions except within established mixing zones or in accordance with site specific effluent limitations."*

The cadmium criteria concentrations, as dissolved[1] cadmium, for coastal and estuarine waters are 33 µg/L for acute exposures and 7.9 µg/L for chronic exposures. The revised[2] freshwater aquatic life criteria for cadmium is expressed as a function of total hardness (mg/L $CaCO_3$) in a water body as indicated in Table 1. Adjustments to the hardness-based cadmium criteria concentrations..

Table 1. Adjustments to the hardness-based cadmium criteria concentrations.

Calculate Criterion Concentration	Conversion Factor to Dissolved Cadmium from Total Cadmium
Acute = $e^{(\cancel{1.0166}\ 0.9789\ [\ln(\text{hardness})] - \cancel{3.924}\ 3.866)}$	1.136672-[(ln hardness)(0.041838)]
Chronic = $e^{(\cancel{0.7409}\ 0.7977\ [\ln(\text{hardness})] - \cancel{4.719}\ 3.909)}$	1.101672-[(ln hardness)(0.041838)]

These criteria calculations are based on the constants arrived at in EPA's 2016 National Water Quality Guideline update for cadmium. The 2016 guidelines incorporated new laboratory toxicity tests, including toxicity data for 75 new species and 49 new genera. The EPA guidelines recommended the criteria concentrations as one-hour average acute and four-day average chronic concentrations not-to-be-exceeded more than once every three years.

The guidelines used to develop the criteria are intended to protect most aquatic ecosystems under most but not all circumstances. Stephen et al. (1985) states:

"Because aquatic ecosystems can tolerate some stress and occasional adverse effects, protection of all species at all times and places it is not deemed necessary for the derivation of a standard. If acceptable data are available for a large number of appropriate taxa from an appropriate variety of taxonomic and functional groups, a reasonable level of protection will probably be provided if all except a small fraction of the taxa are protected, unless a commercially or recreationally important species is very sensitive."

EPA's water quality guidelines, and state water quality criteria based on those guidelines, therefore cannot be assumed to be exposure concentrations that are protective of threatened and endangered species. This is why EPA consults on water quality criteria approvals.

EPA Region 4 considers the updates to the equations to be the revised water quality standards being proposed by Georgia EPD, and for that reason, the EPA Region 4's BEs only cover the numeric criteria irrespective of the duration and frequency at which exceeding those criteria are permissible. It is the EPA's stated position that the updates to Georgia EPD's Cadmium chronic and acute criteria are identical to the updated national guidelines.

[1] Dissolved metal refers to metal concentration in a filtered sample and total metal refers to metal concentration in an unfiltered sample.

[2] The original constants that were replaced under the revised criteria are in red strikeout.

3.1 Stressor of the Proposed Action

Stressors are any physical, chemical, or biological entity that may induce an adverse response in either an ESA-listed species or their designated critical habitat. Cadmium occurs naturally as the cadmium sulfide ore greenockite. It is used in electroplating for corrosion resistance (e.g., brake rotors), nickel cadmium batteries, for pigments in paint, printing ink, and plastics, and as a stabilizer for polyvinyl chloride plastics. Cadmium concentrations can become elevated in surface water through direct contact with cadmium-containing products, cadmium-contaminated stormwater and industrial discharges, and through atmospheric deposition. Sources of cadmium include mining, minerals processing, battery manufacturing and recycling, mining, fossil fuel combustion, stormwater discharges from highways and roads, and the use and disposal of cadmium containing products (Hem 1985, Shaver et al. 2007, McKenzie et al. 2009).

In the environment, cadmium is a proximate stressor. A proximate stressor is the actual toxicant, physiological impact, or resource limitation most directly linked to a biological response. Exposures that result in effects expressed in individuals of a species of interest can also result in effects on the quality and abundance of resources needed by that species due to the interdependence of species (generalized in Figure 1).

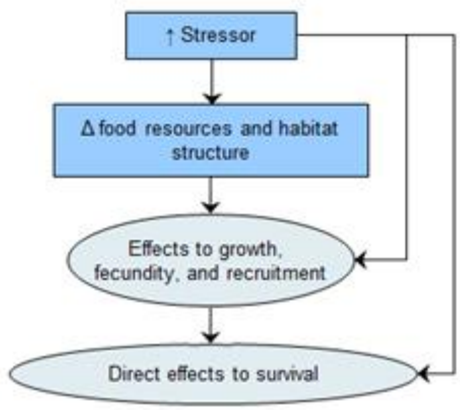

Figure 1. Generalized pathways for stressor effects

Since we are interested in whether the proposed criteria may result in adverse effects to ESA-listed species under NMFS' jurisdiction in Georgia, we first would want to know whether adverse effects have been reported for exposure at or below the proposed criteria concentrations. Ideally, the available toxicity data would report, or allow us to determine, the threshold exposure concentration at which a response would not occur or would be insignificant in ESA-listed species under NMFS' jurisdiction. However, toxicity tests are not performed on ESA-listed species, so species commonly used in laboratories typically serve as surrogates representing the species of interest.

3.2 Conservation Measures to Avoid Exposure

The EPA's action is an approval of Georgia EPD's proposed water quality criteria for cadmium to protect aquatic life from adverse effects due to exposure to this metal. Once approved, as a state with delegated authority under the Clean Water Act, Georgia EPD will implement the criteria in establishing effluent limits for discharge permits and in identifying impaired waters. The only actions within EPA's authority that would minimize or avoid exposure at the criteria, if the criteria are found to be insufficiently protective, is either requiring Georgia EPD revise its criteria concentrations to more protective value(s) or promulgation of cadmium criteria that are more protective if Georgia EPD declines to do so.

4 ACTION AREA

The action area is defined by regulation as "all areas to be affected directly or indirectly by the Federal action and not merely the immediate area involved in the action" (50 CFR 402.02). The proposed cadmium criteria apply to all freshwater in the state of Georgia and all of Georgia's territorial marine waters extending nine nautical miles from shore, regardless of whether or not they are designated waters of the U.S. Other waters affected by these criteria are those rivers, creeks, streams, and marine waters under the jurisdiction of neighboring states which originate from or are affected by water quality in the state of Georgia. Examples of such waters include the Apalachicola River, which originates from Lake Seminole along the Georgia-Florida border and the Savannah and St. Marys Rivers, along Georgia's border with South Carolina and Florida, respectively. The action area considered in this consultation is therefore the territorial waters of Georgia and any other waters affected by the water quality of those waters.

5 Status of Endangered Species Act Protected Resources

Table 2 identifies the ESA-protected species and designated critical habitat under NMFS' jurisdiction that have ranges overlapping with waters affected by Georgia EPD's water quality criteria. Not all of these species require analysis in this opinion for reasons described in subsequent sections.

Table 2. Species protected under the ESA with ranges that overlap with Waters Affected by Georgia's Water Quality Criteria.

Species	ESA Status	Designated Critical Habitat	Recovery Plan
Cetaceans			
Blue Whale (Balaenoptera musculus)	E – 35 FR 18319	--	1998
Fin Whale (Balaenoptera physalus)	E – 35 FR 18319	--	75 FR 47538
North Atlantic Right Whale (*Eubalaena glacialis*)	E – 35 FR 18319 & 73 FR 12024	81 FR 4837	70 FR 32293
Sei Whale (Balaenoptera borealis)	E – 35 FR 18319	--	2011
Sperm Whale (Physeter macrocephalus)	E – 35 FR 18319	--	75 FR 81584
Sea Turtles			
Green sea turtle (*Chelonia mydas*)	E – 43 FR 32800	63 FR 46693	63 FR 28359
Hawksbill sea turtle (*Eretmochelys imbricata)*	E – 35 FR 8491	63 FR 46693	57 FR 38818
Kemp's Ridley sea turtle (*Lepidochelys kempii*)	E – 35 FR 18319	--	75 FR 12496
Leatherback sea turtle (*Dermochelys coriacea*)	E – 61 FR 17	44 FR 17710	63 FR 28359
Loggerhead sea turtle (*Caretta caretta*) – Northwest Atlantic Distinct Population Segment (DPS)	E – 76 FR 58868	78 FR 39856	63 FR 28359
Fish			
Smalltooth Sawfish (*Pristis pectinata*)	E – 68 FR 15674	74 FR 45353	74 FR 3566
Giant Manta Ray (*Manta birostris*)	T – 83 FR 2916	--	--
Oceanic Whitetip Shark (*Carcharhinus longimanus*)	T – 83 FR 4153	--	--
Shortnose Sturgeon (*Acipenser brevirostrum*)	E – 32 FR4001	--	63 FR 69613
Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) South Atlantic (DPS)	E – 77 FR 5914	82 FR 39160	--
Gulf Sturgeon (Acipenser oxyrinchus desotoi)	T – 56 FR 49653	68 FR 13370	1995

5.1 Shared Jurisdiction with the U.S. Fish and Wildlife Service

The Gulf sturgeon, a threatened anadromous subspecies of the Atlantic sturgeon, is under the jurisdiction of both the U.S. Fish and Wildlife Service and NMFS. Its designated critical habitat includes the Apalachicola River originating from Lake Seminole at the Georgia/Florida border to the Gulf of Mexico through the panhandle of Florida. Under shared jurisdiction, the U.S. Fish and Wildlife Service is the consulting service for EPA actions and coordinate with NMFS when the action occurs in brackish or marine waters. The Gulf sturgeon is affected by the action, but is not discussed further in this opinion because it is not within NMFS' jurisdiction.

5.2 Species and Designated Critical Habitat Not Likely to be Adversely Affected

We use two criteria to identify those ESA-listed species or designated critical habitat under NMFS' jurisdiction that are likely to be adversely affected by a proposed action, or by the effects of activities and consequences that occur as a result of the Federal agency's proposed action. The first criterion is exposure, or some reasonable expectation of a co-occurrence, between one or more potential stressors associated with the proposed activities and ESA-listed species or designated critical habitat. If we conclude that an ESA-listed species or designated critical habitat under NMFS' jurisdiction is not likely to be exposed to stressors of the proposed action, we must also conclude that the species or designated critical habitat is not likely to be adversely affected by those activities and make and NLAA determination.

The second criterion is the probability and severity of a response, given exposure. The ESA-listed species or designated critical habitat under NMFS' jurisdiction that are exposed to a potential stressor but are likely to be unaffected by the exposure are also not likely to be adversely affected by the proposed action. An action warrants a "may affect, not likely to adversely affect" finding when its effects are completely *beneficial, insignificant,* or *discountable*.

Beneficial effects have an immediate positive effect without any adverse effects to the species or habitat. Beneficial effects are usually discussed when the project has a clear link to the ESA-listed species or its specific habitat needs and consultation is required because the species may be affected.

Insignificant effects relate to the size or severity of the impact and include those effects that are undetectable, not measurable, or so minor that they cannot be meaningfully evaluated. "Insignificant" is the appropriate effect conclusion when plausible effects are going to happen, but will not rise to the level of constituting an adverse effect. That means the ESA-listed species may be expected to be affected, but not harmed or harassed.

Discountable[3] effects are those that are extremely unlikely to occur. For an effect to be discountable, there must be a plausible adverse effect (i.e., a credible effect that could result from the action and that would be an adverse effect if it did affect ESA-listed species), but it is very unlikely to occur.

Responses that may occur, but are NLAA, are addressed prior to the Effects Assessment of an opinion when existing knowledge clearly indicates that exposures or responses in the species of concern is reasonably expected to be insignificant or discountable. For example, we know that

[3] The Services' 1998 ESA Section 7 Consultation Handbook contains the definition, "Discountable effects are those extremely unlikely to occur." When the terms "discountable" or "discountable effects" appear in this document, they refer to potential effects that are found to support a "not likely to adversely affect" conclusion because they are extremely unlikely to occur. The use of these terms should not be interpreted as having any meaning inconsistent with our regulatory definition of "effects of the action."

ESA-listed sturgeon would be extremely unlikely to respond to ammonia exposures meeting a criterion that is protective of unionid mussels because unionid mussels are orders of magnitude more sensitive to ammonia than any other species group (EPA 2013).

Exposure and Response Considerations

Direct Exposures

The primary exposure pathway for aquatic pollutants in freshwater and saltwater-gilled species (fish and invertebrates) is uptake via the gills as water continuously passes over the gill filaments to oxygenate blood and regulate ion balance. For saltwater fish, exposure to toxicants in water also occurs through ingestion because most marine fish "osmoregulate" by drinking water and excreting solute in order to maintain a lower concentration of solutes in their body fluids than saltwater. Most marine invertebrates have the same internal concentration of solutes as the water they live in and do not osmoregulate (Larsen 2014). The exception is filter-feeding invertebrates, which ingest small quantities of seawater when feeding.

Sea turtles breathe air, but they also drink water and excrete solute to regulate their internal ion balance. Sea turtle exposures are less than those of marine fish because turtles do not drink continuously, whereas saltwater fish both drink and continuously pass water over their gills.

The pathway for direct exposure, and subsequent response, of whales to pollutants in saltwater is limited because whales do not drink seawater. Whale osmoregulation employs physiological and allometric adaptations such as increased filtration rates, urine volume, and kidney size along with tolerance of high solute levels in urine and plasma (Kjeld 2003, Birukawa 2005). Baleen whales, similar to filter feeding invertebrates, do ingest some seawater when feeding.

The above information is helpful when addressing data gaps for species like sea turtles and whales. There are no data for the actual effects of aquatic toxicants on survival, growth, or fitness that can be used to evaluate water quality criteria for these species. A majority of the marine fish and invertebrates inhabiting the same waters as sea turtles are allometrically disadvantaged because they are smaller and also have more intense exposures because they respire through gills. For these reasons, they are more likely to respond to toxicants in water. If NMFS makes a determination that EPA's approval of criteria for the toxicants evaluated in this opinion is not likely to adversely affect these species groups, it is reasonable to expect EPA's approval of the criteria is not likely to adversely affect hawksbill and green sea turtles and whales. The exception to this are those toxicants that accumulate in organisms and those that biomagnify through the food web. In poorly flushed marine systems, legacy inorganic and persistent organic toxicants can become incorporated into the biogeochemical cycle, with contaminants recycling between sediment and organism tissues through the trophic web, resulting in generational exposures.

Regarding fish, allometric differences (e.g., body size, membrane area, and organ size) are factors to be considered when evaluating toxicity data. A smaller individual generally succumbs to toxic effects more rapidly than a larger individual does because it takes a longer time for exposures to reach critical concentrations within the tissues of the larger individual. Therefore, higher exposure concentrations are expected to be needed to elicit the same response over a similar exposure period. For example, adult Atlantic sturgeon grow to up to nearly five meters (about 16 feet) in length versus adult fathead or sheepshead minnows, a common toxicity test species, which are 25 to 75 millimeters in length, but toxicity tests start with or sheepshead minnow eggs or larvae that are about four to five millimeters long (EPA 2002). Shortnose sturgeon typically hatch out at seven to eleven millimeters standard length and Atlantic sturgeon larvae hatch out to seven to nine millimeters standard length (Snyder 1988). Upon hatching, sturgeon larvae seek cover in benthic structure where they feed until they are large enough to migrate into brackish waters of their natal estuary for months to years. It is these early life stages, only slightly larger than larvae used in toxicity tests, which are most likely to be exposed to, and affected by, land-sourced pollutants such as cadmium in effluent discharges and stormwater runoff.

Dietary Exposures and Effects on Quality and quantity of Prey

Aquatic pollutants may also result in exposures to toxicants through the food web or result in effects through altering the quantity or quality of prey. While there are data for toxic effects that may influence prey populations and tissue accumulation in prey or prey-like species under controlled laboratory conditions, information on dietary toxicity through food web exposures is extremely limited, particularly for marine environments. Information on prey items and foraging areas can suggest the potential for toxic exposures, but uncertainty in whether actual adverse effects will occur can be substantial.

Body burdens in marine mammals and sea turtles primarily result from diet. The presence of a contaminant in the tissues of an organism only confirms exposure and does not provide useful information about adverse effects on survival or fitness. The impact of this uncertainty on evaluating a location-specific criterion or activity is attenuated when the action area comprises a very small portion of a species foraging area and exposure to pollutants in sea water is expected to be minimal. For example, whales do not drink seawater and forage over a very wide geographic area relative to the action area affected by the regulation of water quality in Georgia waters, so a determination that EPA's approval of water quality criteria for these waters is not likely to affect these species is reasonable. Similarly, as a pelagic species, white tipped shark are not expected to consume prey from waters affected by Georgia water quality. In general, if a forage species does not respond to exposures under the chronic criteria, adverse effects dietary exposures of species consuming that forage would not be expected unless the pollutant is persistent and potentially accumulates to toxic levels. Identifying toxic levels for an ESA-listed species would require extrapolations from other species and the attendant uncertainties, including differences in metabolism, life span, and diet.

Species and Designated Critical Habitat Not Likely to be Exposed

Georgia's marine waters extend nine nautical miles and reach about 20 meters in depth. Species with ranges that include Georgia waters, but do not frequent waters affected by Georgia's water quality, are not expected to be affected by EPA's approval of the proposed cadmium criteria. While blue and sei whales may be found along the continental slope, they are extremely rare in Georgia waters. Fin whales are found in deep, offshore waters of all major oceans, primarily in temperate to polar latitudes, and less commonly in the tropics. Sperm whales tend to inhabit areas with a water depth of 1968 feet (600 meters) or more, and are uncommon in waters less than 984 feet (300 meters) deep. Waters that are 600 deep or more are about 90 nautical miles from shore. Oceanic white tip sharks occur in the open ocean, well offshore along the southeastern coast of the United States. While NMFS determined that it was not prudent to designate critical habitat for this species, essential fish habitat established under the Magnuson-Stevens Fishery Conservation and Management Act identifies those waters and substrates necessary for spawning, breeding, feeding, or growth to maturity for this species. The essential fish habitat for the oceanic white tip shark is adjacent to, but does not overlap with Georgia state marine waters. For this reason, NMFS does not expect this species to frequent waters affected by Georgia EPD's cadmium criteria. The giant manta is another oceanic species occurring primarily offshore of productive coastlines like Georgia's. They are migratory, with migration lengths of up to about 1500 km (~930 miles), which is about ten-fold the length of Georgia's coast. Georgia has no off shore industrial activities regulated under the clean water act, and land-sourced discharges are not likely to be distinguishable from other sources in waters where these oceanic species occur.

Air breathing species that are not expected to ingest water or prey in waters affected by Georgia's water quality are not expected to be affected by EPA's approval of the proposed cadmium criteria. As an aquatic toxicant, cadmium is not readily absorbed through mammalian skin, so any exposure of whales is primarily direct uptake from the water column through membranes that are in contact with ambient water, ingesting water, or indirect uptake through ingesting organisms that have accumulated cadmium. The North Atlantic right whale, like other whales, does not drink seawater. In addition, the North Atlantic right whale does not feed in waters of the southeast. It migrates to these waters to birth calves.

The range for smalltooth sawfish once extended to waters as far north as North Carolina, but has since contracted to the coast of southern Florida. Reports of sightings in the species' former range are extremely rare. Since smalltooth sawfish, with an elongated toothed rostrum, are an unusual looking nearshore species, NMFS expects that any sawfish encounters by the many recreational and commercial fishermen in Georgia waters are likely reported. Two relatively recent sightings were reported off Georgia's coast: in 2008, 2010. Two other sightings were reported in 2015. In addition to these sightings, a smalltooth sawfish was reported off of Myrtle Beach, South Carolina in 2017 (Poulakis 2019). This contrasts with the thousands of sightings off the coast of Florida over the past 20 years.

CONCLUSION

NMFS has determined that EPA's approval of Georgia EPD's proposed chronic and acute saltwater criteria for cadmium is NLAA for blue, sei, fin, and sperm whales, the oceanic white-tipped shark, and the giant manta because these species are extremely unlikely to be exposed to cadmium from Georgia EPD-regulated waters due to their highly migratory oceanic existence. EPA approval of the proposed saltwater criteria is NLAA for the North Atlantic right whale because this species is extremely unlikely to be exposed to cadmium from Georgia EPD-regulated waters since they do not ingest food or water when in areas affected by Georgia EPD's criteria. Finally, EPA approval of the proposed saltwater criteria is NLAA for smalltooth sawfish because they are extremely rare in waters north of Florida so they are extremely unlikely to be exposed to cadmium from Georgia EPD-regulated waters. These eight species are only expected to be exposed to cadmium in saltwater, and their exposures are extremely unlikely to occur. These species are not discussed further in this opinion.

Species Not Likely to Respond to Exposures

The ESA-listed species under NMFS' jurisdiction that are exposed to waters affected by the cadmium criteria will not necessarily be adversely affected, directly or indirectly, by these exposures. Since ESA-listed green, hawksbill, Kemp's ridley, leatherback, and loggerhead sea turtles breathe air and do not have gills, their only exposures to cadmium in sea-water would be through drinking sea-water and limited absorption through exposed membranes. Indirect exposures occur through the diet if food items have accumulated cadmium. The ECOTOX does not include data on aquatic reptiles exposed to cadmium in the diet or drinking water. Controlled experiments for toxicant exposures are not conducted on ESA- listed species. In addition, sea turtles are a highly migratory species group, complicating the interpretation of the few physiological data associated with cadmium body concentrations.

In order to evaluate effects of dietary exposure in sea turtles, expected concentrations in forage species resulting from exposures that are compliant with EPA's chronic[4] cadmium guideline concentrations (i.e., criterion concentration-compliant) and dietary concentrations that would be expected to result adverse effects in sea turtles must be estimated. Studies typically evaluate accumulation and effects under much higher exposures to evaluate pollution effects. Meanwhile the concentrations evaluated in this opinion are cadmium exposure limits that are intended to be low enough to avoid adverse effects.

The saltwater chronic cadmium criterion is 7.9 µg/L dissolved metal. Cadmium accumulation reported in ECOTOX for criterion concentration-compliant saltwater exposures reported range from 0.03 (background) to 7.6 µg/L dissolved cadmium. Additional data on cadmium uptake is available in the U.S. Army Corps of Engineers Environmental Residue Effects Database (ERED 2019). These data are useful for considering potential prey uptake from saltwater and thus,

[4] Accumulation would occur under chronic, not acute lethal exposures

dietary exposures for sea turtles. Exposure of naïve[5] Black Sea bream to 7.6 µg/L cadmium for one week resulted in a whole body cadmium concentration of about 1 µg/g (reported as dry weight Zhang and Wang 2006). Another study reported that, after 25 days exposure to 5 µg/L cadmium, cockles achieved a whole tissue concentration of 4 µg/g (reported as dry weight Naylor 1987). Concentrations in seagrass exposed to 0.306+/-0.109 µg/L cadmium days accumulated up to 7 µg/g in leaves (reported as dry weight Richir et al. 2013). Cadmium content among forage species is expected to vary. For example the jellyfish *Cassiopea sivickisi* collected from water cadmium concentrations ranging from 0.7 µg/L to 2.96 µg/L had tissue concentrations of 0.22 to 0.691 µg/g, while six other species collected from waters ranging from below the analytical limit of 0.5 µg/L to 7.16 µg/L contained between 0.0005 and 0.184 µg/g cadmium, with most data below 0.07 µg/g (reported as wet weight Templeman and Kingsford 2012). The ERED includes data for oyster exposed to 10 µg/L cadmium over 40 weeks resulted in whole body concentrations of about 176 µg/g (reported as dry weight Zaroogian 1980). Assuming a moisture content[6] for bream of 75 percent (Mortal et al. 2018), for cockles of 76 percent (Gutierrez et al. 2006), for seagrass of 84 percent (average from Ames et al. 2007), and 80 percent for oyster (ERED 2019), suggests dietary exposure for sea turtles of between 0.5 and 35 µg/g cadmium (wet weight) in forage species from waters with cadmium levels below or near the proposed saltwater criteria concentration.

Surrogate species used to assess effects of toxicants on sea turtles include freshwater turtles, other reptiles, and where reptile data are unavailable, birds (which have similar metabolic and excretion processes). Two studies were found evaluating dietary cadmium effects in freshwater turtles at concentrations comparable to the 0.5 to 35 µg/g wet-weight estimates arrived at in the previous paragraph. These studies suggest effects are unlikely in sea turtles under the proposed criteria concentrations. A diet supplemented with 590 µg/g cadmium, well above the maximum estimated dietary content under the proposed criteria concentrations, did not affect specific growth rate in yellow spotted river turtles. After 30 days on the diet, their ability to right themselves when over turned was impaired, but impairment was not evident after 60 days on the cadmium-supplemented diet (Frossard et al. 2013), suggesting acclimation to dietary cadmium. The second study reported that growth, measured as weight and plastron length was not affected in red eared sliders fed diets containing from 0.400 to 0.950 µg/g cadmium over 13 weeks. While cadmium accumulated the kidneys and livers of exposed turtles, organ mass relative to total body weight (an index of organ damage) was not affected (Guirlet and Das 2012). These are short term studies relative to the lifecycle of sea turtles, which take about 10 to 30 years to mature and can live more than 50 years. The sea turtles that occur in Georgia are also highly migratory such

[5] When discussing toxic effects, the term "naïve" refers to previously unexposed organisms

[6] Conversion of dry weight values to wet weight: concentration reported as dry weight × ((100-percent moisture)/100)

that the contribution of pollutants in discharges authorized by one state are indistinguishable from other sources.

Table 3. ECOTOX data summary of minimum saltwater cadmium exposure concentrations in µg/L that may influence the abundance of forage for sea turtles.

	Effects Reported at Exposures Above Criteria		Effects Reported at Exposures Below Criteria	
Endpoints	**Acute**	**Chronic**	**Acute**	**Chronic**
SEAGRASS and ALGAE				
EC50, ED50	61.95-244,773 (N=18)	59.64-39,730 (N=9)	4.56	
LC50	298.2-3,181 (N=4)	298,200		
LOEC	99.4-72,886 (N=12)	99.4-13,459 (N=11)	0.2-3.58 (N=3)	4.97
NOEC	49.7-5,587 (N=8)	62.62-8,678 (N=6)	1.99-29.82 (N=6)	4.97
no survival	9,940-49,700 (N=2)	20.92-41,901 (N=14)		
no mortality		11,174		
FISH				
LC16		2,515-34,790 (N=7)		
LC50	179.22-556,640 (N=139)	149.1-79,520 (N=24)		
LC84		9,940-59,143 (N=7)		
LETC		4,970-19,880 (N=4)		
LOEC	745.5	994		
NOEC	387.66	198.8-556.64 (N=4)		
no mortality		99.4-16,217 (N=3)		
INVERTEBRATES				
EC50	44.73-4,709 (N=6)	60.63-101,289 (N=43)		
LC05		477.12-954.24 (N=4)		
LC10		99.4-13,817 (N=4)		
LC16		19.88-695.8 (N=6)		
LC25		1,843		
LC50	33.6-611,310 (N=764)	21.87-90,454 (N=73)	0.2-32.99 (N=37)	
LC75		5,217		
LC84		1,074-4,473 (N=12)		
LC95		2,336-2,386 (N=4)		
LOEC		79.52-49,700 (N=54)		4.97
NOEC		10.93-24,850 (N=101)		0.1-4.97 (N=42)
no survival		103.38-49,700 (N=37)		
no mortality		22-994 (N=18)		2

Hawksbill, Kemp's ridley, leatherback, and loggerheads eat various species of animal prey while green sea turtle adults eat sea grasses and algae. The available data for the effects of cadmium on marine life on endpoints relatable to the abundance and quality of forage do not suggest exposures at the cadmium concentration would result in limited food resources (Table 3). Very few data suggest exposures at or below the criterion concentrations would affect the abundance of forage species.

CONCLUSION

NMFS has determined that EPA approval of Georgia EPD's proposed chronic and acute criteria for cadmium is NLAA for green, hawksbill, kemp's ridley, leatherback sea turtles, and the Northwest Atlantic DPS of the loggerhead sea turtle because the majority of available data suggest that effects on the abundance of forage species exposed at or below the proposed chronic and acute criteria concentrations would be insignificant. Further, NMFS does not expect sea turtles would respond to accumulated cadmium in forage because cadmium contributions specifically from Georgia waters are incapable of being detected, measured, or evaluated due to the highly migratory nature of these sea turtle species, therefore any effects are considered discountable. Sea turtles are not discussed further in this opinion.

Essential Elements of Designated Critical Habitat Not Likely to Respond to Exposures

Designated critical habitat for the Northwest Atlantic DPS of the loggerhead sea turtle includes nearshore reproductive habitat along the Georgia coastline. This portion of designated critical habitat does not include biological features that would respond to cadmium toxicity. Sargassum and the community of organisms that serve as forage are also identified as critical habitat for this species, but this habitat occurs approximately 60 miles off Georgia's coastline. NMFS expects that at this distance from shore, the origin of pollutants affecting sargassum or its inhabitants would be indistinguishable. For these reasons NMFS has determined that EPA approval of Georgia EPD's proposed criteria for cadmium is NLAA for critical habitat designated for the Northwest Atlantic DPS of the loggerhead sea turtle. Designated critical habitat for this species is not discussed further in this opinion.

The spatial extent of designated critical habitat for the Southeast Atlantic DPS of Atlantic sturgeon includes the Savannah, Ogeechee, Altamaha, Satilla and St. Marys Rivers. However the essential features of this designated critical habitat do not include biological elements (e.g., forage, vegetative cover) that would respond to cadmium toxicity. For this reason, the effects of the action on designated critical habitat for the Southeast Atlantic DPS of Atlantic sturgeon will not be considered further in this opinion. The opinion only discusses designated critical habitat for this species to place the status of the species in context of the action.

While Unit 2 of designated critical habitat for the North Atlantic right whale extends along the southeastern coast from Cape Fear to approximately 31 miles south of Cape Canaveral, the species migrates to these waters for calving and the whales do not forage in calving grounds. Whales also do not drink seawater, so they do not ingest waterborne pollutants.

CONCLUSION

NMFS has determined that EPA approval of Georgia EPD's proposed water quality criteria for cadmium is NLAA for critical habitat designated for the South Atlantic DPS of the Atlantic sturgeon and the Northwest Atlantic DPS of the loggerhead sea turtle because the essential features of designated critical habitat in waters affected by Georgia EPD's regulation of water quality does not include biological features that would respond to toxicant exposures. Approval of the criteria are also NLAA for designated critical habitat for the North Atlantic right whale because the species is not expected to be exposed since they do not forage or drink seawater when in areas affected by Georgia EPD's regulation of water quality. For these reasons, the designated critical habitat for the South Atlantic DPS of the Atlantic sturgeon, the Northwest Atlantic DPS of the loggerhead sea turtle, and the North Atlantic right whale will not be discussed further in this opinion.

5.3 Species Likely to be Adversely Affected

We determined that ESA-listed cetacean, shark, sawfish, and sea turtle species potentially within the action area are not likely to be adversely affected by the proposed action. We have also determined that designated critical habitat affected by Georgia waters is not likely to be adversely modified or destroyed. Below we discuss our analysis of those species likely to be adversely affected: the ESA-listed shortnose sturgeon and the Atlantic sturgeon. The status includes the existing level of risk that the ESA-listed species face, based on parameters considered in documents such as recovery plans, status reviews, and listing decisions. Each species status section helps to inform the description of the species' current "reproduction, numbers, or distribution," which is part of the jeopardy determination as described in 50 C.F.R. §402.02. More detailed information on the status and trends of these ESA-listed species, and their biology and ecology can be found in the listing regulations and critical habitat designations published in the Federal Register, status reviews, recovery plans, and on NMFS' Web-sites.

This consultation applied the most recent recovery plans and status reports available at the time it was conducted. While the following discussions focus on the use of waters affected by Georgia water quality standards by these species, consideration of the status of populations outside of the action area is also important in our evaluating how the risk to affected population(s) influences the status of the species as a whole.

Atlantic Sturgeon and Designated Critical Habitat for the South Atlantic DPS

Sturgeon are among the most primitive of the bony fishes. The Atlantic sturgeon is a long-lived (approximately 60 years), late maturing, iteroparous, estuarine dependent species (Dadswell 2006, ASSRT 2007). Atlantic sturgeon are anadromous, spawning in freshwater but spending most of their subadult and adult life in the marine environment. They can grow to approximately 14 feet long and can weigh up to 800 pounds. Atlantic sturgeon are bluish-black or olive brown dorsally (on their back) with paler sides, a white belly, and have five major rows of dermal "scutes" (Figure 2).

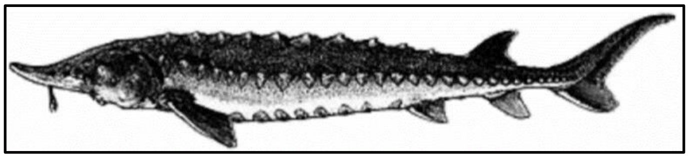

Figure 2. Adult Atlantic Sturgeon

This section provides general information on the Atlantic sturgeon South Atlantic DPS population, including information about the species life history, population dynamics, and status. The subsections that follow provide information and characteristics particular to each of the five listed DPSs of Atlantic sturgeon.

Five DPSs of Atlantic sturgeon were listed under the ESA in 2012. The endangered South Atlantic DPS occurs in waters affected by Georgia EPD's criteria. The natal river systems of the South Atlantic DPS span from Edisto south to the St. Mary's River (Figure 3).

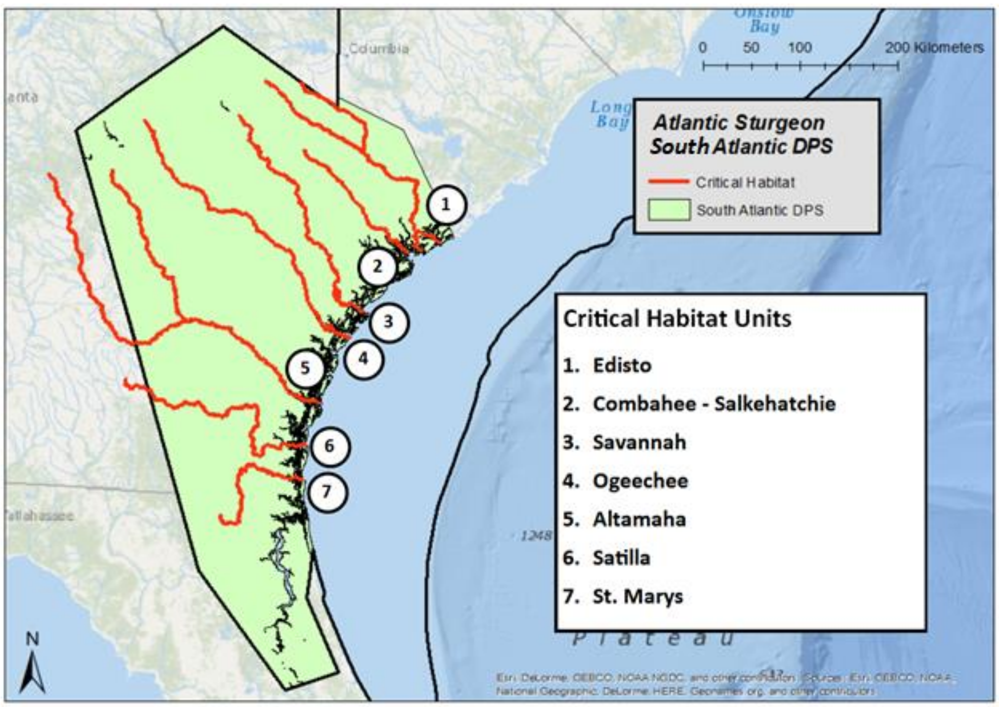

Figure 3. Geographic range and designated critical habitat of Atlantic sturgeon, South Atlantic DPS

Life History

The general life history pattern of Atlantic sturgeon is that of a long lived, late maturing, iteroparous, anadromous species. Atlantic sturgeon spawn in freshwater, but spend most of their subadult and adult life in the marine environment. Atlantic sturgeon feed on mollusks, polychaeta worms, gastropods, shrimps, pea crabs, decapods, amphipods, isopods, and small fishes in the marine environment (Guilbard et al. 2007, Savoy 2007, Collins et al. 2008) while in fresh water they feed on oligochaetes, gammarids, mollusks, insects, and chironomids (Moser and Ross 1995, Johnson et al. 1997, Guilbard et al. 2007, Savoy 2007). The sturgeon "roots" in the sand or mud with its snout, like a pig, to dislodge worms and mollusks that it sucks into its protrusible mouth, along with considerable amounts of mud. The Atlantic sturgeon has a stomach with very thick, muscular walls that resemble the gizzard of a bird. This gizzard enables it to grind such food items as mollusks and gastropods (MSPO 1993).

Atlantic Sturgeon age at sexual maturity varies with latitude with individuals reaching maturity in South Carolina at 5 – 19 years (Smith et al. 1982). Atlantic sturgeon spawn in freshwater, but spend most of their adult life in the marine environment. Spawning adults generally migrate upriver in the late summer/early fall; August-November in southern systems (77 FR 5914, Smith 1985, NMFS 1998, Collins et al. 2000, Balazik et al. 2012, Hager et al. 2014, Kahn et al. 2014). Atlantic sturgeon spawning is believed to occur in flowing water between the salt front and fall line of large rivers at depths of 11-27 meters (Borodin 1925, Leland 1968, Scott and Crossman 1973, Crance 1987, Bain et al. 2000). Atlantic sturgeon likely do not spawn every year. Spawning intervals range from 1-5 years for males (Smith 1985, Collins et al. 2000, Caron et al. 2002) and 2-5 for females (Vladykov and Greeley 1963, Van Eenennaam et al. 1996, Stevenson and Secor 2000).

Sturgeon eggs are highly adhesive and are deposited on the bottom substrate, usually on hard surfaces (Gilbert 1989, Smith and Clugston 1997) between the salt front and fall line of large rivers (Borodin 1925, Scott and Crossman 1973, Crance 1987, Bain et al. 2000). Following spawning in northern rivers, males may remain in the river or lower estuary until the fall; females typically exit the rivers within four to six weeks (Savoy and Pacileo 2003). Hatching occurs approximately 94-140 hours after egg deposition at temperatures of 20˚ and 18˚ Celsius, respectively (Theodore et al. 1980). The yolk sac larval stage is completed in about 8-12 days, during which time larvae move downstream to rearing grounds over a 6 – 12 day period (Kynard and Horgan 2002). During the first half of their migration downstream, movement is limited to nighttime. During the day, larvae use benthic structure (e.g., gravel matrix) as refugia (Kynard and Horgan 2002). The larvae grow rapidly and are 4" to 5 1/2" long at a month old (MSPO 1993). At this size, the young sturgeon bear teeth and have sharp closely spaced spine-tipped scutes. As growth continues, they lose their teeth, the scutes separate and lose their sharpness. During the latter half of migration when larvae are more fully developed, movement to rearing grounds occurs both day and night. Juvenile sturgeon continue to move further downstream into brackish waters ranging from zero to up to 10 parts per thousand salinity. Older juveniles are more tolerant of higher salinities as juveniles typically spend two to five years in freshwater before eventually becoming coastal residents as sub-adults (Smith 1985, Boreman 1997, Schueller and Peterson 2010).

Atlantic sturgeon undertake long marine migrations and utilize habitats up and down the East Coast for rearing, feeding, and migrating (Dovel 1983, Bain 1997, Stevenson 1997). Migratory sub adults and adults are normally located in shallow (10-50 meters) nearshore areas dominated by gravel and sand substrate (Stein et al. 2004). Tagging and genetic data indicate that subadult and adult Atlantic sturgeon may travel widely once they emigrate from rivers (Bartron 2007, Wirgin et al. 2015). Once in marine waters, sub adults undergo rapid growth (Dovel 1983, Stevenson 1997). Atlantic sturgeon have been aged to 60 years (Mangin 1964), but this should be taken as an approximation because the age validation studies conducted to date show ages cannot be reliably estimated after 15 to 20 years (Stevenson and Secor 2000). Vital parameters of sturgeon populations generally show clinal variation with faster growth, earlier age at maturation, and shorter life span in more southern systems. Spawning intervals range from one to five years for male Atlantic sturgeon (Smith 1985, Collins et al. 2000) and three to five years for females (Stevenson and Secor 2000, Schueller and Peterson 2010). Fecundity of Atlantic sturgeon is correlated with age and body size, ranging from approximately 400,000 to 8 million eggs (Smith et al. 1982, Van Eenennaam and Doroshov 1998, Dadswell 2006). The average age at which 50 percent of Atlantic sturgeon maximum lifetime egg production is achieved is estimated to be 29 years, approximately 3 to 10 times longer than for most other bony fish species (Boreman 1997).

Despite extensive mixing in coastal waters, Atlantic sturgeon exhibit high fidelity to their natal rivers (King et al. 2001, Waldman et al. 2002, Grunwald et al. 2008). Because of high natal river fidelity, it appears that most rivers support independent populations (Wirgin et al. 2000, King et al. 2001, Wirgin et al. 2002, Stein et al. 2004, Grunwald et al. 2008).

Seasonal movements and spawning migrations of Atlantic Sturgeon in the South Atlantic distinct population segment suggest the species spawn in the fall when water temperatures are less than 25°C. A stationary array of acoustic receivers was used to monitor the movements of 45 adults in the Altamaha River system revealed that adults exhibited two distinct patterns of upriver migration: a spring two-step migration and a fall one-step migration. In spring and early summer, adults appeared to stage in the upper Altamaha before migrating to suspected spawning habitats in the Ocmulgee and Oconee tributaries in the fall. Fish entering the system in late summer and migrated directly upriver to the Ocmulgee and Oconee tributaries. All fish returned downstream and left the system by early January (Ingram and Peterson 2016).

Population Dynamics

The current abundance of these populations are suspected to be less than 6% of their historical abundance, extrapolated from the 1890s commercial landings (Secor 2002). Few captures have been documented in other populations within this DPS and are suspected to be less than 1% of their historic abundance (less than 300 spawning adults).

Precise estimates of population growth rate (intrinsic rates) for the South Atlantic DPS are unknown due to lack of long-term abundance data. During the last two decades, Atlantic sturgeon have been observed in most South Carolina coastal rivers, although it is not known if all rivers support a spawning population (Collins and Smith 1997).

Genetic Diversity

Relatively low rates of gene flow reported in population genetic studies (King et al. 2001, Waldman et al. 2002) indicate that Atlantic sturgeon return to their natal river to spawn, despite extensive mixing in coastal waters. Atlantic sturgeon throughout their range exhibit ecological separation during spawning that has resulted in multiple, genetically distinct, interbreeding population segments. Studies have consistently found populations to be genetically diverse and indicate that there are between seven and ten populations that can be statistically differentiated (King et al. 2001, Waldman et al. 2002, Wirgin et al. 2007, Grunwald et al. 2008). However, there is some disagreement among studies, and results do not include samples from all rivers inhabited by Atlantic sturgeon. Recent studies conducted indicate that genetically distinct populations of spring and fall-run Atlantic sturgeon can exist within a given river system (Balazik and Musick 2015, Balazik et al. 2017, Farrae et al. 2017).

Distribution

Atlantic sturgeon were once present in 38 river systems and, of these, spawned in 35 of them. Individuals are currently present in 36 rivers, and spawning occurs in at least 20 of these (ASSRT 2007). Other estuaries along the U.S. Atlantic coast formed by rivers that do not support Atlantic sturgeon spawning populations may still be important as rearing habitats. The decline in abundance of Atlantic sturgeon has been attributed primarily to the large U.S. commercial fishery which existed for the Atlantic sturgeon from the 1870s through the mid 1990s. The fishery collapsed in 1901 and landings remained at between 1 – 5% of the pre-collapse peak until ASMFC placed a two generation moratorium on the fishery in 1998 (ASMFC 1998), which was followed by an offshore moratorium implemented by NMFS. The majority of the riverine populations show no signs of recovery, and new information suggests that stressors such as bycatch, ship strikes, and low dissolved oxygen (DO) can and do have substantial impacts on populations (ASSRT 2007). Additional threats to Atlantic sturgeon include habitat degradation from dredging, damming, and poor water quality (ASSRT 2007). Climate change related impacts on water quality (e.g., temperature, salinity, DO, contaminants) have the potential to impact Atlantic sturgeon populations using impacted river systems. These effects are expected to be more severe for southern portions of the U.S. range of Atlantic sturgeon (Carolina and South Atlantic DPSs). None of the spawning populations are currently large or stable enough to provide any level of certainty for continued existence of any of the DPSs.

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The Carolina and South Atlantic DPSs were estimated to have declined to less than three and six percent of their historical population sizes, respectively (ASSRT 2007). Both of these DPSs were listed as endangered in 2012 due to a combination of habitat curtailment and alteration, bycatch in commercial fisheries, and inadequacy of regulatory mechanisms in ameliorating these impacts and threats. The largest estimated adult Atlantic sturgeon populations are currently found in the Hudson (3,000), Altamaha (1,325), Delaware (1,305), Kennebec (865), Savannah (745), and James (705) Rivers. Published estimates of Atlantic sturgeon juvenile abundance are available in the following river systems: 4,314 age 1 fish in the Hudson in 1995 (Peterson et al. 2000); 3,656 age 0-1 fish in the Delaware in 2014 (Hale et al. 2016); between 1,072 to 2,033 age 1-2 fish on average from 2004-2007 in the Altamaha (Schueller and Peterson 2010); and 154 age 1 fish in 2010 in the Satilla (Fritts et al. 2016).

The Altamaha River supports the healthiest Atlantic sturgeon populations in the South Atlantic DPS. In a telemetry study by Peterson et al. (2008), most tagged adult Atlantic sturgeon were found between river kilometer 215 and 420 in October and November when water temperatures were appropriate for spawning. The status review team (ASSRT 2007) found that, overall, the South Atlantic DPS had a moderate risk (less than 50 percent chance) of becoming endangered over the next 20 years. Seventy-six Atlantic sturgeon were tagged in the Edisto River during a 2011 to 2014 telemetry study (Post et al. 2014). Fish entered the river between April and June and were detected in the saltwater tidal zone until water temperature decreased below 25 degrees Celsius. They then moved into the freshwater tidal area, and some fish made presumed spawning migrations in the fall around September to October. Atlantic sturgeon in the Savannah River were documented displaying similar behavior three years in a row—migrating upstream during the fall and then being absent from the system during spring and summer. Forty three Atlantic sturgeon larvae were collected in upstream locations (river kilometer 113 to 283) near presumed spawning locations (Collins and Smith 1997).

Designated Critical Habitat

NMFS designated critical habitat for each ESA-listed DPS of Atlantic sturgeon in August of 2017 (Figure 4; 82 FR 39160). PBFs determined to be essential for Atlantic sturgeon reproduction and recruitment include (1) suitable hard bottom substrate in low salinity waters for settlement of fertilized eggs, refuge, growth, and development of early life stages, (2) transitional salinity zones for juvenile foraging and physiological development, (3) water of appropriate depth and absent physical barriers to passage, (4) unimpeded movement of adults to and from spawning sites, and (5) water quality conditions that support spawning, survival, growth, development, and recruitment.

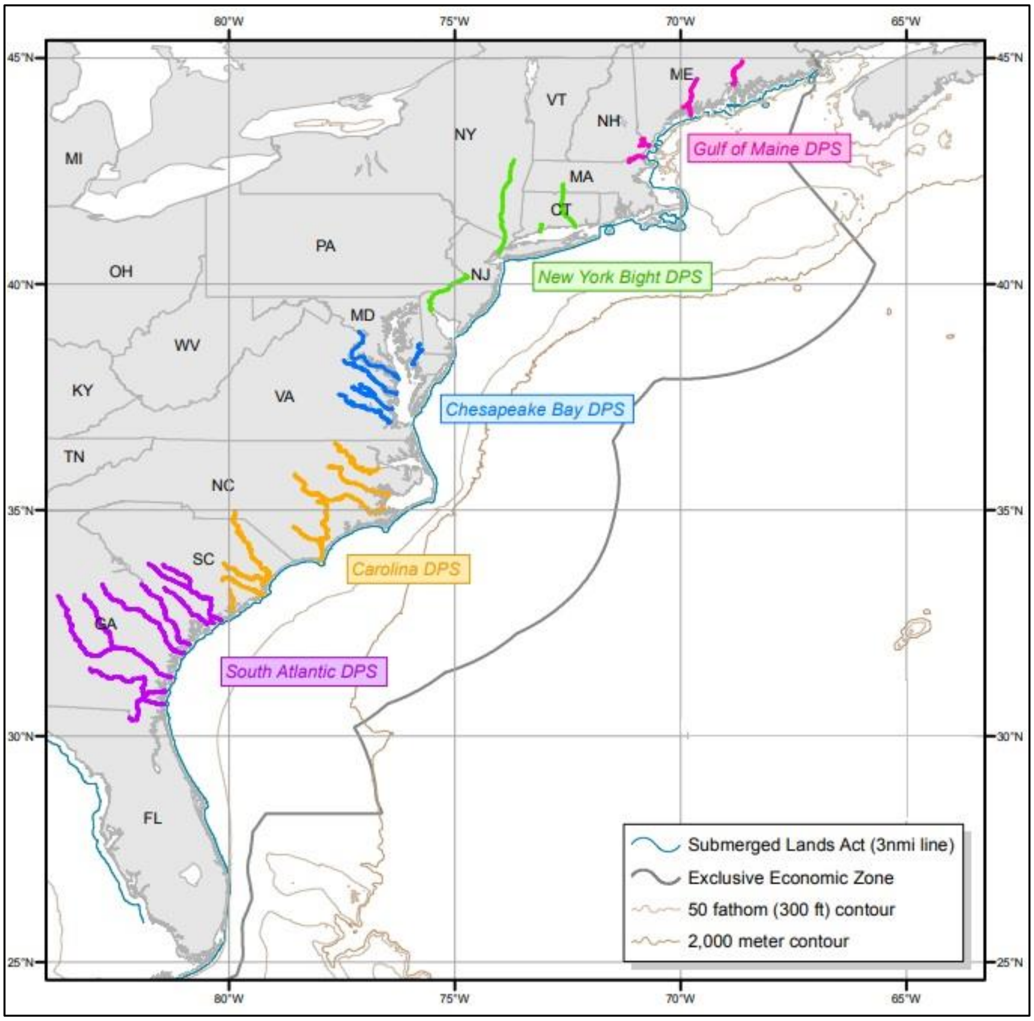

Figure 4. General map of critical habitat for each DPS of Atlantic sturgeon

Recovery Goals

Recovery Plans have not yet been drafted for any of the Atlantic sturgeon DPSs.

Shortnose Sturgeon

The shortnose sturgeon is the smallest of the three sturgeon species that occur in eastern North America; they grow up to 4.7 feet (1.4 meters) and weigh up to 50.7 pounds (23 kilograms). It has a short, conical snout with four barbells in front of its large underslung mouth. Five rows of bony plates occur along its body: one on the back, two on the belly, and one on each side. The body coloration is generally olive-yellow to gray or bluish on the back, and milky-white to dark yellow on the belly. Shortnose sturgeon occur along the Atlantic Coast of North America from the St. John River in Canada to the St. Johns River in Florida (Figure 5).

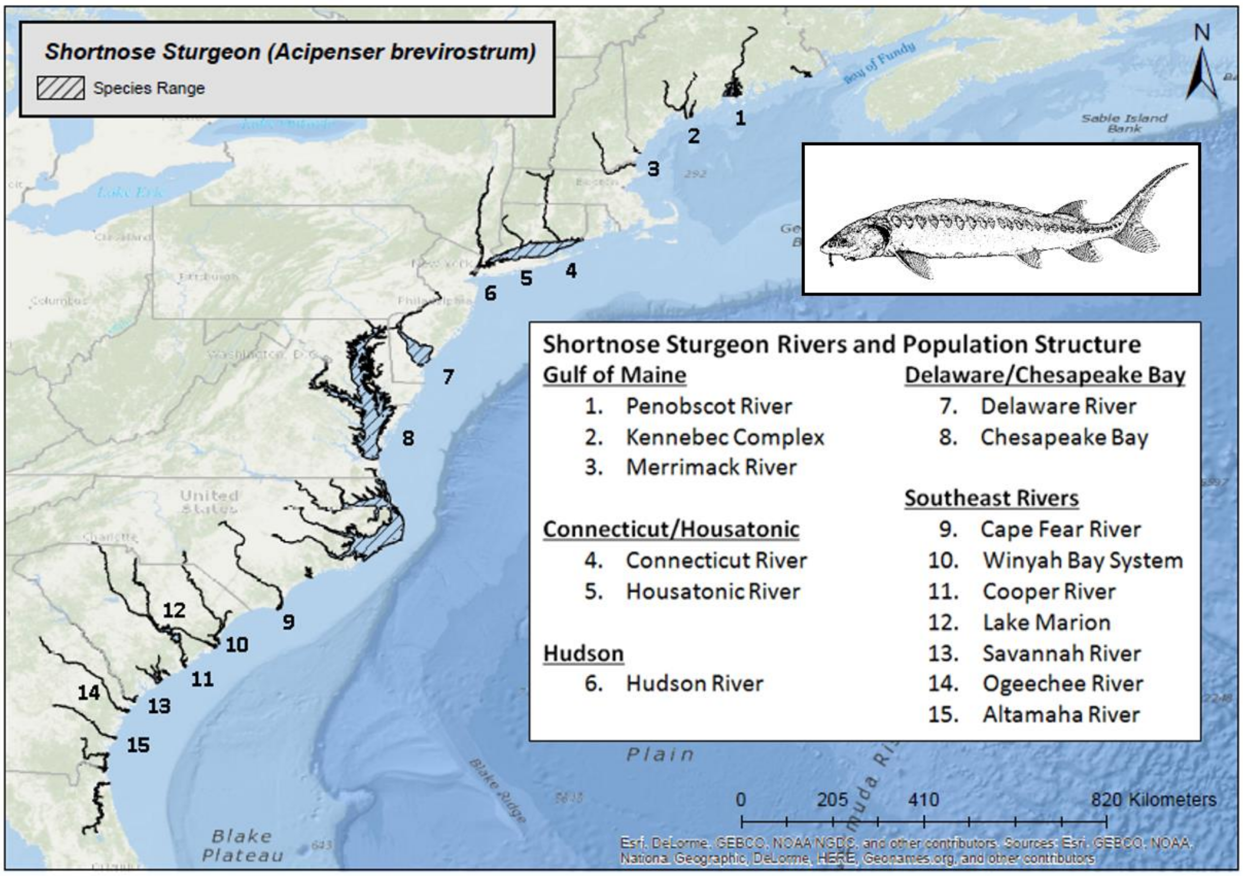

Figure 5. Geographic range of shortnose sturgeon

This section provides general information on the shortnose sturgeon coast-wide population, including information about the species life history, population dynamics, and status.

Life History

The shortnose sturgeon is a relatively slow growing, late maturing, and long-lived fish species. The maximum recorded size of shortnose sturgeon was collected from the Saint John River, Canada, measuring 143 cm total length and weighing 23 kilograms (Dadswell et al. 1984). Shortnose sturgeon typically live longer in the northern portion of their range compared to the southern portion (Dadswell et al. 1984, Gilbert 1989). The maximum ages reported of female shortnose sturgeon by river system include 67 years for the St. John River (New Brunswick), 40 years for the Kennebec River, 37 years for the Hudson River, 34 years for the Connecticut River, 20 years for the Pee Dee River, and ten years for the Altamaha River (Dadswell et al. 1984, Gilbert 1989). Female shortnose sturgeon generally outlive and outgrow males, which seldom exceed 30 years of age (Dadswell et al. 1984, Gilbert 1989). Shortnose sturgeon also exhibit sexually dimorphic growth and maturation patterns across latitudes (Dadswell et al. 1984). In the northern parts of its range, males reach maturity at 5 to 11 years, while females mature between 7 and 18 years. Shortnose sturgeon in southern rivers typically grow faster, mature at younger ages (2 to 5 years for males and 4 to 5 for females), but attain smaller maximum sizes than those in the north which grow throughout their longer lifespans (Dadswell et al. 1984).

Shortnose sturgeon are amphidromous, inhabiting large coastal rivers or nearshore estuaries within river systems (Buckley and Kynard 1985, Kieffer and Kynard 1993). They spawn in upper, freshwater areas, and feed and overwinter in both fresh and saline habitats. During the summer and winter months, adults occur primarily in freshwater tidally influenced river reaches (Buckley and Kynard 1985). Older juveniles or sub adults tend to move downstream in the fall and winter as water temperatures decline and the salt wedge recedes. In the spring and summer, they move upstream and feed mostly in freshwater reaches; however, these movements usually occur above the saltwater/freshwater river interface (Dadswell et al. 1984, Hall et al. 1991). While shortnose sturgeon do not undertake the long marine migrations documented for Atlantic sturgeon, telemetry data indicate that shortnose sturgeon do make localized coastal migrations (Dionne et al. 2013). Non-spawning movements include rapid, directed post-spawning movements to downstream feeding areas in the spring, and localized, wandering movements in the summer and winter (Dadswell et al. 1984, Buckley and Kynard 1985). Young-of-the-year shortnose sturgeon are believed to move downstream after hatching (Dovel 1983) but remain within freshwater habitats.

Shortnose sturgeon have been found in waters with temperatures as low as 2 to 3ºC (Dadswell et al. 1984) and as high as 34ºC (Heidt and Gilbert 1979). However, temperatures above 28ºC are thought to adversely affect shortnose sturgeon (Kynard 1997). Shortnose sturgeon are known to occur at a wide range of depths from a minimum depth of 0.6 m up to 30 m (Dadswell 1979, Dadswell et al. 1984). Shortnose sturgeon exhibit tolerance to a wide range of salinities from freshwater (Taubert 1980) to waters with salinity of 30 parts-per-thousand (Holland and Yelverton 1973). Shortnose sturgeon typically occur in the deepest parts of rivers or estuaries where suitable oxygen and salinity levels are present (Gilbert 1989).

Spawning occurs from late winter/early spring (southern rivers) to mid to late spring (northern rivers) depending upon location and water temperature. Shortnose sturgeon spawning migrations are characterized by rapid, directed and often extensive upstream movement (NMFS 1998). Mature males typically spawn every other year or annually depending on the river they inhabit (Dadswell 1979, NMFS 1998). Age at first spawning for females is around five years post-maturation, with spawning occurring approximately every three to five years (Dadswell 1979).

Shortnose sturgeon are believed to spawn at discrete sites within their natal river (Kieffer and Kynard 1996), typically at the farthest upstream reach of the river, if access is not obstructed by dams (NMFS 1998). Spawning occurs over channel habitats containing gravel, rubble, or rock-cobble substrates (Dadswell 1979, NMFS 1998). Additional environmental conditions associated with spawning activity include decreasing river discharge following the peak spring freshet, water temperatures ranging from 6.5 to 18ºC, and bottom water velocities of 0.4 to 0.8 meters/second (Dadswell 1979, Hall et al. 1991, Kieffer and Kynard 1996, NMFS 1998).

Estimates of annual egg production for shortnose sturgeon are difficult to calculate and are likely to vary greatly in this species because females do not spawn every year. Fecundity estimates that have been made range from 27,000 to 208,000 eggs/female, with a mean of 11,568 eggs/kg body weight (Dadswell et al. 1984). At hatching, shortnose sturgeon are 7 to 11 mm long and resemble tadpoles (Buckley and Kynard 1981). In 9 to 12 days, the yolk sac is absorbed and the sturgeon develops into larvae which are about 15 mm total length (Buckley and Kynard 1981). Sturgeon larvae are believed to begin downstream migrations at about 20 mm total length.

Shortnose sturgeon are benthic omnivores that feed on crustaceans, insect larvae, worms, mollusks (Moser and Ross 1995, Savoy and Benway 2004), oligochaete worms (Dadswell 1979) and off plant surfaces (Dadswell et al. 1984). Sub adults feed indiscriminately, consuming aquatic insects, isopods, and amphipods along with large amounts of mud, stones, and plant material (Dadswell 1979, Bain 1997).

In Georgia, movements between the Ogeechee River population and a much larger population in the Altamaha River have been documented. These two populations may be considered components of a larger meta-population. Recent sampling efforts in the Satilla and St. Marys rivers have documented shortnose sturgeon and there is some evidence (juveniles) for reproduction in the Satilla River system (Flournoy et al. 1992, Weber et al. 1998).

Population Dynamics

Historically, shortnose sturgeon are believed to have inhabited nearly all major rivers and estuaries along the entire east coast of North America. NMFS' shortnose Sturgeon Recovery Plan identifies 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 (NMFS 1998).

The 2010 Shortnose Sturgeon Status Review Team (SSSRT) conducted a three-step risk assessment for shortnose sturgeon at a riverine scale: (1) assess population health, (2) populate a "matrix of stressors" by ranking threats, and (3) review assessment by comparing population health scores to stressor scores. The Hudson River had the highest estimated adult abundance (30,000 to 61,000), followed by the Delaware (12,000), Kennebec Complex (9,000), and Altamaha (6,000; SSSRT 2010). The SSSRT found evidence of an increasing abundance trend for the Kennebec Complex and Ashepoo, Combahee, and Edisto Basin populations; a stable trend for the Merrimack, Connecticut, Hudson, Delaware, Winyah Bay Complex, Cooper, Savannah, Ogeechee, and Altamaha populations; and a declining trend only for the Cape Fear population (all other populations had an unknown trend) (SSSRT 2010).

The SSSRT summarized continuing threats to the species in each of the 29 identified populations (SSSRT 2010). Dams represent a major threat to seven shortnose sturgeon populations and a moderate threat to seven additional populations. Dredging represents a major threat to one shortnose sturgeon population (Savannah River), a moderately high threat to three populations, and a moderate threat to seven populations. Fisheries bycatch represents a major threat to one shortnose sturgeon population (Lakes Marion and Moultrie in Santee-Cooper Reservoir System), a moderately high threat to four populations, and a moderate threat to ten populations (SSSRT 2010). Water quality represents a major threat to one shortnose sturgeon population (Potomac River), a moderately high threat to six populations, a moderate threat to 13 populations, and a moderately low threat to one population. Specific sources of water quality degradation affecting shortnose sturgeon include coal tar, wastewater treatment plants, fish hatcheries, industrial waste, pulp mills, sewage outflows, industrial farms, water withdrawals, and non-point sources. Impingement/entrainment at power plants and treatment plants was rated as a moderate threat to two shortnose sturgeon populations (Delaware and Potomac).

The SSSRT examined the relationship between population health scores and associated stressors/threats for each shortnose sturgeon riverine population and concluded the following: 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 Ashepoo, Combahee and Edisto Basin are of moderate health with low stress and may be most able to recover (SSSRT 2010). Climate warming has the potential to reduce abundance or eliminate shortnose sturgeon in many rivers, particularly in the South (Kynard et al. 2016).

The SSSRT reported results of an age-structured population model using the RAMAS® software (Akçakaya and Root 2007) to estimate shortnose sturgeon extinction probabilities for three river systems: Hudson, Cooper, and Altamaha. 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. 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; SSSRT 2010). The largest shortnose sturgeon adult populations are found in the Northeastern rivers: Hudson 56,708 adults (Bain et al. 2007); Delaware 12,047 (ERC 2006); and St. Johns River greater than 18,000 adults (Dadswell 1979). Shortnose sturgeon populations in southern rivers are considerably smaller by comparison.

Genetic Diversity

Both mitochondrial DNA and nuclear DNA analyses indicate effective (with spawning) coastal migrations are occurring between adjacent rivers in some areas, particularly within the Gulf of

Maine and the Southeast (King et al. 2014). The currently available genetic information suggests that shortnose sturgeon can be separated into smaller groupings that form regional clusters across their geographic range (SSSRT 2010). Both regional population and metapopulation structures may exist according to genetic analyses and dispersal and migration patterns (Wirgin et al. 2010, King et al. 2014).

The SSSRT concluded shortnose sturgeon across their geographic range includes five genetically distinct groupings each of which have geographic ecological adaptations: 1) Gulf of Maine; 2) Connecticut and Housatonic Rivers; 3) Hudson River; 4) Delaware River and Chesapeake Bay; and 5) Southeast (SSSRT 2010). Two additional geographically separate populations occur behind dams in the Connecticut River (above the Holyoke Dam) and in Lake Marion on the Santee-Cooper River system in South Carolina (above the Wilson and Pinopolis Dams).

Although these populations are geographically isolated, genetic analyses suggest individual shortnose sturgeon move between some of these populations each generation (Quattro et al. 2002, Wirgin et al. 2005, Wirgin et al. 2010). The SSSRT recommended that each riverine population be considered as a separate management/recovery unit (SSSRT 2010).

Distribution

Shortnose sturgeon occur along the East Coast of North America in rivers, estuaries and the sea. 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, and south to the St. Johns River, FL (NMFS 1998). The distribution of shortnose sturgeon is disjointed across their range, with northern populations separated from southern populations by a distance of about 400 km near their geographic center in Virginia. Some river systems host populations which rarely leave freshwater while in other areas coastal migrations between river systems are common. Spawning locations have been identified within a number of river systems (SSSRT 2010).

Of the Navy's origination and destination ports for the action, shortnose sturgeon are found in the port of Philadelphia on the Delaware River and in the port of Mayport on the St. Johns River in northern Florida.

Status

The decline in abundance and slow recovery of shortnose sturgeon has been attributed to pollution, overfishing, bycatch in commercial fisheries, and an increase in industrial uses of the nation's large coastal rivers during the 20th century (e.g., hydropower, nuclear power, treated sewage disposal, dredging, construction; SSSRT 2010). In addition, the effects of climate change may adversely impact shortnose sturgeon by reducing the amount of available habitat, exacerbating existing water quality problems, and interfering with migration and spawning cues (SSSRT 2010). 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. This is particularly evident in some southern rivers that are suspected to no longer support reproducing populations of shortnose sturgeon (SSSRT 2010). The number of river systems in which spawning has been confirmed has been reduced to around 12 locations (SSSRT 2010).

Designated Critical Habitat

No critical habitat has been designated for the shortnose sturgeon.

Recovery Goals

The Shortnose Sturgeon Recovery Plan was developed in 1998. The long-term recovery objective, as stated in the Plan, is to recover all 19 discrete populations to levels of abundance at which they no longer require protection under the ESA (NMFS 1998). To achieve and preserve minimum population sizes for each population segment, essential habitats must be identified and maintained, and mortality must be monitored and minimized. Accordingly, other key recovery tasks discussed in the Plan are to define essential habitat characteristics, assess mortality factors, and protect shortnose sturgeon through applicable Federal and state regulations.

6 Environmental Baseline

The environmental baseline includes the past and present impacts of all Federal, state, or private actions and other human activities in the action area, the anticipated impacts of all proposed Federal projects in the action area that have already undergone formal or early section 7 consultation, and the impact of state or private actions which are contemporaneous with the consultation in process (50 CFR 402.02). The key purpose of the environmental baseline is to describe the condition of the ESA-listed species and designated critical habitat within the action area and the consequences of that condition without the action.

Nationwide and global baseline conditions are reflected within Georgia. Flather et al. (1998) identified habitat loss and alien species as the two most widespread threats in the U.S. to endangered species, affecting more than 95 percent and 35 percent of ESA-listed species, respectively. For example, the net effect of human-altered hydrology creates conditions that increase stormwater runoff; transporting land based pollutants into surface waters, and reducing the filtration of stormwater runoff through wetlands prior to reaching surface waters.

Increases in polluted runoff has been linked to a loss of aquatic species diversity and abundance, including many important commercial and recreational fish species. Non-point source pollution has also contributed to fish kills, seagrass bed declines, and algal blooms, including blooms of toxic algae. In addition, many shellfish bed and swimming beach closures can be attributed to polluted runoff. As discussed in EPA's latest National Coastal Condition Report, non-point sources have been identified as one of the stressors contributing to coastal water pollution (EPA 2012).

The Intergovernmental, Panel on Climate Change estimated that average global land and sea surface temperature has increased by 0.85°C (± 0.2) since the late 1800s, with most of the change occurring since the mid-1900s (IPCC 2013). This temperature increase is greater than what would be expected given the range of natural climatic variability recorded over the past 1,000 years (Crowley and Berner 2001). The ESA-listed species using Georgia waters are presently, or are likely to be, affected by the direct and indirect effects of global climatic change. Global climate change stressors, including consequent changes in land and water use and water quality, are major drivers of ecosystem alterations (EPA 2008). Climate change is projected to have substantial direct effects on individuals, populations, species, and the community structure and function of marine, coastal, and terrestrial ecosystems in the foreseeable future (McCarty 2001, IPCC 2002, Parry et al. 2007, IPCC 2013). Climate change is most likely to have its most pronounced effects on species whose populations are already in tenuous positions (Williams et al. 2008). Increasing atmospheric temperatures have already contributed to changes in the quality of freshwater, coastal, and marine ecosystems and have contributed to the decline of populations of endangered and threatened species (Mantua et al. 1997, Karl et al. 2009, Littell et al. 2009).

Increasing surface water temperatures can cause the latitudinal distribution of freshwater and marine fish species to change: as water temperatures rise, cold and warm water species will spread northward (Hiddink and Ter Hofstede 2008, Britton et al. 2010). Climate-mediated changes in the global distribution and abundance of marine species are expected to reduce the productivity of the oceans by affecting keystone prey species in marine ecosystems such as phytoplankton, krill, and cephalopods. (McCarty 2001, IPCC 2002, Parry et al. 2007, IPCC 2013). For example, the abundance of sea turtles in using Georgia beaches may change. A northward shift in loggerhead nest placement was reported for Melborne Beach, Florida, the largest U.S. rookery for this species (Reece et al. 2013). Aquatic nuisance species invasions are also likely to change over time, as oceans warm and ecosystems become less resilient to disturbances (EPA 2008). Invasive species that are better adapted to warmer water temperatures could outcompete native species that are physiologically geared towards lower water temperatures; such a situation currently occurs along central and northern California (Lockwood and Somero 2011). Warmer water stimulates biological processes, which can lead to environmental hypoxia. Oxygen depletion in aquatic ecosystems can result in anaerobic metabolism increasing, thus leading to an increase in metals and other pollutants being released into the water column (Staudinger et al. 2012).

The baseline condition of Georgia's aquatic resources is described in detail in the 2014 Integrated Water Quality Assessment for Georgia (Georgia DNR EPD 2018). The following paragraphs are derived from that document.

6.1 Human Alterations of Surface Waters

Almost all lakes in Georgia are artificially made reservoirs. An EPA estimate of over 4400 dams exceeding six feet makes Georgia the state with the highest density of dams in the southeast.

There are also many other smaller dams throughout the state, so it is difficult to estimate the aggregate impact of fragmented riverine systems and the attendant disruptions in biogeochemical processes, biological communities, and ecological function. For example, only four dams on the Oconee River are large enough to be included in the EPA National Dam Inventory, but there are actually 83 impoundments in the river basin. The University of Georgia River Basin Science and Policy Center (UGA River Basin Science and Policy Center 2002) describes the detrimental impacts of reservoirs as including:

- Reservoirs increase water loss through evaporation, resulting in a net loss of water from the river system.
- Reservoirs disrupt downstream transport of sediment. This effect can have localized benefits but can also result in degradation of aquatic habitat for fish, downstream erosion, and loss of property.
- Reservoirs can decrease a river system's capacity to assimilate waste and thereby cause downstream water quality problems.
- Dams block flows and create conditions that most native fish cannot tolerate within reservoirs and downstream of them.
- Reservoirs impede movement of migratory species and prevent natural recolonization of streams by other fish and organisms after droughts or other disturbances.
- Reservoirs alter highly productive floodplain forests and reduce their contribution to the food base, water quality, and habitat of adjacent rivers and streams.

The most critical impacts on the imperiled Atlantic sturgeon and shortnose sturgeon discussed in this biological opinion is the restriction of restriction of migration pathways and impacts on water quality. Essential features of the designated critical habitat for Atlantic sturgeon include water quality conditions, especially in the bottom meter of the water column, between the river mouths and spawning sites with temperature and oxygen values that support, spawning, annual and inter-annual adult, subadult, larval, and juvenile survival, and larval, juvenile, and subadult growth, development, and recruitment. Specifically, appropriate temperature and oxygen values will vary interdependently, and depending on salinity and temperature in a particular habitat. For example, 6.0 mg/L DO or greater likely supports juvenile rearing habitat, whereas DO less than 5.0 mg/L for longer than 30 days is less likely to support rearing when water temperature is greater than 25 °C. In temperatures greater than 26 °C, DO greater than 4.3 mg/L is needed to protect survival and growth. Temperatures of 13 to 26 °C likely to support spawning habitat.

6.2 Aquatic Invasive Species

Introduced aquatic invasive species are one of the main sources of risk to ESA-listed species, second only to habitat loss (Wilcove et al. 1998). They have been implicated in the endangerment of 48 percent of the species listed under ESA (Czech and Krausman 1997). The

USFWS considers invasive species to be a significant contributing factor in determining the "threatened" or "endangered" status of many native species (OTA 1993, Ruiz et al. 1997). Invasive species affect aquatic environments in many different ways. They can reduce native species abundance and distribution, and reduce local biodiversity by out-competing native species for food and habitat. They may displace food items preferred by native predators, disrupting the natural food web. They may alter ecosystem functions. Exotic plants can clog channels and interfere with recreational fishing and swimming. Introduced non-native algal species combined with nutrient overloading may increase the intensity and frequency of algal blooms. An overabundance of algae can lead to depleted DO.

Georgia has identified a number of aquatic invasive fish species that compete with native species and degrade ecological communities. Blueback herring, spotted bass, and flathead catfish were illegally introduced. The aquatic plants giant *Salvinia* and *Hydrilla* also impair Georgia waterways as does the channeled apple snail, which devours wetland vegetation. Asian carp, zebra mussel, didymo, gill lice, and whirling disease have not yet occurred in Georgia waters, but there are recent reports (October 2019) of snakehead catfish, a voracious predator.[7]

6.3 Aquatic Impairments

Georgia's most recent EPA-approved 303(d) list of impaired waters is for the year 2014.[8] At that time 8,357 miles out of 14,123 assessed rivers and streams were identified as threatened or impaired, with the top five impairment causes from fecal coliform, impaired fish communities attributed to an unknown stressor, low DO, mercury in fish tissue, and impaired benthic macro invertebrate communities attributed to an unknown stressor. Fourteen out of 76 assessed square miles of bays and estuaries were also listed as impaired by arsenic and/or low DO. The assessments that generate the 303(d) list of impaired waters do not include all possible substances that may impair a water body. Most importantly, this monitoring does not typically look for the presence of cadmium.

[7] accessed 11/18/2019 Georgia Wildlife Resources Division at https://georgiawildlife.com/aquatic-nuisance-species

[8] accessed 10/29/2019 at https://ofmpub.epa.gov/waters10/attains_state.control?p_state=GA

7 EFFECTS OF THE ACTION

The effects of the action and cumulative effects are added to the environmental baseline and evaluated in light of the status of the species and critical habitat to determine whether the action is likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of critical habitat. Effects of the action are defined as all consequences to listed species or critical habitat that are caused by the proposed action, including the consequences of other activities that are caused by the proposed action (82 FR 44976). A consequence is caused by the proposed action if it would not occur but for the proposed action and it is reasonably certain to occur (82 FR 44976). A conclusion of reasonably certain to occur must be based on clear and substantial information, using the best scientific and commercial data available. Information supporting such a conclusion includes existing plans for the activity and the economic, administrative, and legal requirements necessary for the activity to go forward. Effects of the action may occur later in time and may include consequences occurring outside the immediate area involved in the action.

This biological opinion addresses EPA approval of Georgia EPD's proposed water quality criteria for cadmium. NMFS considers the consequences of EPA approval to include any adverse effects caused by exposure to cadmium at or below the criteria concentrations and any adverse effects caused by exposure to cadmium at concentrations resulting from Georgia EPD's implementation of the criteria. In other words, NMFS considers the effects of exposures exceeding the criterion concentrations due to the way Georgia EPD plans to implement the criteria to be effects of the action.

Risk hypotheses are statements that organize an analysis by describing the relationships among the stressor, exposure, and the environmental values to be protected (assessment endpoints) by placing information on stressors in context of potential responses (EPA 1998). The risk hypotheses used in this analysis to evaluate whether exposure to cadmium at the proposed criteria will affect the survival and fitness of individual Atlantic or shortnose sturgeon through: (1) increased mortality, (2) impaired growth or development, (3) impaired reproduction, (4) consuming prey that have accumulated toxic levels of cadmium, and (5) reduced availability and quality of forage due to population-level effects on forage species

7.1 Exposure Analysis

In order to determine whether adverse effects would occur, it is necessary to characterize the exposures that would occur under the action. Exposures of ESA-listed sturgeon would occur in the waters identified in Figure 4 and Figure 5. Atlantic sturgeon are thought to spawn in the fall, with the first two years of after hatching spent in the estuary at the head of tide. For shortnose sturgeon in the southeast, spawning migrations occur from January to April and hatchlings drift to brackish waters where they live for a few months. Exposures for both species under the freshwater criteria would be relatively brief for adults, but would occur during critical developmental stages of young fish.

Sources

The mineral resources of Georgia do not include ores that would be associated with cadmium (e.g., zinc ore).[9,10] Since cadmium is not naturally enriched in Georgia soils, we would not expect it to be concentrated or redistributed to aquatic habitats due to soil disturbing activities. A review of EPA Enforcement and Compliance History Online database[11] identified six facilities required to monitor for cadmium in their discharges. These include four kaolin mines which are required to monitor for cadmium in discharges that may affect waters occupied by sturgeon. Kaolin is mined along the fall line where the Appalachian Piedmont transitions to the coastal plain (Figure 6). Comparison of Figure 6 with Figure 4 and Figure 5 shows that these mining activities occur within watersheds containing the inland reaches of sturgeon spawning habitat of the Oconee, Ocmulgee, and Ogeechee Rivers. These waters are characterized by low water hardness.

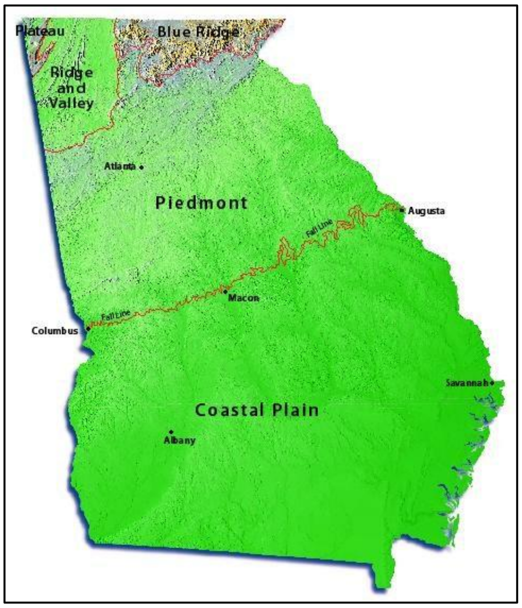

Figure 6. Location of the fall line (red) where the Appalachian Piedmont transitions to the Coastal Plain

Cadmium is actually a contaminant present in kaolin mine residue (Costa da Silva et al. 2003, Bonglaisin et al. 2011). The only violations reported in the database for these permitted discharges are related to schedule violations and the conventional pollutants, total suspended solids, turbidity, and pH. However, discharges from sources to receiving waters characterized by low water hardness may have unmonitored hazardous discharges if their cadmium concentrations are above the hardness-adjusted criteria, but below the analytical limit.

[9] https://www.cdc.gov/niosh/mining/UserFiles/statistics/17m11aoa_commod.svg

[10] https://epd.georgia.gov/sites/epd.georgia.gov/files/related_files/site_page/SM-2.PDF

[11] https://echo.epa.gov/ accessed June 2019.

Other regulated point sources of cadmium for Georgia waters appear to be inconsequential. Soil and groundwater contamination at a secondary lead smelting facility[12] which was taken out of operation in 1984 included cadmium exceeding residential risk reduction standards. Post remediation residual contaminants are either declining or stable, with a hydraulic containment system preventing offsite migration of groundwater (WSP 2018). The site is located in Atlanta, well north of designated critical habitat for Atlantic sturgeon and waters where Atlantic or shortnose sturgeon occur. Review of air quality and water quality permitting in the state identified limited metal plating industries (SIC code 3417) which are located primarily in the northern part of the state. Two plating facilities within the catchments where sturgeon occur are classified as minor emitters under their Clean Air Act permits and do not have effluent discharges regulated under the Clean Water Act. One facility is located upwind of the Satilla River and the other is about three miles downwind of the Savannah River. Considering air dispersion over this distance, atmospheric contributions from this facility are not expected to be distinguishable from background.

The national Total maximum Daily Loads database identifies two Georgia creeks that are impaired by cadmium, with the source of the cadmium attributed to nonpoint runoff and, for one creek, a permitted industrial stormwater discharge. Neither creek is located in a catchment that drains directly into the rivers where sturgeon occur. However, based on the data available, monitoring of cadmium in waters where sturgeon occur does not appear to be routine.

Cadmium is a common pollutant in stormwater. Shaver et al. (2007) reported the median cadmium concentration in urban runoff at 1.0 +/- 4.42 µg/L with highway runoff ranging from 0-40 µg/L and parking lot runoff ranging from 0.5-3.3 µg/L. Median dissolved cadmium concentrations in stormwater commercial, industrial, and freeway land use areas were reported at 0.3, 0.6, and 0.7 µg/L, respectively. However, cadmium was not reported above analytical limits in stormwater from residential and open space land use areas. Review of the National Land Cover Dataset for Georgia indicates that land cover for the catchments adjacent to rivers where sturgeon occur are predominantly forest, cropland, and pasture with wooded wetlands along the rivers and wetlands along the coastline. Exceptions are a portion of the Ocmulgee River as it passes through Macon and a portion of the Savannah River as it passes through Savannah, but, as mentioned earlier, cadmium is apparently not routinely monitored in Georgia waters.

In conclusion, sturgeon are expected to be exposed to cadmium in stormwater runoff from urban areas surrounding Macon and Savannah Georgia and from stormwater runoff and point source discharges to the Oconee, Ocmulgee, and Ogeechee Rivers from areas along the fall line where kaolin is mined.

[12] Secondary lead smeltering facilities recycle lead-bearing scrap material, typically lead acid batteries, into elemental lead or lead alloys

Ability to Detect Cadmium at or Above the Criteria in Practice

The cadmium criteria are hardness-based because the natural presence of ions that increase water hardness, such as calcium and magnesium, counter the toxicity of many metals, including cadmium. Thus the criteria concentrations are lowest in soft waters, potentially lower than the analytical detection limits used in evaluating industrial discharges and screening surface waters for cadmium impairment. With the exception of the Suwanee and Ocklocknee River basins, Georgia's river basins are characterized by soft waters. This means that the applicable criteria concentrations in Georgia waters are potentially lower than the analytical method detection limits and laboratory reporting or quantitation limits used in practice to identify and evaluate cadmium concentrations.

However, EPA guidelines for establishing test procedures for the analysis of pollutants under 136.1(c) states that: *For the purposes of the NPDES program, when more than one test procedure is approved under this part for the analysis of a pollutant or pollutant parameter, the test procedure must be sufficiently sensitive as defined at 40 CFR 122.21(e)(3) and 122.44(i)(1)(iv).* A method is sufficiently sensitive where:

> A. The method minimum level is at or below the level of the applicable water quality criterion or permit limitation for the measured pollutant or pollutant parameter; or
>
> B. In the case of permit applications, the method minimum level is above the applicable water quality criterion, but the amount of the pollutant or pollutant parameter in a facility's discharge is high enough that the method detects and quantifies the level of the pollutant or pollutant parameter in the discharge; or
>
> C. The method has the lowest minimum level of the EPA-approved analytical methods.

Further, boilerplate requirements in Georgia NPDES permits specify that *"All analytical methods, sample containers, sample preservation techniques, sample holding times must be consistent with the techniques and methods listed in 40 CFR Part 136. The analytical method used shall be sufficiently sensitive. EPA-approved methods must be applicable to the concentration ranges of the NPDES permit samples."* Georgia EPD uses two analytical methods to analyze cadmium in monitoring samples. EPA method 200.7 has a detection limit of 0.7 and is better at detecting cadmium in samples with suspended solids. EPA method 200.8 is more sensitive, with a detection limit of 0.2 µg/L. The quantitation limits and reporting limits for monitoring data are actually higher than method detection limits because they incorporate various aspects of analytical uncertainty. The method detection limits represent the lowest achievable detection under ideal laboratory conditions. The saltwater chronic and acute criteria for cadmium (33 and 7.9 µg/L, respectively) are well above these detection limits, so the implications of analytical sensitivity on the implementation of the saltwater criteria are not discussed further in this opinion.

Since the freshwater cadmium criteria are water hardness-based, it is helpful to know what water hardness determines a criterion concentration that can be detected using the EPA standard methods. Using method 200.7 with its detection limit of 0.7 µg/L, water hardness would have to exceed 36 mg/L $CaCO_3$ to detect cadmium at or above the freshwater acute criterion and exceed 97 mg/L $CaCO_3$ to detect cadmium at or above the freshwater chronic criterion. Using method 200.8 with its detection limit of 0.2 µg/L, cadmium concentrations at or exceeding the acute criterion could be identified in water with a hardness as low as 9.6 mg/L $CaCO_3$ and cadmium concentrations at or exceeding the freshwater chronic criterion is could be identified in water with a hardness as low as 18 mg/L $CaCO_3$.

Because monitoring data for surface waters are snapshots in time and samples do not likely reflect a one-hour pulsed exposures (i.e., acute exposure) such as a stormwater first flush or intermittent discharge, monitoring data are considered in context of the hardness-adjusted freshwater chronic criterion for cadmium. There are two databases from which surface water quality data were collected for this assessment: the National Water Quality Monitoring Council's Water Quality Portal (Water Portal), which integrates monitoring data collected by over 400 state, Federal, tribal, and local agencies and GOMAS. Since the Water Portal is a compilation of several water quality monitoring databases, there is some overlap with the GOMAS data.

The Water Portal includes hardness data from 244 monitoring events within inland fresh waters where ESA-listed sturgeon are expected to occur or tributaries to those waters. Hardness values for these samples range from 2.6 to 128 mg/L $CaCO_3$. Five samples had hardness values greater than 97 mg/L $CaCO_3$, so criterion exceedances could not be detected in about 98 percent of the Water Portal sampling events using EPA method 200.7. A total of 170 sampling events had hardness values above 18 mg/L $CaCO_3$. Using method 200.8, exceedances would not be detectable in at least 30 percent of samples analyzed. About 80 percent of the analytical limits reported with these data were 0.7 µg/L or greater.

The GOMAS includes hardness data for 100 monitoring events in inland fresh waters where ESA-listed sturgeon occur, or tributaries to those waters. Hardness values range from 2.55 and 210 mg/L $CaCO_3$. Only one sample had a hardness greater than 97 mg/L $CaCO_3$ at which cadmium could be detected at or above the criterion using EPA method 200.7. There were 82 sampling events with hardness values above 18 mg/L $CaCO_3$. These data indicate that exceedances of the freshwater chronic cadmium criterion would not be detectable in at least 18 percent of samples analyzed using EPA standard method 200.8. About 85 percent of the analytical limits for cadmium reported with these data were 0.7 µg/L or greater.

Both databases identify cases where hardness-adjusted cadmium freshwater chronic criteria fall below method detection limits occur fairly frequently. This suggests that cadmium impairments in waters monitored under Clean Water Act section 503(b) may not be identified. In addition, if data for a discharge permit application indicates that a constituent is not detected, the permitting authority presumes that there is "no reasonable potential" to cause or contribute to an excursion above the criterion in the receiving water, and the permit would not require any monitoring and reporting. As a result, the need to report cadmium in discharges could be dismissed from permit monitoring requirements when cadmium is potentially discharged at harmful levels.

Design Flows

Georgia, like many states, bases its criteria on the hydrologically-based design flow approach used in calculating permit waste load allocations. The hydrologically-based design flow is derived by collecting the single lowest flow event for each year over a number of years and statistically determining an extreme low flow value, such as the lowest 1-day average flow that occurs on average once every 10 years (i.e., 1Q10) or lowest 7-day average flow in a ten year period (i.e., 7Q10).

Identifying critical flow is important because exposure concentrations of discharged pollutants are highest when the receiving water is at its lowest flow. Steady state modeling, which assumes that the composition and flow of the effluent of concern is constant, uses historical stream flow data for the receiving water of concern, or reasonable surrogate for that receiving water, to arrive at design flows. This method is commonly used because the detailed discharge and location-specific data required for dynamic modelling are often not available.

The flow of a receiving water is relatable to the EPA guidelines because it can also be considered in terms of intensity (i.e., cubic feet per second), duration, and frequency. Since the discharge is considered constant, instream concentrations of discharged pollutants would be inversely proportional to receiving water flow. A design flow for a permit could be calculated as the highest discharge rate that will not cause criteria concentration exceedances to occur more often than allowed under the EPA guidelines. This type of design flow is considered a biologically-based design flow. Biologically-based design flows for the lowest one-day and four-day average flow occurring once in three years are expressed as 1B3 and 4B3, respectively, and are synonymous to the 1-hour, 3-year and 4-day, 3-year duration and frequencies specified in the EPA guidelines for chronic and acute criteria.

Hydrologically-based design flow limits, however, do not readily translate to the exposure durations and frequencies of aquatic life specified by the EPA guidelines. Book six of the EPA's Technical Guidance Manual for Performing Waste Load Allocations compared biologically-based and hydrologically-based design flow methods (EPA 1986). The comparison applied both methods to 60 receiving waters distributed throughout the United States. The guidance states that *on average*, the two approaches are equivalent but large differences for individual streams occur and there can be a significant difference in the number of criteria exceedances that occur. In most cases the biologically-based design flow for a given stream was lower than the hydrologically-based design flow, and would thus require a lower waste load allocation. Specifically, the biologically based 1B3 design flow was lower than the 1Q10 for 39 of the 60 streams examined and the 4B3 design flow was lower than the 7Q10 for 46 of the 60 streams examined

The differences in calculated flows between 1B3 and 1Q10 ranged from -50 to 20 percent and the difference between 4B3 and 7Q10 ranged from -44 to 6 percent. The magnitude of these differences is important because, as explained previously, pollutant concentrations from discharges are highest when the receiving water is at its lowest flow. Since both design flows are based on steady state modeling, differences between the hydrologically based and biologically based modeled flow rates will reflect the potential magnitude of exceedances. For example, -50 percent difference means that under the biologically-based 1B3 design flow, the pollutant is assumed to enter half the dilution volume than modeled using the hydrologically-based 1Q10 design flow. The pollutant load limit in a permit written using the 1B3 design flow, which is calculated to match the applicable criterion concentration, theoretically would be half that of a permit written using a 1Q10 design flow. This is an extreme example. The breadth of this "hydrologically-based design flow effect" (HBDF-effect) on cadmium limits, at a hardness 18 mg/L $CaCO_3$ for the 60 streams examined, is summarized in Figure 7. The figure shows that, at a hardness of 18 mg/L $CaCO_3$, the acute hydrologically-based design flow-calculated limits could exceed the intended exposure of 0.35 µg/L by up to 0.19 µg/L and the chronic hydrologically based design flow-calculated limits could be up to 0.09 µg/L higher than intended chronic exposure of 0.2 µg/L.

While we are primarily interested in whether these differences pose biologically significant effects, it is important to consider whether analytical methodology can resolve differences of this size. Method 200.8 requires laboratory fortified blank recoveries to be between 85 and 115 percent of the fortified concentration. That means the analysis of a blank spiked with 0.2 µg/L cadmium, which is the chronic cadmium criterion at 18 mg/L $CaCO_3$, could return a result of between 0.17 and 0.23 µg/L cadmium and be considered acceptable. A blank spiked with 0.35 µg/L cadmium, the acute criterion at the same hardness, could return a result of between 0.3 and 0.4 µg/L and be acceptable. Using flow data from the 60 waterbodies assessed in EPA's guidance to estimate hypothetical cadmium concentrations resulting from the HBDF-effect, our analysis identified 11 streams with 7Q10 estimated cadmium limits of 0.23 µg/L or greater and 13 with 1Q10 estimated cadmium limits of 0.4 µg/L or greater. Detection of an HBDF-effect in soft waters where the applicable chronic criterion is at the method detection limit is analytically achievable. For hard waters, resolution would be less challenging.

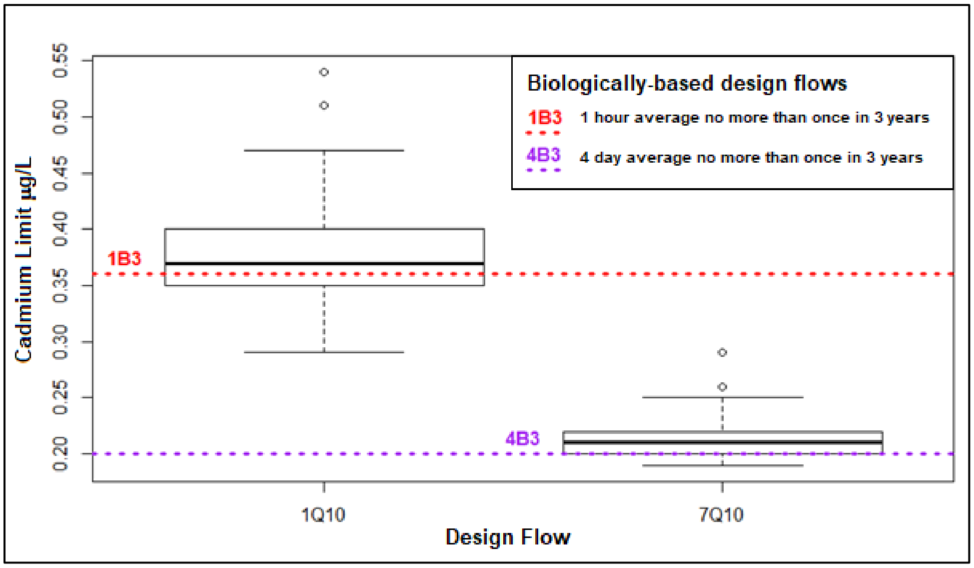

Figure 7. Illustration of the hydrological design flow effect on cadmium limits

The guidance acknowledges the difference between the hydrological and biological design flows as follows:

> *The biologically-based design flows are not always smaller than the corresponding hydrologically-based design flows for a given stream. Thus, it cannot be stated that choosing one method over the other will always result in the most protective wasteload allocation (and therefore the fewest number of excursions over the period of record). However, the biologically-based method will always provide insurance that the design flow calculated will have resulted in no more than the required number of excursions.*

The 1986 guidance also indicated that there can be a significant difference in the frequency of excursions over criteria that may occur when regulating pollutant loads to real world hydrological systems. Over the years, the 7Q10 statistic was criticized as being either over- or under-protective in various areas of U.S. Indeed, a case study conducted in 2002 compared 7Q10 with 4-day/3-year design flows and found that under 7Q10, criteria concentrations would be exceeded more than once a year in 65 percent of streams (Jonaitis 2002).

However, in practice, additional factors are typically applied to permit limits that incorporate aspects such as analytical uncertainty and effluent variability. These adjustments usually have the effect of lowering the limit in the permit (EPA 1991). Data are not available at this time to evaluate the extent to which these adjustments affect permit limits.

Conclusion

The anticipated frequency and magnitude of exceedances due to the HBDF-effect, taken with monitoring that could not detect criterion non-compliance for around a quarter of samples from shortnose and Atlantic sturgeon waters, suggests that EPA approval of the criteria concentrations, as regulated by Georgia EPD and monitored in practice, will result in water quality conditions that potentially harm not only ESA-listed sturgeon, but the aquatic life the guidelines are intended to protect. These implications will be further evaluated in the response analysis of this opinion.

7.2 Response Analysis

Thus far we have determined that exposures at and below the freshwater chronic cadmium concentration will likely go undetected due to the analytical methodology most commonly used in water quality monitoring and discharge characterization. We have also determined that applying the criteria concentrations as pollutant loads will likely result in permit discharge limits that exceed the criterion concentrations. This response analysis will determine whether the HBDF-effect increases the likelihood of adverse effects occurring, whether adverse effects are likely to occur under the proposed water quality criteria concentrations, and whether analytical limitations may result in failure to detect, and act upon, exposures that would cause adverse effects to ESA-listed sturgeon. We evaluate fish and other aquatic organisms because sturgeon may be adversely affected if cadmium under the proposed criteria reduces the quantity or quality of prey species or the aquatic vegetation relied upon by prey species. Since these habitat components are not imperiled, the required degree of protection is not as stringent as for ESA-listed species and essential features of designated critical habitat. For example as explained in Section 2.1, EPA office of pesticides uses a risk quotient threshold for threatened and endangered species is 0.05 while a threshold of 0.5 is used to assess LC50s and EC50s for non-imperiled species. These thresholds are considered general points of reference in this assessment taken in consideration with the breadth and quality of the data available when determining whether adverse effects are likely.

Influence of the HBDF-effect on Responses to Cadmium

In the exposure assessment we established that the use of a pollutant loading approach to calculating permitted discharges will likely result in exposures that exceed cadmium criterion concentrations. While the effect of increasing exposures by 20 percent for 1Q10 flows to 16.7 percent for 7Q10 flows, this may not result in appreciably different biological responses. For example, using the exposure-response relationship for flagfish (Figure 8) to calculate survival responses, there was only a fraction of a percent difference in survival at the criterion concentration versus survival under the higher HBDF-effect concentration The survival rate is 94.5 percent at the criterion of 0.396 µg/L cadmium and was and 93.07 percent under the HBDF-effect exposure at 0.46 µg/L cadmium. Further, The 95 percent confidence interval in Figure 8 suggests that any fractional difference in response due to an HBDF-effect would be undetectable. This flagfish survival exposure-response relationship is typical of other chronic and acute exposure-response relationships for metals EPA (2005). It is not unusual for response thresholds from independently conducted toxicity tests to differ by a factor of two (Norberg-King 1989).

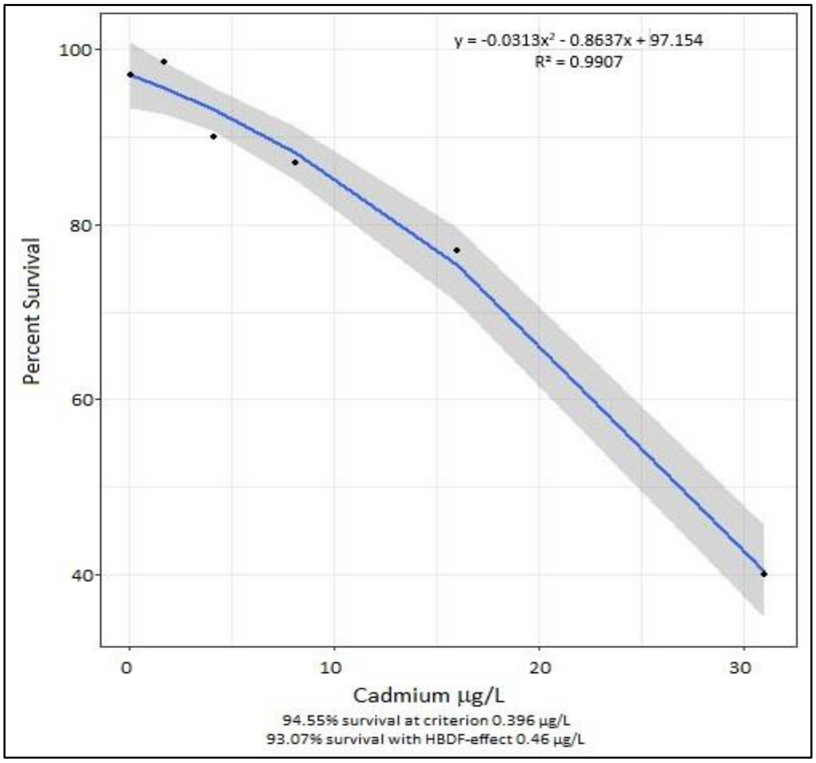

Figure 8. Example of the biological implications of the HBDF-effect using data from Spehar (1976)

CONCLUSION

NMFS has determined that the HBDF-effect on cadmium exposures is NLAA because the biological implications are expected to be insignificant due to the variability inherent in exposure-response relationships masking any fractional change in response under an HBDF-effect. The implications of applying Georgia EPD's proposed cadmium criteria concentrations as hydrologically-based pollutant loads is determined to be NLAA will not be discussed further in this opinion.

Data for Cadmium Effects on White Sturgeon

Mortality

Data for the effects of cadmium on sturgeon mortality found in ECOTOX are limited to two studies exposing white sturgeon larvae and embryos in freshwater. The acute LC50 for two-day old white sturgeon larvae exposed to cadmium over four days was greater than 47.2 µg/L under a water hardness of 103 mg/L $CaCO_3$ (Ingersoll et al. 2014). The applicable hardness-adjusted chronic cadmium criterion concentration for this exposure is 0.73 µg/L, resulting in a risk quotient of 0.015. Immobilization and loss of equilibrium, which are ecologically equivalent to mortality due to increased predation risk or moribund condition, did not occur in fish exposed to 2.1 µg/L cadmium. The lowest exposure that did affect larval survival over the observation period was 4.49 µg/L. However, the response was substantial at this concentration: 20±11.55 percent of exposed larvae were exhibiting immobilization and loss of equilibrium. Another study reported 24 and 63 day sturgeon embryo LC50s at 21.4 and 5.6 µg/L, respectively, for exposures at a water hardness of 77 mg/L $CaCO_3$. The applicable hardness-adjusted chronic cadmium criterion concentration for these exposures is 0.55 µg/L, resulting in risk quotients of 0.02 and 0.1, respectively (Vardy et al. 2011). It should be noted that this study was excluded from the cadmium criterion development. Cadmium was present in the control, but the ECOTOX database did not flag this study as having unacceptable controls. In addition, statistical methods were used to correct for high levels of mortality in the test chambers for all exposures.

Other data on the effects of cadmium on white sturgeon survival were found in the open literature. Four day LC50s for exposures of white sturgeon initiated eight days after hatching were reported at 9.7 µg/L for fish exposed in laboratory water, but at 72 µg/L for fish exposed in water collected from the Columbia River. Four day acute EC50 estimates for immobilization of early life stage white sturgeon were reported at 54.63 µg/L for exposures initiated 30 days post hatch but at 3.02 µg/L for fish exposed at 72 days post hatch. The LC50s and EC50s reported in this study were normalized to a hardness of 100 mg/L $CaCO_3$, which relates to a hardness-adjusted chronic criterion of 0.72 µg/L. The risk quotients suggesting adverse effects in this study were 0.07 for mortality in hatchlings exposed in laboratory water and 0.23 for immobilization of fish exposed 72 days post-hatch (Calfee et al. 2014). Comparisons between sturgeon and rainbow trout are helpful in this analysis since data for rainbow trout are abundant in the screened ECOTOX dataset. The EC50s for rainbow trout in the Calfee et al. (2014) study were reported at 2.55 µg/L and 2.62 µg/L when exposures were initiated at 32 and 74 days post hatch, respectively.

Another study comparing white sturgeon and rainbow trout sensitivity to cadmium, Wang et al. (2014), reported an immobilization EC50 of 5.9 µg/L for seven days post-hatch juvenile sturgeon exposed for 28 days. The EC50 for rainbow trout exposed for 28 days, starting at 26 days post hatch, was lower, at 3.2 µg/L. The data in this study was normalized to a hardness of 50 mg/L $CaCO_3$, which relates to a hardness-adjusted chronic cadmium criterion of 0.43 µg/L, resulting in risk quotients of 0.07 and 0.13 for the sturgeon and trout, respectively.

Fitness

The screened ECOTOX data only included one LOEC and one NOEC observation for fitness effects of cadmium exposures in freshwater. The LOEC of 8.3 µg/L and NOEC of 1.1 µg/L were reported for growth effects in white sturgeon larvae. These data are from the same exposures in the Vardy et al. (2011) study discussed previously. The Wang et al. (2014) study also reported EC20s for growth in larval and juvenile white sturgeon. The larval EC20s for length and dry mass were 6.3 (4.8-5.3) µg/L and 5.4 (4.2-6.8) µg/L, respectively. The juvenile EC20s for length and dry mass were 8.0 (7.4-8.6) µg/L and 6.3 (5.7-6.9) µg/L, respectively. These data were normalized to a hardness of 50 mg/L $CaCO_3$, so the applicable freshwater chronic criterion for cadmium would be 0.43 µg/L. Since the screened ECOTOX data has abundant information about rainbow trout, comparisons made with sturgeon in this study are useful. The cadmium growth EC20s were comparable for both white sturgeon and rainbow trout while the copper, lead, and zinc EC20s for white sturgeon were four- to 21-fold lower than EC20s for rainbow trout.

CONCLUSION

Toxicity data for exposures of shortnose and Atlantic sturgeon to cadmium are not available. Data for white sturgeon and rainbow trout indicate similar sensitivities to cadmium and suggest that exposures to cadmium under the chronic criteria concentrations would cause adverse effects. Section 2.1 indicates sensitivities to toxicants other than cadmium for shortnose and Atlantic sturgeon with that of rainbow trout. Taken together these data support the use of rainbow trout as surrogates for assessing cadmium risks to shortnose and Atlantic sturgeon.

Cadmium Effects on Aquatic Life

The following sections evaluate the screened ECOTOX data against the proposed chronic and acute criteria. Data are presented in paired panels of box and whisker plots that are scaled to indicate the relative abundance of data. Smaller boxes indicate fewer observations than larger boxes.

The NOEC and LOEC-type data are presented in Panel A, with reference lines, where needed, indicating the cadmium criterion concentration, and where appropriate, the detection limit of EPA method 200.7 when the criterion concentration is below 0.7 µg/L. The advantage in using method 200.7 is that it is more suitable for waters with higher levels of total suspended solids.

The LC50 and EC50 data are represented as risk quotients Panel B with a red reference lines indicating a risk quotient of 0.05 for the protection of threatened and endangered aquatic life or 0.5 for the protection of aquatic life (in general) to assess effects on quality and quantity of typical prey for shortnose and Atlantic sturgeon.

FRESHWATER CRITERIA

To understand how this analysis assesses the criteria using response data, it is necessary to review the importance of water hardness. The proposed freshwater chronic and acute criteria are intended to achieve instream concentrations that do not exceed the applicable hardness-adjusted concentration under 7Q10 or higher stream flow conditions and under 1Q10 or higher stream flow conditions, respectively. Our exposure analysis (Section 7.1) determined that exceedances of the chronic criterion concentration occur could not be detected in about 98 percent of the Water Portal sampling events in waters where shortnose and Atlantic sturgeon. The samples in the majority of these events analyzed for cadmium using EPA method 200.7 with its detection limit of 0.7 µg/L. Using method 200.8, with its cadmium detection limit of 0.2 µg/L, chronic criterion concentration exceedances would not be detectable in at least 30 percent of samples. Data from Georgia EPD's GOMAS database indicate that exceedances of the freshwater chronic cadmium criterion concentration would not be detectable in at least 18 percent of samples using EPA standard method 200.8.

As described in Section 2.1, freshwater toxicity data from ECOTOX were normalized to a hardness of 18 mg/L $CaCO_3$. At this hardness, EPA method 200.8 would be able to detect cadmium at the applicable freshwater chronic criterion concentration of 0.2 µg/L (under ideal conditions). This allows ready identification of responses occurring at exposures that might not be identified regardless of analytical method used. The freshwater acute criterion at a hardness of 18 mg/L $CaCO_3$ is 0.36 µg/L. Both the chronic and acute criteria at this hardness are below the detection limit of 0.7 µg/L for EPA method 200.7.

Exposures of Fish at the Freshwater Chronic Cadmium Criterion Concentration

Fish response data for freshwater exposure durations greater than one day (the acute criterion averaging period) up to the chronic criterion averaging period of seven days, are illustrated in Figure 9. Panel A includes three rainbow trout LC0s, a NOEC of 0.16 µg/L cadmium resulting in 2.5 percent mortality over controls (Davies and Brinkman 1994) and a LOEC of 0.17 µg/L cadmium resulting in 2.5 percent mortality over controls for fountain Southwest Texas State University (2000). A seven day NOEC resulting in 2.5 percent mortality in rainbow trout suggests incremental increased mortality risk for ESA-listed sturgeon. The dataset included ten other seven-day mortality NOECs for rainbow trout for different toxicity tests 0.72 +/- 0.4 µg/L cadmium (Davies and Brinkman 1994). The fountain darter LOEC is the lowest reported among four mortality LOECs from the same set of studies (Southwest Texas State University 2000) averaged 0.87 +/- 0.49 µg/L. The data represented in Figure 9, Panel A provided little evidence to suggest fractional increased mortality could occur in fish due to exposures to cadmium at or below the proposed freshwater criterion concentration for durations of up to seven days.

The potential to overlook adverse effects due to the use of EPA method 200.7 (blue dashed line) were indicated by data for three species: fountain darter, rainbow trout, and fathead minnow. Mortality of fountain darter and fathead minnow at their respective NOECs was 10 percent or more than controls (Southwest Texas State University 2000). No mortality was reported at any NOEC reported for rainbow trout and mortality at the single reported LOEC was 2.5 percent (Davies and Brinkman 1994). The average growth of fountain darter at the LOEC was nearly 50 percent that of controls while growth at the NOEC was 80 percent that of controls (Southwest Texas State University 2000).

However, Panel A represents only about a quarter of data (118 out of 457 observations) for one to seven day exposures of fish to cadmium in freshwater. The majority of data are for LC50s which are interpreted in terms of risk quotients plotted in Panel B. The risk quotients for salmonids, perch, temperate bass (family Moronidae) and sculpins (family Cottidae) were greater than the risk quotient reference line of 0.05. In addition, several of the cyprinid risk quotients were also greater than the reference threshold of 0.05. An acute toxicity ratio approach applied in the NMFS (2012) biological opinion to estimate relative percent mortality based on the rainbow trout LC50. The method divides the acute criterion by the LC50 and multiplies by 0.5 for the 50% mortality already accounted for by the endpoint. The LC50 data for rainbow trout suggests fractional increased mortality ranging from one to nine percent for seven-day exposures at the criterion concentration (Daoust et al. , Davies 1975, Chapman 1978, Goettl and Davies 1978, Goettl et al. 1978, Birge et al. 1983, Call et al. 1983, Cusimano et al. 1986, Pascoe et al. 1986, Roch and McCarter 1986, Anadu et al. 1989, Davies et al. 1993, Davies and Brinkman 1994, Hollis et al. 1999, Stratus Consulting Inc. 1999, Hansen et al. 2002, Niyogi et al. 2004, Besser et al. 2007).

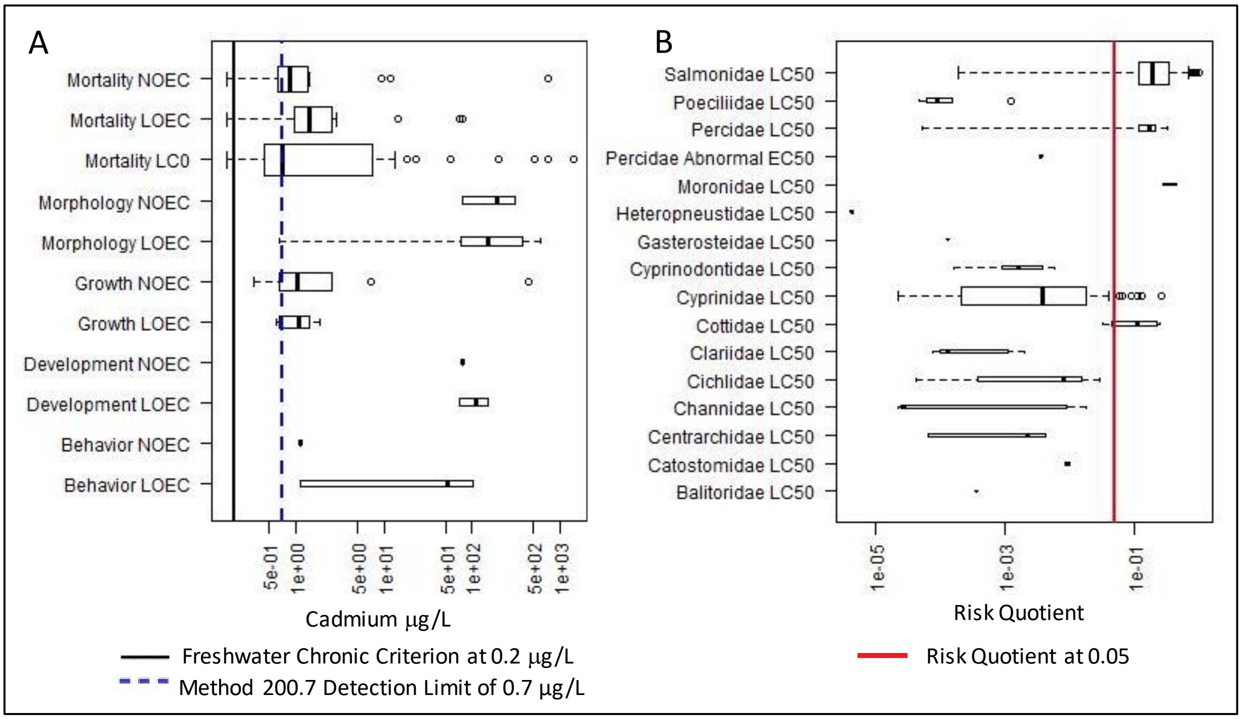

Figure 9. Responses of fish to chronic cadmium exposures in freshwater (>one to seven days)

The absence of data for reproduction and growth in this dataset is not surprising because a dataset that is limited to exposure periods of up to seven days is not likely to include substantive information on fish reproduction or post hatch/early larval growth and development. This is a case where information from exposures lasting longer than seven days are useful. The ECOTOX screened data did not indicate reproduction and population effects would occur at or below the criterion concentrations for exposures longer than seven days. The reproduction LOECs ranged from 3.56 to more than 3100 µg/L cadmium. These were from six studies representing the adults and larvae of four species exposed to cadmium for ten to 132 days (Spehar 1976, Carlson 1982, Shakila et al. 1985, Suedel et al. 1997, Tilton et al. 2003, Sellin and Kolok 2006). The population effects data are from two studies, one for mountain whitefish (Brinkman and Vieira 2008) evaluating hatching success and fry survival and one for fathead minnow (Sellin and Kolok

2006) evaluating spawnings per day, clutch size, hatch success, fry survival, and sex ratio. Few responses occurred below the chronic criterion. These include a single 100 day LOEC of 0.09 µg/L cadmium for mortality juvenile rainbow trout (Davies and Gorman 1987) and effects at 0.11 µg/L cadmium on the length and weight of rainbow trout at 62 days post hatch (Mebane et al. 2008).

Exposures of Invertebrates at the Freshwater Chronic Cadmium Criterion Concentration

Figure 10 illustrates the responses of freshwater invertebrates and plants to cadmium exposures lasting from one to seven days. Only one observation from the data illustrated in Figure 10, Panel A suggests adverse effects could occur in freshwater habitat elements due to exposures at or below the criterion, a daphnia reproduction LOEC at 0.025 µg/L (Elnabarawy et al. 1986). The dataset is comprised of 53 observations for 11 species, including a daphnia LC0 at 0.19 µg/L cadmium (Chadwick Ecological Consultants Inc. 2003). The data represented in Figure 10, Panel A do not strongly suggest adverse effects would occur in fish due to exposures to cadmium at or below the proposed freshwater criterion concentration for durations up to seven days. However, there is potential to overlook discharges and water quality conditions that may result in adverse effects if using EPA method 2007. Two Ceriodaphnia reproduction LOECs occurred at exposures below the EPA method 200.7 cadmium detection limit of 0.7 µg/L (Zuiderveen and Birge 1997). This study compared toxicity test results from multiple laboratories and found that LOECs consistently corresponded to a 50 percent inhibition in reproduction.

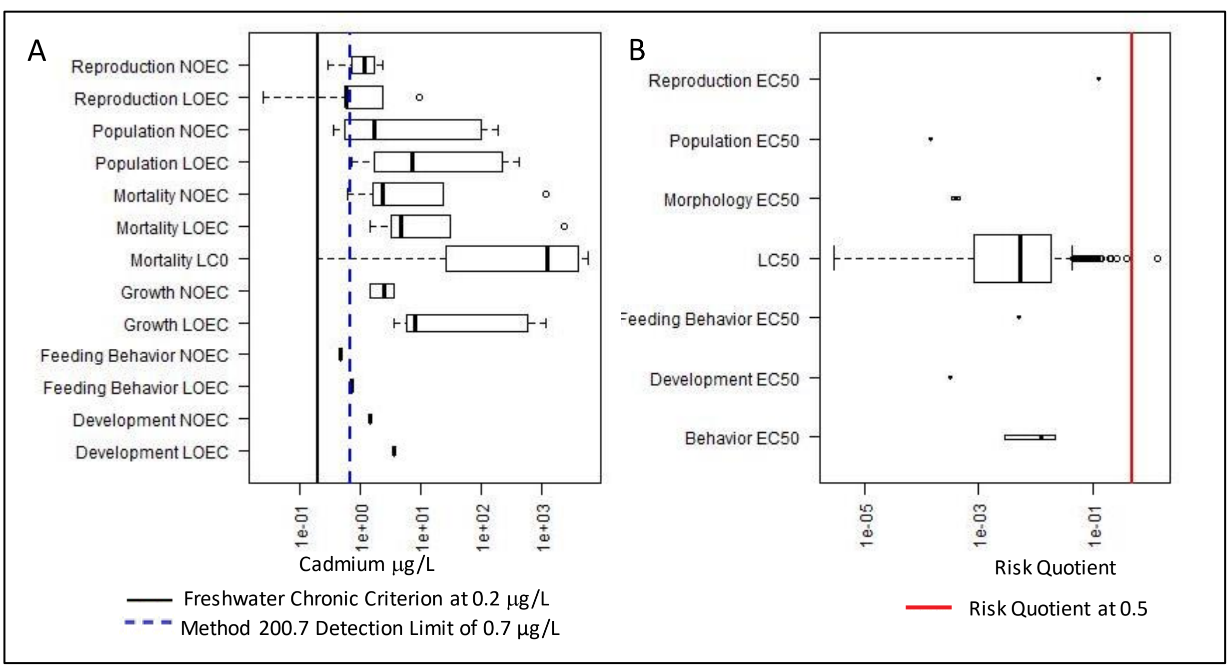

Figure 10. Responses of aquatic invertebrates and plants to chronic cadmium exposures in freshwater (>one to seven days)

The data in Panel A represents about 12 percent (53 out of 445) of the chronic freshwater exposure observations for invertebrates. The majority of data are for LC50s which are interpreted in terms of risk quotients (Figure 10, Panel B). Among the apparent outlier LC50s,[13] is a single observation for scud above the reference line of 0.5 with a risk quotient of 1.37 (Borgmann et al. 2005). The EC50s in, Panel B are sparse, but include both population and reproduction endpoints indicating that ESA-listed sturgeon are not likely to be adversely affected by alternations in the quality and quantity of prey under the chronic freshwater cadmium criterion.

Exposures of Fish at the Freshwater Acute Cadmium Criterion Concentration

The NOEC and LOEC data in Figure 11, Panel A suggests that exposures lasting up to one day would not result in adverse effects at the acute criterion concentration and that the potential for adverse effects would not be overlooked when using EPA method 200.7 (detection limit of 0.7 µg/L at blue dashed line. The lowest reported response to cadmium exposures for up to one day was more than twice the acute cadmium freshwater criterion, at 0.87 µg/L cadmium (Williams and Gallagher 2013).

This is a small dataset. The data in Panel A represent about ten percent of the data for acute exposures to cadmium in freshwater. Twenty one LC50s for one-day exposures of 13 species

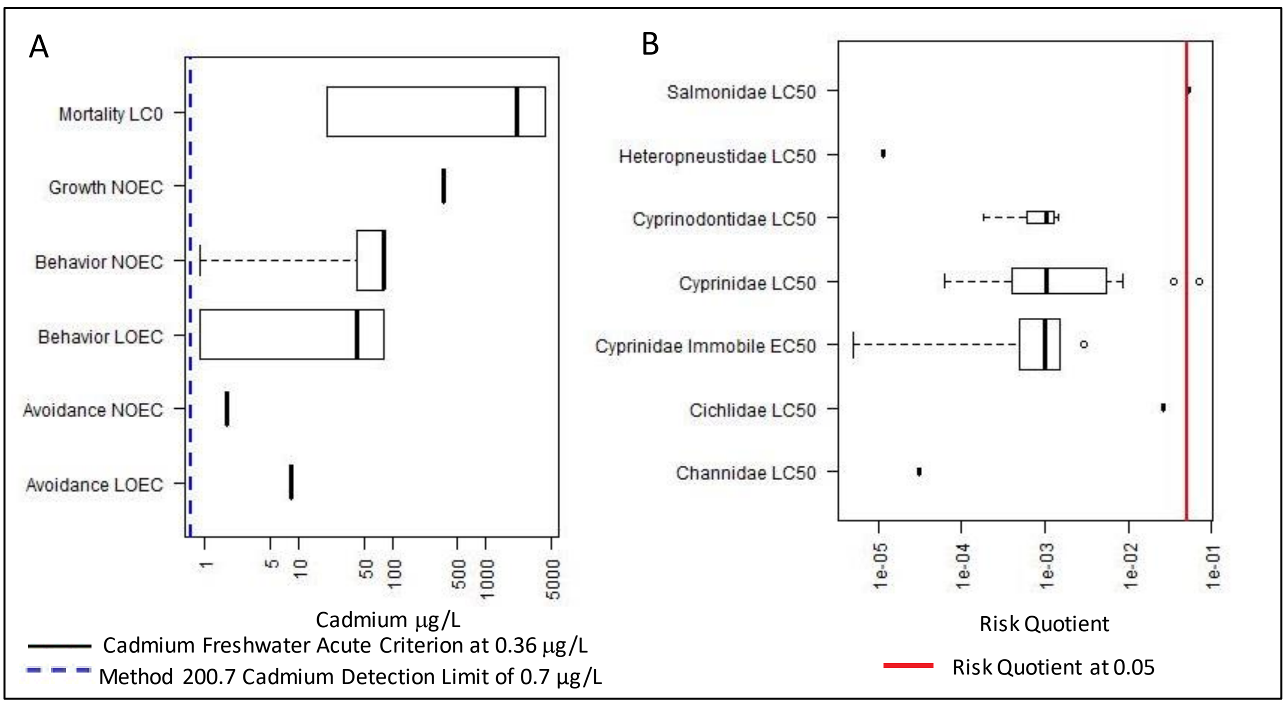

Figure 11. Fish responses to acute cadmium exposures in freshwater for up to one day

[13] Outliers are observations that are greater than on standard deviation from the mean response and are denoted on boxplots as circles flanking wither end of the "whiskers."

were included in the dataset with LC50s ranging from five to 31,715 µg/L cadmium. Among the 76 LC50 and EC50 observations, a single rainbow trout LC50 occurred close to the EPA 0.05 risk quotient threshold at 6.8 µg/L cadmium at 0.053 (Hollis et al. 1999) as did two outlier fathead minnow larva LC50s at 5.1 and 10.1 µg/L cadmium (Welsh 1996). Nearly 70 percent (53 out of 76) of the observations in the dataset were for fathead minnow fry from the same study evaluating latent effects after brief exposures to cadmium concentrations ranging from 400 to 12,800 µg/L for durations ranging from 15 minutes to up to two hours (Brent and Herricks 1998). The calculated LC50s resulting from these exposures ranged up to 71,797 µg/L cadmium. These are extreme exposures with a strong influence on the overall plot in Panel B.

Since rainbow trout are a suitable surrogate species for shortnose and Atlantic sturgeon exposures to cadmium based on response comparison of these species for other toxics (Sections 2.1) and comparison of responses to cadmium with white sturgeon, the acute ratio approach (NMFS 2012) was applied to the rainbow trout LC50 of 6.8 µg/L cadmium (Hollis et al. 1999). This approach suggests 2.6 percent mortality would result from a one-day exposure to cadmium at the acute criterion concentration of 0.36 µg/L. This suggests that a fractional increase in mortality could occur in shortnose and Atlantic sturgeon due to cadmium exposures under the freshwater acute criterion of 0.36 µg/L and that the potential for such exposures may be overlooked when using EPA method 200.7 in regulatory practice.

Exposures of Invertebrates at the Freshwater Acute Cadmium Criterion Concentration

Data for invertebrates exposed in freshwater do not suggest that one day exposure to cadmium at the acute criterion would result in adverse effects (Figure 12). Invertebrate growth data were not available for invertebrate exposures of up to one day and there were no data for aquatic plant exposures, but these response types were generally less sensitive than reproduction (see Figure 10, Panel A).

Reproduction and survival LOECS and NOECs for cadmium exposures of up to one day were reported at concentrations that were ten-fold or more the acute criterion concentrations and risk quotients for the LC50 and EC50s were less than half EPA's risk threshold for non-imperiled species. The dataset included more than 200 observations for 17 different invertebrate species. Given the size of the dataset and diversity of species represented, NMFS does not expect EPA approval of the cadmium freshwater acute criterion will adversely affect the quality and quality of prey for shortnose and Atlantic sturgeon.

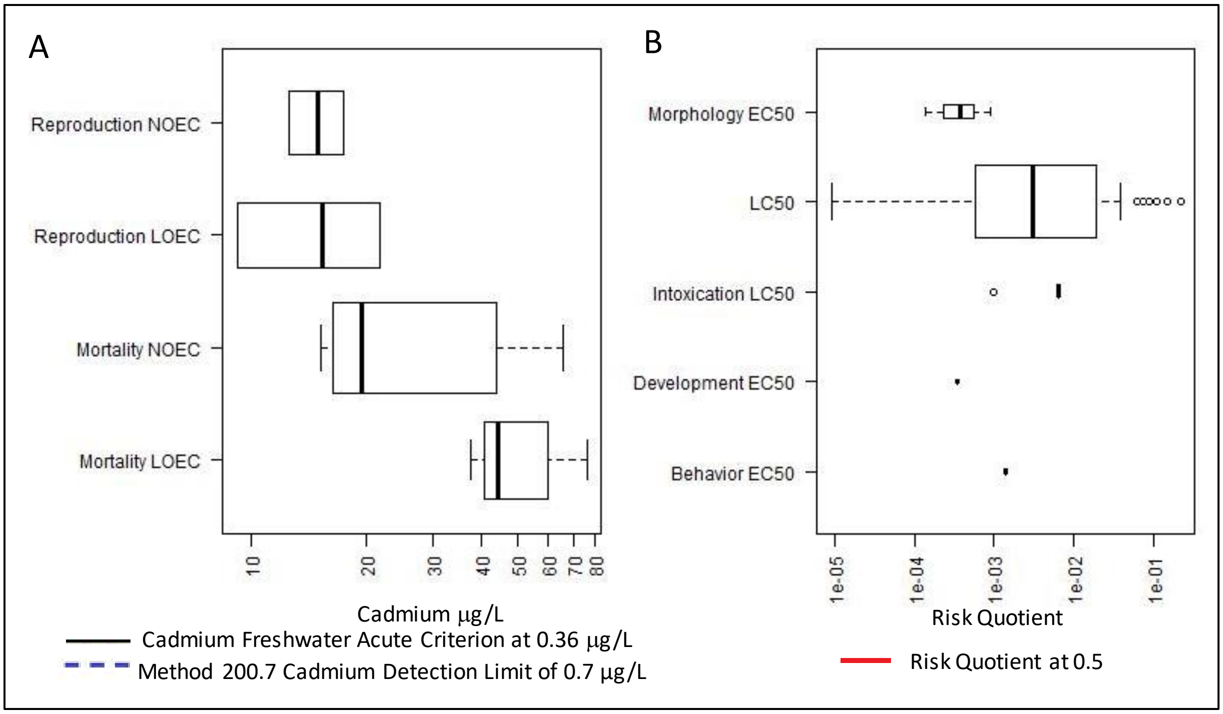

Figure 12. Invertebrate responses to cadmium exposures in freshwater for up to one day

Conclusion

NMFS concludes that adverse effects on shortnose and Atlantic sturgeon related to survival may occur from exposure to cadmium under both the chronic and acute freshwater criteria based on responses of rainbow trout. Adverse effects to these species related to the quality and quantity of prey are not expected due to the responses of aquatic invertebrates under the chronic and acute criteria. Further effects at the chronic and acute criteria concentrations may be overlooked if EPA method 200.7 is used for monitoring or regulating discharges to waters where shortnose and Atlantic sturgeon occur.

SALTWATER CRITERIA

The proposed saltwater criteria for cadmium are not hardness-adjusted. The chronic and acute saltwater criteria are intended to achieve a concentration that does not exceed 7.9 µg/L cadmium under 7Q10 or higher stream flow conditions and 33 µg/L under 1Q10 or higher stream flow conditions.

Exposures of Fish at the Saltwater Chronic Cadmium Criterion Concentration

Data presented in Figure 13, Panel A suggest that adverse effects would not occur under the chronic criterion because all NOECs and LOECs are at least one order of magnitude greater than the criterion of 7.9 µg/L cadmium. While saltwater exposure data are sparse, data for fish do not suggest adverse effects would occur in shortnose or Atlantic sturgeon exposed to cadmium under the acute or chronic criteria. However the LC50s for sheepshead minnow (Cyprinidontidae), scorpion fish (Cottidae), and turbot (Schophthalmidae) approach the risk quotient reference of 0.05. The turbot and sheepshead minnow LC50s are outlier points for larval exposures these species (Hall et al. 1994, George et al. 1996). The single scorpionfish LC50 suggests a 2 percent increased mortality using the acute toxicity ratio approach to interpreting LC50s. Scorpionfish

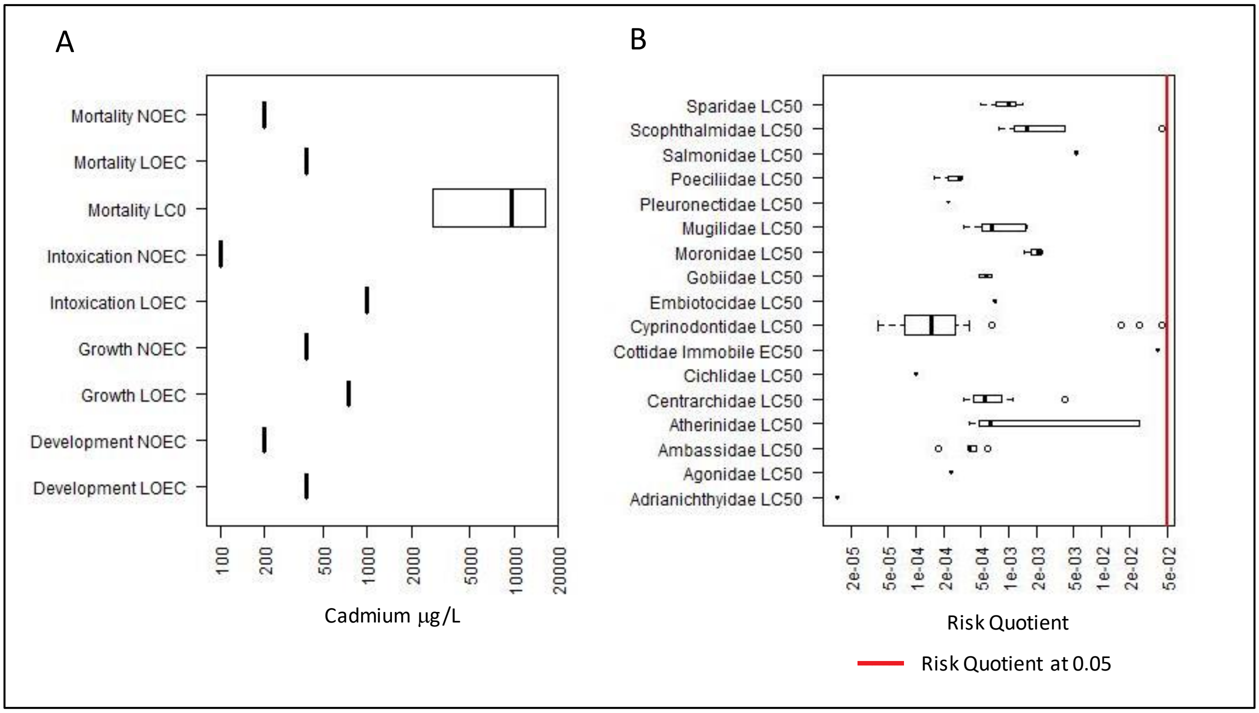

Figure 13. Responses of fish to chronic cadmium exposures in saltwater (>1 to 7 days)

larva are less than half the size of shortnose and Atlantic sturgeon larvae and the larvae of these ESA-listed sturgeon would not be exposed to cadmium in saltwater, so NMFS does not consider data for much smaller larval stages sufficiently comparable to the juvenile and adult sturgeon that occur in saltwater. Minimum LC50s among juvenile and adult saltwater fish were 3,430 µg/L cadmium for sea bass (Gelli et al. 2004a) and 11,000 µg/L cadmium for adult shiner perch (Dinnel et al. 1989). In addition, data for steelhead trout (anadromous rainbow trout) were not available but the data for coho salmon do not suggest adverse effects would occur salmonids (Dinnel et al. 1983, Dinnel et al. 1989).

Exposures of Invertebrates at the Saltwater Chronic Cadmium Criterion Concentration

About 70 percent of the LOEC and NOEC data for saltwater aquatic invertebrates are exposures of species such as opossum shrimp that are not suitable surrogates for juvenile and adult sturgeon prey (Figure 14). The remaining NOECs and LOECs for suitable prey species such as mollusks and crustaceans are orders of magnitude greater than the saltwater chronic criterion of 7.9 µg/L (Panel A). About half of the LC50s and EC50s (233 out of 503) were for 52 different species of

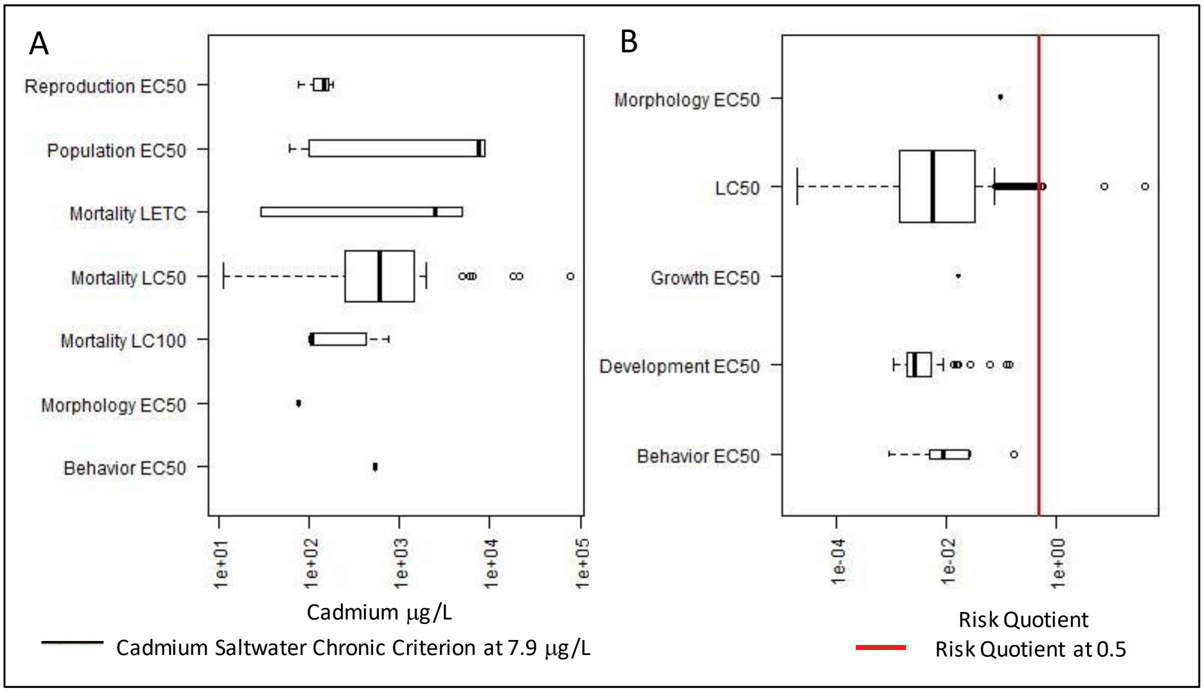

Figure 14. Responses of invertebrates chronic cadmium exposures in saltwater (>one to seven days)

surrogate sturgeon prey species (Panel B). While the average risk quotient among these data was 0.18, 47 species risk quotients fell below EPA's reference threshold of 0.05 for imperiled species.

Exposures of Fish at the Saltwater Acute Cadmium Criterion Concentration

Data for acute, one day or less, exposures of fish in saltwater are extremely sparse, such that providing box and whisker plots would not be helpful. A single LC0 of 90 µg/L cadmium was reported for spot (Middaugh et al. 1975), 19 LC50s for six species of marine fish had risk quotients ranging from 0.00015 to 0.005(Eisler and Hennekey 1977, Gelli et al. 2004b) and the risk quotient for a coho salmon fertilization success EC50 was 0.02 (Dinnel et al. 1983), but this exposure was for cadmium in the saline media for the milt, not ambient water into which the milt was released.

Exposures of Invertebrates at the Saltwater Acute Cadmium Criterion Concentration

About a third of the NOEC and LOEC data for acute, one day or less, saltwater exposures of invertebrates (Figure 15) are observations below the saltwater acute criterion of 33 µg/L cadmium. Most of these were fertilization tests for sea urchin (Jonczyk et al. 1991, Ringwood 1992, Arizza et al. 2009). The lowest NOEC among these, at 0.18 µg/L, was an statistically insignificant decline in sea urchin fertilization success of less than 2 percent relative to controls

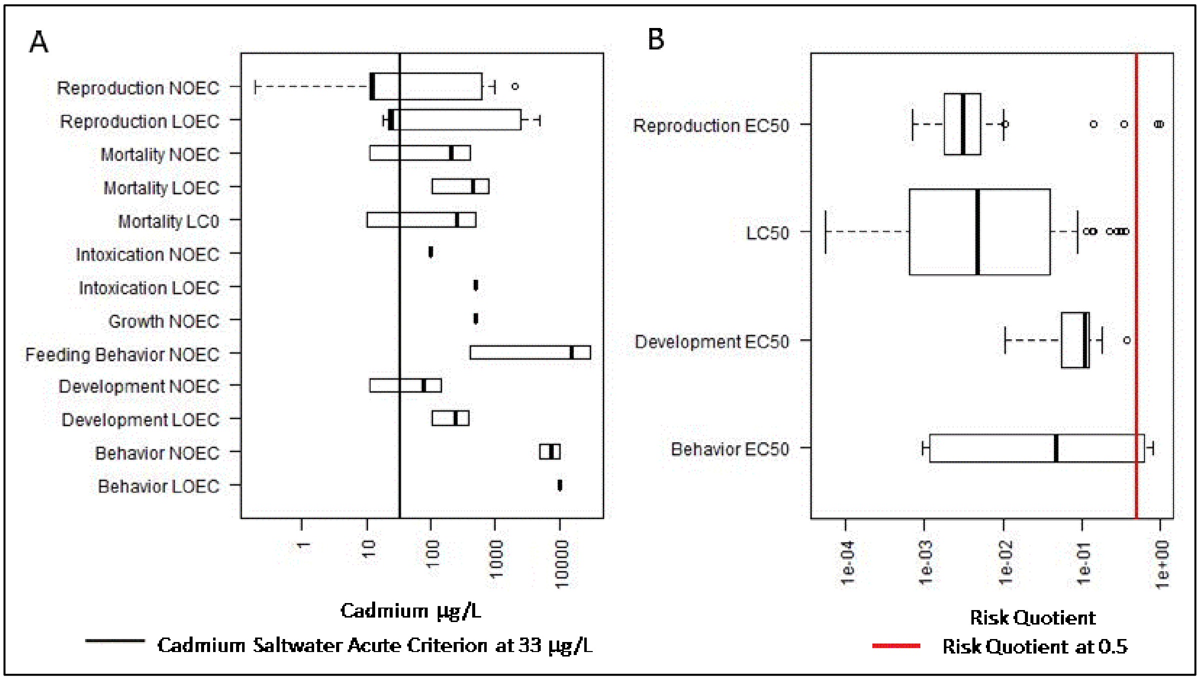

Figure 15. Invertebrate responses to cadmium exposures in saltwater for up to one day

(Arizza et al. 2009). Fertilization success at the LOEC of 18.33 µg/L in this study was a decline of about 15 percent relative to controls. The highest observations among these data were general reproduction success NOECs and LOECs of 12.5 and 25 µg/L for multiple life stages of two different sea urchin species (Jonczyk et al. 1991). Sea urchin may be particularly sensitive to cadmium relative to other saltwater invertebrate species though, as LOECs and NOECs for this species group are not reported at concentrations greater than the proposed saltwater acute criterion for cadmium. Sea urchin are not likely to be consumed by sturgeon due to their mouth size, and data for more suitable prey species and prey species surrogates are at least one order of magnitude higher than the proposed criterion.

Conclusion

NMFS has determined that exposures to cadmium under the chronic and acute saltwater criteria are NLAA for shortnose and Atlantic sturgeon because the best available toxicity data do not suggest effects would occur in other adult and juvenile marine fish and effects to the quality and quantity of prey species are not expected. The proposed cadmium saltwater acute chronic criteria will not be discussed in the risk analysis of this opinion.

7.3 Risk Analysis

In this section we assess the consequences of the responses to the individuals exposed, the populations those individuals represent, and the species those populations comprise. Whereas the Response Analysis identified the potential responses of ESA-listed species to the proposed action, this section summarizes our analysis of the expected risk to individuals, populations, and species given the expected exposure to those stressors and the expected responses to those stressors. We assess risks to individuals of endangered or threatened species using changes in the individuals' fitness, which may be indicated by changes the individual's growth, survival, annual reproductive success, and lifetime reproductive success.

In the response analysis NMFS concluded that exposures under the proposed cadmium chronic and acute freshwater criteria adversely affect the survival of shortnose and Atlantic sturgeon and that discharges or water quality conditions resulting in adverse effects may be overlooked where EPA method 200.7 is used for monitoring or regulating discharges to freshwaters where ESA-listed sturgeon occur. These exposures would occur where shortnose and Atlantic sturgeon spawn and vulnerable early life stages occur. As such, the proposed approval of Georgia EPD's freshwater cadmium criteria is expected to affect recruitment of offspring into shortnose and Atlantic sturgeon populations.

8 Cumulative Effects

"Cumulative effects" are those effects of future state or private activities, not involving Federal activities, that are reasonably certain to occur within the action area of the Federal action subject to consultation (50 CFR 402.02). Future Federal actions that are unrelated to the proposed action are not considered in this section because they require separate consultation pursuant to section 7 of the ESA.

Historical data indicate that Georgia's population had grown at an average annual rate of 1.7 percent since 1970 (Steven Manson 2019). The U.S. Census currently predicts that in 2018, Georgia's population had increased by 8.6 percent since the 2010 census to 10.52 million people (U. S. Census Bureau 2019). General resource demands in Georgia are expected to increase as a result of population growth. These demands are particularly high in coastal areas which have higher population densities and greater resource consumption compared to other parts of the state. Commercial and recreational vessel activity is likely to increase in the future with increases in population size, tourism, and average standard of living. As a result, the cumulative effects of vessel strikes involving sturgeon are also expected to continue to increase.

The future intensity of specific non-Federal activities in the action area is molded by difficult-to-predict future economy, funding levels for restoration activities, and individual investment decisions. In addition, the need to for communities to adapt to climate change and recover from severe climatic events will influence how wetlands, inland surface waters, and coastal areas are managed. Due to their additive and long-lasting nature, the adverse effects of non-Federal activities that are stimulated by general resource demands, and driven by changes in human population density and standards of living, are likely to compound in the future. Specific human activities that may contribute to declines in the abundance, range, and habitats of ESA-listed species in the action area include the following: urban and suburban development; shipping; infrastructure development; water withdrawals and diversion; recreation, including off-road vehicles and boating; expansion of agricultural and grazing activities, including alteration or clearing of native habitats for domestic animals or crops; and introduction of non-native species which can alter native habitats or out-compete or prey upon native species.

Activities which degrade water quality will continue into the future. These include conversion of natural lands, land use changes from low impact to high impact activities, water withdrawals, effluent discharges, the progression of climate change, the introduction of nonnative invasive species, and the introduction of contaminants and pesticides. Under Section 303(c) of the Clean Water Act, individual states are required to adopt WQSs to restore and maintain the chemical, physical, and biological integrity of the nation's waters. EPA must approve of state WQSs and this approval is subject to ESA section 7 consultation, which is the purpose of this opinion. While some of the stressors associated with non-Federal activities that degrade water quality will be directly accounted for in section 7 consultations between NMFS and EPA, some may be accounted for only indirectly, while others may not be accounted for at all. In particular, many non-point sources of pollution, which are not subject to Clean Water Act NPDES permit and regulatory requirements, have proven difficult for states to monitor and regulate. Non-point source pollution have been linked to loss of aquatic species diversity and abundance, fish kills, seagrass bed declines and toxic algal blooms (Gittings et al. 2013). Non-point sources of pollution are expected to increase as the human population continues to grow. Increases in non-point source pollution will need to be addressed in the future to meet the state's water quality goals. Given the challenges of monitoring and controlling non-point source pollution and accounting for all the potential stressors and effects on listed species, chronic stormwater discharges will continue to result in aggregate impacts.

9 INTEGRATION AND SYNTHESIS

The Integration and Synthesis section is the final step in our assessment of the risk posed to species and designated critical habitat as a result of implementing the proposed action. In this section, we add the effects of the action from the Risk Analysis section of this opinion (Section 7.3) to the Environmental Baseline (Section 6) and the Cumulative Effects (Section 8) to formulate the agency's opinion as to whether the proposed action is likely to: (1) reduce appreciably the likelihood of both the survival and recovery of a ESA-listed species in the wild by reducing its numbers, reproduction, or distribution; or (2) reduce the value of designated or proposed designated critical habitat as a whole for the conservation of the species. These assessments are made in full consideration of the status of the species and designated critical habitat (Section 5.3).

The following discussions summarize the probable risks the proposed action poses to shortnose and Atlantic sturgeon that are likely to be exposed. These summaries integrate the exposure profiles presented previously with the results of our response analyses for EPAs proposed approval of Georgia's freshwater cadmium criteria.

Our exposure assessment determined that exposures of shortnose and Atlantic sturgeon to cadmium above background levels are most likely to occur in waters receiving urban and large volumes roadway runoff or discharges from industries which use cadmium (e.g., electroplating) or for which cadmium is a contaminant (i.e. kaolinite mining).

Discharges at the city of Macon, Georgia is of particular concern. Macon, with an estimated population of 150,000 people and transected by interstates 75 and 16, lies at the fall line where the Ocmulgee River, tributary to the Altamaha River, enters the coastal plane. These are waters where both Shortnose and Atlantic sturgeon travel to while spawning (Devries 2006, Ingram and Peterson 2016) so the potential for larval exposures in water affected by Macon runoff is high. The Altamaha River may contain the largest population of shortnose sturgeon south of the Chesapeake Bay (Devries 2006, Bahn et al. 2009). Given the greater abundance of sturgeon in this river, NMFS expects some Atlantic sturgeon, including larvae, will likely be exposed to and affected by cadmium in runoff. These exposures are not expected to extirpate the population because they would be sporadic, affecting only those individuals present at the time of a storm event.

Other urban areas and major roadways of Georgia are not likely to pose a cadmium risk to Atlantic and shortnose sturgeon because they are not within catchments that are adjacent to waters where sturgeon are likely to occur, or the saltwater criteria, which were previously determined to be NLAA. The species does not occur above the fall line where Atlanta is located. The New Savannah Bluff Lock and Dam limits prevents migrating fish from reaching Augusta. The Savannah River is tidal as it flows through Georgia's fourth largest city, Savannah. Finally Interstate 95 primarily transects sturgeon waters at the head of tide where the saltwater criteria are most likely to be applicable.

While data from EPA's Enforcement and Compliance History Online database do not suggest metallurgical operations are discharging to sturgeon waters, six facilities are required to monitor for cadmium in their discharges. These include four kaolin mines along the fall line where the Appalachian Piedmont transitions to the coastal plain in the inland reaches of sturgeon spawning habitat of the Oconee, Ocmulgee, and Ogeechee Rivers (see the Sources section of the Exposure analysis, section 7.1.

10 CONCLUSION

After reviewing the current status of the ESA-listed species affected by EPA's proposed approval of Georgia's cadmium criteria, the environmental baseline within the action area, the effects of the proposed action, consequences of the proposed action, and cumulative effects, it is NMFS' biological opinion that the proposed action is likely to adversely affect, but not likely to jeopardize the continued existence of shortnose or Atlantic sturgeon.

11 INCIDENTAL TAKE STATEMENT

Section nine of the ESA and Federal regulations pursuant to section 4(d) of the ESA prohibit the take of endangered and threatened species, respectively, without a special exemption. "Take" is defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct. Harm is further defined by regulation to include significant habitat modification or degradation that results in death or injury to ESA-listed species by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering.

NMFS has an interim definition for harass as "create the likelihood of injury to wildlife by annoying it to such an extent as to significantly disrupt normal behavioral patterns which include, but are not limited to, breeding, feeding, or sheltering."

Incidental take is defined as take that is incidental to, and not for the purpose of, the carrying out of an otherwise lawful activity. Section 7(o)(2) provides that taking that is incidental to an otherwise lawful agency action is not considered to be prohibited taking under the ESA if that action is performed in compliance with the terms and conditions of this incidental take statement.

11.1 Amount or Extent of Take

Section 7 regulations require NMFS to specify the impact, i.e., the amount of extent, of any incidental take of endangered or threatened species; that is, the amount or extent of such incidental taking on the species (50 CFR § 402.14 (i)(1)(i)). A "surrogate" (e.g., similarly affected species or habitat or ecological conditions) may be used to express the amount or extent of anticipated take provided that the biological opinion or ITS: Describes the causal link between the surrogate and take of the listed species, explains why it is not practical to express the amount or extent of anticipated take or to monitor take-related impacts in terms of individuals of the listed species, and sets a clear standard for determining when the level of anticipated take has been exceeded." (50 C.F.R. § 402.14(i)(1)(i)).

The proposed action is anticipated to cause incidental take because EPA proposes to approve a water quality criterion for cadmium that is greater than exposure concentrations reported to cause adverse effects in fish, specifically rainbow trout which served as surrogates in the response analysis of this opinion. In addition, cadmium may go undetected when an analytical method is used which has a detection level that is not sufficiently sensitive to detect a harmful level of cadmium in waters with low hardness. Use of the proposed criterion by Georgia EPD in its water quality regulatory actions (e.g., NPDES permit effluent limitations, 305(b) assessments) therefore may result in incidental take of ESA-listed shortnose and Atlantic sturgeon under NMFS' jurisdiction. Specifically, incidental take is anticipated to include reduced recruitment through effects on larval and juvenile survival.

Incidental take under the proposed cadmium criterion cannot be accurately quantified or monitored as a number of individuals because the action area includes all waters of Georgia and data do not exist that would allow us to quantify how many individuals of each species and life stage exist in affected waters, especially considering that the numbers of individuals vary with environmental conditions, and changes in population size due to recruitment and mortality. In addition, currently we have no means to detect or determine which impairments to reproduction, development, and growth are due to the water quality under the proposed cadmium criterion versus other natural and anthropogenic environmental stressors. Because we cannot quantify the amount of take, we will use the regulatory application of the criterion as a measure reflecting the potential for harmful exposures to cadmium for the extent of authorized take as a surrogate for the amount of authorized take.

The specified amount or extent of incidental take of ESA-listed shortnose and Atlantic sturgeon species requires that Georgia EPD's intended level of protection is met, as confirmed through the terms and conditions specified in this incidental take statement. The amount or extent of incidental take applies only to exposures in waters monitored using sufficiently sensitive analytical methodology and those discharges for which reasonable potential, monitoring requirements, and discharge limits are determined using sufficiently sensitive analytical methodology. NMFS expects that, upon identification, Georgia EPD and EPA will address any noncompliance with 40 CFR part 136. This reflects Georgia EPD's and EPA's intended level of protection for aquatic life and ensures that exceedances will be detected and addressed, thereby minimizing take. NPDES permits are governed by Section 301(b)1(C) of the CWA, 33 U.S.C. § 1311 which requires that permits include effluent limitations in permits as stringent as necessary to meet water quality standards. In addition, the implementing regulations for the CWA require monitoring data to be collected using sufficiently sensitive methods for NPDES applications (40 CFR § 122.21(e)(3)(i))[14] and permits (40 CFR § 122.44(i)(1)(iv)[15].

11.2 Uncertainty within the Risk Analysis

There are uncertainties associated with our analyses of effects, response, and risk due to the absence of data related to specific concentrations at which cadmium effects shortnose and Atlantic sturgeon, making it necessary to extrapolate effect using data for other species. There also uncertainty regarding the abundance and distribution of shortnose and Atlantic sturgeon in waters affected by Georgia EPD's water quality regulation as there are no ongoing monitoring programs. These uncertainties associated with the availability of data affect our assessment of the effects of exposure to the proposed water quality criteria, as applied by Georgia EPD. NMFS elected to use the existing data as the best available for determining the potential extent of effects to shortnose and Atlantic sturgeon.

11.3 Reasonable and Prudent Measures

The measures described below are nondiscretionary and must be undertaken by EPA in order for the exemption in section 7(o)(2) to apply. Section 7(b)(4) of the ESA requires that when a proposed agency action is found to be consistent with section 7(a)(2) of the ESA and the proposed action may incidentally take individuals of ESA-listed species, NMFS will issue a statement that specifies the impact of any incidental taking of endangered or threatened species. To minimize such impacts, reasonable and prudent measures, and term and conditions to implement the measures, must be provided. Only incidental take resulting from the agency actions and any specified reasonable and prudent measures and terms and conditions identified in the incidental take statement are exempt from the taking prohibition of section 9(a), pursuant to section 7(o) of the ESA.

RPMs are nondiscretionary measures to minimize the amount or extent of incidental take (50 C.F.R. §402.02). NMFS believes the RPMs described below are necessary and appropriate to minimize the impacts of incidental take on threatened and endangered species:

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[14] 40 CFR § 122.21(e)(3)(i)): "Sufficiently sensitive method" is defined in the regulations as (A) The method minimum level (ML) is at or below the level of the applicable water quality criterion for the measured pollutant or pollutant parameter; or (B) The method ML is above the applicable water quality criterion, but the amount of the pollutant or pollutant parameter in a facility's discharge is high enough that the method detects and quantifies the level of the pollutant or pollutant parameter in the discharge; or (C) The method has the lowest ML of the analytical methods approved under 40 CFR part 136 or required under 40 CFR chapter I, subchapter N or O for the measured pollutant or pollutant parameter.

[15] 40 CFR § 122.44(i)(1)(iv): According to sufficiently sensitive test procedures (i.e., methods) approved under 40 CFR part 136 for the analysis of pollutants or pollutant parameters or required under 40 CFR chapter I, subchapter N or O. (A) For the purposes of this paragraph, a method is "sufficiently sensitive" when: (1) The method minimum level (ML) is at or below the level of the effluent limit established in the permit for the measured pollutant or pollutant parameter; or (2) The method has the lowest ML of the analytical methods approved under 40 CFR part 136 or required under 40 CFR chapter I, subchapter N or O for the measured pollutant or pollutant parameter.

NMFS believes all measures described as part of the proposed action, together with the RPM described below, are necessary and appropriate to minimize the likelihood of incidental take of ESA-listed species due to implementation of the proposed action:

1) The EPA will inform Georgia EPD in the Action Letter and Decision Document of the prohibition of unauthorized take of ESA-listed species, of NMFS' findings on the exposure of cadmium on ESA-listed shortnose and Atlantic sturgeon species, and of the conditions which may reinitiate consultation between EPA and NMFS. The EPA will encourage Georgia EPD to enlist NMFS technical assistance as early as practicable.

2) The EPA will, when reviewing permits under its regular permit review practices under the 2007 NPDES Memorandum of Agreement between the State of Georgia and the EPA Region[16] NPDES Memorandum of Agreement (MOA), review draft NPDES permits prepared by Georgia's EPD for compliance with the approved cadmium criteria, including the use of sufficiently sensitive methodology in determining monitoring requirements and discharge limits. The provisions under the 2001 MOA among EPA and the Services[17] allow for Services review of draft state-issued permits for discharges that may affect ESA-listed sturgeon species for the purposes of technical assistance to ensure that permitted cadmium discharges minimize take.

11.4 Terms and Conditions

To be exempt from the ESA prohibitions of take, the EPA must comply with the following terms and conditions, which implement the RPMs described above. These include the take minimization, monitoring and reporting measures required by the section 7 regulations (50 C.F.R. § 402.14(i)). As stated above, these terms and conditions are non-discretionary in order for the EPA to be exempt from the ESA prohibition against take. If EPA fails to ensure compliance with these terms and conditions and their implementing reasonable and prudent measures, the protective coverage of section 7(o)(2) may lapse.

1) The following terms and conditions implement reasonable and prudent measure 1: The terms and conditions provided in this incidental take statement will be included in the Action Letter and Decision Document outlining EPA's analysis of Georgia's Triennial Review revisions. EPA will copy NMFS on the Action Letter and Decision Document. In order for EPA to be exempt from take, this letter will inform Georgia EPD of the following:

    a) Unauthorized take of ESA-listed species is prohibited under section 9 of the ESA, and these prohibitions apply to all individuals, organizations, and agencies subject to United

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[16] National Pollutant Discharge Elimination System Memorandum of Agreement between the State of Georgia and the United States Environmental Protection Agency Region 4. State NPDES Memorandum for Georgia

[17] Memorandum of Agreement Between the Environmental Protection Agency, Fish and Wildlife Service and National Marine Fisheries Service Regarding Enhanced Coordination Under the Clean Water Act and Endangered Species Act. EPA-823-R-02-003

States jurisdiction. "Take" is defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct. Harm is further defined by regulation to include significant habitat modification or degradation that results in death or injury to ESA-listed species by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering.

b) Exposures to cadmium at or below the proposed criterion may adversely affect ESA-listed shortnose and Atlantic sturgeon species under NMFS' jurisdiction.

c) EPA is approving the proposed cadmium criteria. However, if scientifically defensible data[18] becomes available suggesting that exposures to cadmium under the criteria, as implemented by Georgia EPD, results in surface water quality conditions that are found to be more harmful to shortnose or Atlantic sturgeon than anticipated, for example, through monitoring in receiving waters where discharges are considered to be compliant with the cadmium criteria, consultation will be reinitiated.

d) As such, EPA's approval does not foreclose either the formulation by NMFS, or the implementation by the EPA, of any alternatives that might be determined in the reinitiated consultation to be needed to comply with section 7(a)(2).

e) The Action Letter and Decision Document will also strongly encourage Georgia EPD to enlist technical assistance from NMFS as early as practicable in order to avoid prohibited take by any activities, authorizations, or decisions regarding potential cadmium sources or concentrations in waters where ESA-listed species under NMFS' jurisdiction occur. EPA will include the following example:

> *"For example, NMFS could advise Georgia EPD on any ESA implications of 303(d)/305(b) monitoring and listing decisions affecting such waters."*

2) The following terms and conditions implement reasonable and prudent measure 2: In the Action Letter and Decision Document outlining EPA's analysis of Georgia EPD's Triennial Review revisions, EPA will describe its expectations as follows with respect to sources that potentially discharge cadmium based on industrial class or, for urban areas, population size and land use:

   a) EPA intends to implement the 2001 MOA to the extent possible. While not binding, the MOA establishes a framework for coordinating actions for activities under CWA section 402 - EPA review of permits issued by States or Tribes with approved permitting programs. EPA and NMFS expect to follow the nine coordination procedures regarding issuance of State permits specified in Section IX. A. in a manner consistent with these statutory and regulatory procedures.

[18] Information and analyses that are consistent with the Service's Policy on Information Standards Under the Endangered Species Act (59 FR 34271)

b) Pursuant to the NPDES MOA between Georgia EPD and EPA Region 4, EPA will describe its expectations as follows:
   i) Georgia EPD will provide notice and copies of draft NPDES permits, public notice, fact sheet or rationale, and permit application to the Services, in accordance with the NPDES MOA Section IV.D.4 and Section IV.E.1
   ii) Additionally, the EPA will share with Georgia EPD information about permits that may raise issues regarding impacts to federally listed species or designated critical habitats pursuant to NPDES MOA Section IV.E.1.
   iii) During the course of reviewing draft permits for facilities that discharge into streams with ESA-listed sturgeon or adjacent catchments, if the EPA determines that the effluent data submitted with the permit application has not met the requirements under 40 CFR Part 136, the EPA will inform Georgia EPD and copy NMFS in accordance with NPDES MOA Section IV.E.4.
   iv) NMFS may review the draft permit record; including supporting records/analytical results, and let Georgia EPD or EPA know if there are concerns about the effluent test and/or sampling methods as supported by the NPDES MOA Section IV.E.2.

11.5 Conservation Recommendations

Section 7(a)(1) of the ESA directs Federal agencies to use their authorities to further the purposes of the ESA by carrying out conservation programs for the benefit of the threatened and endangered species. Conservation recommendations are discretionary agency activities to minimize or avoid adverse effects of a proposed action on ESA-listed species or designated critical habitat, to help implement recovery plans or develop information (50 C.F.R. § 402.02).

Actions or measures that could also minimize or avoid adverse effects of Georgia EPD's proposed cadmium criterion on ESA-listed sturgeon species under NMFS' jurisdiction include:

3) Coordinate with nationally recognized sturgeon experts from government and academic institutions to close gaps in our understanding of the effects of cadmium on the biology, ecology, and recovery of shortnose and Atlantic sturgeon.

4) Coordinate with state and Federal agencies that carry out water quality monitoring in Georgia waters where sturgeon occur or could reestablish to sample and analyze for cadmium.

5) Use information gained in items 1) and 2) above, along with up-to-date toxicity data, to determine whether sturgeon are at risk from exposure to cadmium.

6) If the analysis in item 3) above indicate species are currently at risk or may be at risk in the future, coordinate with private, state, and Federal stakeholders to develop and implement actions that minimize or prevent such risks.

7) In order for the NMFS Office of Protected Resources ESA Interagency Cooperation Division to be kept informed of actions minimizing or avoiding adverse effects on, or benefiting, ESA-listed species or their designated critical habitat, EPA should notify the ESA

Interagency Cooperation Division of any conservation recommendations they implement in their final action.

11.6 Reinitiation Notice

This concludes formal consultation of EPA's approval of Georgia EPD's cadmium criteria. As 50 C.F.R. §402.16 requires, reinitiation of formal consultation is required where discretionary Federal agency involvement or control over the action has been retained (or is authorized by law) and if:

1. The amount or extent of taking specified in the incidental take statement has been exceeded. Specifically, incidental take in this opinion is achievement of Georgia EPD's intended level of protection for aquatic life, as confirmed through implementing the terms and conditions of the incidental take statement. An exceedance of take would thus be the inability to confirm that the intended level of protection for aquatic life is consistently achieved.
2. New information reveals effects of the agency action that may affect ESA-listed species or designated critical habitat in a manner or to an extent not previously considered, including any new information suggesting that cadmium at concentrations at or below the chronic and acute cadmium criteria are likely to cause greater reductions in fitness, and greater adverse impacts on populations and species, than identified in this opinion.
3. The identified action is subsequently modified in a manner that causes an effect to ESA-listed species or designated critical habitat that was not considered in this opinion.
4. A new species is listed or critical habitat designated under the ESA that may be affected by the action. For example, reinitiation would be triggered upon listing additional marine invertebrates as threatened or endangered under the ESA or upon designation of critical habitat that includes toxicant-sensitive biological features or water quality requirements related to pollutants.

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APPENDIX A: DATA EXAMINED IN THIS OPINION

Table A- 1. Responses of fish exposed to cadmium in freshwater for one to seven days.

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Mortality	LC0	Fathead Minnow	0.36-1.39 n=4	Southwest Texas State University, 2000
		Rainbow Trout	0.16-1.35 n=19	Davies and Brinkman, 1994; Besser, et al., 2007
		Fountain Darter	0.64-0.67 n=2	Southwest Texas State University, 2000
		Goldfish	1,415	Gargiulo, et al., 1996
		Grass Carp	197 N=2	Espina, et al., 2000
		Mottled Sculpin	0.32-18.20 n=6	Besser, et al., 2007
		Mozambique Tilapia	22.73-56.83 n=2	Chang, et al., 1998
		Turquoise Killifish	13.33	Philippe, et al., 2018
		White Sturgeon	11.74	U.S. Geological Survey, 2014
		Zambezi Barbel	718	Nguyen and Janssen, 2001
		Zebra Danio	518	Zhang, et al., 2012
	LC100	Fathead Minnow	23.56	Suedel, et al., 1997
		Rainbow Trout	2.17-9,747 n=15	Beattie and Pascoe, 1978; Birge, et al., 1983b; Davies and Brinkman, 1994; Besser, et al., 2007
		Fountain Darter	0.91-2.60 n=5	Southwest Texas State University, 2000
		Mottled Sculpin	1.03-10.94 n=4	Besser, et al., 2007
		Mountain Whitefish	3.09	Brinkman and Vieira, 2008
		Mozambique Tilapia	0.24	Wu, et al., 2007
		Turquoise Killifish	209 N=2	Philippe, et al., 2018
		White Cloud Mountain Minnow	607	Liu, et al., 2012
	LC50	Fathead Minnow	0.74-1,807 n=37	Birge, et al., 1983a; Hall, et al., 1986; Spehar and Fiandt, 1986; Diamond, et al., 1997; Suedel, et al., 1997; Welsh, 1996; Southwest Texas State University, 2000; Robison, 2011
		Rainbow Trout	0.20-1,047 n=105	Anadu, et al., 1989; Chapman, 1978; Cusimano, et al., 1986; Davies, 1976; Daoust, 1981; Davies, et al., 1993; Goettl and Davies, 1976; Pascoe, et al., 1986; Goettl, et al., 1976; Birge, et al., 1983b; Hollis, et al., 1999; Roch and McCarter, 1986; Hansen, et al., 2002; Stratus Consulting Inc., 1999; Niyogi, et al., 2004; Davies and Brinkman, 1994; Besser, et al., 2007; Call, et al., 1983

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
		Bluegill	45.50-2,949 n=2	Eaton, 1974; Black and Birge, 1980
		Bonytail	21.35-24.23 n=2	Buhl, 1997
		Brown Trout	1.03-2.53 n=7	Davies and Brinkman, 1994
		Bull Trout	0.53-2.94 n=43	Hansen, et al., 2002; Stratus Consulting Inc., 1999
		Carp, Hawk Fish	49.55	Bhilave, et al., 2008
		Chameleon Cichlid	6.78-13.56 n=3	Bulus Rossini and Ronco, 2004
		Chinook Salmon	1.01-2.82 n=4	Chapman, 1978; Finlayson and Verrue, 1982
		Colorado Squawfish	11.25-4,721 n=7	Buhl, 1997; Beleau and Bartosz, 1982
		Dace	273-346 n=3	Shyong and Chen, 2000
		Flagfish	1,202	Spehar, 1976
		Fountain Darter	0.62-1.86 n=9	Southwest Texas State University, 2000
		Goldfish	24.92-8,805 n=9	Busacker, 1980; McCarty, et al., 1978; Birge, et al., 1979; Birge, 1978; Fennikoh, et al., 1978
		Guppy	162	Shuhaimi-Othman, et al., 2013
		Indian Catfish	45,099-47,046 n=3	Kasherwani, et al., 2009
		Minnow	190-242 n=2	Chen and Yuan, 1994
		Mottled Sculpin	0.79-6.14 n=6	Besser, et al., 2007
		Mountain Whitefish	2.16	Brinkman and Vieira, 2008
		Mozambique Tilapia	23.99-2,839 n=3	James and Sampath, 1999; Chang, et al., 1998
		Mummichog	33.24-123 n=2	Gill and Epple, 1992
		Nile Tilapia	4,706	Annune, et al., 1994
		Northern Squawfish	511-995 n=6	Andros and Garton, 1980; Beleau and Bartosz, 1982
		Razorback Sucker	20.05-23.08 n=2	Buhl, 1997
		Silver Salmon	1.67	Chapman, 1975
		Snake-Head Catfish	10.74-8,733 n=3	Saxena and Parashari, 1983
		Stone Loach	559	Solbe and Flook, 1975
		Striped Bass	0.43-0.72 n=2	Palawski, et al., 1985
		Sumatran Rasbora	95.05	Shuhaimi-Othman, et al., 2013
		Taiwan Shoveljaw Carp	271-293 n=3	Shyong and Chen, 2000
		Threespine Stickleback	1,504	Pascoe and Cram, 1977
		Turquoise Killifish	11.03-53.32 n=8	Philippe, et al., 2018
		Western Mosquitofish	1,298-4,075 n=5	Giesy, et al., 1977
		White Cloud Mountain Minnow	140-278 n=3	Liu, et al., 2012
		Yellow Perch	3,729	Niyogi, et al., 2004
		Zambezi Barbel	96.26-2,563 n=3	Annune, et al., 1994; Alkahem, 1995; Nguyen and Janssen, 2001
		Zebra Danio	237-5,799 n=12	Alsop and Wood, 2011; Zhang, et al., 2012; Alsop and Wood, 2013

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
	LETC	Rainbow Trout	2.13-4.21 n=4	Stubblefield, et al., 1999
	LOEC	Fathead Minnow	0.78-14.14 n=6	Suedel, et al., 1997; Southwest Texas State University, 2000
		Rainbow Trout	0.24-2.88 n=11	Goettl, et al., 1976; Davies and Brinkman, 1994
		Fountain Darter	0.17-1.39 n=5	Southwest Texas State University, 2000
		Zambezi Barbel	71.83	Nguyen and Janssen, 2001
		Zebra Danio	77.83	Fraysse, et al., 2006
	NOEC	Fathead Minnow	0.60-9.42 n=6	Suedel, et al., 1997; Southwest Texas State University, 2000
		Rainbow Trout	0.16-1.35 n=11	Davies, 1976; Davies and Brinkman, 1994
		Fountain Darter	0.47-0.84 n=4	Southwest Texas State University, 2000
		White Sturgeon	11.74	U.S. Geological Survey, 2014
		Zambezi Barbel	718 N=2	Nguyen and Janssen, 2001
Growth	EC50	Orangethroat Darter	54.38-56.88 n=2	Sharp and Kaszubski, 1988
	LOEC	Fathead Minnow	1.87	Southwest Texas State University, 2000
		Fountain Darter	0.60-1.39 n=5	Southwest Texas State University, 2000
	NOEC	Fathead Minnow	0.91-438 n=5	Southwest Texas State University, 2000; Pistole, et al., 2008
		Rainbow Trout	1.12	Adiele, et al., 2011
		Fountain Darter	0.33-0.84 n=5	Southwest Texas State University, 2000
		Zambezi Barbel	7.18	Nguyen and Janssen, 2001
Development	LOEC	Zambezi Barbel	71.83	Nguyen and Janssen, 2001
		Zebra Danio	151	Fraysse, et al., 2006
	NOEC	Zebra Danio	77.83	Fraysse, et al., 2006
Morphology	LOEC	Rainbow Trout	0.65	Adiele, et al., 2011
		Zebra Danio	151-609 n=2	Fraysse, et al., 2006
	NOEC	Zebra Danio	77.83-307 n=2	Fraysse, et al., 2006
Behavior	LOEC	Silver Salmon	1.10-104 n=2	Williams and Gallagher, 2013
	NOEC	Silver Salmon	1.1	Williams and Gallagher, 2013

Table A- 2. Responses of fish exposed to cadmium in freshwater for more than seven days.

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Mortality	LC0	Rainbow Trout	0.46-1.36 n=4	Lowe-Jinde and Niimi, 1984; Goettl, et al., 1976
		Brown Trout	0.11-0.55 n=2	Davies and Brinkman, 1994
		Japanese Medaka	2.34	Tilton, et al., 2004
		Mottled Sculpin	0.35	Besser, et al., 2007
		Mountain Whitefish	1.11	Brinkman and Vieira, 2008
		Nile Tilapia	156	Kargin and Cogun, 1999
		Pejerrey	0.72	Carriquiriborde and Ronco, 2008
		Silver Salmon	1.21	Schreck and Lorz, 1978
		White Sturgeon	0.02	Vardy, et al., 2011
	LC100	Fathead Minnow	9.42-14.14 n=2	Suedel, et al., 1997
		Rainbow Trout	4.31	Davies and Gorman, 1987
		Bluegill	33.41-299 n=3	Eaton, 1974
		Brook Trout	3.03()	Benoit, et al., 1976
		Brown Trout	1.51-6.87 n=2	Davies and Brinkman, 1994
		Mottled Sculpin	1.32-1.39 n=2	Besser, et al., 2007
		Mountain Whitefish	3.07	Brinkman and Vieira, 2008
		White Sturgeon	22.9	Vardy, et al., 2011
		White Sucker	50.62	Eaton, et al., 1978
	LC50	Fathead Minnow	0.74-21.46 n=58	Pickering and Gast, 1972; Suedel, et al., 1997; Welsh, 1996
		Rainbow Trout	0.55-37.37 n=336	Chapman, 1978; Chapman and Stevens, 1978; Birge, et al., 1979; Black and Birge, 1980; Birge, 1978; Birge, et al., 1978; Birge, et al., 1980; Stubblefield, et al., 1999; Mebane, et al., 2007; Besser, et al., 2007
		Chinook Salmon	1.29-1.86 n=3	Chapman, 1978
		Goldfish	1,605-7,547 n=2	McCarty, et al., 1978
		Largemouth Bass	237-434 n=2	Black and Birge, 1980; Birge, et al., 1978
		Mottled Sculpin	0.46-0.72 n=3	Besser, et al., 2007
		Silver Salmon	3.09	Chapman and Stevens, 1978
		Turquoise Killifish	9.19-11.95 n=2	Philippe, et al., 2018
		White Sturgeon	1.86-7.10 n=2	Vardy, et al., 2011
		Zebra Danio	14.37	Nguyen and Janssen, 2001
	LETC	Fathead Minnow	1.78-3.33 n=2	Welsh, 1996
		Rainbow Trout	0.67-13.48 n=7	Roch and Maly, 1979; Stubblefield, et al., 1999
	LOEC	Fathead Minnow	7.07	Suedel, et al., 1997
		Rainbow Trout	0.09-4.63 n=16	Davies, et al., 1993; Goettl, et al., 1976; Davies and Gorman, 1987; Mebane, et al., 2007; Besser, et al., 2007; Mebane, et al., 2008

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
		Brook Trout	16.23-142 n=2	Jop, et al., 1995
		Brown Trout	0.38-0.98 n=3	Davies and Brinkman, 1994
		Chinook Salmon	1.45	Chapman, 1975
		Mottled Sculpin	0.35-0.72 n=3	Besser, et al., 2007
		Mountain Whitefish	1.56-1.98 n=2	Brinkman and Vieira, 2008
		White Sturgeon	2.76	Vardy, et al., 2011
		Zebra Danio	21.55	Nguyen and Janssen, 2001
	NOEC	Fathead Minnow	4.71-13.98 n=5	Suedel, et al., 1997; Sellin and Kolok, 2009
		Rainbow Trout	0.02-2.41 n=17	Davies, et al., 1993; Goettl and Davies, 1976; Goettl, et al., 1976; Davies and Gorman, 1987; Mebane, et al., 2007; Besser, et al., 2007; Mebane, et al., 2008
		Brook Trout	7.21-66.80 n=2	Jop, et al., 1995
		Brown Trout	0.11-0.55 n=2	Davies and Brinkman, 1994
		Chinook Salmon	1.02	Chapman, 1975
		Mottled Sculpin	0.16-0.35 n=3	Besser, et al., 2007
		Mountain Whitefish	0.78-1.11 n=2	Brinkman and Vieira, 2008
		White Sturgeon	0.37	Vardy, et al., 2011
		Zebra Danio	215 N=2	Nguyen and Janssen, 2001
Growth	EC50	Fathead Minnow	7.12	Spehar and Fiandt, 1986
		Mottled Sculpin	0.47-0.60 n=2	Besser, et al., 2007
		Orangethroat Darter	67.19	Sharp and Kaszubski, 1988
	LOEC	Fathead Minnow	4.31-4.82 n=3	Welsh, 1996
		Rainbow Trout	0.11-6.42 n=10	Mebane, et al., 2007; Besser, et al., 2007; Mebane, et al., 2008; Adiele, et al., 2011
		Flagfish	3.12	Carlson, et al., 1982
		Mottled Sculpin	0.35-1.32 n=2	Besser, et al., 2007
		Mountain Whitefish	0.78-1.98 n=2	Brinkman and Vieira, 2008
		Pejerrey	1.39	Carriquiriborde and Ronco, 2008
		White Sturgeon	2.76	Vardy, et al., 2011
	NOEC	Fathead Minnow	2.67-7.07 n=5	Suedel, et al., 1997; Welsh, 1996
		Rainbow Trout	0.35-2.70 n=9	Mebane, et al., 2007; Besser, et al., 2007; Mebane, et al., 2008; Adiele, et al., 2011
		Brook Trout	16.23-142 n=2	Jop, et al., 1995
		Chinook Salmon	1.45	Chapman, 1975
		Flagfish	1.44	Carlson, et al., 1982
		Mottled Sculpin	0.16-0.72 n=4	Besser, et al., 2007
		Mountain Whitefish	0.42-1.11 n=2	Brinkman and Vieira, 2008
		Nile Tilapia	358 N=4	Atli and Canli, 2007; Atli and Canli, 2008
		Pejerrey	0.72	Carriquiriborde and Ronco, 2008
		White Sturgeon	0.37	Vardy, et al., 2011
		Zebra Danio	7.18	Nguyen and Janssen, 2001

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Reproduction	LOEC	Fathead Minnow	4.71-8.19 n=2	Suedel, et al., 1997; Sellin and Kolok, 2009
		Flagfish	3.56-3,125 n=3	Spehar, 1976; Carlson, et al., 1982
		Two-Spot Or Tic Tac Toe Barb	5.66-11.33 n=4	Shakila and Wagh, 1985
	NOEC	Fathead Minnow	2.36-13.98 n=8	Suedel, et al., 1997; Sellin and Kolok, 2009
		Flagfish	1.44-1.97 n=3	Spehar, 1976; Carlson, et al., 1982
		Japanese Medaka	2.34 N=4	Tilton, et al., 2004
		Two-Spot Or Tic Tac Toe Barb	5.66-11.33 n=9	Shakila and Wagh, 1985
Development	NOEC	Fathead Minnow	13.98	Sellin and Kolok, 2009
		Zebra Danio	215	Nguyen and Janssen, 2001
Morphology	LOEC	Two-Spot Or Tic Tac Toe Barb	5.66 N=3	Shakila and Wagh, 1985
	NOEC	Fathead Minnow	13.98 N=2	Sellin and Kolok, 2009
		Rainbow Trout	1.12 N=2	Adiele, et al., 2011
		Japanese Medaka	2.34	Tilton, et al., 2004
Population	LOEC	Mountain Whitefish	0.78-1.98 n=2	Brinkman and Vieira, 2008
	NOEC	Fathead Minnow	8.19-13.98 n=4	Sellin and Kolok, 2009
		Mountain Whitefish	0.42-1.11 n=2	Brinkman and Vieira, 2008
Feeding behavior	LOEC	Bluegill	5.99	Bryan, et al., 1995
	NOEC	Pejerrey	1.39	Carriquiriborde and Ronco, 2008

Table A- 3. Responses of fish exposed to cadmium in freshwater for up to one day.

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Mortality	EC50	Killifish	339	Shedd, et al., 1999
	LC0	Rainbow Trout	20.08	Niyogi, et al., 2004
		Yellow Perch	4,306	Niyogi, et al., 2004
	LC100	Rainbow Trout	7,382	Beattie and Pascoe, 1978
		Minnow	616	Chen and Yuan, 1994
	LC50	Fathead Minnow	5.07-1,149 n=6	Birge, et al., 1983a; Welsh, 1996
		Rainbow Trout	6.82	Hollis, et al., 1999
		Chameleon Cichlid	13.44	Bulus Rossini and Ronco, 2004
		Dace	331	Shyong and Chen, 2000
		Indian Catfish	31,746	Kasherwani, et al., 2009
		Killifish	1,952	Shedd, et al., 1999
		Minnow	342	Chen and Yuan, 1994
		Mummichog	243	Gill and Epple, 1992
		Snake-Head Catfish	11,503	Saxena and Parashari, 1983
		Taiwan Shoveljaw Carp	211	Shyong and Chen, 2000
		Turquoise Killifish	41.15-65.07 n=2	Philippe, et al., 2018
		White Cloud Mountain Minnow	211	Liu, et al., 2012
		Zebra Danio	4,679-5,586 n=2	Zhang, et al., 2012
Growth	NOEC	Fathead Minnow	359	Pistole, et al., 2008
Intoxication	EC50	Fathead Minnow	120-71,797 n=53	Brent and Herricks, 1998
Avoidance	LOEC	Rainbow Trout	8.45	Birge, et al., 1993
	NOEC	Rainbow Trout	1.69	Birge, et al., 1993
Behavior	LOEC	Silver Salmon	0.87-81.84 n=2	Williams and Gallagher, 2013
	NOEC	Silver Salmon	0.87-81.84 n=3	Williams and Gallagher, 2013

Table A- 4. Responses of invertebrates exposed to cadmium in freshwater for one to seven days.

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Mortality	EC50	Scud	2.23	Isherwood, 2009
		Tubificid Worm	3,582-12,530 n=12	Rathore and Khangarot, 2002
		Water Flea	3.16	Sofyan, 2004
	LC0	Crustacean Class	9.02	Onuoha, et al., 1996
		Mussel	43.1	Loayza-Muro and Elias-Letts, 2007
		Tubificid Worm	1,255-4,015 n=3	Rathore and Khangarot, 2002
		Water Flea	0.19-5,905 n=2	Nebeker, et al., 1986; Chadwick Ecological Consultants Inc., 2003
	LC100	Crustacean Class	50.49	Onuoha, et al., 1996
		Ostracod	9.02	Onuoha, et al., 1996
		Scud	9.42-14.14 n=2	Suedel, et al., 1997
		Tubificid Worm	12,547-22,585 n=2	Rathore and Khangarot, 2002
		Water Flea	5.04-47,241 n=5	Nebeker, et al., 1986; Suedel, et al., 1997
	LC50	Amphipod	341	Martinez, et al., 1996
		Aquatic Sowbug	24.50-44.65 n=5	Bosnak and Morgan, 1981; Ham, et al., 1995
		Brown Planaria	380	Safadi, 1998
		Crab	49.83-1,154 n=3	Victor, 1993
		Crayfish	902-4,508 n=5	Fennikoh, et al., 1978; Mirenda, 1986; Khan, et al., 2006
		Crustacean Class	42.38-52.30 n=3	Onuoha, et al., 1996
		Damselfly	7,871-36,521 n=4	Thorp and Lake, 1974; Mackie, 1989
		Earthworm	988	Chapman, et al., 1982a
		Fleshy Prawn	13,591-17,628 n=2	Zang, et al., 1993
		Freshwater Shrimp	5.98	Pestana, et al., 2007
		Giant River Prawn	24.08-66.23 n=2	Shazili and Ali, 1988
		Green Floater	14.87-35.89 n=6	Black, 2003
		Hairy River Prawn	3.11-8.21 n=3	Vijayaraman and Geraldine, 1992
		Hydra	2.82-120 n=9	Beach and Pascoe, 1998; Karntanut and Pascoe, 2000; Holdway, et al., 2001
		Isopod	274-293 n=2	Bosnak and Morgan, 1981
		Mayfly	1,317-4,709 n=3	Leonhard, et al., 1980; Thorp and Lake, 1974; Brinkman and Johnston, 2008
		Midge	4.12-69,640 n=24	Qureshi, et al., 1980; Hooftman, et al., 1989; Suedel, et al., 1997; Niederlehner, 1984; Shuhaimi-Othman, et al., 2011a; Shuhaimi-Othman, et al., 2013; Fargasova, 2003
		Mussel	2,898-4,331 n=3	Bhamre, et al., 1996

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
		Naidid	55.83	Smith, et al., 1991
		Oligochaete	423	Niederlehner, 1984
		Oligochaete Worm	25.66-92.64 n=4	Shuhaimi-Othman, et al., 2012; Shuhaimi-Othman, et al., 2013
		Oligochaete, Worm	48.29-78.30 n=2	Bailey and Liu, 1980
		Ostracod	171	Fennikoh, et al., 1978
		Paper Pondshell	5.59-24.20 n=8	Black, 2003
		Protozoa	433-727 n=3	Nalecz-Jawecki and Sawicki, 1998; Nalecz-Jawecki, et al., 1993
		Red Swamp Crayfish	673-9,141 n=4	Naqvi and Howell, 1993; Del Ramo, et al., 1987
		Riceland Prawn	6.65-13.94 n=4	Shuhaimi-Othman, et al., 2013; Shuhaimi-Othman, et al., 2011c
		Ridged-Beak Peaclam	402-2,322 n=3	Mackie, 1989
		Scud	0.15-707 n=64	McCahon, et al., 1988; Fennikoh, et al., 1978; Thorp and Lake, 1974; McCahon and Pascoe, 1988a; Nebeker, et al., 1986; McCahon and Pascoe, 1988b; Collyard, et al., 1994; Suedel, et al., 1997; Borgmann, et al., 1998; McNulty, et al., 1999; Borgmann, et al., 2005; Pestana, et al., 2007; Call, et al., 1983; Shuhaimi-Othman and Pascoe, 2001
		Seed Shrimp	12.36-55.68 n=4	Shuhaimi-Othman, et al., 2011b; Shuhaimi-Othman, et al., 2013
		Shrimp	94.05-282 n=2	Thorp and Lake, 1974
		Snail	1,416	Shuhaimi-Othman, et al., 2013
		Tubificid Worm	18.22-41,999 n=5	Qureshi, et al., 1980; Brkovic-Popovic and Popovic, 1977
		Tubificid Worm, Oligochaete	229-329 n=3	Qu, et al., 2016
		Turbellarian, Flatworm	4,418	Fennikoh, et al., 1978
		Turbellarian, Planarian	6,480	Ham, et al., 1995
		Water Flea	0.74-2,753 n=94	Giesy, et al., 1977; Lee, 1976; Jindal and Verma, 1990; Gale, et al., 1992; Schuytema, et al., 1984; Mount and Norberg, 1984; Nebeker, et al., 1986; Spehar and Fiandt, 1986; Flickinger, 1984; Khangarot, et al., 1987; Roux, et al., 1993; Attar and Maly, 1982; Penttinen, et al., 1998; Diamond, et al., 1997; Suedel, et al., 1997;

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
				Barata, et al., 1998; Hockett and Mount, 1996; Tsui, et al., 2005; Mohammed and Agard, 2006; Mohammed, 2007; Zalizniak and Nugegoda, 2006; Yim, et al., 2006; Black, 2003
		Yellow Fever Mosquito	240	Simonet, et al., 1978
	LOEC	Midge	1.51-2,356 n=2	Suedel, et al., 1997; Niederlehner, 1984
		Scud	4.71	Suedel, et al., 1997
		Water Flea	3.36-30.63 n=2	Suedel, et al., 1997
	NOEC	Midge	0.63-1,178 n=2	Suedel, et al., 1997; Niederlehner, 1984
		Scud	2.36	Suedel, et al., 1997
		Water Flea	1.68-23.56 n=2	Suedel, et al., 1997
Growth	LOEC	Midge	3.59-1,178 n=2	Suedel, et al., 1997; Niederlehner, 1984
		Water Flea	8.21	Niederlehner, 1984
	NOEC	Midge	1.51	Niederlehner, 1984
		Water Flea	3.59	Niederlehner, 1984
Reproduction	EC50	Water Flea	1.53	Spehar and Fiandt, 1986
	LOEC	Water Flea	0.02-9.42 n=5	Elnabarawy, et al., 1986; Suedel, et al., 1997; Zuiderveen and Birge, 1997
	NOEC	Water Flea	0.30-2.36 n=3	Suedel, et al., 1997; Zuiderveen and Birge, 1997
Intoxication	EC50	Amphipod	738-15,021 n=2	Martin and Holdich, 1986
		Aquatic Sowbug	573-1,988 n=2	Martin and Holdich, 1986
		Midge	6,075	Khangarot and Ray, 1989a
		Ostracod	100	Khangarot and Das, 2009
		Rotifer	75.47-1,509 n=12	Buikema, et al., 1974
		Scud	7.66-40.08 n=6	Call, et al., 1983
		Water Flea	4.03-774 n=39	Lalande and Pinel-Alloul, 1983; Khangarot and Ray, 1989b; Hall, et al., 1986; Rossini and Ronco, 1996; Call, et al., 1983; Meyer, et al., 2015
Development	EC50	Protozoa	627	Nalecz-Jawecki and Sawicki, 1998
	LOEC	Midge	3.59	Niederlehner, 1984
	NOEC	Midge	1.51	Niederlehner, 1984
Morphology	EC50	Protozoa	433-601 n=2	Nalecz-Jawecki, et al., 1993
Population	EC50	Protozoan Phylum	1,409	Niederlehner, 1984
	LOEC	Hydra	0.75-11.74 n=3	Holdway, et al., 2001
		Protozoan Phylum	437	Niederlehner, 1984
	NOEC	Hydra	0.38-2.63 n=3	Holdway, et al., 2001
		Protozoan Phylum	197	Niederlehner, 1984

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Behavior	EC50	Mussel	9.19	Loayza-Muro and Elias-Letts, 2007
		Zebra Mussel	70.12	Kraak, et al., 1992
Feeding behavior	EC50	Hydra	39.93	Beach and Pascoe, 1998
	LOEC	Freshwater Shrimp	0.75	Pestana, et al., 2007
		Scud	0.75	Pestana, et al., 2007
	NOEC	Freshwater Shrimp	0.48	Pestana, et al., 2007
		Scud	0.48	Pestana, et al., 2007

Table A- 5. Responses of invertebrates exposed to cadmium in freshwater for more than seven days.

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Mortality	LC0	Oligochaete	6,225	Deeds and Klerks, 1999
		Water Flea	0.08-0.75 n=2	Dillon and Suedel, 1986; Winner and Whitford, 1987
	LC100	Giant River Prawn	0.49	Liao and Hsieh, 1990
		Midge	4.71-609 n=4	Wentsel, 1977; Suedel, et al., 1997; Niederlehner, 1984
		Oligochaete	6,484	Deeds and Klerks, 1999
		Scud	9.42-43.35 n=2	Nebeker, et al., 1986; Suedel, et al., 1997
		Snail	6.06	Holcombe, et al., 1984
		Water Flea	0.75-37.69 n=6	Dillon and Suedel, 1986; Suedel, et al., 1997; Winner and Whitford, 1987; Chadwick Ecological Consultants Inc., 2003
	LC50	Aquatic Sowbug	8.01-21.15 n=14	Ham, et al., 1995
		Crayfish	43.88-731 n=3	Mirenda, 1986
		Midge	1.90-2,269 n=4	Suedel, et al., 1997; Niederlehner, 1984
		Scud	1.03-32.66 n=10	Nebeker, et al., 1986; Suedel, et al., 1997; Shuhaimi-Othman and Pascoe, 2001
		Water Flea	1.83-24.97 n=6	Suedel, et al., 1997; Niederlehner, 1984
		Yellow Fever Mosquito	7,279	Rayms-Keller, et al., 1998
		Zebra Mussel	23.49	Kraak, et al., 1992
	LOEC	Mayfly	1,579	Brinkman and Johnston, 2008
		Midge	0.63-2,356 n=4	Suedel, et al., 1997; Niederlehner, 1984
		Scud	0.24-4.71 n=4	Suedel, et al., 1997; Chadwick Ecological Consultants Inc., 2003
		Water Flea	0.37-30.63 n=8	Suedel, et al., 1997; Niederlehner, 1984; Winner and Whitford, 1987; Chadwick Ecological Consultants Inc., 2003
	NOEC	Mayfly	843	Brinkman and Johnston, 2008
		Midge	1.51-1,178 n=3	Suedel, et al., 1997; Niederlehner, 1984
		Scud	0.11-2.36 n=4	Suedel, et al., 1997; Chadwick Ecological Consultants Inc., 2003
		Water Flea	0.75-23.56 n=12	Suedel, et al., 1997; Niederlehner, 1984; Winner and Whitford, 1987; Chadwick Ecological Consultants Inc., 2003
Growth	LOEC	Midge	3.59-1,178 n=3	Suedel, et al., 1997; Niederlehner, 1984

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
		Scud	0.41-1.61 n=2	Chadwick Ecological Consultants Inc., 2003; Malhi, 2012
	NOEC	Midge	1.51-3.59 n=2	Niederlehner, 1984
		Scud	0.24-4.71 n=4	Suedel, et al., 1997; Chadwick Ecological Consultants Inc., 2003; Malhi, 2012
		Water Flea	1.94	Niederlehner, 1984
Reproduction	EC50	Water Flea	0.27-0.43 n=2	Elnabarawy, et al., 1986; Knowles and McKee, 1987
	LOEC	Water Flea	0.02-9.42 n=14	Elnabarawy, et al., 1986; Suedel, et al., 1997; Niederlehner, 1984; Winner and Whitford, 1987; Chadwick Ecological Consultants Inc., 2003
	NOEC	Water Flea	0.37-6.14 n=16	Suedel, et al., 1997; Niederlehner, 1984; Winner and Whitford, 1987; Chadwick Ecological Consultants Inc., 2003
Development	LOEC	Mayfly	1,579	Brinkman and Johnston, 2008
		Midge	3.59 N=2	Niederlehner, 1984
	NOEC	Mayfly	843	Brinkman and Johnston, 2008
		Midge	1.51 N=2	Niederlehner, 1984
Population	LOEC	Oligochaete	12.99 N=2	Niederlehner, 1984
		Protozoan Phylum	0.49	Niederlehner, 1984
	NOEC	Oligochaete	5.28-8.85 n=7	Niederlehner, et al., 1984; Niederlehner, 1984
		Protozoan Phylum	0.14-3.35 n=2	Niederlehner, 1984
Behavior	EC50	Zebra Mussel	4.88-11.75 n=2	Kraak, et al., 1992

Table A- 6. Responses of invertebrates exposed to cadmium in freshwater for up to one day.

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Mortality	EC50	Tubificid Worm	6,081-8,134 n=4	Rathore and Khangarot, 2002
	LC100	Ciliate Protozoa	183	Schlenk and Moore, 1994
		Ostracod	916	Onuoha, et al., 1996
	LC50	Atlantic Pigtoe	35.55-64.79 n=2	Black, 2003
		Ciliate	55.25-164 n=2	Madoni and Romeo, 2006
		Crab	1,826	Victor, 1993
		Fairy Shrimp	108-120 n=2	Centeno, et al., 1993
		Fleshy Prawn	31,621	Zang, et al., 1993
		Green Floater	61.98	Black, 2003
		Hairy River Prawn	9.34	Vijayaraman and Geraldine, 1992
		Hydra	156-255 n=2	Beach and Pascoe, 1998; Karntanut and Pascoe, 2000
		Midge	48.23-20,747 n=7	Qureshi, et al., 1980; Hooftman, et al., 1989; Bechard, et al., 2008; Shuhaimi-Othman, et al., 2011a
		Mussel	5,665	Bhamre, et al., 1996
		Oligochaete Worm	161	Shuhaimi-Othman, et al., 2012
		Ostracod	31.15-38.48 n=2	Onuoha, et al., 1996
		Paper Pondshell	10.47-16.14 n=4	Black, 2003
		Protozoa	12.89-3,767 n=9	Nalecz-Jawecki and Sawicki, 1998; Nalecz-Jawecki, et al., 1993; Madoni and Romeo, 2006
		Riceland Prawn	23.09	Shuhaimi-Othman, et al., 2011c
		Rotifer	191-333 n=2	Snell and Persoone, 1989a; Couillard, et al., 1989
		Scud	18.21-130 n=4	McCahon, et al., 1988; McCahon and Pascoe, 1988a; McCahon and Pascoe, 1988b; Shuhaimi-Othman and Pascoe, 2001
		Seed Shrimp	146	Shuhaimi-Othman, et al., 2011b
		Tubificid Worm	34.14-38,737 n=5	Qureshi, et al., 1980; Brkovic-Popovic and Popovic, 1977
		Water Flea	17.88-426 n=10	Lee, 1976; Khangarot, et al., 1987; Hockett and Mount, 1996; Tsui, et al., 2005; Black, 2003
		Yellow Fever Mosquito	805	Simonet, et al., 1978
	LOEC	Water Flea	37.56-76.19 n=3	Jop, et al., 1995; Poynton, et al., 2008
	NOEC	Rotifer	66.04	Snell and Persoone, 1989a
		Water Flea	15.24-21.66 n=3	Jop, et al., 1995; Poynton, et al., 2008
Reproduction	LOEC	Water Flea	9.16-21.66 n=2	Jop, et al., 1995
	NOEC	Water Flea	12.54-17.41 n=2	Jop, et al., 1995
Intoxication	EC50	Midge	17,122	Khangarot and Ray, 1989a

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
		Ostracod	254	Khangarot and Das, 2009
		Rotifer	1,048-8,469 n=6	Buikema, et al., 1974
		Scud	9.17-917 n=34	Brent and Herricks, 1998
		Water Flea	1.62-4,786 n=82	Khangarot and Ray, 1989b; Brent and Herricks, 1998; Rossini and Ronco, 1996; Haap and Kohler, 2009
	LC50	Scud	55.02-367 n=6	Brent and Herricks, 1998
Development	EC50	Protozoa	1,005	Nalecz-Jawecki and Sawicki, 1998
Morphology	EC50	Protozoa	387-2,511 n=6	Nalecz-Jawecki, et al., 1993
Behavior	EC50	Yellow Fever Mosquito	254	Simonet, et al., 1978

Table A- 7. Responses of fish exposed to cadmium in saltwater for one to seven days.

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Mortality	LC0	Left-Eyed Flounder, Turbot	16,315	Alvarado, et al., 2006
		Rock Bream, Parrot Fish	2,810	Cho, et al., 2006
	LC50	Goby	12,040-16,620 n=2	Kidwai and Ahmed, 1999
		Guaru	25,000-51,000 n=3	Chung, 1983
		Hooknose	33,000	Portmann and Wilson, 1971
		Japanese Medaka	560,000	Michibata, 1981
		Killifish	12,000-27,000 n=3	Chung, 1983
		Left-Eyed Flounder, Turbot	180-10,000 n=6	George, et al., 1996
		Mozambique Tilapia	80,000	Chung, 1983
		Mud Dab	35,000	Hutchinson and Manning, 1996
		Mummichog	22,000-200,000 n=59	Eisler and Hennekey, 1977; Burton and Fisher, 1990; Voyer, 1975; Eisler, 1971; Jackim, et al., 1970; Upjohn Co., 1989
		Plain-Head Perchlet	13,500-45,000 n=5	Denton and Burdon-Jones, 1986
		Red Sea Bream	5,600-16,200 n=3	Cao, et al., 2009
		Sea Bass	3,430-5,490 n=6	Gelli, et al., 2004
		Sheepshead Minnow	180-50,000 n=8	Eisler, 1971; Hall, et al., 1994; Hall, et al., 1995
		Shiner Perch	11,000-11,170 n=2	Dinnel, et al., 1989; Dinnel, et al., 1983
		Silver Salmon	1,480-1,500 n=2	Dinnel, et al., 1989; Dinnel, et al., 1983
		Small-Mouthed Hardyhead	12,700-21,000 n=3	Negilski, 1976
		Square Tail Mullet	5,250-7,800 n=2	Denton and Burdon-Jones, 1986
		Striped Killifish	21,000-59,000 n=2	Eisler, 1971
		Striped Mullet	5,090	Rajkumar, 2012
		Tidewater Silverside	310 N=2	Hansen, 1983; D'Asaro, 1985
		White Mullet	5,000-24,000 n=4	Chung, 1978
		White Sea Bass	1,990-24,400 n=9	Shazili, 1995; Sulaiman and Noor, 1996
		Yelloweye Mullet	14,300-15,500 n=2	Negilski, 1976
	LETC	White Mullet	5,000	Chung, 1978
	LOEC	Red Sea Bream	390	Cao, et al., 2009
	NOEC	Red Sea Bream	200	Cao, et al., 2009
Growth	LOEC	Red Sea Bream	750	Cao, et al., 2009
	NOEC	Red Sea Bream	390	Cao, et al., 2009
Intoxication	EC50	Cabezon	200	Dinnel, et al., 1989
	LOEC	Orange Spotted Grouper	1,000	Chen and Liu, 2006
	NOEC	Orange Spotted Grouper	100	Chen and Liu, 2006
Development	LOEC	Red Sea Bream	390	Cao, et al., 2009
	NOEC	Red Sea Bream	200	Cao, et al., 2009

Table A- 8. Responses of fish exposed to cadmium in saltwater for more than seven days.

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Mortality	LC0	Mud Dab	1,300	Hutchinson and Manning, 1996
		Spot	100	Middaugh, et al., 1975
		White Sea Bass	100	Shazili, 1995
	LC50	Atlantic Silverside	540-730 n=4	Voyer, et al., 1979
		Guaru	20,000	Chung, 1983
		Killifish	10,000	Chung, 1983
		Mozambique Tilapia	48,000	Chung, 1983
		Spot	200	Middaugh, et al., 1975
		White Sea Bass	750-14,200 n=6	Shazili, 1995
	LETC	Guaru	20,000	Chung, 1983
		Killifish	5,000	Chung, 1983
		Mozambique Tilapia	20,000	Chung, 1983
Growth	LOEC	Hirame, Flounder	26.79 N=2	Cao, et al., 2010
	NOEC	Hirame, Flounder	13.86-51.29 n=3	Cao, et al., 2010

Table A- 9. Responses of fish exposed to cadmium in saltwater for up to one day.

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Mortality	LC0	Spot	90	Middaugh, et al., 1975
	LC100	Spot	800	Middaugh, et al., 1975
	LC50	Left-Eyed Flounder, Turbot	9,000-14,000 n=3	George, et al., 1996
		Mummichog	150,000-220,000 n=9	Eisler and Hennekey, 1977; Voyer, 1975
		Red Sea Bream	6,600-18,900 n=3	Cao, et al., 2009
		Sea Bass	6,170	Gelli, et al., 2004
		Sheepshead Minnow	100,000	Eisler, 1971
		Striped Killifish	125,000	Eisler, 1971
Reproduction	EC50	Silver Salmon	1,490	Dinnel, et al., 1983

Table A- 10. Responses of invertebrates exposed to cadmium in saltwater for one to seven days.

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Mortality	EC50	Brine Shrimp	4,898	Kissa, et al., 1984
		Harpacticoid Copepod	190	Macken, et al., 2009
		San Francisco Brine Shrimp	10,569-11,859 n=2	Brix, et al., 2006
	LC0	Amphipod	75 N=2	Ritterhoff and Zauke, 1997
		Brine Shrimp	917	Trieff, 1980
		Calanoid Copepod	10	Lussier and Cardin, 1985
		Clam	320	Neuberger-Cywiak, et al., 2003
		Common Bay Mussel,Blue Mussel	200	Geret, et al., 2002
		Pacific Oyster	200	Geret, et al., 2002
		Ragworm	1,000	Sun and Zhou, 2007
		Starlet Sea Anenome	38-250 n=3	Harter and Matthews, 2005
		White Shrimp	500	Wu and Chen, 2004
	LC100	Calanoid Copepod	1,000-10,000 n=4	Lussier and Cardin, 1985
		Clam	10,000	Mizrahi, et al., 1993
		Daggerblade Grass Shrimp	403-9,166 n=10	Sunda, et al., 1978
		Opossum Shrimp	104-164 n=2	DeLisle, 1994; Lussier, et al., 1999
		Pink Shrimp	700-6,000 n=2	Devineau and Triquet, 1985; Thebault, et al., 1996
		Rock Shells	20,000	Dalla Via, et al., 1989
		Rock Snail	5,000	Devi, 1997
		Sea Urchin, Echinoderm	4,583	Congiu, et al., 1984
		Starlet Sea Anenome	50,000	Harter and Matthews, 2005
		Tubeworm	2,560	Gopalakrishnan, et al., 2008
	LC50	American Lobster	78-56,000 n=5	Johnson and Gentile, 1979; McLeese, 1976
		Amphipod	14.50-27,660 n=32	Hong and Reish, 1987; Scott, et al., 1982; Schlekat, et al., 1992; Meador, 1993; Kohn, et al., 1994; DeWitt, et al., 1992; Boese, et al., 1997; McGee, et al., 1998; King, et al., 2006; Ungherese and Ugolini, 2009
		Aquatic Oligochaete Worm	50,000-135,000 n=5	Chapman, et al., 1982b
		Aquatic Sowbug, Isopod	1,290	Annicchiarico, et al., 2007
		Atlantic Dogwinkle	23,200	Leung and Furness, 1999
		Atlantic Oyster Drill	6,600-28,000 n=2	Eisler, 1971
		Banana Prawn	80-1,850 n=8	Denton and Burdon-Jones, 1982; Sulaiman and Noor, 1996
		Barnacle	160	Lang, et al., 1981
		Bay Shrimp, Sand Shrimp	320-500 n=2	Eisler, 1971
		Bivalve	1,600	Amiard, et al., 1985

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
		Blacklip Abalone	3,700	Gorski and Nugegoda, 2006a
		Blue Crab	1,000-2,500 n=4	Guerin and Stickle, 1995
		Brine Shrimp	1,500-416,000 n=9	Kissa, et al., 1984; Espiritu, et al., 1995; Del Ramo, et al., 1995; Gajbhiye and Hirota, 1990
		Bristle Worm	14,390-24,370 n=2	Kidwai and Ahmed, 1999
		Brittle Star	2,020-9,040 n=2	Kidwai and Ahmed, 1999
		Brown Mussel	1,517-3,103 n=8	Baby and Menon, 1987a
		Calanoid Copepod	51.60-1,910 n=11	Lussier and Cardin, 1985; Hall, et al., 1994; Hall, et al., 1995
		Caridean Shrimp	2,260-2,300 n=2	Dinnel, et al., 1989; Dinnel, et al., 1983
		Carribean Bait Prawn	6,000	Chung, 1980
		Clam	654-7,600 n=6	Kulkarni, 1983; Wahbeh and Zughul, 1995; Neuberger-Cywiak, et al., 2003; Fathallah, 2014
		Cockle	3,300	Portmann and Wilson, 1971
		Common Bay Mussel,Blue Mussel	960-165,000 n=6	Amiard-Triquet, et al., 1986; Dinnel, et al., 1983; Eisler, 1971; Nelson, et al., 1988; Martin, et al., 1975
		Common Starfish	700-7,100 n=4	Eisler and Hennekey, 1977; Eisler, 1971
		Cone Worm	2,600	Reish and Lemay, 1991
		Copepod	300	Hwang, et al., 2010
		Crab	47.80-106,800 n=10	Greenwood and Fielder, 1983; Selvakumar, et al., 1996; Ferrer, et al., 2006
		Crayfish/Crab Order	80	Selvakumar, et al., 1996
		Daggerblade Grass Shrimp	1.10-6,810 n=32	Khan, et al., 1988; Thorpe, 1988; Burton and Fisher, 1990; Howard and Hacker, 1990; Upjohn Co., 1989
		Dungeness Or Edible Crab	250	Dinnel, et al., 1983
		Eastern Mud Snail	10,500-125,000 n=4	Eisler and Hennekey, 1977; Eisler, 1971
		Estuarine Bivalve Clam	68-237 n=2	Wang, et al., 2009a
		Fiddler Crab	7,660-69,660 n=7	Devi, 1987; Baby and Menon, 1987; Zanders and Rojas, 1996
		Freshwater Clam	21,400	Udoidiong and Akpan, 1991
		Gammarid Amphipod	200-630 n=3	Hong and Reish, 1987; Bach, et al., 2014
		Green Crab	4,100-16,600 n=2	Eisler, 1971
		Green Mussel	1,570-6,620 n=4	Chan, 1988; Kidwai and Ahmed, 1999; Rajkumar, 2012
		Grooved Snail	3,630-9,270 n=2	Kidwai and Ahmed, 1999

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
		Harpacticoid Copepod	17.40-25,200 n=6	Green, et al., 1993; Forget, et al., 1998; Lee, et al., 2007; Prato, et al., 2013
		Horn Shell	9,193-39,788 n=3	Ramakritinan, et al., 2012
		Horse Clam	68-370 n=2	Cardwell, et al., 1979
		Horse Clam, Pacific Gaper	1,700	Cardwell, et al., 1979
		Indian Prawn	3,119	Chinni and Yallapragda, 2000
		Isopod	110-410 n=2	Hong and Reish, 1987
		Jumbo Tiger Prawn	48-1,700 n=3	Sulaiman and Noor, 1996; Rajkumar, 2012
		Kuruma Shrimp	50-6,319 n=15	Bambang, et al., 1995
		Littleneck Clam	13,900	Cardwell, et al., 1979
		Longwrist Hermit Crab	320-1,300 n=3	Eisler and Hennekey, 1977; Eisler, 1971
		Maculated Ivory Whelk	3,350-21,530 n=12	Tanhan, et al., 2005; Hajimad and Vedamanikam, 2014
		Marsh Grass Shrimp	420-5,800 n=3	Nimmo, et al., 1977a; Eisler, 1971
		Mediterranean Mussel	590-1,800 n=3	Pavicic and Jarvenpaa, 1974; Annicchiarico, et al., 2007
		Mud Crab	0.20-4,900 n=2	Thorpe, 1988; Collier, et al., 1973
		Mussel	1,200-4,700 n=12	Roman, et al., 1994
		Mysid	39.50-140 n=7	Birmelin, et al., 1995; Garcia, et al., 2008
		Nematode	13,000-91,000 n=3	Vranken, et al., 1985
		Northern Pink Shrimp	509	Cripe, 1994
		Oligochaete	10,000	Chapman, et al., 1982b
		Opossum Shrimp	15.50-318 n=50	Voyer and Modica, 1990; Nimmo, et al., 1977b; Lussier, et al., 1985; Ward, 1989; Verslycke, et al., 2003
		Oyster	3,820-4,000 n=2	Suryawanshi and Langekar, 2006
		Pacific Oyster	800-19,500 n=3	Park and Kim, 1978; Cardwell, et al., 1979; Watling, 1981
		Pacific Sand Crab	2,110	Boese, et al., 1997
		Pebble Crab	7,170	Kidwai and Ahmed, 1999
		Penaeid Shrimp	1,310-7,070 n=2	Kidwai and Ahmed, 1999
		Philippine Horse Mussel	221-566 n=3	Ramakritinan, et al., 2012
		Pink Shrimp	4,000	Thebault, et al., 1996
		Polychaete	1,370-19,090 n=6	Reish and Lemay, 1991; Reish, et al., 1977
		Polychaete Worm	700-84,000 n=24	Eisler and Hennekey, 1977; Reish and Lemay, 1991; Reish, et al., 1977; Reish, 1978; Eisler, 1971; Amiard, et al., 1985
		Ragworm	3,880	Zhang, et al., 2008
		Rock Crab	100-250 n=2	Johns and Miller, 1982

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
		Rock Snail	2,060	Devi, 1997
		Rockpool Prawn	780-10,900 n=6	Lorenzon, et al., 2000
		Sand Gaper, Soft Shell Clam	700-50,000 n=4	Eisler and Hennekey, 1977; Eisler, 1971
		Sand Shrimp	990-1,000 n=2	Portmann and Wilson, 1971; Amiard, et al., 1985
		Santo Domingo Falsemussel	710	Devi, 1996
		Scud	190-13,300 n=21	Hong and Reish, 1987; Schlekat, et al., 1992; Wright and Frain, 1981; Kohn, et al., 1994; Boese, et al., 1997; Bat, et al., 1998; Annicchiarico, et al., 2007; Prato and Biandolino, 2005
		Scud, Amphipod	780	Ahsanullah, et al., 1988
		Snail	1,520-16,220 n=4	Moller, et al., 1996; Wo, et al., 1999; Cheung, et al., 2002
		Southern King Crab	2,070-4,370 n=3	Amin, et al., 2003
		Southern White Shrimp	180-540 n=3	Barbieri, 2007
		Starfish	9,710-16,340 n=2	Kidwai and Ahmed, 1999
		Starlet Sea Anenome	1,092-1,284 n=2	Harter and Matthews, 2005
		Tropical Mussel	3,000-4,000 n=2	Wahbeh and Zughul, 1995
		Tubeworm	230	Gopalakrishnan, et al., 2008
		Tubificid Worm	10,000	Chapman, et al., 1982b
		Tubificid Worm, Oligochaete	5,000	Chapman, et al., 1982b
		Water Flea	1,870	Wang, et al., 2009b
		Whelk	4,990-6,560 n=2	Kidwai and Ahmed, 1999
		White Shrimp	1,070-1,300 n=3	Wu and Chen, 2004
		Wood Borer	2,140-7,120 n=2	Hong and Reish, 1987
	LOEC	Amphipod	400-510 n=2	King, et al., 2006
		Clam	376	Fathallah, 2014
		Estuarine Bivalve Clam	104 N=3	Wang, et al., 2009a
		Harpacticoid Copepod	200	Macken, et al., 2009
		Nematode	7,500-60,000 n=9	Vranken, et al., 1985
		Tubeworm	80	Gopalakrishnan, et al., 2008
	NOEC	Amphipod	250	King, et al., 2006
		Clam	145	Fathallah, 2014
		Copepod	100	Hwang, et al., 2010
		Estuarine Bivalve Clam	11 N=3	Wang, et al., 2009a
		Harpacticoid Copepod	100-10,000 n=2	Lee, et al., 2007; Macken, et al., 2009
		Horse Clam	42 N=2	Cardwell, et al., 1979
		Nematode	2,500-50,000 n=8	Vranken, et al., 1985
		Opossum Shrimp	5-7,600 n=7	Khan, et al., 1992; Woods, et al., 2004
		Pacific Oyster	340-520 n=2	Cardwell, et al., 1979
		Pink Shrimp	2,000	Thebault, et al., 1996

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
		Tubeworm	40	Gopalakrishnan, et al., 2008
Growth	EC50	Common Bay Mussel,Blue Mussel	500	Martin, et al., 1975
	LOEC	Starlet Sea Anenome	250	Harter and Matthews, 2005
		White Shrimp	400	Wu and Chen, 2005
	NOEC	Mangrove Oysters	0.1	Ringwood, 1992
		Opossum Shrimp	5-15 n=6	Khan, et al., 1992
		Starlet Sea Anenome	75	Harter and Matthews, 2005
		White Shrimp	200-400 n=2	Wu and Chen, 2005
Reproduction	NOEC	Nematode	11,800	Lira, et al., 2011
		Opossum Shrimp	5-15 n=3	Khan, et al., 1992
Intoxication	EC50	Calanoid Copepod	50-130 n=2	Madhupratap, et al., 1981
		Clam	7,100	Park and Kim, 1979
		Crab	490	Ahsanullah and Arnott, 1978
		Dungeness Or Edible Crab	200	Dinnel, et al., 1989
		Estuarine Crab	15,700-101,900 n=8	Sullivan, 1977
		Shrimp	970-6,330 n=2	Ahsanullah, et al., 1981
	LOEC	Clam	1,000	Chen and Liu, 2006
		Jumbo Tiger Prawn	1,000	Chen and Liu, 2006
		Moon Jelly	50	Faimali, et al., 2014
	NOEC	Clam	100	Chen and Liu, 2006
		Jumbo Tiger Prawn	100	Chen and Liu, 2006
		Moon Jelly	10	Faimali, et al., 2014
Development	EC50	Blacklip Abalone	4,515	Gorski and Nugegoda, 2006b
		Doughboy Scallop	295	Krassoi, et al., 1997
		Estuarine Bivalve Clam	131	Wang, et al., 2009a
		Green Sea Urchin	1,800-1,840 n=2	Dinnel, et al., 1989; Dinnel, et al., 1983
		Horse Clam	56-64 n=2	Cardwell, et al., 1979
		Horse Clam, Pacific Gaper	590	Cardwell, et al., 1979
		Littleneck Clam	1,290	Cardwell, et al., 1979
		Mediterranean Mussel	1,800-4,800 n=30	Williams and Hall, 1999; Pavicic, 1980
		Pacific Mussel	502	Nadella, et al., 2009
		Pacific Oyster	920-1,300 n=2	Cardwell, et al., 1979
		Purple Sea Urchin	500-510 n=2	Dinnel, et al., 1989; Dinnel, et al., 1983
		Sand Dollar	7,400 N=2	Dinnel, et al., 1989; Dinnel, et al., 1983
		Sea Urchin	924-2,392 n=2	Xu, et al., 2011a; Xu, et al., 2011b
	LOEC	Blacklip Abalone	1,280	Gorski and Nugegoda, 2006b
		Doughboy Scallop	100	Krassoi, et al., 1997
		Estuarine Bivalve Clam	104	Wang, et al., 2009a
		Nematode	2,500-50,000 n=2	Vranken, et al., 1985
		Southern King Crab	100	Amin, et al., 2003
	NOEC	Blacklip Abalone	320	Gorski and Nugegoda, 2006b
		Doughboy Scallop	50	Krassoi, et al., 1997

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
		Estuarine Bivalve Clam	11	Wang, et al., 2009a
		Horse Clam	42	Cardwell, et al., 1979
		Mangrove Oysters	20	Ringwood, 1992
		Opossum Shrimp	5-25 n=6	Khan, et al., 1992
		Pacific Oyster	340-420 n=2	Cardwell, et al., 1979
		Southern King Crab	10	Amin, et al., 2003
Morphology	EC50	Estuarine Bivalve Clam	84	Wang, et al., 2009a
Population	EC50	Diatom	60-22,390 n=6	Canterford and Canterford, 1980; Rachlin, et al., 1982; Torres, et al., 1997; Torres, et al., 1998; Gentile and Johnson, 1982
	LOEC	Diatom	0.20-5,000 n=2	Torres, et al., 1998; Wang.M.J., 2009
		Dinoflagellate	0.22	Wang.M.J., 2009
	NOEC	Diatom	1,000	Torres, et al., 1998
Behavior	EC50	Amphipod	360-8,690 n=3	Boese, et al., 1997
		Pacific Sand Crab	2,020	Boese, et al., 1997
		Scud	290-890 n=2	Boese, et al., 1997
		Tubeworm	47.46	Gopalakrishnan, et al., 2008
	LOEC	Clam	1,000	Neuberger-Cywiak, et al., 2007
		Striped Barnacle	10,000	Wu, et al., 1997
	NOEC	Clam	100	Neuberger-Cywiak, et al., 2007
		Pacific Calico Scallop	200	Sobrino-Figueroa and Caceres-Martinez, 2009
		Striped Barnacle	1,000	Wu, et al., 1997
Feeding behavior	LOEC	Snail	100-500 n=2	Cheung, et al., 2002
	NOEC	Snail	50-500 n=3	Cheung, et al., 2002

Table A- 11. Responses of invertebrates exposed to cadmium in saltwater for greater than seven days.

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Mortality	LC0	American Or Virginia Oyster	100	Engel and Fowler, 1979
		Arcid Blood Clam	50	Cortesi, et al., 1992
		Mediterranean Mussel	418	Bebianno and Langston, 1992
		Starlet Sea Anenome	50	Harter and Matthews, 2005
	LC100	Crab	100	Selvakumar and Haridasan, 2000
		Harpacticoid Copepod	110	Le Dean and Devineau, 1985
		Starlet Sea Anenome	750	Harter and Matthews, 2005
	LC50	Amphipod	36-470 n=2	Berry, et al., 1996; King, et al., 2006
		Blue Crab	186-250 n=14	Guerin and Stickle, 1995
		Clam	750-2,000 n=4	Wahbeh and Zughul, 1995
		Marsh Grass Shrimp	120-180 n=2	Nimmo, et al., 1977a
		Mediterranean Mussel	360-620 n=2	Pavicic and Jarvenpaa, 1974
		Nematode	5,000-77,000 n=5	Vranken, et al., 1985
		Northern Pink Shrimp	718	Nimmo and Bahner, 1977
		Opossum Shrimp	11.3	Nimmo, et al., 1977b
		Pink Shrimp	300	Le Dean and Devineau, 1985
		Polychaete	22-35 n=2	Mendez and Green-Ruiz, 2006
		Polychaete Worm	570-6,510 n=8	Reish, et al., 1977
		Ragworm	585	Zhang, et al., 2008
		Starlet Sea Anenome	190	Harter and Matthews, 2005
		Tropical Mussel	500-2,000 n=4	Wahbeh and Zughul, 1995
	LETC	American Lobster	30-5,000 n=2	McLeese, 1976
	LOEC	Amphipod	400	King, et al., 2006
		Daggerblade Grass Shrimp	6.55	Manyin and Rowe, 2009
		Nematode	1,000-50,000 n=5	Vranken, et al., 1985
		Scud, Amphipod	25	Ahsanullah and Williams, 1991
		Water Flea	26.7	Wang, et al., 2009b
	NOEC	Daggerblade Grass Shrimp	4.65-6.17 n=2	Manyin and Rowe, 2009
		Nematode	5,000-25,000 n=3	Vranken, et al., 1985
		Opossum Shrimp	4	Voyer and McGovern, 1991
		Water Flea	12.9	Wang, et al., 2009b
Growth	LOEC	Common Cuttlefish	0.31	Lacoue-Labarthe, et al., 2010
		Daggerblade Grass Shrimp	6.17	Manyin and Rowe, 2009
		Scud, Amphipod	38	Ahsanullah and Williams, 1991
		Snail	220-1,380 n=3	Wo, et al., 1999
		Starlet Sea Anenome	250 N=2	Harter and Matthews, 2005
		White Shrimp	100-200 n=6	Wu and Chen, 2005
	NOEC	Common Cuttlefish	0.06-0.61 n=2	Lacoue-Labarthe, et al., 2010
		Daggerblade Grass Shrimp	4.49	Manyin and Rowe, 2009
		Mediterranean Mussel	80	Soto, et al., 2000

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
		Opossum Shrimp	4	Voyer and McGovern, 1991
		Snail	1,000	Wo, et al., 1999
		Starlet Sea Anenome	75 N=2	Harter and Matthews, 2005
		White Shrimp	100 N=2	Wu and Chen, 2005
Reproduction	EC50	Harpacticoid Copepod	78	Le Dean and Devineau, 1985
		Sea Anemone	145-185 n=2	Howe, et al., 2014
	LOEC	Sea Anemone	211 N=2	Howe, et al., 2014
		Starlet Sea Anenome	500 N=2	Harter and Matthews, 2005
		Water Flea	3.01-172 n=5	Wang, et al., 2009b
	NOEC	Opossum Shrimp	4	Voyer and McGovern, 1991
		Sea Anemone	107 N=2	Howe, et al., 2014
		Starlet Sea Anenome	250	Harter and Matthews, 2005
		Water Flea	1.11-172 n=4	Wang, et al., 2009b
Intoxication	EC50	Polychaete Worm	400-1,500 n=10	Reish, et al., 1978
		Shrimp	490-610 n=2	Ahsanullah, et al., 1981
Development	LOEC	Southern King Crab	10	Amin, et al., 2003
	NOEC	Nematode	1,000-25,000 n=4	Vranken, et al., 1985; Lira, et al., 2011
Morphology	EC50	Bay Scallop	78	Pesch and Stewart, 1980
	LOEC	Mediterranean Mussel	8	Soto, et al., 2000
	NOEC	Mediterranean Mussel	0.8	Soto, et al., 2000
Population	EC50	Diatom	75	Latala and Surosz, 1999
		Harpacticoid Copepod	61-100 n=2	Marcaillou-Le Baut, 1988
		Nematode	6,900-8,820 n=4	Lira, et al., 2011
	LOEC	Diatom	100	Latala and Surosz, 1999
		Hydroid	110-280 n=2	Moore and Stebbing, 1976
		Nematode	2,400-3,350 n=4	Lira, et al., 2011
		Scud, Amphipod	11	Ahsanullah and Williams, 1991
		Water Flea	4.10-12.90 n=2	Wang, et al., 2009b
	NOEC	Water Flea	4.1	Wang, et al., 2009b
Behavior	EC50	Bay Scallop	540	Pesch and Stewart, 1980
	LOEC	Pacific Calico Scallop	20-100 n=3	Sobrino-Figueroa and Caceres-Martinez, 2009
	NOEC	Pacific Calico Scallop	20	Sobrino-Figueroa and Caceres-Martinez, 2009
Feeding behavior	LOEC	White Shrimp	200	Wu and Chen, 2005
	NOEC	Daggerblade Grass Shrimp	6.17	Manyin and Rowe, 2009
		White Shrimp	100-200 n=2	Wu and Chen, 2005

Table A- 12. Responses of invertebrates exposed to cadmium in saltwater for up to one day.

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
Mortality	EC50	Foraminiferan	103-2,986 n=12	Bresler and Yanko, 1995
		Harpacticoid Copepod	840	Macken, et al., 2009
	LC0	Balthica Macoma Or Clam	500	Eldon, et al., 1980
		Southern White Shrimp	10	Barbieri, 2007
	LC100	Brine Shrimp	2,500	Gajbhiye and Hirota, 1990
		Common Bay Mussel,Blue Mussel	2,500	Amiard-Triquet, et al., 1986
	LC50	Atlantic Oyster Drill	158,000	Eisler, 1971
		Bay Shrimp, Sand Shrimp	2,400	Eisler, 1971
		Blacklip Abalone	6,200	Gorski and Nugegoda, 2006a
		Brine Shrimp	1,700-615,000 n=7	Espiritu, et al., 1995; Gajbhiye and Hirota, 1990
		Calanoid Copepod	2,710	Arnott and Ahsanullah, 1979
		Ciliate	92	Roberts and Berk, 1990
		Ciliated Protozoan	480	Al-Rasheid and Sleigh, 1994
		Common Bay Mussel,Blue Mussel	1,500-8,000 n=2	Sunila and Lindstrom, 1985
		Common Starfish	12,000-71,000 n=2	Eisler and Hennekey, 1977; Eisler, 1971
		Crab	287-283,200 n=2	Ferrer, et al., 2006
		Eastern Mud Snail	175,000	Eisler and Hennekey, 1977
		Green Crab	100,000	Eisler, 1971
		Harpacticoid Copepod	660	Arnott and Ahsanullah, 1979
		Horn Shell	51,442	Ramakritinan, et al., 2012
		Kuruma Shrimp	667	Bambang, et al., 1995
		Longwrist Hermit Crab	15,000	Eisler and Hennekey, 1977
		Marsh Grass Shrimp	43,000	Eisler, 1971
		Mediterranean Mussel	1,700	Vlahogianni and Valavanidis, 2007
		Mussel	8,400	Roman, et al., 1994
		Philippine Horse Mussel	705	Ramakritinan, et al., 2012
		Polychaete Worm	25,000-56,000 n=2	Eisler and Hennekey, 1977; Eisler, 1971
		Rockpool Prawn	18,190-49,770 n=3	Lorenzon, et al., 2000
		Rotifer	36,300-56,800 n=5	Snell and Persoone, 1989b; Snell, et al., 1991
		Sand Gaper, Soft Shell Clam	32,000	Eisler and Hennekey, 1977
		Southern King Crab	14,490	Amin, et al., 2003
		Southern White Shrimp	980	Barbieri, 2007
		Tubeworm	757	Gopalakrishnan, et al., 2008
		Water Flea	9,590	Wang, et al., 2009b
		White Shrimp	1,558-2,580 n=2	Wu and Chen, 2004; Chang, et al., 2009
	LOEC	Estuarine Bivalve Clam	104	Wang, et al., 2009a
		Harpacticoid Copepod	800	Macken, et al., 2009

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
	NOEC	Estuarine Bivalve Clam	11	Wang, et al., 2009a
		Harpacticoid Copepod	400	Macken, et al., 2009
Growth	NOEC	Starlet Sea Anenome	500	Harter and Matthews, 2005
Reproduction	EC50	Green Sea Urchin	36-47,000 n=10	Dinnel, et al., 1989; Dinnel, et al., 1983; Jonczyk, et al., 1991
		Pacific Oyster	11,600-35,700 n=3	Dinnel, et al., 1983
		Purple Sea Urchin	16,400-18,400 n=3	Dinnel, et al., 1989; Dinnel, et al., 1983
		Purple-Spined Sea Urchin	38,000	Nacci, et al., 1986
		Rea Sea Urchin	12,000-12,500 n=2	Dinnel, et al., 1989; Dinnel, et al., 1983
		Sand Dollar	6,400-9,700 n=6	Dinnel, et al., 1989; Dinnel, et al., 1983; Brix, et al., 1994
		Sea Urchin	33-15,056 n=3	Jonczyk, et al., 1991; Xu, et al., 2011a; Xu, et al., 2011b
		Tubeworm	94.34-228 n=2	Gopalakrishnan, et al., 2008
	LOEC	Coral	5,000	Reichelt-Brushett and Harrison, 2005
		Green Sea Urchin	25	Jonczyk, et al., 1991
		Sea Urchin	25	Jonczyk, et al., 1991
		Sea Urchin, Echinoderm	18.33	Arizza, et al., 2009
	NOEC	Coral	2,000	Reichelt-Brushett and Harrison, 2005
		Green Sea Urchin	12.5	Jonczyk, et al., 1991
		Reef Coral	1,000	Reichelt-Brushett and Harrison, 1999
		Scleractinian Coral	200	Reichelt-Brushett and Harrison, 1999
		Sea Urchin	10-12.50 n=2	Ringwood, 1992; Jonczyk, et al., 1991
		Sea Urchin, Echinoderm	0.18	Arizza, et al., 2009
Intoxication	EC50	Brine Shrimp	457,000	Kalcikova, et al., 2012
	LOEC	Moon Jelly	500	Faimali, et al., 2014
	NOEC	Moon Jelly	100	Faimali, et al., 2014
Development	EC50	Clam	417	Fathallah, 2014
		Estuarine Bivalve Clam	1,014	Wang, et al., 2009a
		Mangrove Oyster	212-371 n=15	Da Cruz, et al., 2007
		Sea Urchin	1,544-3,087 n=5	Xu, et al., 2011b
		Tubeworm	86.66-177 n=2	Gopalakrishnan, et al., 2008
	LOEC	Clam	376	Fathallah, 2014
		Estuarine Bivalve Clam	104	Wang, et al., 2009a
	NOEC	Clam	145	Fathallah, 2014
		Estuarine Bivalve Clam	11	Wang, et al., 2009a
Behavior	EC50	Black Mussel	35,000	Watling, 1981
		Brown Mussel	28,000	Watling, 1981
		Ciliate	40-53 n=2	Roberts and Berk, 1990
		Oyster	850	Watling, 1981
		Pacific Oyster	610	Watling, 1981

Effect	Endpoint	Species	Observation or range (µg/L) and number of observations	Sources
	LOEC	Amphipod	10,000	Ungherese and Ugolini, 2009
	NOEC	Amphipod	5,000	Ungherese and Ugolini, 2009
		Cockle	10,000	Naylor, 1987
Feeding behavior	NOEC	Rotifer	30,000	Juchelka and Snell, 1995
		White Shrimp	400	Wu and Chen, 2005