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The Effects of Turbidity and Suspended Sediments on ESA-Listed Species from Projects Occurring in the Greater Atlantic Region

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Amanda Johnson

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Table of Contents

Figures

Tables

EXECUTIVE SUMMARY

Section 7(a)(2) of the Endangered Species Act (ESA) of 1973, as amended, requires federal agencies to consult with the National Marine Fisheries Service (NMFS) or the United States Fish and Wildlife Service (USFWS) on activities that may affect ESA-listed species. Federal agencies must consult on proposed activities to ensure that these activities do not jeopardize the continued existence of listed species or adversely modify critical habitat. During section 7 consultation, action agencies and section 7 biologists consider stressors resulting from proposed activities to evaluate the type and magnitude of effects that may occur. This white paper focuses on effects related to turbidity and suspended sediment. Turbidity and suspended sediment are commonly associated with projects involving dredging, jet plowing, and pile driving. In the Greater Atlantic Region (Maine through Virginia), these activities may occur in riverine, estuarine, and marine environments. As these projects typically involve contact with the substrate and the movement of heavy equipment, sediment disturbance and plumes may result. The level of sediment disturbance varies by activity type and equipment used, ranging from small disturbance levels (e.g. jet plowing) to greater disturbance levels (e.g. hopper dredging activities). Based on published and gray literature on this topic, we have developed exposure concentration and duration thresholds for listed species to use in the analysis of projects that generate suspended sediments.

A number of studies have examined the effects of turbidity and suspended sediments on aquatic animals, particularly fish and invertebrates. The general conclusion is high concentrations of suspended sediment and longer exposure times cause more severe impacts than exposure to lower concentrations and shorter exposure times. After reviewing the available studies relative to the ESA-listed species in the Greater Atlantic Region — Atlantic salmon, Atlantic sturgeon, shortnose sturgeon, large whales, and sea turtles — we believe the effects of turbidity and suspended sediment are greatest for fish species, especially for early life stages (i.e., eggs and larvae). Fish receive oxygen from the water rather than the air, and harmful effects may include the clogged gills, reduced feeding ability, and movement away from the affected areas, thus disturbing important biological behaviors. We conclude that the most sensitive ESA-listed species in the Greater Atlantic Region to turbidity and suspended sediment is Atlantic salmon. As such, we suggest conservative exposure concentration and duration thresholds based on instantaneous, acute, and chronic exposure. While not well represented in the literature, we believe sturgeon species are more tolerant to changes in turbidity and suspended sediment based on the relatively high turbidity levels associated with the habitats in which they are found, such as coastal rivers and estuarine environments. Overall, our proposed thresholds aim to minimize effects to ESA-listed fish species so that effects are immeasurable or extremely unlikely to occur.

Effects of turbidity and suspended sediments on large whales and sea turtles are nearly absent from the literature; as such, we provide a qualitative discussion in lieu of providing thresholds for exposure levels and duration of exposure as they are impossible to determine based on the best available science. For these air-breathing animals, our analysis concludes that effects are minimal since these animals exist in the oceanic environment, which is already subject to dynamic levels of suspended sediments from currents and storms.

We also provide a discussion of possible effects to prey species and habitat, including critical habitat, for listed species. Not surprisingly, we conclude that effects are greater on the habitats of listed fish species in the Greater Atlantic Region when compared to large whales and sea turtles as these fish make use of the substrate during the egg and larval life stages. The prey species for listed species in the Greater Atlantic Region vary substantially, ranging from benthic organisms (polychaetes, sand lance, insect larvae, and bivalves) to plankton (copepods) to schooling fish (herring). Effects to these species from turbidity and suspended sediment vary by species, life stage, mobility level, and tolerance.

Through our research, we found a variety of studies examining and tracking concentration levels and behavior of suspended sediments generated during substrate-disturbing activities over many years that may prove useful in developing minimization measures that reduce the potential for effects from these stressors. These studies have led to efforts that reduce the amount of sediments that are released into the water column, including modifications to the equipment itself (e.g., use of a closed bucket) as well as to the overall operation of the equipment (e.g., slower speeds, overflow reduction).

INTRODUCTION

This paper reviews recent information about turbidity and suspended sediment, including the potential effects of sedimentation on Greater Atlantic Region marine and anadromous species listed under the ESA, as well as effects to their habitats (including critical habitats, as defined by the ESA, where applicable) and prey species. The intent of this document is to provide guidance to the Greater Atlantic Regional Fisheries Office's Protected Resources Division with respect to consultation on federally-proposed activities that will release or re-suspend sediments into the water column and to ensure consistency in conducting effects analyses and in communicating information needs to individual action agencies.[1] After considering concentration level thresholds for various effects (behavioral, physiological, and lethal) on listed fish species, our suggestions for exposure concentrations and durations are primarily based on a summary of the literature and a review of effects on these and related species. We also provide examples of "best management practices" that have been developed to help reduce the environmental impact associated with resuspended sediments from activities such as dredging, jet plowing, and pile driving to assist section 7 biologists during their consultations. We qualitatively considered the effects of turbidity and suspended sediments on ESA-listed whales and sea turtles rather than establishing exposure concentration and duration thresholds because no information was available in the literature that could be used to inform such determinations.

STATEMENT OF ISSUE

Natural, ambient levels of turbidity and suspended sediments exist in any water body and can range from clear water (total suspended solids (TSS) measuring approximately 20 mg/L or less)

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[1] Under section 7 of the ESA, federal agencies that fund, conduct, or authorize activities that could affect ESA-listed species are required to consult with biologists within NMFS or USFWS to ensure that these activities will not jeopardize the continued existence of any listed species.

to cloudy (TSS measuring 40-80 mg/L) to murky/dirty water (TSS measuring over 150 mg/L).[2] These levels are highly influenced by environmental conditions such as waves and tides, stream flows, storms, and runoff and biological conditions such as the presence and abundance of planktonic organisms. Aquatic species have adapted to live under different levels of turbidity. Some are more tolerant than others are, or may actually prefer turbid conditions to clearer waters (i.e., turbid waters may provide some level of protection against predation or may assist in foraging). Human-induced changes in water turbidity and suspended sediment concentration levels resulting from in-water projects, such as dredging and dredge material disposal, have the potential to affect ESA-listed species, their habitat, and their prey species. ESA biologists must consider effects to ESA-listed species for any project that can cause changes to turbidity and suspended sediment levels.

Turbid environments can affect living organisms negatively or positively in a number of ways, depending on the species, their physiological and behavioral tolerance levels, and their adaptability. General characteristics of turbid waters include reduced visibility, shortened photic zone depths, and altered heat stratification in the water column (Wilber and Clarke 2001). Turbid waters exhibit increased temperatures, as suspended solids absorb more heat from sunlight than water molecules, and retain less dissolved oxygen. Further, reduced photosynthesis in turbid waters inhibits dissolved oxygen production (EPA 2014).

Some species benefit from living in turbid waters and prefer this type of environment to help reduce the risk of predation or assist with foraging. For example, turbid waters may allow certain predators to stealthily hunt their prey by providing some measure of cover; for others, foraging efficiency may be reduced if turbid waters allow their prey to effectively hide (Anchor Environmental 2003). It is likely that fish living in naturally turbid environments have adapted to exist and thrive under those conditions.

ESA-listed fish species found in the Greater Atlantic Region — Atlantic salmon, shortnose sturgeon, and Atlantic sturgeon — may have a greater chance of encountering changes in turbidity and suspended sediments than would ESA-listed large whales or sea turtles. These fish spend some or most of their lives in riverine and estuarine environments, which are more susceptible to changes in turbidity and suspended sediment levels than an open ocean environment.

While a number of studies on the effects of suspended sediments have been conducted on salmonids, only a few have been conducted on Atlantic salmon, and even fewer have been conducted on sturgeon species. We found very little literature describing the effects of turbidity and suspended sediments on listed sea turtles or large whales. However, based on what we know about the life histories of these species, we can make general assumptions about potential effects to these species groups. For example, the presence of suspended sediments at levels above ambient may reduce foraging success for sea turtles or negatively affect the species upon which they prey, possibly making them less available or less desirable to sea turtles. We know that sea turtles utilize a variety of habitats throughout their lives. Females use nesting beaches to lay

[2] The total suspended solid values were taken from a Michigan state government website related to handling total suspended solids in National Pollutant Discharge Elimination System (NPDES) permits (see http://www.michigan.gov/documents/deq/wb-npdes-TotalSuspendedSolids_247238_7.pdf).

eggs. Young hatchlings and small juveniles mostly occupy oceanic habitats, many times associating with *Sargassum* seaweed, feeding in the open ocean. For some species, feeding closer to shore in nearshore coastal areas may expose them to natural coastal processes that cause frequent changes in turbidity and suspended sediments.

For listed large whales that live in the open ocean their entire lives, we expect effects from turbidity and suspended sediments to be minor due to the expansive nature of the oceanic environment. This expansive nature increases the chances for sediment dispersion and allows more opportunities for whales to avoid any detrimental effects. Undesirable effects could occur, however, if whales 1) become less visible to each other (e.g., a calf is less visible to its mother), 2) are unable to avoid predators, or 3) alter their normal behaviors, such as visually foraging or migrating, to avoid the effects of turbidity or suspended sediments. If individuals become less visible to one another, a mother may take her calf to another habitat to avoid turbidity/suspended sediment effects, increasing their vulnerability to other risks (e.g., vessel strikes, entanglements). While we are unable to quantify these risks or establish threshold levels for acceptable changes in turbidity or suspended sediment concentrations, section 7 biologists must consider these factors when examining when and where projects will take place and assessing the possible effects to listed sea turtles and large whales.

This white paper describes the terms turbidity and suspended sediments. It reviews published literature, describing the results of experiments examining the effects of turbidity and suspended sediment concentrations above ambient on various fish species, including salmonids and sturgeon, their life stages, prey species, and habitat (including designated critical habitat). We suggest consideration of the effects of multiple stressors (e.g., low dissolved oxygen levels, high temperatures) that, when combined, can reduce a species' tolerance to turbidity and suspended sediments.

Finally, we consider the effects of turbidity and suspended sediments on designated and proposed critical habitat for listed species in this region. NMFS designated or has proposed critical habitat under the ESA for four listed species that occur in this region: Atlantic salmon, Atlantic sturgeon[3], loggerhead sea turtles, and North Atlantic right whales.[4] NMFS designated critical habitat for the Gulf of Maine Distinct Population Segment (DPS) of Atlantic salmon as all perennial rivers, streams, estuaries, and lakes connected to the marine environment in Maine, except for those specifically excluded. One of 38 marine areas designated as critical habitat for the Northwest Atlantic DPS of loggerhead sea turtles extends into this region: the *Sargassum* critical habitat, which occurs offshore of Delaware, Maryland, and Virginia (and extends around Florida and through the Gulf of Mexico to Texas). North Atlantic right whale critical habitat in this region formerly included two areas: the Cape Cod Bay and Great South Channel Critical Habitat Areas. On January 27, 2016, NMFS finalized revisions to right whale critical habitat in both the northeast (Unit 1) and southeast (Unit 2) regions; however, only the northeast region's

[3] Critical Habitat for Atlantic Sturgeon was designated on August 17, 2017, (82 FR 39160).
[4] Note that NMFS designated critical habitat for loggerhead sea turtles, Atlantic sturgeon, and North Atlantic right whales in the Southeast Region. The U.S. Fish and Wildlife Service also designated approximately 685 miles of terrestrial critical habitat for the Northwest Atlantic loggerhead DPS, comprising 88 nesting beaches from North Carolina through Mississippi. However, this white paper focuses only on critical habitat in the Greater Atlantic Region.

Unit 1 is included in this paper. The area designated by Unit 1 includes the northern edge of Georges Bank and the entire Gulf of Maine (from the shorelines of Massachusetts, New Hampshire, and Maine) out to the Exclusive Economic Zone (EEZ). This northeast critical habitat area is discussed revision that we consider in this white paper. On June 3, 2016 NMFS published two proposed rules to designate critical habitat for the five DPSs of Atlantic sturgeon. In the Greater Atlantic Region, proposed critical habitat includes aquatic habitats in rivers in Maine, New Hampshire, Massachusetts (for the Gulf of Maine DPS); Connecticut, Massachusetts, New York, New Jersey, Pennsylvania, and Delaware (for the New York Bight DPS); and Maryland, Virginia, and the District of Columbia (for the Chesapeake Bay DPS). Each critical habitat or proposed critical habitat area and the effects of turbidity and suspended sediments will be discussed later in the paper.

TURBIDITY AND SUSPENDED SEDIMENTS

This section describes the differences between turbidity and suspended sediments, their relationship, and changes due to natural and anthropogenic impacts on baseline conditions.

Turbidity

Turbidity is a measure of the clarity of a liquid (water) and is usually expressed as the amount of light that is scattered and absorbed by materials or particulates found in the water. The more light scattering that occurs, the higher the turbidity. Turbidity causes water to appear cloudy or muddy but is not a measure of the concentration of suspended sediments. Particulate matter in the water that contribute to turbidity includes inorganic solids (e.g., sediments), organic solids or detritus produced by living organisms, and living organisms (e.g., phytoplankton, zooplankton). Turbidity is influenced by a number of factors associated with sediment particles aside from the concentration of particles, including particle size and shape, refractive index (measure of the bending of light when it proceeds through one medium into another), color, and absorption spectra (Anchor Environmental 2003).

Various devices, many of which use different units, measure water turbidity. Nephelometric turbidity units (NTUs) are the most commonly used unit when reporting turbidity associated with sediment plumes (Puckette 1998). In this case, water turbidity is measured using a nephelometer. The lower the NTU value, the lower the turbidity (i.e., the water is clearer and less turbid). Turbidity, readily and easily measured in the field, is often used as an indicator of water quality near dredging activities and may be used as a proxy for other measurements (e.g., TSS) which are more labor intensive and require subsequent laboratory analysis (Anchor Environmental 2003).

Light transmission or attenuation can be used to measure water clarity. It can be related to sediment concentration but, like turbidity measurements, is not a direct measure of TSS. Transmissometers measure the amount of light that penetrates the water and can be easily used in the field (similar to turbidity). Similar to turbidity, light transmission is affected by particulate matter, including its size, shape, and opacity (Anchor Environmental 2003). Turbidity and light transmission are commonly used to measure/monitor the effects of dredging activities on water clarity.

There are many contributors to water turbidity, both natural and anthropogenic. Naturally-occurring factors that affect turbidity include phytoplankton presence, storms, freshets, tidal flows, water currents, and runoff and discharges that flow in from upland locations (Wilber and Clarke 2001; Anchor Environmental 2003). Anthropogenic contributors to turbidity and TSS include dredging, dredge material disposal, pile driving and pile removal, jetting/jet plowing, barrier removals, culvert replacements, and cofferdams.

Total Suspended Solids or Suspended Sediments

Total suspended solids (TSS) is a quantitative measure of the total dry weight mass of the particles or material present in a given amount water. The units used for reporting TSS are milligrams of material per liter of water (mg/L). Natural contributors to the amount of suspended sediments in the marine environment include plankton blooms, bioturbation, soil erosion, and waves, currents, and tidal influences (Wilber and Clarke 2001). Baseline TSS conditions are subject to change, especially following natural environmental events such as storms and wildfires that cause water disturbance and/or elevated levels of runoff. However, to date, few studies have measured TSS following such events.

Measuring TSS is important for considering their effects on living organisms, especially when elevated concentration levels can harm organisms through gill choking or smothering eggs on the riverbed. Concentrations of TSS can also be proxies for chemical concentrations, as chemicals often bind to or are absorbed by particulates (Anchor Environmental 2003).

Some researchers have suggested that turbidity and light transmission could be used as a proxy for TSS measurements, but this should be done on a site-specific basis and the correlation must be developed at the beginning of the project to ensure that the measurements taken over the duration of the project are consistent and comparable (Anchor Environmental 2003). This may save on monitoring costs, as it is less expensive to monitor turbidity and light transmission levels than to monitor TSS. Anchor Environmental (2003) provides the following list of studies correlating turbidity and TSS: Thackston and Palermo (2000), MBC (2000), Hartman (1996), Malin et al. (1998), WDOE (1997), Christensen et al. (2000), and Herbich and Brahme (1991).

EFFECTS ON LISTED FISH

Turbidity and suspended sediment can affect Atlantic salmon, shortnose sturgeon, and Atlantic sturgeon in a number of ways. These species are already exposed to various ambient TSS levels due to their life history patterns with different life stages spending time in different environments (at sea, in estuaries, in rivers) at different times of year. In general, the published literature indicates that suspended sediment concentration (hereafter referred to as either suspended sediment or TSS) and exposure duration are important considerations when evaluating potential effects on fish species from elevated TSS levels. Additionally, we consider the effects when fish may be experiencing other environmental stressors (e.g., temperature, dissolved oxygen levels) that could lower their tolerance to TSS.

Newcombe and Jensen (1996) completed a literature review of 80 studies that examined fish responses to various concentrations of and exposure durations to suspended sediments for a range of life stages. Species groups included salmonids and non-salmonids; life stages included adults (mature fish), juveniles (immature fish including fry, parr, and smolts), eggs, and larvae (with larvae being recently hatched fish, including yolk-sac fry).

A severity of ill effect (SEV) score was used to rank effects associated with varying levels of suspended sediment concentrations and exposure times into four broad categories of effects. These included: 1) no effect; 2) behavioral effects (alarm response, fish leaves the area); 3) sub-lethal effects (physiological signs of stress, temporary reduction in feeding); and 4) lethal (mortality) and paralethal (reduced growth rates, damage to habitat, reduced population sizes) effects. During preliminary analyses, the authors found that logarithmic transformations of exposure duration and concentration levels provided linear relationships such that the information from the published studies could be regressed to determine SEV based on the sediment dose (which refers to the sediment concentration and its associated exposure duration). The authors completed six exercises for six groupings, including adult and juvenile salmonids, adult salmonids, juvenile salmonids, eggs and larvae of salmonids and non-salmonids, adult estuarine non-salmonids, and adult freshwater non-salmonids (Newcombe and Jensen 1996).

The regressions became predictive models capable of associating SEV with estimated exposure duration and concentration level. The authors compared the model outputs with new studies that were not included in their paper and found that these study results agreed well with the model and helped validate it.

When comparing the model to information from other studies we reviewed, the predicted sediment concentration levels and exposure durations were fairly consistent with the information resulting from the model, further validating it. Therefore, we are using the information from the model presented in Newcombe and Jensen (1996), as well as other species-specific literature, to make comparisons to help determine thresholds for which we expect effects from TSS to occur for ESA-listed fish under our jurisdiction in this region. Where available, information on the fish species found in the Greater Atlantic Region — Atlantic salmon, shortnose sturgeon, and Atlantic sturgeon — is provided. However, where information is unavailable for these species, studies conducted on related species are summarized.

Table 1 provides the SEV scores for the four response categories — no effect, behavioral, sub-lethal, and lethal/paralethal — and the effects associated with each score as described in Newcombe and Jensen (1996). These scores correspond to the figures in the following sections describing the effects, based on the literature reviewed by Newcombe and Jensen (1996), of varying suspended sediment concentration levels and exposure durations for fish.

Table 1: List of effects associated with the four broad response categories to turbidity and/or suspended sediment concentrations.

Response Category	SEV Score	Associated Effects
No Effect	0	None
Behavioral	1	Alarm response
	2	Abandon cover
	3	Avoidance/leave the area
Sub-lethal	4	Short-term reduction in feeding rates and/or success
	5	Minor physiological stress (e.g., increased coughing, increased respiration rate)
	6	Moderate physiological stress
	7	Moderate habitat degradation; impaired homing
	8	Indications of major physiological stress (e.g., long-term reduction in feeding rates or success, poor condition)
Lethal/paralethal	9	Reduced growth rate; delayed hatching; reduced fish density
	10	0-20% mortality; increased predation; moderate to severe habitat degradation
	11	>20-40% mortality
	12	>40-60% mortality
	13	>60-80 mortality
	14	>80-100% mortality
Source: Newcombe and Jensen (1996)		

Effects on Atlantic Salmon Adults and Juveniles

Salmonids, especially West Coast species (coho, chinook, sockeye) due to their commercial and recreational value, have been the focus of numerous studies that examined the effects of turbidity and TSS on the various life stages. Adult salmonids are believed to be the most sensitive of adult fishes studied to date to changes in turbidity and TSS (Berry et al. 2003). Even so, the literature typically demonstrates that adult salmonids can tolerate relatively high levels of turbidity and TSS. Many other tests have been conducted using non-salmonid fish species and invertebrates, including eggs, larvae, and early life stages.

While many studies have been completed, it is very difficult to generalize findings to determine thresholds for which effects will be apparent. The studies vary in their locations (laboratory vs field), sediment types and sizes, sediment concentrations, background conditions (temperature), exposure durations, species involved, and study goals (measuring behavioral responses vs determining lethal concentration levels). As such, results vary greatly. Literature reviews focused on gathering information related to Atlantic salmon as much as possible; however, we also provide information on West Coast salmonids. The literature review revealed many more studies completed for West Coast salmonids than Atlantic salmon. As such, we used information on West Coast salmonids to help make determinations of how turbidity and TSS might affect Atlantic salmon. These species have similar life histories, are anadromous, and are in the same family (Salmonidae). Not doing so would have limited our ability to draw conclusions about effects of turbidity and TSS on Atlantic salmon.

Of the six model groups presented in Newcombe and Jensen (1996), four are included here. These are: 1) adult and juvenile salmonids (particle sizes 0.5 – 250 µm); 2) adult salmonids only (particle sizes 0.5 - 250 µm); 3) juveniles salmonids only (particle sizes 0.5 - 75 µm, although in a few cases sediment sizes reached 150 µm); and 4) eggs and larvae of salmonids and non-salmonids (particle sizes 0.5 - 75 µm, although sediment sizes exceeded 75 µm in a few studies). Numerous fish species were considered in Newcombe and Jensen (1996) due to wide array of literature that was reviewed. Salmonid species (family Salmonidae) included salmon (genus and species unknown), salmon (Atlantic, Chinook, chum, coho, Pacific, sockeye), trout (genus and species unknown), trout (steelhead, brook, brown, cutthroat, lake, rainbow, sea), Arctic grayling, and whitefish (lake and mountain). Non-salmonid fish species included bay anchovy, bass (largemouth, smallmouth, and striped), bluegill, common carp, cunner, darters, fish (genus and species unknown), goldfish, herring (Atlantic, lake, Pacific), hogchoker, striped killifish, Atlantic menhaden, sheepshead minnow, mummichog, perch (white and yellow), harlequin rasbora, American shad, Atlantic silverside, rainbow smelt, spot, stickleback (fourspine and threespine), sunfish (green and redear), and oyster toadfish.

Only the model results are presented in this white paper (Figure 1). Empirical data are not presented for two reasons. First, some data are lacking for certain sediment concentrations and exposure durations, decreasing the utility for use during section 7 consultations. In addition, the outputs generated by the model were significantly fitted to the empirical data groups ($P < 0.01$), providing confidence that the model sufficiently predicted severity scores to reflect what was presented in the literature.

Juvenile and Adult Salmonids											
Concentration (mg SS/L)											
162,755	10	11	11	12	12	13	14	14	-	-	-
59,874	9	10	10	11	12	12	13	13	14	-	-
22,026	8	9	10	10	11	11	12	13	13	14	-
8,103	8	8	9	10	10	11	11	12	13	13	14
2,981	7	8	8	9	9	10	11	11	12	12	13
1,097	6	7	7	8	9	9	10	10	11	12	12
403	5	6	7	7	8	9	9	10	10	11	12
148	5	5	6	7	7	8	8	9	10	10	11
55	4	5	5	6	6	7	8	8	9	9	10
20	3	4	4	5	6	6	7	8	8	9	9
7	3	3	4	4	5	6	6	7	7	8	9
3	2	2	3	4	4	5	5	6	7	7	8
1	1	2	2	3	3	4	5	5	6	7	7
	1	**3**	**7**	**1**	**2**	**6**	**2**	**7**	**4**	**11**	**30**
	Hours			**Days**			**Weeks**		**Months**		

Figure 1: Average severity of ill effects (SEV) scores for juvenile and adult salmonids. This figure corresponds to Figure 1B in Newcombe and Jensen (1996) for juvenile and adult salmonids (particle sizes 0.5 - 250 µm). Cell highlighting: green = behavioral effects; yellow = sub-lethal effects; red = lethal and paralethal effects. Dashes mean "no data."

Behavioral changes for adult and juvenile salmonids combined begin to occur at relatively low TSS levels around 20 mg/L after one hour of exposure (avoidance response). If animals remain exposed to elevated TSS levels, sub-lethal effects begin to occur with major physiological stress occurring at approximately 1,100 mg/L for 24 hours of exposure. Paralethal and lethal effects begin to occur at extremely high concentration levels for shorter exposure durations and lower levels as exposure time increases. The threshold concentrations represented by the darker terraced lines in Figure 1 follow the same orientation as the empirical data, but in general are occurring at higher sediment concentrations (Newcombe and Jensen 1996).

Adult Salmonids												
Concentration (mg SS/L)	162,755	11	11	12	12	13	13	14	14	-	-	-
	59,874	10	10	11	11	12	12	13	13	14	14	-
	22,026	9	10	10	11	11	12	12	13	13	14	14
	8,103	8	9	9	10	10	11	11	12	12	13	13
	2,981	8	8	9	9	10	10	11	11	12	12	13
	1,097	7	7	8	8	9	9	10	10	11	11	12
	403	6	7	7	8	8	9	9	10	10	11	11
	148	5	6	6	7	7	8	8	9	9	10	10
	55	5	5	6	6	7	7	8	8	9	9	9
	20	4	4	5	5	6	6	7	7	8	8	9
	7	3	4	4	5	5	6	6	7	7	7	8
	3	2	3	3	4	4	5	5	6	6	7	7
	1	2	2	3	3	4	4	5	5	5	6	6
		1	**3**	**7**	**1**	**2**	**6**	**2**	**7**	**4**	**11**	**30**
		Hours			**Days**			**Weeks**		**Months**		

Figure 2: Average severity of ill effects (SEV) scores for adult salmonids. This figure correlates with Figure 2B in Newcombe and Jensen (1996) for adult salmonids (particle sizes 0.5 - 250 μm). Cell highlighting: green = behavioral effects; yellow = sub-lethal effects; red = lethal and paralethal effects. Dashes mean "no data."

When considering only adult salmonids (Figure 2), the model depicts a similar trend to adults and juveniles combined (Figure 1). Adults are able to tolerate relatively high TSS levels of nearly 1,100 mg/L for 24 hours before the onset of paralethal and lethal effects. According to Newcombe and Jensen (1996), the model predicts the onset of sub-lethal effects occurring at slightly lower TSS levels than implied by the empirical data.

Juvenile salmonids alone (Figure 3) demonstrate similar trends as those depicted in Figure 1 for adults and juveniles combined. Similar to the adult salmonids, Newcombe and Jensen (1996) find that the model predicts the onset of sub-lethal effects occurring at slightly lower TSS levels than implied by the empirical data.

Juvenile Salmonids												
Concentration (mg SS/L)	162,755	9	10	11	11	12	13	14	14	-	-	-
	59,874	9	9	10	11	11	12	13	14	14	-	-
	22,026	8	9	9	10	11	11	12	13	13	14	-
	8,103	7	8	9	9	10	11	11	12	13	13	14
	2,981	6	7	8	9	9	10	11	11	12	13	13
	1,097	6	6	7	8	9	9	10	11	11	12	13
	403	5	6	6	7	8	9	9	10	11	11	12
	148	4	5	6	6	7	8	9	9	10	11	11
	55	4	4	5	6	6	7	8	8	9	10	11
	20	3	4	4	5	6	6	7	8	8	9	10
	7	2	3	4	4	5	6	6	7	8	8	9
	3	1	2	3	4	4	5	6	6	7	8	8
	1	1	1	2	3	4	4	5	6	6	7	8
		1	**3**	**7**	**1**	**2**	**6**	**2**	**7**	**4**	**11**	**30**
		Hours			**Days**			**Weeks**		**Months**		

Figure 3: Average severity of ill effects (SEV) scores for juvenile salmonids. This figure correlates with Figure 3B in Newcombe and Jensen (1996) for juvenile salmonids (particle sizes 0.5 - 75 µm). Cell highlighting: green = behavioral effects; yellow = sub-lethal effects; red = lethal and paralethal effects. Dashes mean "no data."

Based on the figures presented above, some general conclusions can be made.

1) According to Newcombe and Jensen (1996), the predicted thresholds provided in their tables represent the responses of more sensitive fish. Thus, the above figures are conservative measures of the onset of behavioral, sub-lethal, and lethal/paralethal effects. This is confirmed when the values provided in the tables are compared to some of the literature reviewed, especially for the onset of behavioral effects (discussed below).
2) Adult and juvenile salmonids seem able to tolerate relatively high TSS levels (around 1,100 mg/L) for 24 hours before the onset of paralethal or lethal effects. However, this exposure can cause physiological effects that could have long-term implications (e.g., long-term reduction in feeding rates or success, poor condition, reduction in fecundity). Moderate effects would be seen in under a day's exposure to approximately the same concentration level. Since experimental fish have a tendency to avoid areas of TSS, we expect that wild fish exposed to TSS are free to move elsewhere if exposed to similar scenarios (Newcombe and Jensen 1996). Effects experienced by fish that are subjects of controlled studies may not necessarily reflect what might happen in the wild, as the fish in the controlled studies typically are not allowed to move away from exposure to TSS (Newcombe and Jensen 1996).

Presented below are summaries of the literature reviewed on studies measuring the behavioral, sub-lethal, and lethal responses to TSS for salmonids.

Behavioral Responses

Behavioral effects, as described by Newcombe and Jensen (1996), include no response, alarm response, abandonment of cover, and/or avoidance/departure from the area. Avoidance can occur in areas of turbidity and suspended sediments that reduce the quality of suitable habitat (Robertson et al. 2007). Behavioral and minor physiological effects due to increased sedimentation should be temporary if the exposure is short in duration (e.g., hours to days) and infrequent. Effects are likely reversed when turbidity levels return to ambient levels (Robertson et al. 2006). While changes in feeding rates and success due to TSS could be considered behavioral responses, Newcombe and Jensen (1996) characterized these effects as sub-lethal so we have included them in the next section.

The most common behavioral response of fish to turbidity or suspended sediments is avoidance. This can be coupled with an alarm response in the form of erratic swimming behavior and attempts to leave the turbid area likely at turbidity levels above 40 NTUs (Robertson et al. 2006; Berg and Northcote 1985; Servizi and Martens 1992; Chiasson 1993). Sigler et al. (1984) conducted experiments that demonstrated the preference of young steelhead and coho salmon for clear water over turbid water (11-49 NTUs).

Bisson and Bilby (1982) found juvenile coho salmon demonstrated some level of avoidance to increased turbidity levels, but the responses varied based on prior exposure to either clear or slightly turbid water. Fish originally acclimated to clear water showed varying levels of avoidance to the introduced turbidity levels, but started showing significant avoidance at 70 NTUs. The highest level of avoidance occurred at 158 NTUs. For experiments with juveniles already acclimated to slightly turbid water, two types of behaviors were observed when water turbidity was increased — normal behavior (a reaction that was similar to the reactions of fish acclimated to clear water) and fright behavior. Fish exhibiting normal behavior demonstrated slightly higher tolerance for turbidity than fish acclimated to clear water with significant avoidance beginning around 100 NTUs as opposed to 70 NTUs for fish that were acclimated to clear water (Bisson and Bilby 1982). Fish exhibiting fright behavior demonstrated darting movements, huddling together, and attempting to hide in the corners of the tank. All individuals in the group exhibited the same behavior in these cases and all preferred the turbid portion of the tank even as turbidity levels increased. The authors were unclear on why fish acclimated to turbid water exhibited fright behaviors in some trials; they believed the reaction may have occurred because the test fish were suddenly placed into a tank that lacked cover.

Alarm responses in fish exposed to turbidity and/or TSS may be influenced by the speed at which the stressor is introduced (i.e., a sudden exposure to increased sedimentation levels versus a more gradual exposure). In their study of juvenile coho salmon, Berg and Northcote (1985) noted an alarm response (swimming in sporadic spurts, entering and remaining in the gravel for several hours) when fish experienced a sudden introduction of sedimentation and turbidity (reaching the highest level of 60 NTUs by one hour) versus a gradual increase in turbidity (reaching the highest level of 60 NTUs over the course of two days). In the sudden exposure experiment, the fish initially swam toward the leading edge of the sediment slurry but then drifted downstream staying in clear water until they were consumed by the turbid water and stopped by a downstream screen. In this experiment, the visible fish appeared alarmed. Alarm responses lasted approximately three hours, after which activity was infrequent. With the gradual turbidity increase, no alarm reaction was observed. Interestingly, the researchers observed a breakdown in the dominance hierarchy observed during the pre-treatment phase. In the pre-treatment phase, one salmon was dominant over the others, a second was subdominant, and the other subordinate fish formed three levels of social rankings. The dominant fish established its territory and acted aggressively to the non-dominant fish. However, the aggressive behavior declined quickly during the sudden exposure experiment and dominance and territoriality no longer occurred. During the gradual introduction of turbidity, the social hierarchy was significantly altered at 30 NTUs. While withstanding exposure to the higher turbidity levels, the fish remained close to the bottom of the tank in the lower 10 cm of the water column (Berg and Northcote 1985). During the post-treatment phase turbidity levels returned to zero, dominance hierarchy levels were reestablished, and fish moved higher into the water column.

In a fall (water temperatures of 12.8 – 14.1 ºC) and winter (water temperatures of 3.1 – 3.8 ºC) laboratory experiment using wild juvenile Atlantic salmon, Robertson et al. (2007) found foraging behavior increased when TSS ranged from approximately 15 to 35 NTUs (about 20 mg/L to 180 mg/L). The salmon were attempting to forage on the sediment particles as they were being introduced. However, foraging attempts declined in TSS above 35 NTUs (180 mg/L). The decline in foraging was associated with a decline in territorial behavior as well an increase in alarm reactions (in the fall only) in the form of erratic swimming behavior and apparent attempts to avoid the turbid water with TSS between approximately 22 and 42 NTUs (about 60 and 180 mg/L).[5] The use of cover for predator avoidance declined as suspended sediment increased for both the fall and winter trials. By 22 NTUs (60 mg/L) during the fall trial, all fish had abandoned cover. In the winter trials, cover use declined much more gradually, and some fish never emerged from cover at all during the study. For juveniles in the winter, the daylight hours are usually spent under cover in the substrate, preserving fat reserves and maximizing predator avoidance. It may not be worthwhile for the juveniles to search for less turbid waters in the winter. In the fall, it might be more worthwhile to search for less turbid water if there will be more feeding opportunities to help replenish lipid stores for the winter. Physiological responses were not measured in this study.

In other studies, avoidance of TSS in the form of movement toward the surface has been documented (Servizi and Martens 1987 for underyearling sockeye salmon; Servizi and Martens 1992 for coho salmon; McLeay et al. 1987 for Arctic grayling). In one of these studies, this behavioral effect occurred within minutes of being exposed to TSS (Servizi and Martens 1992). Movement to the surface may mean fish are trying to avoid lower sediment-ridden water to get more air. This was noted in the study by Servizi and Martens (1992) where juvenile coho salmon first exhibited avoidance behavior through vertical movement toward the surface at approximately 37 NTUs (about 300 mg/L). Cough frequency was significantly increased at 240 mg/L after 24 hours of exposure. The authors theorized that avoidance might have been a response to stress induced coughing.

Changes in TSS can alter predator/prey relationships. For example, Gibson (1933), as reported in Newcombe and Jensen (1996), demonstrated an increased risk of predation to adult Atlantic

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[5] It should be noted that the relationship between turbidity and sediment concentration levels (mg/L) in the Robertson et al. (2007) study were slightly, but significantly, different between the fall and winter seasons, with higher turbidity levels recorded at higher sediment concentrations during the fall than in the winter. This is why one concentration level may be associated with a different turbidity reading depending on the season (fall or winter). The authors conjectured that this might have been related to the properties of the water and its ability to hold sediments in suspension at lower temperatures.

salmon after 24 hours of exposure to 2,500 mg/L of suspended sediment. This has also been demonstrated for juvenile chinook and coho salmon in which chinook salmon exhibit a reduction in avoidance response to bird and fish predators and coho salmon swam to the surface, increasing their risk of predation (Wilber and Clarke 2001). Therefore, behavioral effects can result in an increased risk of mortality.

Due to the variability of concentration levels and exposure duration in experiments, as well as the ability of the fish to leave the area (in many cases, fish were forced to remain exposed to the sediment increases), it is difficult to use lab experiments to determine the concentration levels at which behavioral effects would occur in the wild. Additionally, prior exposure of fish to suspended sediments as opposed to clear water may make them more tolerant of further increases in sediment concentrations (Bisson and Bilby 1982). According to the models presented by Newcombe and Jensen (1996), behavioral effects for adult and juvenile salmonids can begin to occur at approximately 20 mg/L after one hour of exposure. Compared to the information presented by Newcombe and Jensen (1996), the studies we reviewed for this white paper generally provide consistent or higher TSS and turbidity for behavioral effects thresholds. Therefore, using the thresholds provided in Newcombe and Jensen (1996) likely represent a conservative level at which effects can be expected to occur. We also acknowledge that salmon may experience other stressors simultaneously, which could lower an individual's tolerance to turbidity and suspended sediments. This is discussed in further detail below in the section, "Additional Considerations and Cumulative Effects on Salmon and Sturgeon."

Sub-Lethal Physiological Responses

Sub-lethal responses to turbidity and suspended sediments were characterized by Newcombe and Jensen (1996) and were slightly adapted by Wilber and Clarke (2001). Sub-lethal effects include short-term reductions in feeding rates/success, minor to moderate levels of stress, habitat degradation, and major physiological stress (Newcombe and Jensen 1996). Sub-lethal effects can occur as TSS levels increase and vary based on species, duration of exposure, and size and shape of the particles.

The presence of suspended sediments can reduce or increase feeding rates in larvae. For example, larval Pacific herring appear to maximize feeding with TSS levels between 500 and 1,000 mg/L; feeding was reduced at concentrations above 1,000 mg/L (Boehlert and Morgan 1985, as reported in Bash et al. 2001). Some salmonid species seem to prefer slightly turbid water for foraging, despite being visual feeders, but results from studies examining this seem to vary greatly by species (Bash et al. 2001).

Reduced feeding may occur due to a reduction in prey capture rates. Juvenile coho salmon experienced reduced feeding from lower prey capture rates when turbidity levels were between 25 and 45 NTUs (Madej et al. 2007). Similarly, in an experiment introducing sediments to juvenile coho salmon beginning with turbidity levels of zero NTUs and increasing to 20, 30, and 60 NTUs, feeding was significantly reduced with prey capture success most reduced at 30 NTUs (Berg and Northcote 1985). Prey ingestion rates were significantly reduced to well below 50% at 30 and 60 NTU turbidity levels with approximately 40% of the prey ingested at these levels. This varied from the pre-turbid conditions when 100% of the introduced prey was ingested. Finally, the mean reaction distance in the salmon's capture of adult brine shrimp was significantly lowered from 30 cm to approximately 12 cm at all three turbidity levels (Berg and Northcote 1985).

Aside from visual impediments to foraging due to TSS, changes in feeding could be due to changes in light conditions, perceptions about predation risk, and the size of the fish. Some fish may even prefer slightly higher turbidity levels to assist them in feeding bouts.

Redding et al. (1987) reported reduced feeding rates for coho salmon and steelhead trout at relatively high levels of suspended sediments (2,000 to 3,000 mg/L). Chinook salmon seem to prefer moderate levels of turbidity for feeding. Two studies demonstrated that between approximately 35 to 200 NTUs feeding rates were highest for this species. Rates diminished in waters with concentration levels over 200 mg/L and diminished further at levels over 800 mg/L (Gregory 1990 and Gregory and Northcote 1993 as reported in Robertson et al. 2006).

Adult Atlantic salmon typically do not feed while actively migrating upstream during their annual spawning run in freshwater rivers, so turbidity or TSS conditions will not affect how well adults feed during this time. However, post-spawn adults (kelts) enter a reconditioning period following spawning and may spend time feeding in the lower river and estuary before migrating to the ocean (Chaput and Benoit 2012). Migrating Atlantic salmon kelts tagged and tracked in the LaHavre River (Nova Scotia) demonstrated variable and complex rates of movements, both downstream and within the estuary, that were likely tied to a variety of behaviors, possibly including feeding within the estuary (Hubley et al. 2008). Chaput and Benoit (2012) demonstrated that an increased biomass of salmon prey species within the Gulf of St. Lawrence contributed to higher return rates for consecutive repeat spawners in the Miramichi River. Effects to kelt prey species or a kelt's ability to find prey due to turbidity or TSS during the reconditioning process could have negative impacts on the salmon population, especially when combined with other stressors these fish face during their life history. Turbidity could also affect feeding behavior during other freshwater and estuarine life stages, including fry (which eat microscopic organisms in the river) and parr (fish that are over a year old and feed on small aquatic insects in the river). For example, in an experiment of steelhead and coho salmon fry exposed to turbid conditions for over two weeks (e.g., chronic exposure), growth was reduced at turbidity levels as low as 25 NTUs, likely from a reduction in feeding ability (Sigler et al. 1984). In this study, fish exposed to turbid waters exhibited a significantly slower growth rate in most tests than fish raised in clear water.

According to a literature review completed by Robertson et al. (2006), no studies on the physiological effects of suspended sediments on Atlantic salmon have been completed. Other salmon species (coho salmon, steelhead trout, Chinook salmon, and sockeye salmon) have been studied. Examples of sub-lethal physiological effects include: stress responses (measured through increases in blood glucose or plasma cortisol levels) at concentration levels ranging from 500 mg/L in yearling steelhead trout exposed to topsoil (Redding et al. 1987) and clay to over 40,000 mg/L in juvenile coho salmon exposed to round and extremely angular silicate sediments (Lake and Hinch 1999). Yearling coho salmon exposed to 2,000-3,000 mg/L of topsoil and clay temporarily (48 hours) experienced increased plasma cortisol levels during an experiment lasting 7-8 days (Redding et al. 1987 as cited in Robertson et al. 2006).

Adult Fraser river sockeye salmon exposed to 500 mg/L of fine sediments experienced a 39% increase in plasma glucose levels compared to control fish that were not exposed to sediment increases. Similarly, plasma glucose levels increased 150% for fish exposed to 1,500 mg/L of fine sediments (Servizi and Martens 1987). However, exposure periods for these fish lasted nine days at 1,500 mg/L and 15 days at 500 mg/L. This would be considered chronic exposure (over 96 hours). Underyearling sockeye salmon in this study experienced gill trauma at both lethal and non-lethal concentration levels and all particle sizes, which ranged from less than 74 µm to 740 µm (Servizi and Martens 1987). At 3,148 mg/L of fine sediment (<74 µm), gill trauma resulted from sediments lodged in the gills of underyearlings. This level was 18% of the concentration level that killed half of the fish in the study (LC50) when exposed for 96 hours (17,560 mg/L).

Sockeye smolts exposed to 7,447 mg/L of suspended sediments for 96 hours had plasma chloride levels that were significantly elevated above the levels of control fish. However, the level was not high enough to reach an acute stress level (Servizi and Martens 1987). Additionally, no gill trauma was observed for smolts. The smolts were placed in sediment-free water for 48 hours prior to being sampled, giving them a chance to free their gills of sediments. This could indicate some exposure to suspended sediments could cause harm gills, but recovery is possible in conditions of lower or no sediment concentrations.

Particle shape may also play a role in a fish's stress response to TSS. Lake and Hinch (1999) compared round to extremely angular sediments in juvenile coho salmon at varying concentration levels. They found that extremely angular sediments produced a significantly higher hematocrit response than round sediments at the lowest level tested (1-40 g/L, which is the same as 1,000-40,000 mg/L). Similarly, extremely angular sediments at the lowest level tested resulted in a decreased leukocrit, another stress response. Both types of sediments caused similar mortality rates, indicating that extremely angular particles may not be a main cause of acute mortality. Physical gill damage was also noted at concentrations exceeding 40 g/L for both sediment shapes.

Gill flaring (increased respiration rates) in reaction to increased turbidity levels occurred in the study conducted by Berg and Northcote (1985). Gill flaring increased during both the sudden and gradual sediment introduction phases. With the sudden introduction phase, gill flaring increased significantly in the 20 to 30 NTUs levels and remained high for those fish that could be observed during the highest turbidity level of 60 NTUs. With gradual introduction of sediment, gill flaring frequency reached the levels observed during the sudden introduction phase at 30 NTUs; a more gradual reaction as turbidity increased. Gill flaring remained high during the 2.5-day exposure period and did not significantly decline until the post-treatment phase when turbidity levels returned to zero NTUs. This may have been a reaction to an irritation of the gills from the sediment particles and attempts to flush them. There has also been documentation of coughing reactions in fish species exposed to suspended sediments with coughing significantly higher (eight times higher than control levels) in coho salmon exposed to 240 mg/L of suspended sediments, equivalent to 30 NTUs compared to no coughing at 20 mg/L (Servizi and Martens 1992). The coughing was coupled with increased blood sugar levels during the 96-hour experiment.

In conclusion, if exposure of fish to turbidity and suspended sediments is small, infrequent, and relatively short in duration (lasting hours or days as opposed to weeks, months, or years), it is likely that behavioral and minor sub-lethal responses will be temporary and will eventually cease (i.e., once the stressor has passed and environmental conditions return to normal or when the animal leaves the area) (Robertson et al. 2006). In reviewing information on the amount of suspended sediments generated through dredging activities, it is unlikely that mobile fish will be killed from higher than normal turbidity/TSS if the duration is short and fish have the ability to move to another area if concentration levels exceed tolerable levels. Water temperature and dissolved oxygen levels in the project area during the time of activity should be taken into account. Stressful temperature and dissolved oxygen levels could exacerbate the stress an animal may be experiencing from changes in turbidity and TSS, making them less tolerant of sediment concentrations at lower than normal levels. These considerations are discussed in more detail in the below section, "Additional Considerations and Cumulative Effects on Salmon and Sturgeon."

Lethal Responses

Newcombe and Jensen (1996) describe lethal and paralethal effects based on a severity score. These effects include reduced growth rate, delayed hatching, and reduced fish density They also describe levels of mortality categorized by percent death, ranging from 0-20% death (which includes increased predation and moderate to severe habitat degradation), >20-40% death, >40-60% death, >60-80% death, and >80-100% death.

According to Sigler et al. (1984), acute lethal effects to yearling and older salmonids generally occur when concentration levels exceed 20,000 mg/L. Direct mortality of fish can occur at very high TSS with half of the tested populations dying after 96 hours of concentration levels exceeding 10,000 to 100,000 mg/L (Robertson et al. 2006; Servizi and Martens 1987; Lake and Hinch 1999). There is evidence that animal size can make a difference in terms of physiological effects. Larger fish may be able to tolerate higher concentration levels than smaller or newly hatched fish (Robertson et al. 2006). Sigler et al. (1984) found that newly emerged steelhead trout and coho salmon exposed to turbidity levels of 100-300 NTUs (500-1,500 mg/L) died or exited the experimental laboratory stream channels (a trap mechanism allowed fish to freely exit the experimental channels). Subsequent experiments used turbidities between 25 and 50 NTUs. Both species preferred clearer water, evidenced by fish moving from the channels with turbid conditions to areas with clear water. Further, fish inhabiting clearer water had faster growth rates. The results acquired by Sigler et al. (1984) differed from those recorded by Noggle (1978, as reported in Sigler et al. 1984) who found that fish remained in their initial habitat even when exposed to turbid conditions for short periods, even if clearer water was available. However, the fish in Noggle's study were larger than the fish in the Sigler et al. (1984) study and may have been better suited to tolerate elevated turbidity levels.

TSS effects on fish may also be influenced by temperature with animals tolerating higher TSS at certain temperatures. Servizi and Martens (1991) (as reported in Robertson et al. 2006) found varying tolerances to TSS at certain water temperatures in juvenile coho salmon during a 96-hour exposure period. A temperature range of 1 to 18 ºC was tested. Coho salmon were most tolerant of TSS at 7 ºC (96 hr-LC50 was 22,700 mg/L). At 18 ºC, the 96-hr LC50 ranged from 7,000 to 8,100 mg/L. At 7 ºC, the first mortality occurred at 8,200 mg/L. In contrast, at 18 ºC, the first death occurred at about 3,000 mg/L. If certain water temperatures are already known to cause stress to fish, increasing TSS at those temperatures would likely cause additional stress, especially if the amount of available dissolved oxygen is reduced.

In a study of juvenile Chinook salmon exposed to increased concentrations of volcanic ash, 500 mg/L did not cause acute problems after 36 hours of exposure (Newcombe and Flagg 1983). At levels greater than approximately 6,100 mg/L, half of the test fish died after exposure for 36 hours. At approximately 34,900 mg/L, 90% of the fish exposed died within 36 hours. The authors noted that the gills of the dead fish were coated with ash particles and mucous, indicating a blockage of the osmoregulatory surface was the cause of death (Newcombe and Flagg 1983). Adult Chinook salmon were more tolerant of higher concentration levels with no mortality occurring after an exposure to 39,300 mg/L for 24 hours (ECORP Consulting 2009).

Servizi and Martens (1987) found that lethality was related to particle size. Particles under 74 μm required a concentration of 17,560 mg/L to kill half of the sample of underyearling sockeye salmon, whereas coarse sand particles (180 to 740 μm) caused 100% mortality at a concentration level of 3,359 mg/L. These fine sediments were observed on the gill lamellae at both lethal and sublethal concentrations. Fine particles were also observed on the gill lamellae of adults when TSS was 1,500 mg/L and 500 mg/L but were not associated with mortality or gill trauma. Smolts did not have sediments lodged in their gills when exposed to concentrations of nearly 7,500 mg/L. However, these fish were placed in clear water for 48 hours prior to sampling which may have allowed the particles to flush out prior to sampling (Servizi and Martens 1987).

When examining the effects of suspended sediments, consideration should be given to particle size and angularity as larger particles seem to have more ill effects than smaller ones (Newcombe and Flagg 1983; Newcombe and Jensen 1996). Unfortunately, a universal methodology for classifying particles sizes has not been developed and different studies categorize particle sizes differently (Newcombe and Jensen 1996).

Summary of Effects to Adult and Juvenile Salmonids

In selecting TSS exposure thresholds and durations for adult and juvenile Atlantic salmon, we do not recommend levels that would result in mortality based on the literature we reviewed. Additionally, the levels chosen account for the cumulative effects to the species if also subjected to additional uncontrollable environmental stressors such as extreme temperature and dissolved oxygen levels. The levels apply to adult and juvenile salmonids combined, accounting for the slightly lower tolerance levels of juveniles to TSS (Wilber and Clarke 2001).

According to the literature review conducted by Wilber and Clarke (2001) and the other literature reviewed for this paper, most adult fish studied, including salmonids, tolerate relatively high levels of TSS for short periods. It is likely that any effects experienced during anthropogenic activities such as dredging would be of short duration, as fish will respond to changes in TSS by moving away from the stressor. This lowers the likelihood that the fish will be exposed to the stressor for an extended period. However, the location of the dredging project (e.g., proximity to important habitat) as well as the distance the sediment plume travels downstream may affect a fish's behavioral response possibly by attracting fish to the plume and/or extending the duration of exposure.

It is difficult to determine the concentration levels at which behavioral and sub-lethal effects will begin to occur due to the variability in the experiments conducted. Variable sediment concentration levels and exposure durations, as well as the ability of the fish to leave the area (in many cases, the fish were forced to remain exposed to suspended sediments) all affect the results of the studies. In a summary of salmonid and freshwater fishes (reviewed in Wilber and Clarke 2001), behavioral and sub-lethal effects occurred in adult fish during 24 hours of exposure to TSS up to 1,000 mg/L. One study demonstrated 10-25% mortality occurring at the one-day mark at about 500 mg/L. Aside from this study, adults appeared to tolerate exposure to TSS below 1,000 mg/L for up to 10 days, after which mortality began to occur. The effects on juvenile fish species were similar, except that mortality began occurring at five days of exposure over a wide range of TS with the lowest being approximately 750 mg/L. At concentration levels above 1,000 mg/L, mortality began to occur shortly after 24 hours of exposure and at a concentration levels slightly above 1,000 mg/L (Wilber and Clarke 2001). Since juvenile and adult life stages are mobile, it is likely they will be exposed to suspended sediments for less than 24 hours. It is much more likely that exposure would occur for minutes to hours unless the fish are attracted to the sediment plume (Wilber and Clarke 2001). However, exposure durations could vary based on the activity conducted and its associated TSS, the location of the activity (spawning or rearing habitat), and the behavioral response of the fish.

According to Newcombe and Jensen's (1996) model for adult and juvenile salmonids, lethal effects could begin to occur at TSS upwards of 3,000 mg/L after 24 hours of exposure. This seems consistent with the literature reviewed where adults and juveniles appear to have the ability to tolerate relatively high levels of TSS for relatively short periods.

Table 2 provides suggested onsets of behavioral, sub-lethal, and lethal effects to fish from TSS based on the literature reviewed and Newcombe and Jensen's (1996) model. However, these concentrations are not specific to Atlantic salmon, as most of the salmonid studies have occurred on West Coast salmon species. However, these species are similar to Atlantic salmon, and we use them as a proxy in the absence of Atlantic salmon-specific studies.

Table 2: Suggested concentration levels associated with the onset of behavioral, sub-lethal, and lethal effects to salmon from suspended sediments for acute exposure (less than 96 hours) rather than chronic (over 96 hours). This information is based on a variety of salmon species, including Atlantic salmon and other species in the Salmonidae family, which were use as a proxy for Atlantic salmon.

Adults/Juveniles	TSS (mg/L)	Turbidity (NTUs)
Behavioral Effects Onset	20 – 300	22 – 100 (likely above 40)
Sub-Lethal Effects Onset	240	~25
Lethal Effects Onset	500 –3,000*	Not reported
*Some studies show that juveniles and adults can be exposed to levels greater than this without resulting in mortality. For example, juvenile coho salmon exposed to 8,100 mg/L of suspended sediments for 96 hours did not die, but the first mortality occurred at 8,200 mg/L (Servizi and Martens 1991). This was at a temperature of 7 ºC that seems to be preferred by this species. At higher and lower temperatures, the onset of mortality occurred at much lower concentration levels. It is important that environmental conditions be taken into account when considering the effects of suspended sediment concentrations on fish species.		

TSS Exposure Thresholds for Adult and Juvenile Salmonids

As stated earlier, salmon can withstand turbidity and suspended sediments if their exposure is relatively short and the increases above ambient are small and infrequent (Robertson et al. 2006). Due to their critical population status, we suggest avoiding, if possible, sediment-generating activities and TSS exposure in areas and times when Atlantic salmon may be present.

In developing TSS concentration thresholds and exposure durations for projects that occur in areas where Atlantic salmon are expected to be present, we considered the information for other salmon species and the data presented in Table 2. Atlantic salmon are an endangered species and our goal is recovery. Therefore, we took a conservative approach by developing three exposure thresholds that incorporate a gradual reduction in TSS as exposure duration increases (Table 3). Based on the literature, we believe Atlantic salmon will avoid or move away from areas in which TSS levels are above ambient. If they do become exposed to TSS, we believe our exposure thresholds and durations will have insignificant effects on Atlantic salmon as the effects will be temporary and will not significantly disrupt their normal behaviors.

Threshold one is for very short duration exposures (less than or equal to 3 hours). We believe this represents the maximum TSS and exposure duration that salmon could experience without dying if exposed to typical sediment plumes generated by dredging-related activities (Wilber and Clarke 2001). Of all man-made activities we considered, sediment plumes from dredging activities create the highest level of TSS. We set the concentration threshold at 1,000 mg/L with the assumption that salmon will move away from the sediment-generating activity. If they do not, this level of exposure for 3 hours or less is not expected to result in mortality. Further, we believe that salmon moving through an area of TSS will avoid or change course, reducing exposure time, and would return to the area once ambient conditions are normal.

Threshold two is for exposure durations lasting less than 24 hours. TSS during this exposure is necessarily much lower than threshold one exposure because fish become less tolerant of higher TSS amounts as exposure duration increases. We suggest that TSS does not exceed 50 mg/L above ambient for more than 24 hours in areas of salmon occurrence. We do not expect that salmon will remain exposed to these levels for this amount of time due to their frequent movements. In addition, below this level, we do not believe there will be harmful effects to salmon habitat.

Threshold three is for exposure durations that are less than or equal to 144 hours (six days) after the first 24 hours of exposure. For this length of time, we recommend that TSS does not exceed 10 mg/L as salmon tolerance to TSS is lowered with increasing exposure duration. Again, we do not expect Atlantic salmon to remain in uncomfortable environmental conditions. However, due to the sensitive nature of this species to TSS, we want to ensure that expected effects are insignificant.

Table 3: Total suspended sediment thresholds and exposure durations for adult and juvenile Atlantic salmon for activities that occur in areas when Atlantic salmon may be present.

TSS Thresholds for Exposure Durations for Adult and Juvenile Atlantic Salmon
Threshold one: ≤ 1,000 mg/L at any one time, and not lasting more than 3 hours. Threshold two: ≤ 50 mg/L (above baseline/ambient concentrations) for no more than 24 hours. Threshold three: ≤ 10 mg/L (above baseline/ambient concentrations) for no more than 144 hours (six days) after the first 24 hours of exposure.

Effects on Atlantic Salmon Early Life Stages

Two concerns exist when considering the effects of sediments on early life stages such as eggs and larvae: 1) effects of suspended sediment concentrations and 2) sedimentation on eggs and larvae. These life stages lack the ability to move to another location to avoid suspended sediments. In addition to direct mortality, sedimentation has the potential to reduce growth rates of eggs and feeding rates of larvae (Wilber and Clarke 2001). This reaction occurs in a variety of fish species such as striped bass, Pacific herring, and white perch. White perch eggs seem to be the most sensitive of these to TSS, specifically for shorter durations, with lower tolerances than striped bass and Pacific herring. White perch eggs exposed to TSS concentrations of 100 mg/L for one day experienced delayed hatching, and eggs exposed to 500 mg/L or less for 4 days experienced increased mortality. Sigler et al. (1984) reported a reduction in larval growth rates for steelheads and coho salmon raised in turbid streams as opposed to clear streams.

According to Newcombe and Jensen (1996), the onset of sub-lethal effects occurs at relatively low concentration levels for eggs and larvae of salmonids and non-salmonids combined (Figure 4). Paralethal and lethal effects begin to occur at relatively low sediment concentrations between one and two days of exposure, demonstrating the sensitivity of this life stage to elevated TSS. The predicted onset of effects from the model coincided well with the empirical data.

The sensitivity of the earliest life stages (i.e., eggs and larvae), is clearly depicted in Figure 4. At relatively low sediment doses (e.g., 403 mg/L for one hour), moderate physiological stress can begin to occur. Physiological stresses to eggs can include reduced growth rates and delayed hatching. At approximately 24 hours of exposure, low levels of mortality (SEV=10) can begin at nearly 3,000 mg/L TSS and at much lower levels around two days of exposure (148 mg/L).

Eggs and Larvae of Salmonids and Non-Salmonids												
Concentration (mg SS/L)	162,755	7	9	10	11	12	13	14	-	-	-	-
	59,874	7	8	9	10	12	13	14	-	-	-	-
	22,026	7	8	9	10	11	12	13	-	-	-	-
	8,103	7	8	9	10	11	12	13	14	-	-	-
	2,981	6	7	8	10	11	12	13	14	-	-	-
	1,097	6	7	8	9	10	11	12	14	-	-	-
	403	6	7	8	9	10	11	12	13	14	-	-
	148	5	6	7	9	10	11	12	13	14	-	-
	55	5	6	7	8	9	10	12	13	14	-	-
	20	5	6	7	8	9	10	11	12	13	-	-
	7	4	5	7	8	9	10	11	12	13	14	-
	3	4	5	6	7	8	10	11	12	13	14	-
	1	4	5	6	7	8	9	10	11	13	14	-
		1	**3**	**7**	**1**	**2**	**6**	**2**	**7**	**4**	**11**	**30**
		Hours			**Days**			**Weeks**		**Months**		

Figure 4: Average severity of ill effects (SEV) scores for eggs and larvae of salmonids and non-salmonids. This figure correlates with Figure 4B in Newcombe and Jensen (1996) for eggs and larvae of salmonids and non-salmonids (particle sizes 0.5 - 75 µm). Cell highlighting: green = behavioral effects; yellow = sub-lethal effects; red = lethal and paralethal effects. Dashes mean "no data." Note that there are no behavioral effects with this life stage.

Effects of Suspended Sediment

Prior to spawning, a female Atlantic salmon targets a suitable area for developing eggs (i.e.., proper water flow, groundwater upwellings, locations such as the head of a riffle, the tail of a pool, or the upstream edge of a gravel bar) and creates a redd by using her tail to dig a depression in the substrate (Kircheis and Liebich 2007). During spawning, the female deposits eggs in the gravel and then buries them under approximately 12 – 20 cm of gravel substrate after fertilization by one or more males. High egg survival depends on the permeability of the gravel and the ability of the egg to receive sufficient oxygen. Larger particle sizes ensure the presence of interstitial space in the gravel substrate. The interstitial space allows water to flow over the egg, which provides much-needed oxygen. Most successful redds are created at the tails of pools where the water velocity is increasing, and the substrate particle size tends to increase because of natural stream processes. Typical coarse gravel and cobble sizes in successful redds range from 1.2 to 10 cm in diameter (Kircheis and Liebich 2007). Fewer natural redds exist in areas of the river with low velocity and substrates with small particle size. It is believed that the creation of the redd also cleans the gravel substrate by removing small particles that could fill in the spaces between the eggs, which would reduce oxygen available to them.

Particle size may play a role in the survival of developing eggs. Filling in the interstitial spaces between the gravel in Atlantic salmon redds with fine sediments can reduce the amount of oxygen available to incubating eggs. There is evidence that fine sediments (silts and clays, < 0.063 mm) strongly reduce the survival of Atlantic salmon to the pre-eyed and eyed development stages (Julien and Bergeron 2006). This study was conducted in the field (Quebec, Canada) at six sites to simulate the effect of sediments on salmon redds by burying incubation baskets containing fertilized eggs and sieved gravel and examining effects to three life stages (pre-eyed, eyed, and hatched). While each site varied in terms of sediment sizes and amount of sediment that infiltrated the baskets, silts and clays (< 0.063 mm) represented a relatively small portion of the particle sizes that were found within the baskets (0.03 – 0.41%). However, these low levels significantly reduced the survival of the pre-eyed and eyed stages and possibly created a thin coating over the egg, reducing the amount of available oxygen. Survival of the pre-eyed and eyed stages was reduced to below 50% when silt and clay weight values were between 0.3 and 0.4%. Survival to the hatched stage was most strongly correlated with infiltration by medium sand particles (0.25 – 0.50 mm). The results clearly demonstrated an increasingly negative correlation between embryo survival and an increased percentage of fine sediments infiltrating the baskets. Overall, a reduction in survival occurred with increased concentrations of suspended sediments within the baskets (Julien and Bergeron 2006).

Newcombe and Jensen (1996) provide Table A.1, which describes the results of the experiments, and fish species (salmonids and non-salmonids) included in their literature review and models. Salmonid eggs and larvae appear to be less tolerant to suspended sediments than other fish species included in this review. Salmonid eggs and larvae exhibited low tolerance to TSS, however, many of the durations of exposure were in excess of six days (with the longest exposure being 117 days). Therefore, the results depicted in these studies may not be reflective of shorter exposure durations that might occur from activities such as dredging. The Arctic grayling is the only salmonid tested for exposure durations ranging from 24 to 96 hours. The results demonstrated increasing percentages of mortalities with increasing concentration levels. At 25 mg/L for 24 hours, mortality was 5.7%, and exposure to 230 mg/L for 96 hours resulted in 47% mortality (J. LaPerriere, pers. comm. in Newcombe and Jensen 1996).

Newcombe and Jensen (1996) report a relatively high TSS associated with the onset of mortality (severity = 10) for salmonid eggs and larvae (24 hours of exposure to nearly 3,000 mg/L). However, different fish species respond differently to changes in sediment concentrations. Paralethal effects begin to occur at approximately 148 mg/L after exposure for 24 hours (Newcombe and Jensen 1996). It should be noted that while Newcombe and Jensen's (1996) model represents the eggs and larvae of both salmonids and non-salmonids, the sensitivity of these early life stages remains apparent.

In Wilber and Clarke's (2001) literature review of suspended sediment effects to salmonids and freshwater fish from dredging, five studies concluded that < 25% mortality for eggs and larvae occurred at TSS between 10 and 100 mg/L at exposures of up to 3.5 days. Four of these studies demonstrated < 25% mortality at 20 mg/L ranging from one to 3.5 days of exposure, and one study exhibited < 25% mortality at about 60 mg/L after one day of exposure. Studies evaluating higher levels of TSS (>100 mg/L) demonstrated higher levels of mortality even with relatively low exposure durations (e.g., 26-75% mortality at 100-120 mg/L in under 3.5 days of exposure) (Wilber and Clarke 2001). Higher exposure durations of 50 or more days demonstrated high mortality (> 75%) at relatively low TSS concentrations (20-100 mg/L). Information that depicts egg and larvae survival of Atlantic salmon is not available.

From the studies presented, it is clear that as exposure duration and TSS concentrations increase, mortality percentages also increase. Even at low TSS concentrations, at least some mortality to eggs and larvae would be expected to occur. Atlantic salmon eggs require high oxygen levels during their entire incubation period (3-4 months). As such, we advise strict limitations on human-induced stressors to developing eggs.

Effects of Sediment Deposition

Some studies completed in the laboratory and the field show negative effects to eggs and larvae from both fine and coarse sediments. Fine sediments fill interstitial spaces between eggs preventing oxygen flow as well as limiting or preventing the ability of the eggs to hatch. Coarse sediments bury the eggs and larvae.

For salmonids, most of the literature describes the percentage of fine sediments placed within redds and how increases in fine sediments lead to increased mortality. Sediment deposition can occur through direct deposit of sediments or through residual sedimentation associated with the settling of sediment plumes or sediments that are resuspended by activities during dredging (Bridges et al. 2008). According to Birtwell (1999), the European Inland Fisheries Advisory Commission recommended the avoidance of placing finely divided solids in salmon and trout spawning habitat because these areas are sensitive to sedimentation.

Fine sediment negatively affects eggs deposited in redds because the sediments inhibit oxygen exchange and prevent the removal of toxic metabolites (Robertson et al. 2006) by filling in interstitial space between gravel that would otherwise allow water flow. According to Peterson and Metcalf (1981), as reported in Robertson et al. (2006), finer sand has a larger negative effect than coarser sand because the smaller grain size becomes trapped between larger gravel. Marty et al. (1986), as reported in Robertson et al. (2006), found similar results. Embryo survival for Atlantic salmon was highly affected by increased volumes of sediment sizes less than 0.2 mm. O'Conner and Andrew (1998) completed a 126 day laboratory study where they varied the percentage (10%, 15%, 20%, and 25%) of fine sand (0.063 to 1 mm) placed in an Atlantic salmon red. They examined the effect of these fine sand percentages on alevin survival.[6] At 10% fine sand, alevin survival was reduced by 28%; at 15% fine sand, it was reduced by 35%; and at 20% fine sand, it was reduced by 37%. At 25% , there was 100% alevin mortality. In the river portion of the study, the researchers placed 15 incubators with salmon embryos in the river. Alevin survival was highly variable between incubators (ranging from 2-51%), and the percent fine sediment accumulations ranged from approximately 9-17%. No distinct relationship between alevin survival and percent fine sediment could be determined. No fine sediments were added to the incubators used in the river experiment portion of this study; only naturally occurring sedimentation was documented in the incubators at the conclusion of the study. It is likely that sedimentation influx into the incubators occurred on a sporadic basis. This differed from the laboratory experiment where the redds were immediately subjected to specific fine sediment concentrations for the duration of the study (O'Connor and Andrew 1998). This may have led to the variations in survival rates in each river incubator. O'Connor and Andrew (1998) concluded that the addition of greater than 10% fine sediments would have a detrimental effect on the survival of salmon eggs.

In a study of Atlantic salmon by Levasseur et al. (2006), silt and very fine sand particles (< 0.125 mm) had a dramatic effect on the percentage of embryos that survived to hatching in artificial redds placed in two field locations in Quebec, Canada. Embryo survival to hatching was stationary at around 90% when redds consisted of 0.04% to 0.16% silt and very fine sand. However, when the silt and very fine sand percentages reached 0.2%, embryo survival to

[6] An alevin is a newly hatched salmon that is still attached to the yolk sac.

hatching was drastically reduced to less than 50%. According to these studies, the addition of very fine sediments in the gravely redd fill in the interstitial spaces that salmon embryos rely on for gas exchange, thus reducing their ability to survive to hatching.

Studies on West Coast salmon found in Table 1 of Robertson et al. (2006) support the conclusion that increases in fine particles/sedimentation reduce the survival of fish larvae and eggs. However, there is no consistent or widely accepted definition of a fine particle as each study has varied with the particle sizes used and their definitions of fine or very fine sand. Redds could be covered with sand particles that could result in significant mortality of eggs and/or emerging larvae. This would be in addition to natural mortality that occurs under normal riverine conditions. Filling in the spaces between the gravel and/or burying the eggs could have detrimental effects on their development and on larvae emergence.

To summarize the studies examined in Robertson et al. (2006), increasing concentrations of fine sediments (less than or equal to 6 mm) led to declines in the survival of eggs when fine sediment percentage levels within the redds reach 5-10%. Unfortunately, this is difficult to translate into an acceptable sedimentation concentration level to use as a threshold for evaluating effects of human activities, such as dredging, occurring within spawning habitat. The percentage of fine sediments that eggs can tolerate varies with species, location, and environmental conditions.

Summary of Effects to Salmonid Eggs and Larvae

There are two sediment-related issues associated with fish eggs and larvae — suspended sediment and sediment deposition. Salmonids, particularly early life stages, seem less tolerant than other species to changes in suspended sediment concentrations. Natural events occurring during spawning, such as wintertime variation in stream flows, can have devastating effects on Atlantic salmon egg survival (Kircheis and Liebich 2007). Table 4 provides guidance for addressing total suspended sediments and sediment deposition in Atlantic salmon spawning habitat during egg incubation and rearing.

Table 4: Guidance for addressing total suspended sediments and sediment deposition in spawning habitat during egg incubation and rearing for eggs and larvae of Atlantic salmon.

TSS and Sediment Deposition Guidance for Atlantic Salmon Eggs/Larvae
Considering the extinction risk faced by this species, we recommend avoiding introduced turbidity or TSS in spawning habitat during egg incubation and rearing. In areas where salmon eggs and larvae are expected to occur, we recommend suspended sediment producing activities occur within a specified work window (July 15 – September 30) to minimize the effects to spawning areas and to prevent the mortality of salmon eggs and larvae resulting from TSS. Additionally, sediment from disposal activities should not be deposited in known salmon spawning habitat containing eggs and larvae. Placement of low levels of fine-grained sediment into redds has the potential to bury eggs and larvae and fill the spaces between developing eggs, reducing the amount of oxygen available to them. Biologists should consider downstream effects of sediments deposited from sediment producing activities like dredging. Based on the activity that is occurring, its location, and TSS levels generated, biologists must determine an appropriate distance upstream of spawning sites where the activity can occur or whether limitations should be placed on when the activity can occur (e.g., outside the spawning season).

Effects on Sturgeon

Effects of turbidity and suspended sediment have largely been tested on salmonids (mainly West Coast species). Little work has been conducted on sturgeon to investigate direct effects associated with suspended sediments and turbidity resulting from activities such as dredging. After conducting a literature search, no studies depicting effects to sturgeon from various sediment concentration levels could be found, making the determination of thresholds for the onset of behavioral, sub-lethal, and lethal effects very difficult.

Newcombe and Jensen's (1996) review included an examination of the effects of TSS on adult estuarine non-salmonids, and the model included bay anchovy, Atlantic herring, Atlantic menhaden, sheepshead minnow, Atlantic silverside, spot, and fourspine stickleback. These seven species are thought to be more sensitive to the effects of TSS than other estuarine species considered in the analysis. SEV scores indicating the onset of lethal effects (score of ten) began at nearly 3,000 mg/L after approximately seven hours of exposure. After 24 hours of exposure, lethal effects began at concentrations as low as 3 mg/L (Newcombe and Jensen 1996). For less than seven hours of exposure, which is expected for animals exposed to sediment plumes from activities such as dredging, nearly all concentration levels resulted in some sub-lethal (i.e., physiological) stress response at concentrations ranging from 3 to nearly 2,000 mg/L (SEV scores of six and seven). These responses could include increased coughing and respiration rates, moderate habitat degradation (e.g., underutilization and/or avoidance of habitat, including spawning habitat), and impaired homing (Newcombe and Jensen 1996).

However, a later review by Wilber and Clarke (2001) indicates that this model included erroneous data and produced misleading results. Results indicated that concentration levels were too low (by a factor of ten) due a conversion error when using mortality effects data from Sherk et al. (1975). Wilber and Clarke (2001) reported having personal communications with C.P. Newcombe, who indicated that a revised model using the correct data from Sherk et al. (1975) predicted results that were less severe. It is unclear from the literature if this revised model was published to correct the erroneous one used in Newcombe and Jensen (1996) for adult estuarine non-salmonids. Since the model from Newcombe and Jensen (1996) does not truly represent severity effects from suspended sediments in adult estuarine non-salmonids, the figure has not been included here.

In spite of the errors found in Newcombe and Jensen (1996) for adult estuarine non-salmonids, it should be noted species tolerances to changes in environmental conditions vary widely. For example, the sheepshead minnow lives in brackish water and tolerates a variable range of salinities, including hypersaline conditions. It can also tolerate low oxygen levels by gulping air at the water's surface. It is known to bury itself in the sediment at the bottom to over-winter as well as to seek refuge from predators or very warm or cold water. Similarly, the bay anchovy is widely tolerant of salinity and temperature fluctuations and low dissolved oxygen levels.

Other species such as Atlantic silversides, Atlantic herring, and menhaden are sensitive to environmental changes that include low dissolved oxygen levels. Similarly, sturgeon live in flowing water and have relatively narrow oxygen and temperature ranges they can tolerate.

Therefore, TSS may put additional stress on fish that may already be living under relatively stressful conditions.

Some studies indicate that projects, such as dredging, have altered the environmental conditions (e.g., water quality, hydrography) for sturgeon in some rivers such that the habitat is no longer suitable, causing them to move away to different habitat (e.g., further upstream) (Collins et al.2002; Breece et al.2013). These changes, coupled with a changing climate and other natural environmental factors, can reduce suitable habitat for these animals and possibly place them into less suitable habitats and conditions that may cause them stress (e.g., suboptimal temperature or dissolved oxygen levels). Studies indicate that stressed fish can have lower tolerance for new stresses, such as those that could occur from TSS (Servizi and Martens 1991; Robertson et al. 2006). We discuss this in more detail below in the section "Additional Considerations and Cumulative Effects on Salmon and Sturgeon."

In general, sturgeon species are adapted to living in turbid environments (Hastings 1983; ECORP Consulting 2009), and this can be taken into consideration when evaluating the effects of turbidity and suspended solids on sturgeon species. It is likely that suspended sediments may be tolerated fairly well by adult sturgeon, at least. Certain life history traits allow sturgeon to exist in the bottom portion of the water column; these traits include poor vision, benthic diet, and a mouth on the ventral side of the head (Secor and Niklitschek 2001). Sturgeon are known to seek out cooler waters (thermal refuges) during warm summer months in the Southeast Region of the United States as warm temperatures are usually associated with conditions of low dissolved oxygen to which sturgeon are very sensitive.

Sensitivity to a stressor such as TSS can be elevated beyond normal levels if the animals are already exposed to stressful conditions, including increased temperatures and lower dissolved oxygen levels. This is discussed in more detail below in, "Additional Considerations and Cumulative Effects on Salmon and Sturgeon". Sturgeon respond to hypoxic conditions (less than 40% saturation of oxygen) by increasing their ventilation rates, swimming to the upper surface waters with relatively higher levels of oxygen, and decreasing their amount of swimming and routine metabolic activities (Secor and Niklitschek 2001). Consideration must be given to sturgeon that may be exposed to increased sedimentation levels during periods that may be especially stressful for them, such as during hypoxic conditions, as they are already compromised and may be ill suited to respond sufficiently to the stressor and avoid harmful effects.

Behavioral Effects

A 24-hour study of the behavior of sub-adult white sturgeon (*Acipenser transmontanus*) in the Columbia River in relation to hopper dredge disposal operations indicated that there was little effect on these fish. Six of seven tagged fish demonstrated a slight attraction to the disposal area. One sturgeon moved further away from the site (Parsley et al.2011). One tagged fish actually remained in the dredge disposal location the entire time that dredge disposal operations were occurring. The disposal operation did not appear to affect the core areas occupied by the tagged fish prior to or after disposal operations. For the sturgeon that moved toward the disposal site, it appeared that they were stimulated by the activity (i.e., risk in suspended sediment levels and increased noise in their environment). The authors attribute the slight attraction to the disposal site as a perceived foraging opportunity for the tagged fish after they detected a rise in organic matter, causing them to explore their environment for feeding opportunities that may have been non-existent. Unfortunately, the study did not collect sediment concentration levels associated with the dredge disposal operation.

A study examining the effects of dredge disposal on Atlantic and lake sturgeon in the St. Lawrence estuary showed a significant decrease in the presence of Atlantic sturgeon after the introduction of dredged material at an open water disposal site (Hatin et al. 2007). The authors considered a variety of factors that could be related to this finding including changes in depth, topography, dissolved oxygen levels, turbidity, and benthic community composition. The authors concluded that the evacuation by Atlantic sturgeon at the open water disposal site following dredged material disposal was due to changes in sediment grain size from dumping very coarse and coarse sand onto the naturally occurring silt-clay dominated substrate. Prior to dredging disposal, the substrate possessed adequate populations of oligochaetes that are the dominant prey species of Atlantic sturgeon in this area. After dredged material was disposed, the concentration of oligochaetes significantly declined due to the change in substrate, likely causing the Atlantic sturgeon to move away from the site due to lack of food availability (Hatin et al.2007). In this geographic area, Atlantic sturgeon prefer to prey on oligochaetes, exclusively. The researchers recommend that dredge disposal sites be located downstream of known important sturgeon habitats to avoid potential impacts from sedimentation (Hatin et al. 2007).

There is also evidence that sturgeon may not return to an area affected by dredging. The Gulf Sturgeon Recovery Plan (USFWS and GSMFC 1995) indicates that Gulf sturgeon found in the Apalachicola River abandoned habitat at Rock Bluff (river km 148.8) after dredged material started drifting downstream (from river km 150) to this area from a routine maintenance dredging disposal site. While not mentioned in the recovery plan as a potential reason for habitat abandonment, it could be possible that sturgeon may not have preferred the grain sizes in the dredged sediments resulting in them moving away from the area. Hatin et al. (2007) discussed this possibility after their study on Atlantic sturgeon in the St. Lawrence estuary where dredged disposal materials consisted of coarse sand as opposed to the silt-clay substrate preferred by Atlantic sturgeon. They also indicated that to help avoid impacts to sturgeon from dredged sediments, disposal sites should be located downstream of important sturgeon habitats.

Moser and Ross (1995) studied Atlantic and shortnose sturgeon in the Cape Fear River in North Carolina. Tracked individuals occurred in both undisturbed areas as well as areas regularly dredged. This study focused on learning about sturgeon movements and distribution patterns in an understudied portion of their range. Captures and tagging occurred during all four seasons. The researchers were also interested in learning more about potential disruptions, including the presence of dams, incidental capture in gillnets, and dredging activities, to behaviors and movements. Behavior and activity levels varied based on the time of year. There was evidence that sturgeon were moving through Wilmington Harbor, which was dredged on a regular basis, during dredging operations. The authors found no ill effects to sturgeon from dredging activities, although animals had an affinity for deep, mid-channel areas that could expose them to effects of the dredges. However, in this case, shortnose sturgeon were found to remain within two meters of the surface while they were moving which would take them out of the path of a dredge. Two tagged Atlantic sturgeon moved into Wilmington Harbor and remained for a month. One of these fish moved with 100 m of an operational hydraulic pipeline dredge twice during that month and appeared to be unaffected. In any case, this study provides some evidence that sturgeon continue to use migratory corridors that are subject to frequent dredging, may return to areas previously dredged, or remain within areas being dredged. No suspended sediment concentration levels were measured in this study.

In conclusion, there are limited studies that examine the behavioral effects associated with suspended sediments on sturgeon. The studies we reviewed largely involved capturing, tagging, and tracking sturgeon to observe how they react to dredging-related disturbances. It is likely that adults and juveniles will avoid areas in which suspended sediment levels are unsuitable for or disruptive to them. As long as important prey species and/or preferred habitats and substrates are not eliminated from the area, it is likely that sturgeon will return to areas post-dredging. Unfortunately, none of the reviewed literature measured suspended sediment levels in relation to sturgeon behavior. Thus, it is impossible to determine TSS thresholds that would cause behavioral effects. However, Atlantic and shortnose sturgeon remained in an actively dredged area (Moser and Ross 1995) where some level of turbidity and TSS was likely to be occurring. This may demonstrate a tolerance to some extent to TSS for these species. This study also reported shortnose sturgeon swimming within two meters of the surface. This may have been a behavioral avoidance response to the sediment plume located closer to the bottom.

Sub-Lethal and Lethal Effects

Adults and juvenile sturgeon should have the ability to avoid intolerable suspended sediment levels, although this ability may be limited. This should be considered depending on the activity and project location (e.g., a sturgeon's movement could be inhibited by water depth or width of the waterway). Further, sturgeon species are adapted to living in fairly turbid environments. Although, it is unclear how increased stress from suspended sediments in an already turbid environment might affect them. As discussed earlier, coho salmon tested by Bisson and Bilby (1982) exhibited varied reactions to changes in turbidity based on prior exposure to clear versus already turbid water.

None of the literature we reviewed documented laboratory studies in which sub-lethal and physiological effects to sturgeon species were measured in response to TSS. However, we reviewed one study that documented sturgeon fingerling tolerances to various concentrations of suspended sediments during four exposure days. Two sturgeon species were examined — stellate sturgeon (*Acipenser stellatus*) and Persian sturgeon (*Acipenser persicus*) — both occur in the Sepidrud River, which empties into the Caspian Sea north of Iran (Garakouei et al. 2009). Hatchery raised fingerlings averaged 7-10 cm in length and weighed 3-5 grams. Fingerlings of both species were exposed for four days to various concentrations of suspended sediments, ranging from 1,000 to 28,640 mg/L for stellate sturgeon and 5,000 to 39,530 mg/L for Persian sturgeon. The researchers controlled water temperature, pH, and dissolved oxygen levels were controlled, which remained the same for each trial of the experiment. The LC50 value (50% mortality) after four days of exposure was 8,539 mg/L for stellate sturgeon and 15,367 mg/L for Persian sturgeon (Garakouei et al. 2009). For stellate sturgeon, all fingerlings survived exposure to 1,000 and 2,320 mg/L of suspended sediments for two days, and all Persian sturgeon fingerlings were alive after two days of exposure to concentrations of 5,000, 7,440, and 11,310 mg/L (Garakouei et al. 2009).

While physiological effects were not directly observed in this study, sediments were found to clog the gills and spiracles of dead fingerlings while mucous and small amounts of sediments were observed on the gill filaments of dying specimens. When sediments begin to accumulate on the gills, the natural response of a fish is to rapidly open and close the gills to remove the sediment. Sediment irritation leads to the production of mucous to protect the surface of the gills, but this can reduce proper water circulation over the gills reducing respiration (Garakouei et al. 2009).

Striped bass, another estuarine species, exposed to 1,500 mg/L of suspended sediments (Fuller's earth) for 14 days experienced an increase in hematocrit, indicating minor physiological stress (severity score of five when looking at Table 1) (Wilber and Clarke 2001). By comparison, adult and juvenile salmonids exposed to 1,097 mg/L of suspended sediments for two weeks began experiencing lethal effects, including low levels of mortality (severity score of ten) (Figure 2).

Summary of Effects to Adult and Juvenile Sturgeon

Very little information exists on behavioral, physiological, and lethal effects to Atlantic and shortnose sturgeon from suspended sediments. Subsequent information indicated that the Newcombe and Jensen (1996) model for estuarine fish was not accurate, and it has not been considered in this white paper. The few behavioral studies reviewed indicate that responses to suspended sediments can vary. In some studies, the fish remained near dredging activities while in others, they moved through areas being actively dredged. In some studies, fish seemed to abandon habitat within a dredging site potentially because prey species were removed or possibly because of changes in substrate type.

From the literature, it is evident that various fish species exhibit different tolerances to suspended sediments. Even similar, co-existing species like stellate and Persian sturgeon seem to tolerate TSS differently when exposed to the same environmental conditions.

Garakouie et al. (2009) examined the lethality of various suspended sediment concentrations on fingerling *Acipenser* sturgeon species native to the Sepidrud River. Persian sturgeon exhibited a higher tolerance to suspended sediments than stellate sturgeon. Neither species experienced mortality at concentration levels of 1,000 mg/L for two days of exposure. They showed tolerances of higher concentrations at this exposure duration. The number of deaths increased with increased concentration levels and longer exposure duration (Garakouie et al. 2009). Sediments clogged the gills and spiracles of dead fingerlings; mucous and small amounts of sediments were observed on the gill filaments of dying specimens. In others, bleeding was noted at the base of some of the fins as well as caudal fin erosion (Garakouei et al. 2009).

It is unclear at what TSS level above ambient sturgeon will begin to experience physiological stress. When evaluating projects, section 7 biologists must also consider the environmental conditions (e.g., extreme temperatures, low dissolved oxygen levels) at the project's location and factor in possible added stress to fish. Based on sturgeon behaviors and habitats and on the literature describing their responses to TSS in dredged areas, we believe these species are relatively tolerant to TSS increases above ambient levels.

We recommend that suspended sediment concentrations do not exceed 1,000 mg/L above baseline/ambient concentrations at a project site for longer than 14 days. We believe any effects to sturgeon would be insignificant and discountable (e.g., unable to meaningfully measure, detect, or evaluate) at concentrations below this level, because it is likely that sturgeon will move away from the area. If they do not, their relative tolerance to TSS in their normal environment lessens the effects of project-generated TSS. While adults and juveniles may have to change their behaviors to avoid the sediments, we expect effects to be temporary, and fish will return to the area if their prey species and habitat are not affected. The literature evaluated indicates that sturgeon may move away from the sediment-generating activity (dredging) and return to the habitat or continue using the area during the activities (Moser and Ross 1995). We expect any sediment plumes generated to dissipate and settle to ambient levels fairly quickly (within a few hours; Anchor Environmental 2003; Morris et al. 2005), and this is discussed further later in the document (Activities that Produce or Change Turbidity and/or TSS).

Section 7 biologists must also consider how TSS may contribute to any additional reductions in tolerance the fish may experience when exposed to other external environmental factors. Further discussions on cumulative effects and additional considerations to be made by the consulting biologist can be found in the below section "Additional Considerations and Cumulative Effects on Salmon and Sturgeon."

Effects on Sturgeon Early Life Stages

For all fish species in which effects to early life stages have been measured, it is clear that eggs and larvae are the most sensitive stages to suspended sediments and sediment deposition. As discussed above for salmon species, the deposition of sediment from dredging or other human activities can be harmful to eggs and larvae through burial or encasement of eggs in fine particles occupying interstitial spaces. Sturgeon eggs and larvae have not been subjects of this type of research. Therefore, it is difficult to establish appropriate, specific threshold levels.

Atlantic and shortnose sturgeon eggs vary in their hatching times, and these times are dependent on water temperature (Wang et al. 1985, Hardy and Litvak 2004). Based on hatchery studies, Atlantic sturgeon eggs hatch approximately 60 hours after egg deposition at water temperatures of 20 – 21 °C and 96 hours if spawning occurs at lower water temperatures (~18 °C). Shortnose sturgeon eggs, also correlated with water temperature, hatch in approximately 13 days when water temperatures are between 8 and 12 °C (Meehan 1910). In warmer waters of approximately 17 °C, hatching occurs after eight days (Buckley and Kynard 1981).

There has been some research on the effects of suspended sediments on white perch eggs. White perch eggs are similar to sturgeon eggs (adhesive and demersal) and take about the same time to hatch (two to five days) as Atlantic sturgeon eggs. According to the literature review by Wilber and Clarke (2001), white perch is considered a sensitive estuarine species because fairly low levels of suspended sediment result in mortality of some fish (e.g., 10% mortality in concentrations of under 1,000 mg/L when exposed for two days).

White perch eggs experienced delayed hatching after 24 hours of exposure to 100 mg/L of TSS (Schubel and Wang 1973, as reported in Newcombe and Jensen 1996) and a reduction in hatching success when exposed to 1,000 mg/L for seven days (Auld and Schubel 1978). In the experiment conducted by Auld and Schubel (1978), various stages of egg development were tested at four different sediment concentration levels: 50 mg/L, 100 mg/L, 500 mg/L, and 1,000 mg/L. When results were compared with controls, concentrations of 1,000 mg/L significantly affected the hatching success of white perch eggs. In this experiment, there were variations in percent survival of the different developmental stages with increased sediment concentrations; however, no clear pattern seems to have emerged (Auld and Schubel 1978).

These results are similar to those found by Morgan et al. (1973). They found the growth and development rate of white perch eggs was significantly reduced at sediment levels greater than 1,500 ppm (which is nearly equivalent to 1,500 mg/L), but percent hatch was not significantly affected by any of the concentration levels tested (concentrations through 5,250 ppm were tested). When comparing these results with those for the eggs and larvae of salmonids and non-salmonids presented by Newcombe and Jensen (1996), white perch eggs appear to exhibit a higher tolerance to suspended sediments. In contrast, eggs and larvae of salmonids and non-salmonids began exhibiting lethal effects (severity score of ten) after two days of exposure to 148 mg/L of suspended sediments. At similar concentrations but exposure durations between three and seven hours, lethal responses are not expected, but physiological responses are expected (Newcombe and Jensen 1996).

In considering the effects of sediment deposition on sturgeon eggs and larvae, we refer to the discussion provided above for salmonids and make similar assumptions for sturgeon. While sturgeon eggs incubate for shorter periods than eggs of Atlantic salmon, any sediment that is deposited on top of eggs could have detrimental impacts regardless of the incubation time. Additionally, shortnose sturgeon eggs incubate from one week to nearly two weeks, likely increasing the detriment to these eggs from longer exposure durations.

Section 7 biologists must also consider the location and timing of the activity in relation to known spawning and larvae rearing areas to inform how the activity may change the baseline conditions of turbidity and suspended sediment and how those changes may affect eggs and larvae. For example, Atlantic sturgeon spawning and nursery areas are believed to occur in the freshwater portions of tidal-affected river waters. Knowing the timing and location of the activity in relation to spawning/nursery areas will determine if effects of suspended sediments will be a concern. Biologists should also evaluate, if possible, the type and grain size of sediments that could be resuspended during project activities. For example, in Atlantic salmon, studies of fine sediments (silts and clays) show that these particles adhere to eggs, form a thin layer, and reduce oxygen absorption (Julien and Bergeron 2006; Levasseur et al. 2006). It is unclear how prevalent an issue this would be for sturgeon eggs. Sturgeon eggs incubate for a shorter period but the effects of sedimentation should be considered. Additionally, larger particle sizes that could bury incubating eggs should be considered for projects that generate larger suspended sediment particle sizes. Further, when considering movement of sediments, larger, denser particles typically settle out of the water column in a shorter amount of time than suspended fine silts and clays. This could have implications for projects upstream of spawning and larvae rearing areas.

Summary of Effects to Sturgeon Eggs and Larvae

In light of the lack of information about effects of suspended sediments to sturgeon eggs and larvae, we examined sediment concentration effects on white perch eggs and considered the effects to salmonid and non-salmonid eggs and larvae as presented by Newcombe and Jensen (1996). In the absence of suitable information on the effects to sturgeon eggs, we provide guidance based on two scenarios when biologists consider the effects of suspended sediment and sediment deposition for projects occurring in or near sturgeon spawning and/or larval rearing habitat (Table 5). The first parameter applies to projects within spawning and/or larval rearing habitat but outside the times for which spawning, egg incubation, and larval rearing occurs. The second applies to projects within spawning and/or larval rearing habitat during times in which spawning, egg incubation, and larval rearing could occur.

Table 5: Guidance for addressing total suspended sediments and sediment deposition in spawning habitat both during and outside of the time for spawning and/or larval rearing for Atlantic and shortnose sturgeon eggs and larvae.

TSS and Sediment Deposition Guidance for Atlantic and Shortnose Sturgeon Eggs/Larvae
For projects within spawning and/or larval rearing habitat but <u>outside</u> of the time periods for which spawning, egg incubation, and larval rearing occurs, no sturgeon life stages would be present. However, the biologist should evaluate the timing and scope of the project to determine if suspended sediments or sedimentation would substantially alter habitat such that it became unsuitable for sturgeon during future spawning seasons. If negative impacts are expected, mitigation measures should be implemented. An addendum to this provision may be warranted pursuant to the future designation of critical habitat for shortnose sturgeon and/or the final rule designating critical habitat for Atlantic sturgeon for management actions to avoid adverse modification and destruction from activities that generate suspended sediments or sediment deposition. For projects within spawning and/or larval rearing habitat during times in which spawning, egg incubation, and larval rearing could occur, the biologist should evaluate the timing and scope of the project to determine where the project would occur in relation to spawning, egg incubation, and/or rearing habitat. The biologist then must consider the degree to which suspended sediments may negatively affect these areas and life stages and proceed with either parameter (a) or (b) below. Parameter (a) applies a 24-hour exposure duration with a suspended sediment concentration limit of 50 mg/L above ambient for projects that occur in the vicinity of sensitive spawning and rearing areas found downstream of an activity that generates suspended sediments. Since we are unsure of direct effects of suspended sediments to sturgeon eggs and larvae, we refer to the literature and the Newcombe and Jensen (1996) model of effects to salmonid and non-salmonid eggs that indicates the onset of physiological stress at relatively low concentrations and short exposure durations. A 24-hour exposure to 50 mg/L above ambient would likely prevent the mortality of eggs and larvae due to acute suspended sediment concentrations. Parameter (b) provides biologists with the flexibility to apply work windows to activities that 1) cannot achieve a reduction in suspended sediments to levels approaching 50 mg/L above ambient; 2) would require exposure durations of longer than 24 hours; or 3) may damage spawning, egg incubation, and/or rearing habitat such that these habitats would be unsuitable for sturgeon.

We do not recommend the direct placement of sediments within areas considered spawning, egg incubation, or rearing habitats when these life stages are expected to be present.

Additional Considerations and Cumulative Effects on Salmon and Sturgeon

The physiological effects of environmental and water quality conditions within areas occupied by Atlantic salmon and sturgeon throughout their life histories are complex. Adding stressors like turbidity and TSS have the potential to exacerbate stress levels that these species regularly encounter. Therefore, the consulting biologist must weigh the effects of all possible stressors combined which, depending on which stressors fish are being subjected to, can lead to more severe, aggregrate responses and lower tolerances than would be expected from exposure to a single stressor. For example, a reduction in suitable habitat due to water quality degradation through a combination of factors such as turbidity/suspended sediments, low dissolved oxygen levels, and increased temperatures could cause higher levels of stress to sturgeon than would be observed during exposure to one stressor. Shortnose sturgeon are very sensitive to low dissolved oxygen levels and have limited behavioral and physiological means to adapt. Younger fish are also less tolerant of low dissolved oxygen levels than older fish (Jenkins et al. 1993). Continuous exposure to temperatures greater than 28 °C is likely to be harmful to shortnose sturgeon as is continued exposure to dissolved oxygen levels below 5 mg/L (NMFS 1998). In general, these levels also apply to Atlantic sturgeon, although there may be slight variations. For example, shortnose sturgeon have been shown to be more sensitive to lower dissolved oxygen levels than Atlantic sturgeon but more tolerant of higher temperatures than Atlantic sturgeon (Secor and Niklitschek 2001). At higher temperatures, these species are generally more sensitive to low dissolved oxygen levels and may seek refuge from these types of conditions (e.g., cool thermal refuges in deeper waters).

Environmental and habitat conditions as well as water quality near the planned activity must be considered when evaluating projects that can generate TSS. As such, section 7 biologists should use their best judgement when recommending suspended sediment threshold levels for individual projects. A lower threshold of exposure concentration and/or duration may be warranted if listed species are likely to experience multiple stressors simultaneously. Below are some examples for consideration, which are not meant to be an exhaustive list or discussion.

Environmental Conditions and Water Chemistry

Because fish already stressed due to other factors may have lower tolerances to environmental changes such as turbidity or TSS, section 7 biologists should consider the ambient environmental conditions (e.g., temperature, dissolved oxygen) and water chemistry (e.g., pH, dissolved organic carbon, aluminum) in a project area. We discuss below examples of how Atlantic salmon and sturgeon species respond to environmental conditions and how water chemistry variables can physiologically affect fish species.

<u>Temperature</u>. Temperature plays a role in the life histories of Atlantic salmon and sturgeon. For salmon, temperature affects the timing of spawning and migrations, feeding, predation and disease vulnerability, and egg development (Kircheis and Liebich 2007). For sturgeon, temperature affects the timing of migrations, spawning, and may influence the time it takes eggs to hatch (Wang et al. 1985; Hardy and Litvak 2004; Meehan 1910; Buckley and Kynard 1981).

Fish can begin exhibiting stress when temperatures warm. For example, shortnose sturgeon show signs of stress when water temperatures exceed 28 °C (NMFS 1998). Warm water is usually correlated with reductions in dissolved oxygen levels that may increase stress to fish.

Dissolved oxygen. Sturgeon may become stressed when dissolved oxygen falls below certain levels. Stress symptoms may even include immobility (Jenkins et al. 1993). They may also respond with increased ventilation rates, swimming to the surface, and decreased movement and metabolism (Secor and Niklitschek 2001). Low dissolved oxygen levels can reduce growth, feeding, and metabolic rates. Fish may swim to the surface in low oxygen conditions to receive more oxygen-rich water at the air-water interface (SNS Biological Assessment 2010; Secor and Niklitschek 2001). Shortnose sturgeon exhibited varying age-related tolerances after being exposed for six hours to low dissolved oxygen levels. Younger juvenile specimens (e.g., 25, 32, and 64 days old) experienced high levels of mortality (100%, 96%, and 86%, respectively) at dissolved oxygen levels of 2.5 mg/L. Older juveniles (104 and 310 days old) experienced 12% mortality at this level (Jenkins et al. 1993). This demonstrates the ability of older sturgeon to tolerate reduced dissolved oxygen levels for short periods. Tolerances may decline if chronic exposure to low dissolved oxygen levels occurs.

Similarly, ideal dissolved oxygen conditions vary with life stage in Atlantic salmon. Earlier life stages (e.g., eggs and fry) require oxygen levels at saturation, whereas adults can tolerate lower levels closer to approximately 5.0 mg/L (NMFS 2009).

Salinity. With the exception of eggs, sturgeon can tolerate a wide range of salinities, as various life stages of these species exist in both freshwater and saltwater environments. Eggs are almost entirely intolerant of salinity. Similar to findings demonstrating that early life stages are intolerant of low dissolved oxygen levels, Allen et al. (2013) found reduced growth rates in juvenile Atlantic sturgeon (approximately two months old) over a six month time period as salinity increased. While all fish grew and were physiologically able to move between habitats with varying salinities, fish grew faster in lower salinities (0 and 10 ppt as opposed to 33 ppt) (Allen et al. 2013). Niklitschek (2001) indicated that shortnose sturgeon showed signs of stress and reduced survival when salinities reached 29 ppt. Jenkins et al. (1993) found increased salinity tolerance with age, similar to the findings for dissolved oxygen, and stressed the importance of estuarine habitat as nursery areas for juvenile shortnose sturgeon.

Acidification. Acidification (low pH levels) negatively affects aquatic life (Liebich et al. 2011). Atlantic salmon parr were more tolerant than smolts to lower pH levels (i.e., more acidic conditions) and increased levels of aluminum in a controlled study (Kroglund et al. 2008). Low pH levels can reduce the saltwater tolerance in smolts. In combination with elevated levels of aluminum, this can cause smolt mortality (Kircheis and Liebich 2007). When using plasma chloride and plasma glucose as a measure of physiological stress, Liebich et al. (2011) found strong correlations to changes in pH. Plasma chloride content decreased and plasma glucose content increased in response to decreases in pH.

Aluminum. Studies have shown that inorganic aluminum present in freshwater at toxic levels accumulates on and in the gill tissue of Atlantic salmon. This can disrupt ionoregulation, hinder respiration, and lead to physiological stress in the form of elevated blood glucose (Kroglund and

Finstad 2003). According to Kroglund et al. (2008), H^+ ions at pH levels as low as 5.4 have no effects on Atlantic salmon. However, water with low pH levels are highly toxic to fish when combined with the presence of aluminum cations. Aluminum retains its toxicity at pH levels of 6 and below but is detoxified quickly (in a matter of minutes) when pH levels are above 6.4 (Kroglund et al. 2001). After being exposed for over three months to sub-lethal acidic water (pH of 5.9 and <25 ug Ali/L), Atlantic salmon presmolts demonstrated physiological signs of stress, including decreased seawater tolerance, increased aluminum concentrations on the gills, major changes in the gill tissues, and raised blood plasma glucose concentrations. No effects were seen on blood plasma chloride (Kroglund et al. 2001). Gill morphology returned to normal after presmolts spent 210 hours in water with a pH of 6.3. Recovery was not clearly demonstrated for presmolts that were exposed to water with lower pH levels (5.8, 6.0, and 6.1) (Kroglund et al. 2001).

Chemicals and metals. Chemicals and metals found in the food web have the potential to affect Atlantic sturgeon, shortnose sturgeon, and salmon through bioaccumulation. In some cases, these compounds can physiologically affect fish and weaken their ability to handle stress (SNS Biological Assessment 2010). Chemicals can also negatively affect fish growth rate, especially for sensitive life stages like Atlantic salmon smolts (Khots et al. 2011).

Effects of combined stressors. From conditions in Chesapeake Bay, Niklitschek (2001) determined that the combined stress of increased temperatures, low dissolved oxygen, and high salinity during the summer substantially reduced the amount of potential nursery habitat for both shortnose and Atlantic sturgeon. Modeling work has been done to help quantify habitat impacts due to climate change and eutrophication on Atlantic sturgeon based on their known tolerances to these variables (Schlenger et al. 2013). These fish are constrained by these three environmental conditions, and effects can be exasperated by other human-caused stressors.

Studies indicate that shortnose sturgeon exhibit higher sensitivity to sub-optimal dissolved oxygen levels at higher temperatures (NMFS 1998). The EPA developed dissolved oxygen criteria that would be sufficiently protective of shortnose sturgeon at stressful (≥ 29 °C) and non-stressful (< 29 °C) temperatures. For example, at a lower dissolved oxygen concentration of < 3.2 mg/L at temperatures less than 29 °C, mortality is expected to occur within two to four hours. However, at a higher dissolved oxygen concentration of > 4.3 mg/L at temperatures exceeding 29 °C, mortality still began to occur within two to four hours (US EPA 2003).

Liebich et al. (2011) found that exposure to acidic conditions and aluminum can lead to a reduction in an Atlantic salmon smolt's salinity tolerance that can reduce survival in the ocean. The study demonstrated physiological changes through decreases in plasma chloride levels and increases in plasma glucose levels, and these were significantly correlated with pH, dissolved organic carbon (DOC), and sodium. When pH drops to below six, smolts can be physiologically compromised, especially when other factors such as high aluminum and low DOC levels are present. When DOC levels are low, organic aluminum complexes decrease. This leads to high amounts of toxic inorganic aluminum and a subsequent reduction in proper gill function (Liebich et al. 2011). Additionally, the authors recorded 40% smolt mortality at only one sampling study site after three days of exposure. When compared to other study sites with similar pH and aluminum concentrations, this site had DOC concentrations below 1.9 mg/L; other similar study sites all had concentrations that were greater than 4.23 mg/L. On the other side, high DOC levels may buffer smolts against negative consequences of low pH and high aluminum levels (Liebich et al. 2011).

Habitat Displacement

For salmon, fish that are exposed to frequent and sudden increases in turbidity may exhibit an alarm response, causing them to move downstream and away from turbid conditions. This may displace them into less suitable habitats, which may affect their ability to grow and survive. Thus, it can affect their overall fitness. Additionally, it may send them into territorial waters of dominant fish. This has been shown to suppress feeding in non-dominant fish as was found in juvenile coho salmon (Berg and Northcote 1985). Even if fish are not startled by the onset of turbid conditions, biologists must consider if sufficient habitat refuge allows them to escape impacts.

Location and Timing of the Project

When assessing how a project might affect listed salmon or sturgeon, section 7 biologists should consider where the species and their habitats, including critical habitat, occur in relation to the project's location and timing. The direction of tidal and river flows should be considered. For example, biologists should consider where various life stages and habitats (e.g., overwintering, spawning, rearing) may occur in relation to the direction in which a dredging or disposal sediment plume will travel. Project locations downstream of important spawning habitat need less scrutiny than those upstream or within spawning habitat do.

Known Movements and Habitat

Any known patterns of movement and habitat areas (e.g., resting/overwintering, feeding, or spawning) should be considered with respect to the location and timing of the planned activity. Having species habitat and distribution information available to action agencies allows them to also consider how their project can operate in a manner that causes the least disturbance, as possible, to fish species.

Life Stages

Biologists should consider the life stage(s) that may be present near an activity (e.g., adults, juveniles, or eggs/larvae). TSS affects each life stage differently. Life stages must also be considered in light of cumulative effects and other stressors that may have an effect. Some life stages are more or less tolerant of "stress" than others.

For example, in a controlled study, Atlantic salmon smolts exhibited higher levels of stress from acute handling and confinement than parr (Carey and McCormick 1998). The authors also discussed the possibility of blood plasma ion loss occurring in smolts, not only from smolt development but also from the presence of a stressor. Ion regulation is thought to play a role in triggering downstream movement in smolts. Therefore, if smolts perceive turbidity/TSS as stressful, this may hinder the trigger mechanism indicating when they should move downstream.

This could affect their proper development. The physiological changes occurring in smolts that prepare them for the transition from fresh to salt water make them very sensitive to fluctuations in their environment.

Cumulative Effects

Section 7 biologists must gain an understanding of the expected concentration levels associated with the TSS from project and the expected duration of exposure. Additionally, other physiological (e.g., timing of spawning and migration) and environmental factors (e.g., depth and width of the area to be dredged, availability of other suitable habitat nearby) that could affect an animal's response or influence its tolerance when exposed to turbidity or TSS should be considered.

As described above in the section on "Environmental Conditions and Water Chemistry," Atlantic salmon and sturgeon are exposed to a variety of environmental and water quality conditions that can affect them. These can have a larger aggregate influence when several stressors are combined. When a combination of stressors exists beyond an animal's tolerance level (e.g., high temperatures and low dissolved oxygen levels), their ability to withstand these and/or additional stressors (e.g., TSS) may be reduced, making the animal even more sensitive to stressors in the environment than it might normally be. A section 7 biologist must consider these aggregate effects when evaluating how a certain project might affect a fish species.

Summary of Effects on Atlantic Salmon and Sturgeon

In summary, the threshold levels for Atlantic salmon found in Table 6 are conservative. Fairly informative literature exists for salmon species (although not always focused on Atlantic salmon). This literature demonstrates a relatively lower tolerance to TSS when compared to sturgeon.

The largest scale projects that section 7 biologists consult on that generate TSS are those that involve dredging. Evidence, presented in the sections below related to dredging, indicates that sediment plumes generated from these activities likely dissipate within a few hours. It is unlikely that sediment plumes generated at any one point in time would exceed 1,000 mg/L of TSS, especially if mitigation measures are used. This level is not expected to result in any juvenile or adult mortality for exposure durations of a few hours, but exposures lasting longer than a few hours could result in physiological stress (Newcombe and Jensen 1996). After a literature search of TSS effects on fish, LaSalle et al. (1991) provided a TSS of 500 mg/L as a conservative level at which no effects to fish would be expected but believed that a strong argument could be made to increase this level to 1,000 mg/L. Further, the authors conclude that all life stages of estuarine and anadromous fish species seem to be fairly tolerant of TSS. As such, elevated TSS levels that occur during short-duration activities like dredging should not cause concern. However, TSS resulting from disposal operations that could be longer in duration may warrant concern (LaSalle et al. 1991).

In Table 6, we identify three threshold concentration levels for adults/juveniles. These are based on the amount of exposure that could occur by allowing higher concentrations for short periods and lower concentration levels with longer period. The data presented by Newcombe and Jensen (1996) and other studies considered for this white paper demonstrate that fish can tolerate lower TSS concentration levels for longer periods. However, the introduction of suspended sediments or sediment deposition in spawning habitat when eggs and larvae are present creates unsuitable conditions that could hamper the growth of or kill these early life stages.

Table 6: Total suspended sediment (TSS) thresholds for each life stage for Atlantic salmon. The threshold levels represent total sediment exposure in which baseline sediment concentration levels are factored into this threshold such that baseline and TSS concentrations combined should not exceed these thresholds.

Species	Life Stage	Exposure Duration	Threshold (total suspended sediments)
Atlantic Salmon	Adults / Juveniles	Threshold one: ≤ 3 hours	≤ 1,000 mg/L
		Threshold two: ≤ 24 hours	≤ 50 mg/L
		Threshold three: ≤ 144 hours (six days) after the first 24 hours of exposure	≤ 10 mg/L
	Eggs/Larvae[1] (TSS and sediment deposition)	Avoid spawning habitat (Oct 1 – July 14)	0 mg/L outside of July 15 – Sept 30
		Operate within specified work window (July 15 – Sept 30)	See above limits for adults/juveniles

[1]The work window suggested to minimize impacts to migrating juvenile and adult Atlantic salmon and eggs/larvae within spawning habitat is July 15 through September 30. However, the section 7 biologist must consider the location of the project and type of activity as salmon may not always be present in the action area. Species presence depends on the ability of salmon to access the habitat from the ocean or direct stocking of fish from a hatchery. Therefore, it is possible that much of the available spawning habitat is vacant.

For sturgeon, our literature review revealed very little data on the effects of TSS. Since adult and juvenile sturgeon already exist in turbid environments, we believe they have a higher tolerance to TSS than salmon do. If we use Figure 1 for adult and juvenile salmonids as an example, lethal effects of exposure to approximately 1,100 mg/L can be expected to occur after about two weeks of exposure. If sturgeon are more tolerant of TSS, exposure at these levels for two weeks should result in less severe effects, assuming the fish remain in the area for the duration of the exposure. We do not expect that to happen. As such, we recommend that sediment-generating activities not exceed 1,000 mg/L above ambient sediment concentration levels for longer than two weeks (Table 7).

Like salmon, sturgeon eggs and larvae are less tolerant of TSS and are the most sensitive life stage. For projects within spawning and rearing habitat but outside of the time for spawning, egg incubation, and larval rearing, biologists are encouraged to ensure that the habitat is not altered by the project such that it becomes unsuitable for sturgeon in the future. For projects within the time when spawning, egg incubation, and larval rearing occur, the biologist can consider two parameters. Parameter (a) applies a 24-hour exposure duration with a suspended sediment concentration limit of 50 mg/L above ambient for projects that occur in the vicinity of sensitive spawning and rearing areas found downstream of an activity that generates suspended sediments. The distance downstream will depend on the activity and equipment used. Since we are unsure of direct effects of suspended sediments to sturgeon eggs and larvae, we refer to the literature and the Newcombe and Jensen (1996) model of effects to salmonid and non-salmonid eggs, which indicates the onset of physiological stress at relatively low concentrations and short exposure durations. A 24-hour exposure to 50 mg/L above ambient would likely prevent the mortality of eggs and larvae due to TSS.

Parameter (b) provides biologists with the flexibility to apply work windows to activities that 1) cannot achieve a reduction in suspended sediments to levels approaching 50 mg/L above ambient; 2) would require exposure durations of longer than 24 hours; or 3) may damage spawning, egg incubation, and/or rearing habitat such that these habitats would be unsuitable for sturgeon. For both Atlantic salmon and sturgeon, we do not recommend the direct placement of sediments within areas considered to be used by fish for spawning, egg incubation, and larval rearing.

Table 7: Total suspended sediment (TSS) thresholds for each life stage for Atlantic and shortnose sturgeon. The threshold levels represent total sediment exposure, in which baseline sediment concentration levels are factored into this threshold such that baseline and TSS concentrations combined should not exceed these thresholds.

Species	Life Stage	Exposure Duration	Threshold (total suspended sediments)
Atlantic and shortnose sturgeon	Adults / Juveniles	14 days	≤ 1,000 mg/L
	Eggs/larvae (TSS and sediment deposition)	Project occurs outside of the period when spawning, egg incubation, and larval rearing occurs (no sturgeon life stages present)	Review project to ensure that habitat is not altered such that it becomes unsuitable for spawning, egg incubation, or larval rearing
		Project occurs within the period when spawning, egg incubation, and larval rearing occurs (sturgeon life stages present)	Parameter (a): ≤ 50 mg/L above ambient; no sediment deposition
			Parameter (b): Work windows [1]; no sediment deposition

[1]Parameter (b) allows section 7 biologists the flexibility to apply work windows to activities that 1) cannot achieve a reduction in suspended sediments to levels approaching 50 mg/L above ambient; 2) would require exposure durations of longer than 24 hours; or 3) may damage spawning, egg incubation, and/or rearing habitat such that these habitats would be unsuitable for sturgeon.

We acknowledge that Atlantic salmon, shortnose sturgeon, and Atlantic sturgeon have complex life histories in which they are exposed to and sensitive to a variety of environmental conditions. Changes in their environment (e.g., warmer temperatures, lower dissolved oxygen) could reduce their ability to tolerate other stressors such as TSS. As such, conservative thresholds are warranted for sufficient protection of these species. Based on knowledge of the best technology available, we believe that these levels are achievable for projects that occur in the Greater Atlantic Region. In the sections below, we also consider the effects of turbidity and suspended sediments on habitat, including critical habitat.

EFFECTS ON ESA-LISTED WHALES

Direct and indirect effects to listed whales from turbidity or suspended sediments may occur. However, these effects are not as well studied as they are for fish species. We do not expect direct physical or lethal impacts to occur as they do in fish and other underwater species like invertebrates, which have been documented to experience negative effects such as gill clogging and mortality of eggs/larvae. We believe direct effects to whales would most likely be behavioral (e.g., changes in movements, effects on vision) and possibly physiological in the form of stress due to exposure to suspended sediments or difficulty with foraging. There is limited information on these stressors at present. Whales may be visually affected, which may limit their ability to forage, interact with or contact conspecifics, or avoid predators. Indirect effects include a potential reduction in prey availability if TSS drives the prey away (Todd et al. 2015). The physical characteristics of the marine environment constantly change due to natural influences such as tides, waves, and storms. Small-scale changes from activities such as dredging are not likely to have much influence. However, repeated alterations to the physical environment due to dredging and on a larger scale could cause larger scale effects (Todd et al. 2015).

Direct Effects

Direct effects to ESA-listed large whales from suspended sediments can cause changes in behavior (animals leave the area, change course), may affect vision (inhibit foraging), or may induce physiological responses (increased respiration rate). No studies have been conducted to measure these possible effects. We primarily consider the potential effects to vision and the relationship to foraging and communication with conspecifics.

We believe behavioral effects, such as individuals altering their course or moving away from the source of stress, are typical reactions to stimuli made by marine mammals when they are startled or bothered. It is possible, however, that behavioral changes could cause animals to stop feeding or to move away from important foraging areas that could have survival implications if the stressor is present for an extended period.

In a review of dredging impacts to marine mammals, Todd et al. (2015) found that direct effects from turbidity have not been documented in the literature. Sediments generated from dredging plumes are typically short-lived, dissipate within four to five tidal cycles at a maximum, and likely extend a few hundred meters away from the discharge point. Some marine mammals inhabit relatively turbid waters, and the ocean itself, especially at depth, is dark. Studies on pinnipeds and turbidity effects indicated that visual sharpness decreased in turbid waters above one formazin nephelometric unit (FNU); however, it is likely that pinnipeds use other senses besides vision to forage.[7] In one area in the North Sea where pinnipeds are found, turbidity levels ranged from 7 to 40 FNU. This suggests that in order to survive in that environment, pinnipeds must be using other senses to forage. Additionally, foraging studies demonstrated the ability of blind seals to successfully to feed despite their visual limitations (Todd et al. 2015). While no

[7] A formazin nephelometric unit (FNU) is similar to a NTU in that both are a unit of measure of water turbidity. Reporting in FNUs indicates that the water turbidity was measured using an infrared light source rather than a white light source as is used when reporting in NTUs (http://or.water.usgs.gov/grapher/fnu.html).

pinnipeds in this region are listed under the ESA, these studies indicate the adaptive ability of marine mammals to survive in their environment.

While it appears that at least some pinnipeds do not rely on vision to forage, it is unclear how large mysticetes, such as ESA-listed whales, use vision for foraging. In general, Shi and Wang (2010) demonstrated most of the global ocean waters are clear of turbidity with coastal waters showing higher turbidity levels on a seasonal basis. The most turbid waters of the U.S. east coast are found within Chesapeake and Delaware Bays as well as in Pamlico Sound, North Carolina. Large mysticetes do not use these habitats (Shi and Wang 2010). However, in open water environments, waters deeper than depths of light penetration are dark. Therefore, vision is likely not the only method employed during foraging when whales feed at depth. As such, suspended sediments that reduce visibility beyond baseline levels may not contribute to a reduction in foraging.

Recent studies of right whale eyes indicate that they see in black and white, with their vision being sensitive in the blue/green range of the spectrum. Therefore, the ocean water appears white to them. Red, which appears dark against the white background, is the one color they can see in the water. Copepods are reddish in color and copepod concentrations will appear to them as dark masses (Fasick et al. 2011). However, it is unclear if suspended sediments would affect how right whales see their prey. It is likely that these animals use other cues to locate feeding habitats and prey, including learning and memory as well as physical oceanographic and chemical conditions that aggregate copepod prey (Baumgartner et al. 2007). In some areas, right whales skim feed at the ocean surface (e.g., in Cape Cod Bay). Therefore, light would be brightest here, possibly offsetting any vision-related effects from suspended sediments. In other areas, right whales feed at depth (e.g. Bay of Fundy), even at or near the bottom as evidenced by whales observed surfacing with mud on their heads. At depth, it is unlikely that vision plays a role in foraging. Therefore, suspended sediments on or close to the bottom should not affect how whales locate prey. Rather, they may use tactile cues when feeding at depth, although we note that these concepts are somewhat speculative as it is very difficult to observe right whales feeding at depth (Baumgartner et al. 2007). Additionally, it is unknown what role TSS would play in affecting the efficacy of tactile cues used for foraging.

Humpback and fin whales feed on larger prey items like schooling fish by taking in huge amounts of prey and water at the same time using a variety of tactics (e.g., lunge feeding in fin whales, bubble net feeding in humpbacks). It is difficult to determine if suspended sediments would have negative visual effects on the ability for these whales to forage. It seems likely that any effects of suspended sediments resulting in reduced visibility would be offset by the fact that both whales and their prey are highly mobile. Effects to prey species themselves are discussed in the below sections on "Effects on Prey Species" (for listed fish) and "Effects on Habitat (including Critical Habitat)."

Sperm whales live in deep waters, usually along the continental shelf and over the continental slope (Waring et al. 2014). They do not appear to regularly occupy the Gulf of Maine and, instead, tend to stay further offshore. Sperm whales have been sighted along the southern and eastern edges of Georges Bank. They feed on large prey items such as large squid, sharks, skates, and fish. Due to their tendency to inhabit very deep waters, it is unlikely that changes in suspended sediments generated from oceanic projects would affect them, as they likely do not overlap in time and space.

For conspecific interactions, it is possible, for example, that suspended sediments may cause mother and calf mysticetes to become visually separated. There is evidence, however, of the use of vocal communication between mothers and calves that have become separated, as was demonstrated in southern right whales (Clark 1983). Therefore, although mothers and calves may become separated by the presence of suspended sediments, it is likely that they will be able to reconnect through vocal communication. Other problems could arise if TSS becomes so intense that animals are unable to engage in normal activities such as breeding, and these levels remain high for extended periods or occur in sensitive habitats. The inability to see predators is another visual impediment that may detrimentally affect whales. How whales perceive predators or threats (e.g., through vision, hearing, or both) is unknown, but temporarily losing visual access to their environment could put them at a higher risk of predation (e.g., from sharks, killer whales) especially if the animal is young or sick and weak. Conversely, TSS may provide temporary cover from predators or provide an opportunity to escape predation.

In the Mid-Atlantic region, ESA-listed whales generally use these waters as a corridor between their breeding and feeding grounds. Certain species like humpback whales may spend additional time in these waters if foraging opportunities are present. In recent years, humpbacks were documented feeding in waters just miles away from New York City. Additionally, juveniles were observed feeding during the winter (January through March) in the waters off Virginia, near the mouth of Chesapeake Bay (Swingle et al. 1993). It is unknown how the presence of TSS along migratory routes would affect their behavior or food source if they were feeding in these areas. It is likely that whales are using oceanographic and other cues to help them along their migratory routes. Therefore, slight changes in turbidity or suspended sediments are unlikely to have lasting negative effects preventing individuals from reaching their destinations. For the humpbacks feeding off Virginia, one animal was observed with sediment pouring from its mouth and others had scuff marks on their jaws. This evidence is consistent with feeding at or near the bottom in shallow water. Reports indicated that animals feeding in the shallow water stirred up sediments from the bottom, which created turbulence and sediment plumes that could be seen at the surface (Swingle et al. 1993). This may perhaps indicate that sediments in the water column do not negatively affect whales.

Finally, generation of suspended sediments and turbidity plumes from projects may block access to important areas for whales or prohibit them from leaving a confined space (e.g., bays, inlets) if they must travel through the plume. An animal may become stressed if it feels trapped. No evidence in the literature suggests this occurrence has happened or that this would occur, but there is also no evidence that demonstrates whether a whale would swim through a plume. The section 7 biologist should review the layout of the activity area, consider what listed whales might be doing there, and determine if desired habitat may be blocked by the activity or if an animal's movement out of an enclosed or confined area might be restricted. In the "Best Management Practices" section, we recommend the use of trained observers to watch for listed species prior to project commencement.

Other Effects

ESA-listed whales may also experience environmental effects from suspended sediments such as effects to their habitat and prey species. If TSS displaces prey species, whales may be forced to forage elsewhere. Effects to prey and habitat are discussed in the sections "Effects to Prey Species" and "Effects to Habitat (Including Critical Habitat)."

Summary of Effects on Listed Whales

In summary, effects from suspended sediments on ESA-listed whales are largely unknown and speculative. Therefore, we have not set thresholds for sediment exposure concentrations and exposure duration. As such, section 7 biologists should review the potential for suspended sediment effects to whales qualitatively at this time. Biologists should consider the location of the project with regard to whale distribution, life stages likely to be present, and behaviors that likely to be occurring. Since marine mammals are adapted to temporary sediment disturbances because of their oceanic existence and exposure to large storms, anthropogenic disturbances that temporarily generate suspended sediments should not prevent animals from returning to the area after the disturbance has passed (Tillin et al. 2011).

While whales do not face lethal effects or effects to respiration since they breathe air, they could experience stress that could lead to behavioral (avoidance) effects. Whales occur in the open ocean where oceanic currents over large expanses may dissipate sediments and minimize effects relatively quickly or reduce the risk of experiencing effects in the first place. This may lower the risks to whales present in areas with sediment-generating activities. We also do not anticipate effects to prey species because whale prey are mobile and exposure to suspended sediments is likely to be temporary.

EFFECTS ON ESA-LISTED SEA TURTLES

Effects of turbidity or suspended sediments on listed sea turtles are likely to be similar to those on listed whales. However, like whales, the effects have not been studied. We do not expect direct physical or lethal impacts to occur because sea turtles are anatomically (air breathers s) and physiologically different from more susceptible organisms such as fish and invertebrates. Exposure of individuals could result in behavioral changes (e.g., moving away from an affected area), reduced vision (e.g., to forage, avoid predators, find a mate), restrictions to normal activities (e.g., feeding, migrating), or increased stress (e.g., inability to forage adequately, general exposure). Effects to physical habitat as well as prey and forage could also occur. Turtles are mobile species that will likely be able to move away from the turbid area. Since they feed in water that varies in turbidity levels, changes in such conditions are unlikely to inhibit sea turtles foraging (Michel et al. 2013) even if they use vision to forage.

Direct Effects

We expect that immediate behavioral responses to suspended sediments might take the form of a startle response to a novel stimulus in sea turtles. This has been observed in some fish species where an alarm response occurred after fish were exposed to suspended sediments (Robertson et al. 2006; Berg and Northcote 1985; Servizi and Martens 1992; Chiasson 1993). After the initial response, turtles exposed to TSS may have difficulty foraging.

Studies suggest that sea turtles use vision to forage but the effects of added suspended sediments on visual acuity in turtle species is unknown. A study of loggerhead sea turtles conducted off Japan showed that turtles use visual cues to detect their prey, which consisted of two jellyfish species and several unidentified siphonophores (Narazaki et al. 2013). Turtles tagged with 3D loggers and, at times, a Crittercam used a straight-line course to approach their prey. When using other senses (e.g., olfactory sense), approaches were usually characterized by a zigzag rather than a straight line. One animal approached a plastic bag in a similar manner to other turtles approaching actual prey species. However, after approaching the bag, the bag was not emitting any other cues and, presumably, that is why the turtle did not ingest it. Narazaki et al. (2013) also indicated that vision was used to detect prey in captive juvenile loggerhead turtles. Since vision may play a role at least during daytime feeding for loggerhead turtles, suspended sediments in foraging areas may reduce a turtle's visual effectiveness at finding food.

Visual effects could also reduce a turtle's ability to see and avoid predator, as vision is thought to be the primary cue used by turtles for avoiding predators. Chemical cues may also play a role (Southwood et al. 2008). Sea turtles display a clear avoidance response when presented with predator (shark) replicas or shapes. Alternatively, turbidity and TSS may provide a turtle with protective cover to evade predators, assuming the turtle was aware of the predator. Another negative visual impact could be reduced ability to seek out potential mates.

Suspended sediments could also cause sub-lethal effects. Unlike fish, sea turtles breathe air, eliminating the potential for direct physical impacts such as gill clogging. However, sea turtles may experience startle effects and stress upon exposure to turbidity or suspended sediments, but this has not been studied or measured. Other sub-lethal effects could include a reduction in foraging because of reduced visibility as described above. This could lead to a reduction in overall fitness if sea turtle prey species are affected. Similarly, foraging habitats could be destroyed or become unsuitable, forcing turtles to seek food elsewhere.

Restricted migratory abilities and access to important habitats could also occur. However, it is unclear to what extent suspended sediments might affect migrating animals or prevent them from accessing certain habitats, such as those used for mating, feeding, or resting. We believe slight disruptions could occur if animals were required to swim around or through a sediment plume or alter their preferred course during migration.

Finally, suspended sediment and turbidity plumes have the potential to deny sea turtles access to biologically important areas (e.g., feeding or breeding areas) or prohibit them from leaving a confined area if the only path would be to travel through the plume. This has the potential to cause stress if the animal feels that it is trapped. There is no evidence in the literature whether this occurs or whether a sea turtle would swim through a plume. When considering possible impacts to sea turtles, section 7 biologists should review the layout of the area in which the activity would occur, consider what listed sea turtles might be doing there, and determine if desired habitat may be blocked by the activity or an animal's movement out of an enclosed or confined area might be restricted. In the "Best Management Practices" section, we recommend the use of trained observers to watch for listed species prior to project commencement.

Other Effects

ESA-listed turtles may experience environmental effects from suspended sediments including to their habitat and to prey species. Effects to prey and habitat are discussed in the sections below ("Effects to Prey Species" and "Effects to Habitat (Including Critical Habitat)").

Summary of Effects on Sea Turtles

Similar to large whales, direct and indirect effects of suspended sediments on ESA-listed sea turtles are largely unknown and speculative. While turtles do not face the threat of lethal effects or effects to their respiratory system from suspended solids, we believe they could experience many of the same behavioral (e.g., avoidance, temporary reduction in feeding) and possibly physiological (e.g., increased respiration rate) effects that fish do.

We have not set thresholds for sediment exposure concentrations and exposure duration for listed sea turtles. There is no reason to believe long-term negative impacts will occur to sea turtles from suspended sediments generated by projects such as dredging. This is due to a turtle's ability to move away from the source, its lack of underwater breathing, and oceanic currents dissipating suspended sediments. Section 7 biologists should review suspended sediment effects to turtles qualitatively at this time by reviewing the nature of the project and the species that could be present and possibly affected. We expect effects to be limited to behavioral responses.

EFFECTS ON PREY SPECIES

Turbidity and suspended sediments could change feeding behaviors and feeding opportunities for listed species. Shifts in prey species communities may also occur. Additionally, prey species may exhibit behavioral changes (mobile species leaving previously suitable habitat), may be buried by sediment deposition, may experience physiological stress (reducing fecundity or growth/size), and even possibly experience death.

Prey Species for Listed Fish

Madej et al. (2007) found a reduction in feeding and prey capture rates for juvenile coho salmon when turbidity levels were between 25 and 45 NTUs. Unfortunately, measurements in mg/L were not provided. This is similar to results found by Berg and Northcote (1985) for juvenile coho. They found feeding was significantly reduced at 30 NTUs and prey ingestion rates significantly reduced to well below 50% at 30 and 60 NTU, with approximately 40% of the prey being ingested at these levels as compared to 100% at zero turbidity.

Redding et al. (1987), as reported in Robertson et al. (2006), reported reduced feeding rates for coho salmon and steelhead trout at relatively high levels of suspended sediments (2,000 to 3,000 mg/L). Chinook salmon seem to prefer moderate levels of turbidity for feeding. Two studies demonstrated feeding rates were highest for this species between approximately 35 to 150 NTUs

(50 to 200 mg/L) but rates diminished in waters with concentration levels over 200 mg/L. Rates were further reduced in levels over 800 mg/L (Gregory 1990 and Gregory and Northcote 1993, as reported in Robertson et al. 2006). However, controlled experiments may not reflect what would happen in wild habitat where fish would likely have opportunities to forage elsewhere.

Atlantic and shortnose sturgeon are benthic feeders and typically select a variety of benthic prey including insect larvae, crustaceans (crabs), polychaetes (worms), small benthic fish, and mollusks (gastropods, bivalves). Adult and juvenile shortnose sturgeon forage over sandy-mud bottoms, and have been known to feed off plant surfaces (Shortnose Sturgeon Status Review Team 2010). Sturgeon have tactile receptors called barbels on the ventral side of their mouths that are used to locate prey on the bottom. The mouth protrudes and extends downward to act as a vacuum to suction-up prey. Since these animals do not appear to use vision to aid in foraging, it is unlikely that suspended sediments or turbidity will affect their ability to forage. These animals are adapted to living in relatively turbid environments. It is more likely that prey removal (e.g., through dredging) and/or depositing materials (e.g., dredge disposal) on top of foraging habitat could reduce the availability of prey species. In these cases, the animals should have the ability to swim to another area to forage. However, this assumes that another suitable forage area is available nearby. This also does not take into account the energetic costs associated with searching for new foraging areas, which would be extremely difficult to quantify in an empirical study.

Sediment loads in the water column have the potential to impede feeding on organisms such as larvae and plankton by early life stage sturgeon and salmon. Suspended sediments could also negatively affect these prey organisms. Two oceanic zooplankton species, *Calanus finmarchicus* and *Pseudocalanus* spp., exhibited reduced feeding on the diatom, *Thalassiosira weissflogii*, when suspended sediments increased to >20 mg/L and > 50 mg/L, respectively (Arendt et al. 2011). Additionally, *C. finmarchicus* fecal pellets indicated the ingestion of sediments that could have led to a reduction in the production of eggs due to the reduction in food uptake. Similarly, Tester and Turner (1989) indicate that zooplankton ingestion of suspended sediment particles ultimately reduces survival through starvation, as increased particle ingestion reduces feeding on nutritious particles. This could lead to a reduction in egg production and fecundity.

Suspended sediments can affect adult benthic organisms limited in mobility in a variety of ways. First, they can be buried, and this can lead to a reduction of available oxygen. Higher than normal concentrations of suspended sediments can cause a reduction in respiratory pumping rates in bivalves and require filter feeders to sort through the particles to find food. Hinchey et al. (2006) examined the effects of burial on five estuarine benthic species and found variations in the physiological tolerance to sediment burial and the ability to move back through the sediment to reach the water-sediment interface. Burrowing bivalve clams, burrow-forming amphipods, and juvenile oysters were highly tolerant to burial. A tube-dwelling polychaete in the spionid family (*Stresblospio benedicti*) was relatively unsuccessful at moving through the sediment to regain the sediment-water interface. This animal is more sedentary and was not observed to move upward through the deposited sediment. The authors used overburden stress as a measure of how the animals responded to burial intensity.[8] The polychaete experienced a steep, exponential decline

[8] Overburden stress was presented in Hinchey et al. (2006) as the calculation (reported in kilopascals, kPa) of the amount of force exerted on organisms when buried in sediment for six days.

in survival as overburden stress increased. After six days, a survival rate of 4% to 16% was observed for *S. benedicti* in silty sand and burial depths of 5.8 to 6.5 cm (Hinchey et al. 2006). However, survival rates increased to 40% with burial in 5.0 to 6.9 cm of silty clay for six days. This demonstrates that not only burial depth, but also the type of sediment can have an effect on the benthic species. This polychaete may be particularly important to sturgeon; spionid polychaetes were an important prey species of Atlantic and shortnose sturgeon in the Penobscot River (Dzaugis 2013).

Wilber and Clarke (2001) examined effects to invertebrates in their literature review and results vary, similar to those demonstrated by Hinchey et al. (2006). A typical bivalve response to suspended sediment is to reduce their net pumping rates and reject excess filtered material. This could be considered a sub-lethal response (Wilber and Clarke 2001). Suspended sediment can affect the ability of filter feeders to eat floating food like algae. Adult bivalves are relatively tolerant of TSS but could still exhibit reduced growth and survival rates, although very high concentrations are needed to induce mortality. Therefore, adult bivalves should be able to withstand changes in TSS associated with activities such as dredging.

According to Wilber and Clarke's (2001) literature review, adult bivalves like the eastern oyster are highly resilient to suspended sediment concentrations at levels about 1,000 mg/L for exposure durations of two days or more. Larval stages, like the larvae of fish, are less resilient. Eastern oyster larvae experienced 40% mortality when exposed to 1,000 mg/L of suspended sediments for 12 days (Wilber and Clarke 2001), which is longer than would be expected in an actively dredged area.

Mobile crustaceans are likely able to avoid areas with suspended sediments (Wilber et al. 2005). Mysid shrimp exposed to 1,020 mg/L of suspended sediments for four days experienced no effect but suffered 60-80% mortality when exposed to this concentration for four weeks (28 days). According to the literature review completed by Wilbur and Clarke (2001), most studies on crustaceans have sought to examine concentration levels that induce mortality. For exposures of fewer than two weeks, very high concentrations of suspended sediments (around 10,000 mg/L) were required to induce some level of mortality. Generally, this level was less than 25%.

Similarly, for adult bivalves, high concentrations and longer exposure durations are generally required to induce mortality. No mortality occurred for exposure durations that were shorter than five days at levels below approximately 100,000 mg/L (Wilber and Clarke 2001). Softshell clams experienced sub-lethal effects between 100 and 200 mg/L after about two days of exposure. Despite the relative high tolerance of bivalves to suspended sediments, they can still experience reduced growth and lower survival at high sediment concentration levels. However, these levels would generally not be expected to persist with the activities that are being considered in this white paper.

Similar to fish larvae, bivalve larval stages can be affected by suspended sediments. However, quaghog (hardshell clam) larvae exposed to 750 mg/L of suspended sediments for about two days experienced no effect (Wilber and Clarke 2001). Generally, quahog and oyster larvae examined for exposure of two days did not experience mortality until levels were beyond 1,000 mg/L. However, mortality occurred at lower concentrations after exposures of 10-12 days.

Prey Species for Large Whales

Large mysticetes feed on relatively concentrated prey in areas where large schools or aggregations occur. Right whales feed on copepod aggregations at the surface or closer to the bottom. Humpback and fin whales feed on small schooling fish such as mackerel, capelin, and sand lance and blooms of plankton (e.g., krill). It is unknown how turbidity and suspended sediments in the water column affect how prey is perceived by whales. Since the prey is aggregated rather than single individuals, they may be easier for whales to see if vision is used for foraging.

It is unclear if TSS affects whale prey behaviorally, but it is likely based on other studies demonstrating startle and avoidance responses in some fish species. For schooling fish (e.g., clupeids (herring, mackerel)) that rely on visual cues, turbidity and the resulting lack of water clarity can make it difficult for fish to visually locate one another. This affects their schooling abilities and the resulting sizes (Appleby and Scarratt 1989). In the context discussed by Appleby and Scarratt (1989), the loss of schooling may result in lower catch per unit effort for fishing gear targeting these species (e.g., trawl gear). Similarly, humpback and fin whales rely on the schooling behavior of prey to ingest huge mouthfuls of fish and water. As such, suspended sediments could lead to a reduction in foraging opportunities for whales as well as an overall reduction in prey consumed if schooling sizes are reduced or the prey species vacate the affected area in search of clearer water. In a laboratory study of individual smelt (*Osmerus mordax*), a normally schooling fish species, smelt avoided suspended sediments at a concentration of 20 mg/L, although the researchers noted that the study design may have biased this sediment avoidance threshold (Wildish and Power 1985). Fish swimming was inhibited by a change in light color from white to red (Wildish and Power 1985). We must also consider the energetic costs to whales that may need to seek other foraging areas and opportunities if their prey move or are dispersed.

Research on three copepod species taken from a fjord in Greenland demonstrated a reduction in feeding rates for *Calanus finmarchicus* on phytoplankton at sediment concentration levels greater than 20 mg/L when exposed to various suspended sediment concentrations over four days (Arendt et al. 2011). At these concentrations, *C. finmarchicus* ingested sediments, unable to differentiate between the sediments and their prey. This in turn led to a decrease in the copepods' egg production ability. Ingestion of fine sediments, however, is likely linked to the concentration of available phytoplankton with lower food concentrations leading to higher ingestion rates of sediments (Arendt et al. 2011). Across the three copepod species tested over four days and all concentrations of TSS (0 through 100 mg/L), survival was greater than 95%. While direct survival remained relatively high in this particular experiment, suspended sediment levels that result in decreased egg production would reduce the population of future copepod generations, leading to a reduction in food availability for species like right and sei whales that feed on copepods.

Sand lance, a prey species for humpback whales, burrows into the substrate but does forage in schools in the water column during the day. It is unclear if additional sediments would affect the burrowing ability of sand lance or if suspended sediments in the water column would affect their schooling and foraging abilities.

Sperm whales feed on individual prey such as squid. Echolocation is likely used for foraging as these species exist at depth where light penetration is low to non-existent. It is unknown how suspended sediments in the deep ocean may impact echolocation and how effectively sperm whales forage. Additionally, it is unclear how suspended sediments might affect sperm whale prey species.

There is no information available to conclude how large whale prey species are affected by turbidity or suspended sediments. If feeding animals are inhibited by elevated turbidities or suspended sediment levels, they will likely move to another area (Michel et al. 2013). However, section 7 biologists should consider the energetic costs associated with moving to another area to find prey, whether or not the prey species are likely to be in those areas, and if whales that follow their prey are moving into areas with higher threats (e.g., higher amounts of fishing gear, vessel traffic, etc.). Since the ocean environment is so dynamic, it is likely that sediments will dissipate rather quickly, perhaps allowing prey species to return in a relatively short period.

Prey Species for Sea Turtles

Sea turtles feed on a variety of prey species and are visual predators (Southwood et al. 2008). Kemp's ridley turtles prefer crabs, mollusks, jellyfish, and fish; loggerheads prefer conch and whelks; greens prefer sea grass and algae; and leatherbacks prefer jellyfish, salps, and pyrosomes. Studies on how green sea turtles were affected by dredging activities in Florida concluded that turtles utilized adjacent unaffected habitats but returned to the dredged area within two years. This could have been related to the recovery of macroalgae that had been affected by the dredging activity (Michel et al. 2013). Therefore, any effects to prey species from suspended sediments, sediment deposition, or turbidity may cause turtles to move to other areas and then return to the affected areas at some time in the future. However, we did not find studies that evaluate the behavioral effects of suspended sediments on mobile prey species to determine how prey behaviorally react and how those reactions might affect foraging sea turtles.

Wilber and Clarke's (2001) review of the biological effects of suspended sediments mentions a study by Peddicord and McFarland (1976) in which Dungeness crab juveniles and adults exposed to very high suspended sediment concentration levels (over 9,200 mg/L) for varying periods (from four to as many as nine days) experienced some level of mortality. For example, crabs exposed to 9,200 mg/L for eight days experienced 5% mortality.

In a more general review of adult and juvenile crustacean response to suspended sediments, exposures for four days at levels ranging from approximately 50 to 1,000 mg/L resulted in no effects (Wilber and Clarke 2001). In studies lasting under two weeks, concentrations upwards of 10,000 mg/L were required to induce mortality and mortality was less than 25%.

Wilber and Clarke (2001) also reviewed studies of suspended sediment effects on bivalves. Adults exposed for 3.5 days experienced either no effects or sub-lethal effects at concentrations at and above 100 mg/L; sub-lethal effects occurred through approximately 5,000 mg/L. Bivalve adults began experiencing mortality at extremely high concentration levels (100,000 mg/L) after five days of exposure and at lower concentrations (2,000 to over 10,000 mg/L) between seven and ten days of exposure.

For turtle species that feed on pelagic species like jellyfish and salps, it is possible that turbidity and suspended sediments could make prey more difficult to see and find. Studies have shown that sediment plumes created by activities such as dredging experience higher sediment concentration levels in the lower portion of the water column (ECORP Consulting 2009). However, this may vary with dredge type, as certain types of dredges such as the clamshell dredge can lose sediments as they move through the water column (Bridges et al. 2008). Despite this, animals feeding in the middle to upper portions of the water column may not experience suspended sediment concentrations that are as high as if they were feeding closer to the bottom.

It is likely that changes in turbidity and suspended sediments could temporarily disrupt normal sea turtle behaviors, especially if turtles rely on vision to forage. However, it is not thought that this would permanently change the prey base (Michel et al. 2013). Deposition of sediments onto the seafloor has the potential to change the abundance of sea turtles in an area in the short-term due to a reduction in prey base, but there is no indication that this would be permanent so long as the prey base returns (Michel et al. 2013). We must also consider the energetic costs to turtles moving in search of suitable forage, the availability of equally or more suitable foraging areas, and the level of threats (e.g., fishing gear interactions, vessel strikes) present in new foraging areas.

In summary, the review conducted by Wilber and Clarke (2001) demonstrates that these bivalves and crustaceans appear to be tolerant of suspended sediment levels that would be generated by projects occurring in the Greater Atlantic Region, which likely would not reach levels exceeding 1,100 mg/L (see Tables 10 and 11), and are likely tolerant of even higher levels. For these sea turtle prey species, it is unlikely that suspended sediments from projects occurring in this region would kill them. We lack information on how suspended sediments affect the behavior of mobile prey species and how their reactions to turbidity and suspended sediments might cause them to leave an area and become unavailable as sea turtle prey. We also lack information on how suspended sediments found in the water column might affect sea turtle vision and their ability to forage.

Summary of Effects to Prey Species

Prey species vary widely for the ESA-listed species that occur in this region as do effects on them from suspended sediments. Section 7 biologists should: 1) consider what, if any, prey species will be in the project area for the listed species being considered; 2) determine the possible effects to prey species from suspended sediments, taking into account ambient versus project-generated suspended sediment concentration levels, exposure durations, mobility, life stage, etc.; and 3) examine the availability of other equally or more suitable foraging areas for listed species in the vicinity of the project. Modifications to the project timing and/or area may be warranted to help alleviate impacts resulting from potential damage to prey species and/or reductions in potential foraging opportunities.

EFFECTS ON HABITAT

Adding sediment to the water column and depositing sediments on the bottom has the potential to alter habitats, including critical habitat, of ESA-listed species in this region. Listed fish species rely on certain bottom habitats and environmental conditions during different life stages, making them more vulnerable to changes in habitat than other listed species like large whales and sea turtles. Changes and possible effects to habitat resulting from TSS are discussed below.

Fish Habitats

For listed fish species, sediments have the potential to alter habitat. Sediment deposition on spawning habitat could make the substrate unsuitable for salmon or sturgeon eggs. Sediments could also be deposited on top of salmon redds and sturgeon eggs. Depending on the sizes of the sediments, they can settle on the eggs themselves, fill in the spaces between the cobbles in which the eggs are laid, or form a thin coating around the eggs, ultimately decreasing available oxygen and reducing survival to hatching. Covering redds with a layer of sediment and filling in spaces between the cobble with fine sediments could reduce the ability of emerging fry to exit the redd (Julien and Bergeron 2006).

Changes in turbidity and suspended sediments could alter the sediment type in areas close to the activity as the sediment particles settle out of the water column. It is likely, however, that currents could pull these sediments downstream. This should be considered when examining where activities will be taking place as activities upstream could affect listed habitats downstream.

Atlantic Salmon Critical Habitat

NMFS designated critical habitat for the Gulf of Maine DPS of Atlantic salmon in 2009. It encompasses 45 specific areas occupied by salmon representing 19,571 km of river, stream, and estuary habitat and 799 square km of lake habitat within the range of the DPS and that contain the physical and biological features essential to the conservation of this species (74 FR 29300, June 19, 2009). There are three Salmon Habitat Recovery Units (SHRUs) for the Gulf of Maine DPS: Downeast Coastal, Penobscot Bay, and Merrymeeting Bay.

When designating critical habitat, NMFS must identify specific areas that contain those physical and biological features essential to the conservation of the species and focus on the primary constituent elements (PCEs) to identify those features. For Atlantic salmon, the two identified PCEs are spawning and rearing and migration. They are described with respect to five important salmon life stages including adult spawning, embryo and fry development, parr development, adult migration, and smolt migration. This white paper considers the effects of turbidity and suspended sediments to these PCEs.

When we consult on a project that could generate suspended sediments, we must consider whether the project will occur in an area that has been designated as critical habitat. If so, the biologist must determine if one or more PCEs would be present in the area during the time of the project. It is also possible that while a project is in critical habitat, there are no salmon present due to a barrier downstream or other factor preventing access of the area by salmon.

If salmon are expected to be present within critical habitat when a project occurs, the biologist must determine what the impacts on salmon could be. To guide them through a determination of effects, biologists use the "Framework to Assist in Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions Occurring in Designated Critical Habitat in the Gulf of Maine Distinct Population Segment of Atlantic Salmon" (NMFS 2009). This document uses a matrix to make determinations of effects to salmon.

The matrix expresses impacts in terms of essential physical and biological features that have unique descriptions and/or values associated with them; these essential features are necessary to support the continued existence of Atlantic salmon. They exist on three levels representing baseline conditions — full function, limited function, and not properly functioning — that have associated characteristics for each essential feature. This white paper considers possible effects to each PCE from turbidity and suspended sediments by considering as much as possible the effects to the essential features of each PCE.

Adult Spawning

The essential features of the adult spawning PCE are substrate, depth, velocity, temperature, pH, cover, and fisheries interactions. The time of year associated with the presence of this PCE is October 1 through December 14.

Suspended sediments and/or sediment deposition can deposit fine sediments on substrates that are important for successful spawning. Fully functioning spawning substrates are highly permeable coarse gravel and cobble between 1.2 and 10 cm in diameter (NMFS 2009). If sediments are deposited onto formerly suitable spawning habitats that can no longer support spawning, the female may abandon spawning or may have to search for another area with more suitable habitat.

It is unlikely that turbidity or suspended sediments resulting from activities we routinely consult on have the potential to largely affect water depth. The actual dredging process itself, rather than suspended sediments generated from the project, could cause shifts in water depth. Sediment deposition has the potential to change water depth in disposal areas. However, water flow and velocity will affect the extent to which particles are transported after disposal (Fondriest Environmental Inc. 2015b).

Waters with higher turbidity levels can be warmer because the sediment particles absorb heat. However, suspended sediments generated during typical dredging or construction activities are not expected to result in any more than temporary and minor increases in suspended sediments that, alone, likely would not generate enough sediment to affect river temperatures. Additionally, there is no evidence in the literature indicating that turbidity or TSS have any effects on pH.

The amount of available cover for spawning adults that arrive early to the spawning grounds could be positively or negatively affected by suspended sediments. Increased cover for salmon could occur from suspended sediments if predators are less likely to see them due to decreased water clarity. However, TSS could make sources of cover (e.g., boulders, logs, submerged vegetation) less visible to salmon. It could also fill in (depending on the amounts of sediment generated) or reduce the availability of pools that would be used for shelter.

Fisheries interactions refer to the benefits to salmon provided by sea lampreys that arrive in the rivers to spawn in mid-June (Kircheis and Liebich 2007). In building their nests, lampreys gather stones (usually of similar size to those preferred by salmon) and place them in loose piles. Similar to salmon, lampreys clean the stones to free them from silt. Thus, these nests can be beneficial to spawning Atlantic salmon adults. However, the eventual settlement of suspended sediments cause sediment deposits on lamprey nests, making them less visible to or beneficial for spawning salmon.

Embryo and Fry Development

The essential features of embryo and fry development are temperature, dissolved oxygen, pH, depth, velocity, and fisheries interactions. The time of year relevant to this PCE is October 1 through April 14.

Temperature, pH, depth, and velocity are unlikely to be affected by temporary increases above ambient in turbidity or suspended sediments generated by typical dredging or construction projects. Ambient water velocity can affect the movement of suspended sediments and the sizes of the particles carried. For example, higher flow rates can suspend larger particles and contain a higher concentration of suspended particles (Fondriest Environmental Inc. 2015a).

While substrate is not listed as an essential feature for embryo and fry development, it is known that the coarse gravel and cobble required for adult spawning is necessary for proper incubation and oxygenation during embryo development. Filling in the spaces between the gravel with fine sediments can affect the amount of oxygen available to incubating eggs. There is evidence that fine sediments (silts and clays, < 0.063 mm) strongly affect survival of Atlantic salmon to the pre-eyed and eyed development stages (Julien and Bergeron 2006). This study was conducted in the field (Quebec, Canada) at six sites to simulate the effect of sediments on simulated salmon redds by burying incubation baskets containing fertilized eggs and sieved gravel and examining effects to three life stages (pre-eyed, eyed, and hatched). While each site varied in sediment sizes and amounts that infiltrated the baskets, silts and clays (< 0.063 mm) represented a relatively small portion of the particle sizes found within the baskets (0.03 – 0.41%). These low levels significantly reduced the survival of the pre-eyed and eyed stages, possibly creating a thin coating over the egg and, thereby, reducing the amount of available oxygen. Survival of the pre-eyed and eyed stages was reduced to below 50% at silt and clay weight values that were between 0.3 and 0.4%. Survival to the hatched stage was most strongly correlated with infiltration by medium sand particles (0.25 – 0.50 mm). Additionally, the results clearly demonstrated an increasingly negative correlation between embryo survival and an increased percentage of fine sediments infiltrating the baskets. Further, a general reduction in survival occurred with increasing percentages of sediments within the baskets (Julien and Bergeron 2006).

The survival rates documented by Julien and Bergeron (2006) (below 50% when silt and clay values reached 0.3 – 0.4%) were similar to those documented by Levasseur et al. (2006), whose study also involved Atlantic salmon embryos in simulated redds. Although Levasseur et al. (2006) defined silt and very fine sand as particles < 0.125 mm (rather than < 0.063 mm as described by Julien and Bergeron (2006)), when silt and very fine sand percentages reached 0.2%, embryo survival to hatching was also drastically reduced to less than 50%.

The fisheries interactions essential feature for this life stage refers to the risk of predation to Atlantic salmon eggs and emerging fry occurring from the presence of non-native, introduced fish species (e.g., smallmouth bass, non-indigenous salmonids like brown trout). It is unclear how turbidity or suspended sediments resulting from activities such as dredging might affect fisheries interactions. It is possible it could provide an advantage to non-native fish species by providing them with cover or potentially give them an advantage when hunting for prey. Decreased visibility from TSS or above-ambient turbidity could also provide cover for Atlantic salmon fry to help protect them from becoming prey to non-native fish species.

Parr Development

The essential features of the parr development PCE are substrate, depth, velocity, temperature, dissolved oxygen, food, passage, and fisheries interactions. The time of year considered for this PCE is year-round.

Depth, velocity, temperature, and dissolved oxygen are unlikely to be affected by temporary increases above ambient in turbidity or suspended sediments generated by typical dredge or construction projects. Dissolved oxygen levels would primarily be affected by chronic turbidity. Suspended particles absorb heat from the sunlight more easily than in clear water, thus reducing dissolved oxygen. Warmer water holds less dissolved oxygen. We do not expect chronic turbidity to occur during the activities (e.g. dredging, pile driving) we consult on.

Suspended sediments can affect suitable substrates. Parr require substrates that will provide them with protection from extreme temperatures, predators, sedimentation, and high flows (Kircheis and Liebich 2007). These areas also serve as foraging grounds for parr. Turbidity or suspended sediments could reduce visibility and the ability of parr to find suitable substrates on which to forage. Flow velocity affects how quickly sediments are carried to or away from parr substrates. Velocity could also affect the size of the particles that could be carried to and settled out within these habitats. For example, larger particles settle out first whereas finer particles like clay and silt remain suspended and can be carried longer distances in areas with high flow velocities (Fondriest Environmental Inc. 2015b). Areas with higher flow velocities that experience TSS generated by typical dredging or construction projects may experience the transport of these small grain sized sediments away from the immediate area, making them less suitable foraging areas. A number of factors can influence sediment transport rates including particle diameter and density, depth, fluid density, and water viscosity (Fondriest Environmental Inc. 2015b).

Adequate food resources provide energy to support the development of salmon parr. Parr forage on drifting invertebrates and larvae, including larvae of mayflies, stoneflies, chironomids, caddisflies, blackflies, aquatic annelids, mollusks, and terrestrial invertebrates that fall into the river. As parr grow in size, they also feed on small fish such as alewives, dace, or minnows (Kircheis and Liebich 2007). Turbidity or suspended sediments can restrict a parr's ability to forage by making prey less visible, especially because many of the parr's prey species are drifting larvae, and can reduce prey capture rates. Turbidity can also alter social hierarchy structures (Berg and Northcote 1985) in juvenile coho salmon. During the pre-treatment phase (clear water, no turbidity), the dominant fish established its territory and made aggressive acts toward the non-dominant fish. After the introduction of sediments, its aggressive behavior declined and dominance and territoriality no longer occurred. While withstanding exposure to the higher turbidity levels, the fish remained close to the bottom, within the lower 10 cm of the water column, of the tank. This behavior, too, may alter a parr's ability to forage during in turbid conditions.

In a study of wild juvenile Atlantic salmon, Robertson et al. (2007) found that foraging behavior increased when TSS ranged from 20 (approximately 15 NTUs) to 180 mg/L (approximately 35 NTUs) as the salmon were attempting to forage on the sediment particles as they were being introduced. However, foraging attempts declined when TSS exceeded 180 mg/L as perhaps the fish realized that the sediment was not food. The decline in foraging was associated with a decline in territorial behavior as well as an alarm reaction.

Juvenile coho salmon experienced reduced feeding from lower prey capture rates when turbidity levels were between 25 and 45 NTUs (Madej et al. 2007). In an experiment introducing sediments to juvenile coho salmon beginning with turbidity levels of 0 NTUs and increasing to 20, 30, and 60 NTUs, feeding was significantly reduced with prey capture success most reduced at 30 NTUs (Berg and Northcote 1985). Prey ingestion rates were also significantly reduced to well below 50% at 30 and 60 NTU turbidity levels with approximately 40% of the prey ingested at these levels. This varied from pre-turbid conditions when 100% of the introduced prey was ingested. Finally, the mean reaction distance in the salmon's capture of adult brine shrimp was significantly lowered from 30 cm to approximately 12 cm for all three turbidity levels (Berg and Northcote 1985).

Aside from visual impediments to foraging with increasing TSS, changes in feeding could be due to shifts in light conditions, perceptions of predation risk, and the size of the fish. Some fish may even prefer slightly higher turbidity levels to assist them in feeding as the turbidity may reduce their visibility to their prey, enhancing the element of surprise.

Parr are limited to the use of specific habitat features to protect them from predation and withstand the presence of competitors (Kircheis and Liebich 2007). Any blockages to fish passage that would restrict parr from reaching these habitats are detrimental. Passage may be affected by the presence of dams but may also be affected by suspended sediments, as it is known that fish may become alarmed and avoid or leave areas of high turbidity (Robertson et al. 2006; Berg and Northcote 1985). The avoidance or abandonment of suitable habitat or restricted ability to access suitable habitat because of suspended sediments could lead to increased risk of predation, loss of food availability, and/or loss of habitat to competitors.

The fisheries interactions essential feature for this life stage refers to the risk of predation to Atlantic salmon eggs and emerging fry occurring from the presence of non-native, introduced fish species (e.g., smallmouth bass, non-indigenous salmonids like brown trout). It is unclear how turbidity or suspended sediments might affect interactions with other species, but it is possible that it could provide an advantage to non-native fish species by providing them with cover or give them an advantage when foraging. However, it could also provide cover for Atlantic salmon fry to help protect them from becoming prey to non-native fish species.

Adult Migration

The essential features of the adult migration PCE are velocity, dissolved oxygen, temperature, passage, and fisheries interactions. The time of year considered for this PCE is April 15 through December 14.

Velocity, dissolved oxygen, and temperature are unlikely to be affected if turbidity or suspended sediment levels increased above ambient. Dissolved oxygen levels are primarily affected by chronic turbidity in which the suspended particles absorb heat from the sunlight more easily than clear water, thus reducing dissolved oxygen and increasing the water temperature. As such, temporary, small-scale changes in turbidity and suspended sediment levels should not have an effect on dissolved oxygen levels or water temperatures. Similarly, velocity is likely not affected by the presence of suspended sediments. However, velocity itself has the potential to affect the particle sizes that remain suspended and how quickly particles settle out, with larger particles typically settling out quicker than smaller particles (e.g., silt and clay) (Fondriest Environmental Inc. 2015b).

Man-made blockages to passage may include the presence of structures like dams. Sudden increases in turbidity/suspended sediments could cause an alarm reaction in fish, causing them to avoid turbid areas that may affect their migration patterns, at least temporarily. Despite spawning occurring in the late fall, Atlantic salmon have adapted an early migration trait where the majority of adults enter the rivers between May and mid-July, with a peak occurring in June (Kircheis and Liebich 2007). This ensures that they have enough time to travel upriver to the spawning areas while accounting for unfavorable conditions that they may encounter during their travels.

Other fish species such as American shad, alewives, blueback herring, and striped bass occur in the estuary when migrating adult salmon are present. These species are thought to be prey buffers for salmon against predators like seals, porpoises, and otters. If the abundance of these prey buffer species declines, threats to Atlantic salmon could increase. While it is difficult to know the effects of suspended sediments to these species, any negative impacts such as causing these species to abandon areas in which salmon exist could translate into negative impacts to adult salmon by increasing their vulnerability to predation.

Smolt Migration

The essential features of the smolt migration PCE are temperature, pH, and passage. The time of year for the presence of this PCE is April 15 through June 14.

Temperature and pH are unlikely to be affected by increased turbidity or suspended sediments above ambient. Temporary changes in turbidity and suspended sediment levels should not have an effect on water temperatures, as chronic turbidity is more likely to result in increased temperatures because the particles absorb heat from the sun. Additionally, pH levels are related to chemical changes in river systems due to acid rain, bedrock and soil composition, plant growth and organic material, and chemicals entering river systems as waste (WRC 2015). Suspended sediments containing toxins/contaminants may change pH but are not considered in this white paper.

Similar to passage for Atlantic salmon parr and migrating adults, man-made blockages to passage are primarily due to the presence of structures like dams. However, sudden increases in turbidity/suspended sediments could also create a blockage by causing an alarm reaction in fish where they avoid certain areas along their migratory corridor, thus affecting their migration at least temporarily. Smolts, however, have a narrow physiological window, which some have termed a "survival window," that occurs in the spring and slowly closes in the summer. During this time, smolts seem to migrate more successfully due to a variety of favorable conditions. Any delays to migration can lower a smolt's survival, as this life stage is sensitive due to the physiological requirements to transition from freshwater to saltwater.

Summary

Suspended sediments can affect all Atlantic salmon critical habitat PCEs described above for the five life stages but do not affect all of the essential features associated with each PCE. Clearly, the most sensitive stages to suspended sediments are the adult spawning and embryo and fry development stages as sediments have the potential to affect the substrate, which is an important essential feature for these two life stages. We generally establish work windows to avoid work during the adult spawning and embryo and fry developmental periods. This helps mitigate the effects of activities that may raise sediment concentration levels during spawning activities, in spawning habitat, and during the most sensitive stages of development. However, section 7 biologists must first carefully consider if these life stages are likely to be present in the project area before placing restrictions on project activities.

Suspended sediments could also hamper visibility for various Atlantic salmon life stages when searching for cover, foraging, or migrating upstream or downstream. Parr life stage foraging may be negatively affected since this stage feeds on drifting prey. The prey could be less visible, or sediments could be mistaken for prey. TSS can also cause alarm reactions and area avoidance, which could delay important migrations for adults and smolts. Further, suspended sediments may alter interactions between Atlantic salmon and other fish species within the river system. For predatory fish, the presence of suspended sediments may provide the advantage of cover or increased stealth when hunting.

Proposed Atlantic Sturgeon Critical Habitat

Critical habitat has not been designated for shortnose sturgeon. For Atlantic sturgeon, NMFS issued two proposed rules on June 3, 2016, for the designation of critical habitat for all ESA-listed DPSs of Atlantic sturgeon. For DPSs occurring in the Greater Atlantic Region, this includes the Gulf of Maine, New York Bight, and Chesapeake Bay DPSs (81 FR 35701).[9] We will only discuss proposed critical habitat for these three DPSs.

To designate critical habitat, NMFS must identify the physical or biological features that are essential to the conservation of the species. NMFS identified two conservation objectives: 1) reproduction and recruitment to the marine environment; and 2) increase the abundance of each DPS by increasing the survival of subadults and adults (fish survive to maturity and reproductive status, and survive to spawn more than once).

The following physical features were identified for the first conservation objective (reproduction and recruitment): 1) hard bottom substrate (rock, gravel, limestone, boulder) in low salinity waters (0 to 0.5 parts per thousand, ppt) for settlement of fertilized eggs, refuge, growth, and development of early life stages; 2) aquatic habitat with a gradual downstream salinity gradient of 0.5 to 30 ppt and soft substrate (sand, mud) downstream of spawning sites for juvenile foraging and physiological development; 3) water of appropriate depth and without physical barriers to passage (dams, reservoirs) between the river mouth and spawning sites; and 4) water, especially in the bottom meter, with temperature, salinity, and oxygen values that, when combined, support spawning; annual and interannual adult, subadult, larval, and juvenile survival; and larval, juvenile, and subadult growth, development, and recruitment.

For the second conservation objective (increasing subadult and adult survival), NMFS considered information related to Atlantic sturgeon foraging and prey types, abundance, and their estuarine habitats, acknowledging the importance of successfully finding food as essential to successful growth and development. After its review, NMFS was unable to identify the physical or biological features associated with estuarine environments that are essential to the conservation of Atlantic sturgeon.

NMFS concluded that the physical and biological features associated with reproduction and recruitment may require special management considerations or protections. For those activities that could generate suspended sediments or sediment deposition, dredging was discussed. NMFS noted that excessive sediment deposition has the potential to reduce the ability of sturgeon eggs to adhere to hard substrates and can fill in the interstitial spaces between cobble that are used by larvae for protection from predators. Dredging activities themselves could also dig up and remove hard substrates that are needed for egg adherence and larvae protection. It was also noted that channel deepening dredging projects could alter the salt wedge within an estuary and cause changes to other water quality characteristics such as dissolved oxygen and temperature.

The rivers for which critical habitat is being designated in the Greater Atlantic Region include:

- Gulf of Maine DPS Rivers – Penobscot, Kennebec, Androscoggin, Piscataqua, Merrimack
- New York Bight DPS Rivers – Connecticut, Housatonic, Hudson, Delaware

[9] The other, separate proposed rule was published by the NMFS Southeast Region to designate critical habitat for the Carolina and South Atlantic DPSs of Atlantic sturgeon (81 FR 36078).

- Chesapeake Bay DPS Rivers – Susquehanna, Potomac, Rappahannock, York River System (includes Pamunkey and Mattaponi Rivers), and James

General Discussion of Sturgeon Habitat

For both sturgeon species, we are primarily concerned about effects of suspended sediment to spawning habitat and the possibility of reductions in its availability and/or use. Spawning habitat is considered to be exposed, clean, hard substrate that does not contain fine particles (Sulak et al. 2000). Water quality variables also contribute to suitable sturgeon spawning habitat. These attributes include dissolved oxygen, water velocity, temperature, salinity, depth, and suspended sediment (Austin 2012). For example, high siltation levels in the James River, likely due to land use changes and modernization within the Chesapeake Bay watershed, have contributed to the alteration of suitable spawning habitat. Austin (2012) found a 28% loss in hard bottom habitat in the James River since 1853, likely resulting from channel alteration and increased sediment loading due to dredging. In this paper, spawning habitat was defined as hard bottom occurring at depths greater than or equal to 10 m. Within the freshwater tidal reach of the James River, Austin (2012) characterized approximately 8% as essential spawning habitat. However, specific portions of the river do still contain hard bottom that would be suitable for sturgeon spawning. Some of these suitable habitat areas were created from dredging and flow modification due to channel deepening and may offset some of the lost historical suitable habitat.

Sturgeon that occur in overwintering areas exist as sedentary groups of older adult fish. While no literature exists on effects of suspended sediments on overwintering habitats, we believe that the sturgeon occurring in these areas would be able to tolerate TSS at the thresholds we suggest (e.g., ≤1,000 mg/L for 14 days). However, if suspended sediments increased to levels that became intolerable, fish could be forced to leave the area. Similarly, suspended sediments could alter overwintering site characteristics that are necessary for the habitat to be suitable for sturgeon (e.g., deep water, deep holes, mud substrate) (NMFS 1998). Given the typical suspended sediment concentrations generated by activities that occur in this region, we believe it is unlikely that suspended sediment levels and/or exposure durations would be so high based on the thresholds established in this paper that overwintering sturgeon would be forced out of these habitats. Further, we do not believe that the characteristics of overwintering sites would be altered to such a degree that sturgeon would abandon these areas.

Nursery areas are habitats that are utilized by juvenile sturgeon. Recently hatched larvae require refuge in gravel and cobble substrates. Any changes in this habitat due to suspended sediments and subsequent siltation within the cobble could make this habitat less suitable for developing sturgeon, resulting in an overall reduction of habitat. Section 7 biologists must consider the possible effects to nursery areas from sediment generating activities.

Other important habitats include resting, feeding, and aggregation areas that are attractive to sturgeon due to the physical characteristics of the river such as depth. For shortnose sturgeon in the Delaware River, these areas usually occurred in deeper waters (Hastings et al. 1987). Additionally, sturgeon seek refuge from unsuitable water quality conditions (e.g., extreme temperatures and salinities) and during these times can tightly aggregate in relatively small areas within a river (e.g., a section that was less than 1 km in length) (Collins et al. 2002). Juvenile shortnose sturgeon that were tracked in the Savannah River traveled upriver when temperatures became too warm and downriver when the river temperatures were cooler (Collins et al. 2002). They found refuge in more tolerable portions of the river and aggregated there. If fish aggregate in these areas and a project occurs that generates suspended sediments, it is unclear if they would seek other refuge areas or if they would remain in place and tolerate the temporary change in conditions.

Summary

For proposed critical habitat for Atlantic sturgeon DPSs (Gulf of Maine, New York Bight, and Chesapeake Bay), NMFS noted the possibility of special management needed for the protection of the physical and biological features associated with reproduction and recruitment. Relevant to this paper, this includes dredging which could alter spawning habitat, but the concern is not necessarily suspended sediment or turbidity. Rather, sediment deposition and substrate removal are the two primary areas of concern from a critical habitat standpoint.

While it is important to consider impacts to sturgeon habitats when fish are present, we must also consider the effects of turbidity and suspended sediments to these habitats when fish are not expected to be present. Additionally, other factors may affect the suitability of habitat in the future. For example, a project occurring in or near spawning habitat outside of the spawning period, where suspended sediments settle out and fill in cobble areas with fine sediments, could reduce the suitability of this habitat in the future for spawning sturgeon.

To reduce impacts to sturgeon species and their habitats from turbidity and suspended sediments, the location and timing of projects must be considered with river and substrate characteristics as well as other environmental conditions that could cause sturgeon to aggregate in and/or utilize specific locations. We do not make turbidity/suspended sediment threshold recommendations for sturgeon habitat itself, because it is difficult to quantify the possible effects to habitat from turbidity or suspended sediments as a variety of physical, biological, and environmental factors must be considered. Section 7 biologists should make qualitative assessments of effects to habitat at this time.

Large Whale Habitats

Most ESA-listed marine mammals in the Greater Atlantic Region, with the exception of the sperm whale, are large mysticete whales. All mysticetes feed by taking large amounts of water into their mouths that filters through the baleen while prey remains inside. Their feeding habitats are nearshore and pelagic. Right whales occupy Cape Cod Bay for a portion of the year in order to forage but also occupy other important habitats such as the Gulf of Maine and Great South Channel. Humpback and fin whales do not regularly utilize Cape Cod Bay but rather remain in the waters of the Gulf of Maine and southern Georges Bank, particularly the Great South Channel. Blue whales are rarely found in these waters, and sei whales feed in the Gulf of Maine, Stellwagen Bank, and Georges Bank. Sperm whales typically are found along the continental shelf and along the shelf slope in very deep waters. The ocean is a dynamic environment and suspended sediments will not affect ocean currents, tides, temperatures, or salinity levels.

North Atlantic Right Whale Critical Habitat

On February 20, 2015, NMFS proposed a revision to North Atlantic right whale critical habitat in both the northeast and southeast regions (we discuss only the northeast region here). The revised critical habitat was finalized on January 27, 2016. In the northeast, the new critical habitat area has been expanded to include the northern edge of Georges Bank and the entire Gulf of Maine (from the shorelines of Massachusetts, New Hampshire, and Maine) out to the Exclusive Economic Zone (EEZ). We consider this critical habitat area in this white paper. This area is approximately 21, 334 nm^2 (approximately 73,174 km^2 (NMFS 2015).

NMFS identified four essential physical and biological features present within right whale foraging habitat in the Gulf of Maine and Georges Bank region. They are: 1) physical oceanographic conditions and structures of the Gulf of Maine and Georges Bank region that combine to distribute and aggregate *Calanus finmarchicus* for right whale foraging, namely prevailing currents and circulation patterns, bathymetric features (basins, banks, and channels), oceanic fronts, density gradients, and temperature regimes; 2) low flow velocities in Jordan, Wilkinson, and Georges Basins that allow diapausing *C. finmarchicus* to aggregate passively below the convective layer so that the copepods are retained in the basins; 3) late stage *C. finmarchicus* in dense aggregations in the Gulf of Maine and Georges Bank regions; and 4) diapausing *C. finmarchicus* in aggregations in the Gulf of Maine and Georges Bank regions (NMFS 2015).

Any suspended sediments generated from projects occurring within critical habitat would be affected by the large-scale physical oceanographic conditions that would act to dissipate any generated sediment plumes. As such, we do not expect suspended sediments to affect the physical oceanographic conditions and structures within the Gulf of Maine and Georges Bank that distribute and aggregate *C. finmarchicus* (essential feature 1), nor do we expect suspended sediments to affect the low flow velocities in Jordan, Wilkinson, and Georges Basins that aggregate dispausing *C. finmarchicus* (essential feature 2).

Further, we have not identified any concerns associated with effects to essential foraging features (3 and 4) from turbidity or suspended sediments. As stated above, it is likely that ocean currents will act to dissipate plumes that are associated with any activities that generate or deposit sediments. Additionally, salt ions within seawater act to bind sediment particles together, increasing their weight and causing them to sink, which removes them from the water column (Fondriest Environmental Inc. 2015b).

There are not studies in the literature that have measured or described the effects of turbidity or suspended sediments on copepods or a right whale’s ability to feed on them. Right whales feed with their mouths open by skimming the water through their baleen, capturing large quantities of copepods in their mouths with their baleen plates. In certain areas they are known to feed at the surface but have also been documented feeding at depth. Some whales have been documented with mud on their heads, demonstrating that they come into contact with the ocean bottom.

NMFS identified four activities and events that could negatively affect the essential features of right whale foraging habitat: 1) zooplankton fisheries; 2) effluent discharge from municipal outfalls; 3) discharges and spills of petroleum products to the marine environment as a result of oil and gas exploration; and 4) climate change (NMFS 2015). None of the identified activities and events that could negatively affect critical habitat generates suspended sediments or causes sedimentation. While future oil and gas exploration might lead to drilling activities that could generate suspended sediments, it is unclear at this time if those activities will occur, if they would be authorized within critical habitat, and, if so, how they would affect the essential features of right whale critical habitat.

Sea Turtle Habitats

Sea turtles occupy different habitats depending on their life stage. The oceanic habitats are largely linked to foraging and prey, but also to protection for earlier life stages. For example, once hatched, young loggerhead turtles swim away from land and find oceanic habitats that are associated with floating material, such as seaweed like *Sargassum*, which protects them and helps them save energy while they feed. Juvenile turtles then move into bays, sounds, and estuaries to important foraging habitats. Loggerheads feed primarily on shellfish that are found on the seafloor, such as conchs, whelks, mussels, and crabs. Any changes to these prey items within these benthic habitats due to turbidity or suspended sediments could affect loggerhead turtle foraging. However, these animals seem to be fairly tolerant of suspended sediments (Wilber and Clarke 2001). Biologists should consider the area affected, the prey species present, and whether other suitable prey habitats exist nearby when analyzing proposed projects.

Green turtles have a similar life history to loggerheads. Adult green turtles feed on sea grasses and algae. They rely on benthic habitats for foraging. Sea grass beds are sensitive to the effects of dredging, including sediment deposition. Caution should be used when considering projects that could generate suspended sediments if the project will occur in green turtle foraging habitats. Biologists should examine the extent of the area affected and whether suitable foraging areas exist close by that turtles may utilize.

Kemp's ridley turtles have similar life histories to those of green and loggerhead turtles. Adults inhabit nearshore muddy or sandy bottom areas and feed primarily on crabs, but also other invertebrates. Similar to loggerheads, any projects that occur in these areas have the potential to affect Kemp's ridley prey species. As such, biologists must consider these effects and determine if other suitable prey species and foraging habitat are available.

Leatherback turtles are primarily pelagic. They will feed in coastal waters. Their prey consists primarily of jellyfish and salps. It is unclear how suspended sediments might affect their prey species. The ocean is a dynamic environment and suspended sediments will not affect ocean currents, tides, temperatures, or salinity levels. For pelagic turtles, effects to habitat are likely to be minor.

Loggerhead Sea Turtle Critical Habitat – *Sargassum*

One of 38 marine areas designated as critical habitat for the Northwest Atlantic DPS of loggerhead sea turtles extends into this region. The *Sargassum* critical habitat occurs offshore of

Delaware, Maryland, and Virginia and extends around Florida and through the Gulf of Mexico to Texas.

NMFS identified four PCEs that support *Sargassum* habitat, including: 1) convergence zones, surface-water downwelling areas, and other locations where there are concentrated components of the *Sargassum* community in water temperatures suitable for the optimal growth of *Sargassum* and inhabitance of loggerheads; 2) concentrations of *Sargassum* that can support sufficient prey abundance and cover; 3) available prey and material that is associated with *Sargassum* (such as plants and cyanobacteria, and animals like hydroids and copepods); and 4) adequate water depth (>10 m) and proximity to currents to ensure offshore transport and foraging and cover requirements for post-hatchling loggerheads (NMFS 2013).

The dynamic nature and broad range of *Sargassum* critical habitat, location from shore (depths greater than 10 m, thus occurring in the open ocean environment in our region), and distribution on the ocean surface likely decreases its vulnerability from turbidity or suspended sediments that may be generated by human activities.

NMFS identified five activities that may require special management due to their potential effects on *Sargassum* habitat, including: 1) commercial *Sargassum* harvesting; 2) oil and gas activities; 3) vessel operations that result in the disposal of trash and wastes; 4) ocean dumping (e.g., debris, toxins); and 5) global climate change (NMFS 2014). None of the activities that could negatively affect *Sargassum* critical habitat generates suspended sediments or causes sedimentation that would impair the existence of *Sargassum* habitat. While future oil and gas activities might lead to drilling activities that could generate suspended sediments, it is unclear at this time if those activities will occur, if they would be authorized within critical habitat, and, if so, how they would affect the essential features of *Sargassum* critical habitat.

ACTIVITIES THAT PRODUCE OR CHANGE TURBIDITY AND/OR TSS

Dredging

Dredging activities can create areas with high turbidity and suspended sediment concentrations. Dredging is an activity used by agencies such as the Army Corps of Engineers (ACOE) to excavate material (silt, clay, sand, gravel, etc.) from ocean or river bottoms, which is then transported to another location. Dredging may occur in conjunction with channel deepening projects, maintenance projects for waterway navigation, and beach nourishment projects.

While removing sediment, dredging activities cause the resuspension of particulate matter into the water column. This alters the ambient conditions, at least temporarily, and has the potential to affect ESA-listed species that may be present in the action area. Regardless of dredge type, there will be sediment resuspension. In this section, we review commonly used dredges and their associated sediment plumes.

A number of factors, aside from the dredge itself, affect the dredging activity and sediment plume created. These factors include weather, sediment type, water conditions in the area of the action, and the experience and skill level of the dredge operator.

Various factors also affect the concentration of resuspended sediments within the sediment plume. These include: 1) particle size with smaller particles (silt/clays) tending to create larger concentrations of resuspended sediment than larger particles (sand/gravels); 2) vertical location in the water column with resuspended sediment concentrations usually greater in the lower part of the water column closer to the bottom than further up in the water column; 3) distance from the dredge activity with concentrations decreasing rapidly away from the dredge operation; 4) width of the action area (e.g., channel, river, canal); 5) water quality and characteristics at the project site; and 6) water current with sediment concentrations generally greater if the natural water currents are strong enough to move the sediments (all derived from Anchor Environmental 2003).

The persistence of turbidity levels associated with sediment plumes depends on factors such as current speed, water temperature, salinity, and the sizes of the particles being carried within the plume (Johnson et al. 2008). Tillin et al. (2011) indicated that sediment plumes created by activities such as dredging typically settle out of the water column in 10-15 minutes within 300 to 500 m downstream of the activity. Johnson et al. (2008) described a return to ambient conditions after 1-4 hours, and Bridges et al. (2008) indicated that even under extreme hydrodynamic conditions, most suspended sediments should settle out within a few hours.

Water currents (e.g., tides, river flow, wind/wave generated) are a very important factor that help determine the shape and size of the sediment plume. Anchor Environmental (2003) reviewed existing literature and found that, in most cases, the suspended sediment resettled close to the dredge in less than an hour with only a small amount taking a longer amount of time to settle.

The following factors (Table 8) can affect sediment resuspension and should be considered when conducting analyses of the potential effect of sediment resuspension on aquatic organisms (from Anchor Environmental 2003).

Table 8: Factors affecting sediment resuspension

Dredge Site Characteristics	• Waterway shape and size • Water depth • Structures present (bridges, piers, docks, pilings, etc.)
Dredged Material Characteristics	• Grain/sediment size • Water content • Density • Specific gravity • Organic/detritus content • Debris content
Nature of Dredging Operation	• Dredge type and size • Production rate • Dredge operation characteristics (dredge cut depth, swing of cutterhead, etc.)
Physical Site Characteristics	• Currents/tides • Vessel activity/wakes • Waves
Site Water Quality and Characteristics	• Salinity • Temperature • Background/ambient suspended sediment concentrations • Background water chemistry

The two most commonly used dredges are mechanical dredges and hydraulic dredges. We explain the differences below.

Mechanical Dredges

In the aquatic environment, mechanical dredges (e.g., clamshell and bucket) typically operate from a barge. They scoop materials and water from the bottom and carry them to the surface where the contents are offloaded onto another barge and brought to a disposal site (ACOE 2014). Often at least two collection barges (called scows) are present so that one can be loaded while the other is towed away to the disposal area. Having more than one scow present ensures continued and efficient operations.

Mechanical dredges can generate suspended solids during four phases of operation: 1) when the bucket comes into contact with the bottom; 2) while the bucket is being hauled to the surface (material can be washed out while being pulled through the water as well as when the bucket breaks the water's surface); 3) while the contents are being loaded onto the barge; and 4) sediments can be returned to the water if the barges are allowed to overflow.

These dredges are usually used for small projects near docks or piers and in rocky areas. They are more efficient for use in deeper water than hydraulic dredges. They can also be used in areas that are further away from the disposal site. Hydraulic dredges are less practical in these cases.

The clamshell dredge is a commonly used mechanical dredge and operates by raising and lowering a clamshell bucket with a crane or derrick mounted to a barge. Variations on the clamshell dredge have been developed to make the operation more efficient and precise and to reduce sediment loss. Modifications include leveling of the bucket (to increase the removal footprint) and incorporation of rubber seals (to help reduce sediment loss). "Specialty dredges" can be used to remove contaminated sediment without risking the release of contaminated sediment into the water column. One example is the environmental clamshell dredge, which has an outer covering that seals over the bucket when the bucket is closed. Water is allowed to flow through vents on the top as the dredge is moved up through the water column, but sediments are not released.

Estimated maximum concentration of the sediment plume of a clamshell dredge is 1,100 mg/L; the plume may extend as far as 1,000 m along the bottom (LaSalle 1990 as reported in Wilber and Clarke 2001 and Clarke and Wilber 2000). More typical concentrations are, on average, approximately 500 mg/L above ambient levels near the dredging operation (LaSalle et al. 1991). Most sediment plumes extend 500 m downstream along the bottom and 300 m downstream at the surface, although this is depth-dependent (LaSalle et al. 1991; Clarke and Wilber 2000). The sediment plume exists throughout the water column with sediment concentrations and plume widths highest at the bottom due to the direct dredging effects from the operating equipment. Suspended sediment concentrations are gradually reduced closer to the water's surface (Hayes 1986, LaSalle et al. 1991). Modifications to the clamshell dredge operation, such as the use of a closed bucket rather than an open one and reducing the raising and lowering speed of the bucket, reduce the amount of suspended sediments lost from the dredge as it is pulled to the surface, thus lowering TSS within the plume (Hayes 1986). Measuring TSS 200 feet from an open versus an enclosed clamshell dredge operating in the St. Johns River, bottom concentrations for the open bucket were 300 mg/L as opposed to under 100 mg/L for the enclosed bucket. In the middle portion of the water column, TSS was approximately 100 mg/L for the open bucket versus about 50 mg/L for the enclosed. In the upper portion, TSS measured approximately 50 mg/L for the open bucket and about 40 mg/L for the enclosed bucket (Hayes 1986).

The average advance rate of a clamshell dredge is 12-18 m/hr which would take a 1,000 m sediment plume 2.3 to 3.5 days to pass a stationary point (Wilber and Clarke 2001), although the paper does not provide the duration of dredging. The exposure of a sedentary organism varies based on the environmental and hydrodynamic conditions present (Clarke and Wilber 2000).

Hydraulic Dredges

Hydraulic dredges (e.g., cutterhead, hopper) mix sediments with large volumes of water and pump them through pipelines to a specific location or store them in a hopper bin. The combination of sediment and water creates a mixture, called slurry. These dredges are typically used for large volume sediment extractions (LaSalle et al. 1991).

Hopper dredges are ships with containers (known as hoppers) that collect and store dredged material before it is transported to the disposal site. The water contained in the slurry can be drained from the material while the dredging operation is taking place (ACOE 2014). Hopper dredges are most suitable for use in high-traffic, exposed harbors and channel areas due to their mobility and because they can efficiently pump heavy and unconsolidated sands. They move along the bottom, suctioning the material on the seabed (mixed with water) into the pipeline and into the hoppers to store until disposal occurs. A good management practice with hopper dredges is to keep the suction pumps off until the draghead is in contact with the bottom. This eliminates the suctioning of sediments as the draghead is being lowered to the bottom.

Cutterhead dredges are mounted to barges and are not mobile themselves. These dredges operate by suctioning material and water through a pipeline and transporting the material directly to the disposal site. On the suction end of the pipeline is a cutterhead, which is a device that has rotating blades that break up the bottom material before it enters the pipeline. These dredges are best for use in larger and deeper areas and areas with less vessel traffic. The dredge moves as the barge is repositioned. Typically, it moves small distances each day.

Another type of hydraulic dredge is the dustpan dredge, which uses a widely flared dredge head to which water jets are mounted. The water jets agitate the sediment and the dustpan dredge head collects the material as it moves forward. This dredge is best for use with granular sediment rather than fine-grained sediment that tends to clog the dustpan dredgehead (Hayes 1986).

For hydraulic dredges, sediment resuspension mostly occurs when the dredge contacts the seabed and the draghead is pulled through the sediment to remove the dredged material. Some of the sediments are disturbed as part of this operation but are not captured by the dredge. Other sources of sediment resuspension during hopper dredging include prop wash from tugs and attendant vessels, movement of the dredge, loss of sediments from hopper overflow, placement of anchoring systems, silt curtain management, and debris removal activities (Bridges et al. 2008). Since the slurry is transported via pipeline, it is generally not possible for the dredged sediment to contact any other part of the water column. However, in hopper dredges, it is possible for material to contact the water's surface if the hoppers are allowed to overflow, which creates more room for dredged material. This creates sediment resuspension in the upper part of the water column.

Hopper dredges can maintain speeds of 12.6 km/hr (nearly 8 mph) and can create sediment plumes at the bottom and the surface if overflow occurs during hopper loading. The concentration of suspended sediments at the surface resulting from overflow depends on the size of the particles (e.g., silt and clay tend to remain suspended due to low settling velocity; Palermo and Randall 1990). Hayes and Raymond (1984) conducted a hopper dredge field study and with no overflow, TSS did not exceed ambient levels at the surface. One study in Grays Harbor, Washington demonstrated low TSS concentrations when no overflow was allowed (less than 50 mg/L) while hopper overflow caused a plume with TSS measuring up to 800 mg/L (McLellan et al. 1989). Further, the overflow affected the entire water column and obtained lengths of 7,000 ft. (2,133.6 m) while dredging with no overflow affected the lower water column only and extended approximately 3,000 ft (914.4 m).

According to Wilber and Clark (2001), suspended sediment plumes can extend 3,937 ft (1,200 m) on the bottom at concentrations as great as 800 mg/L. ACOE (1983) provides a slower rate of advancement of 2-3 mph.

Estimated maximum concentration of sediment plume is less than 500 mg/L for a cutterhead and the bottom sediment plume is expected to extend about 500 m from the dredge (LaSalle 1990; Hayes et al. 2000, as reported in Wilber and Clarke 2001). In our region, cutterhead dredges are the most common type of dredge used for maintenance dredging by the ACOE.

Average advance rate for the cutterhead varies based on sediment size and is between 6 m/h (for 51.2 – 61.4 cm diameter pipelines for sand) and 18 m/h (for 69.1 to 76.8 cm pipelines for silty material). Wilber and Clarke (2001) describe a quicker dredge rate pumping silt creating the smallest duration plume exposure duration of 1 day with a slower advancing dredge collecting a mix of sand and silt creating a plume of exposure duration of 3.4 days. Exposure of a single set point to a cutterhead sediment plume could last anywhere from 1 to 3.5 days depending on the project conditions and other factors such as sediment type (silt, sand, combination of silt/sand), diameter of pipeline, and rate of advance of the dredge. This can vary based on environmental and hydrological conditions at the dredge site.

Mechanical dredges (clamshell, bucket) typically produce higher TSS than hydraulic dredges (e.g., cutterhead and hopper dredges), provided there is no hopper overflow (Hayes 1986; Wilber and Clarke 2001). Anchor Environmental (2003) created an equation to measure resuspension rates for hydraulic versus mechanical dredges using information reported by a number of researchers. These researchers independently estimated resuspension rates associated with hydraulic and mechanical dredging activities. Using the equation developed by Anchor Environmental (2003), a resuspension rate averaging 0.77% for hydraulic dredges and 2.1% for mechanical dredges was determined in terms of "R" which is a resuspension factor equivalent to the percentage of dry weight. When determining these resuspension rates and making direct comparisons, all other factors (e.g., sediment size, hydrodynamic conditions) were considered equivalent. This indicates that hydraulic dredging produces lower amounts of resuspended sediment than mechanical dredges.

Comparisons of TSS by Dredge Type

LaSalle et al. (1991) provides a summary of sediment concentration levels near cutterhead, hopper (without overflow), and bucket dredges. This includes concentrations at the surface and bottom as well as the sediment plume length at the surface and bottom (Table 9). Information about TSS within the plume and its persistence assists in analyses of the broader impacts of dredge operations.

Table 9: TSS at the dredge site (surface and bottom) and sediment plume persistence (surface and bottom). This table was taken from LaSalle et al. (1991). While the paper does not specify if these measurements represent total suspended sediment levels or levels that are above background, we assume that these represent total suspended sediment levels.

	TSS (mg/L)		**TSS Plume Length (m)**	
Dredge Type	**Surface**	**Bottom**	**Surface**	**Bottom**
Cutterhead	0-150	≤ 500	0-100	≤ 500
Hopper (no overflow)	0-100	≤ 500	0-700	≤ 1,200
Bucket	0-700	≤ 1,100	100-600	≤ 1,000

Anchor Environmental (2003) summarized and provided graphic representations of TSS measured in numerous studies that have measured TSS at the dredge site and at range of distances away from the site. These studies occurred in the United States and abroad and under varying environmental conditions. TSS is lower for hydraulic dredges compared to mechanical dredges. Fifty percent of the measured TSS for hydraulic dredges were reported as 15 mg/L or lower; fifty percent of the measured TSS for mechanical dredges were reported as 66 mg/L or lower (Anchor Environmental 2003). Aside from three outliers reported for hydraulic dredging (577 mg/L, 2,962 mg/L, and 5,000 mg/L), TSS did not exceed 1,000 mg/L for either hydraulic/hopper dredges or mechanical dredges. Table 10 provides a summary of the TSS reported in the literature examined by Anchor Environmental (2003).

Table 10: Total suspended solids (TSS) concentrations from the studies included in the literature review completed by Anchor Environmental (2003) for hopper, hydraulic, and mechanical dredges. The values reported below were derived from Appendix A, Table A-2. The lowest and highest reported mean TSS values above background (VAB mean) as found in Table A-2.

Dredge Type	**No. of Reported Studies in Total (n)**	**No. of Studies Reporting Nearfield TSS**	**Lowest Reported Nearfield TSS (mg/L)**	**Highest Reported Nearfield TSS (mg/L)**	**Average Nearfield TSS (mg/L)**	**Average TSS for All Studies (all distances)**
Hopper*	5	5	80 mg/L	475 mg/L	194.8 mg/L	194.8 mg/L
Hydraulic+	26++	13	5.4 mg/L	411 mg/L	100.3 mg/L	84.8 mg/L
Mechanical	47	20	15 mg/L	449 mg/L	121.6 mg/L	86.4 mg/L

Source: Anchor Environmental (2003) literature review paper.
*This does not include one study with a reported TSS measurement of 3,000 mg/L in San Francisco Bay, as this represents an outlier that is well above typical reported levels of TSS for hopper dredges.
+This does not include two hydraulic dredge outlier concentrations of 594 and 5,000 mg/L, both of which were reported as nearfield concentration levels.
++For hydraulic dredges, the authors considered 30 studies in the literature review. However, in this table, four studies were excluded. Two studies reported outlier TSS measurements – 594 mg/L in the Savannah River and 5,000 mg/L in Tokyo Bay, Japan. The other two studies did not provide TSS measurements associated with the dredging activities (both were from Yokkaichi Harbor, Japan).

In the early 1980s, the ACOE completed field studies to measure concentrations of resuspended sediments resulting from dredging activities as part of its Improvement of Operations and Maintenance Techniques (IOMT) Research Program. The ACOE provided a summary table of sediment concentration levels at different distances from the dredge for cutterhead, hopper, and clamshell dredges. We have included it here for reference (Table 11) and comparison to the literature summarized by Anchor Environmental (2003).

Table 11: Reported resuspended sediment concentrations during studies conducted by the ACOE in the early 1980s as reported in Hayes (1986).

Dredge Type	Distance from Dredge		
	Within 100 ft.	Within 200 ft.	Within 400 ft.
Cutterhead	25 – 250 mg/L	20 – 200 mg/L	10 – 150 mg/L
Hopper			
With overflow	250 – 700 mg/L	250 – 700 mg/L	250 – 700 mg/L
Without overflow	25 – 200 mg/L	25 – 200 mg/L	25 – 200 mg/L
Clamshell			
Open bucket	150 – 900 mg/L	100 – 600 mg/L	75 – 350 mg/L
Closed bucket	50 – 300 mg/L	40 – 210 mg/L	25 – 100 mg/L
Source: Hayes (1986) Note: These concentrations were adjusted to account for ambient sediment concentration levels.			

Measured TSS is similar between the TSS dredge characteristics provided by LaSalle et al. (1991), the literature review completed by Anchor Environmental (2003), and the study completed by Hayes (1986) with the levels reported in the literature review falling within the boundaries reported by the ACOE study. According to these three sources, TSS generated by all dredge types will likely be below approximately 1,000 mg/L at the dredge source and less as the plume moves further from the dredge activity. With the use of mitigation measures, these concentrations will likely be reduced further.

Disposal of Dredged Material

After dredging occurs, the dredged material that has been removed by the dredging activity must be disposed of, often at an upland site where no impacts on listed species would occur. There are three types of in-water or nearshore disposal to be considered: 1) open water; 2) confined; and 3) habitat development (e.g., beach nourishment) (ACOE 1983). Prior to disposal operations, ESA biologists must determine what, if any, species and life stages may be present in the area of proposed disposal.

Upland disposal areas are used for certain projects, especially for dredging that occurs in riverine environments such as channel deepening projects. In these cases, dredged material may be pumped by a pipe to the disposal site or loaded onto a scow/barge to be towed to the site. Upland disposal areas are typically land-based and would not increase turbidity or suspended sediments to a level that could affect listed species. Other types of disposal include containment disposal, where dikes are set up to contain the dredged solids while the water that was carrying the sediments is released (ACOE 1983). Still other times, dredged materials are used for beneficial habitat purposes such as beach nourishment or for the development of marsh, island, or aquatic habitats (ACOE 1983).

For hopper dredges, the material is stored in hoppers and then transported to the disposal site and released. For offshore disposal, split hull hoppers travel to the disposal site, and the dredged material is released into the water when the hull is opened. Regardless of the disposal method, suspended sediment levels above ambient will result. For hydraulic cutterhead dredges, the material is transported from the pipeline directly to the disposal site. For mechanical dredges, the material is placed on a barge and disposed of elsewhere. The Environmental Protection Agency

(EPA) and ACOE regulate and issue permits for the ocean disposal of dredged material, and disposal sites have monitoring and management plans in place to help ensure the impacts to the human and oceanic environment are minimized (EPA 2015). The EPA implements the Marine Protection, Research and Sanctuaries Act (MPRSA), also known as the Ocean Dumping Act, which regulates and prohibits without a permit the disposal of all materials that would adversely affect human health, welfare or amenities, or the marine environment, ecological systems or economic potentialities (EPA 2015).

Morris et al. (2005) examined the sediment plumes associated with the disposal of dredged material at a site in Rhode Island Sound. They concluded that disposal effects are minor and usually limited to the seafloor of the disposal location. Typically, immediately following sediment disposal, a concentrated column of turbid water existed at the site of sediment placement for up to 15 minutes. The sediment plumes then began to diffuse because of water currents. For three to four hours following sediment disposal and during diffusion of the plume, portions of the plumes occurred in the upper, middle, and lower portions of the water column. The highest values (centroid of the plumes) were recorded in the lower 3-5 m. Measurements taken from the sediment plumes in this study demonstrated relatively concentrated sediment plume centroid readings for 40 to 60 minutes after sediment disposal with turbidity values consistently decreasing after this time. TSS measurements taken near the plume centroids during the first hour of monitoring commonly depicted concentrations in excess of 20 mg/L before turbidity levels began to decline. Currents helped diffuse the plumes throughout the water column. After 3.5-4 hours, the plume had dissipated and TSS was reduced to background levels of 2-5 mg/L.

Deposited sediments have the potential to build up at open-water disposal sites if the bottom is not sloped such that the disposal materials can disperse (ACOE 1983). Further, salt ions in seawater cause the suspended sediment particles to combine with other particles. This causes an increase in weight and eventual settling to the bottom (Fondriest Environmental Inc. 2015b). Once at the bottom, the substrate will shift due to waves and currents so effects will differ in different areas.

In-water dredged material disposal is not expected to have an impact on mobile adult and juvenile fish species, as they are able to move away from turbid or suspended sediment concentrations that they cannot tolerate. Parsley et al. (2011) found little behavioral effect on sub-adult white sturgeon in the Columbia River from in-water dredge material disposal activities and no change in the core area occupied by the fish. Effects of deposition on eggs and larval stages were discussed in the above sections on dredging and the same effects would result for dredge disposal. Placement of large amounts of sediments on top of early life stages can cause development and growth issues, burial, and oxygen deprivation. However, the rate and amount of material that settles in one place depends on a number of factors including the strength of the currents that can allow for rapid dispersal of the sediments, as seen in Morris et al. (2005). Similarly, if tidal currents are high, they can disperse disposed materials over a wider area, reducing turbidity and suspended sediment affects in the area of the disposal because the sediments would not necessarily be settling in one place (Van Dolah et al. 1984). Effects to the ESA-listed species' habitat, including critical habitat, from dredge material disposal could occur if these areas overlap with disposal areas.

The EPA designates and manages ocean dumping sites according to the regulations found at 40 CFR Part 228 Criteria for the Management of Disposal Sites for Ocean Dumping. A range of criteria is listed for selecting disposal sites. One of these states that the EPA must consider disposal site "location in relation to breeding, spawning, nursery, feeding, or passage areas of living resources in adult or juvenile phases."

Two of the oceanic EPA-designated disposal sites within the Greater Atlantic Region's jurisdiction overlap with listed species critical habitat at this time. EPA's Region 1 (Maine through Connecticut) contains five disposal sites — Portland, Massachusetts Bay, Rhode Island Sound, Central Long Island Sound, and Western Long Island Sound. The Portland and Massachusetts Bay disposal areas overlap with North Atlantic right whale critical habitat. Additional disposal areas occur within EPA's Regions 2 (off New York and New Jersey) and 3 (off Virginia). However, no ESA-listed species in this region have designated critical habitats in these areas at this time.

Based on this information and the scope of the projects that typically occur in the Greater Atlantic Region, effects to listed species from dredged material disposal are variable. The effects of disposal on prey species, such as invertebrates, depends on environmental factors (e.g., depth of the disposal area, currents affecting where and how quickly disposed materials settle to the bottom), water conditions (e.g., salt ions binding to the sediments causing them to sink to the seafloor), sediment type and size, extent of affected area, the timing and frequency of the disposal disturbance (Wilber and Clarke 2007), and the prey species' relative tolerance to a high energy environment. Effects may be more related to sediment deposition than turbidity or suspended sediment concentrations. For example, benthic impacts such as changes in sediment composition might create an unsuitable habitat for the existing species, allowing others to colonize. Most benthic organisms migrate vertically through sediments and are likely adapted to changes in natural conditions (Wilber et al. 2005). Early life stages (settlement and recruitment) of benthic organisms, such as bivalves, can be negatively affected by even small amounts of sedimentation. However, disposal of dredged materials at sites that have substrates that shift constantly due to waves and currents could reduce potential burial effects as dredged materials are quickly dispersed and spread over a larger area rather than falling in one place (ACOE 1983).

Jetting/Jet Plowing

Jetting or jet plowing is used to bury cables under the substrate. This can occur offshore in the marine environment or in freshwater environments. A jet plow uses a water jet to fluidize the sediment and create a trench in which the cables will be buried. The weight of the cable allows the cable to sink into the trench where sediments will bury it. After reviewing literature on suspended sediments associated with jet plowing activities, it appears that this activity generates minor suspended sediment concentrations well below levels found to cause mortality in fish.

SSFATE (Suspended Sediment FATE) is a model developed by a group called Applied Science Associated (ASA) and the ACOE Environmental Research and Development Center (ERDC) to predict and model the transport, dispersion, and settling of suspended sediments that are in the water column during dredging operations. This model has been expanded to model jet plowing burial of cables and pipelines (Vinhateiro et al. 2013).

ASA used the SSFATE model to predict the concentration of suspended sediment that would result from the operation of a jet plow used for the installation of a 1,000 MW power cable to be embedded in a 77-mile portion of the Hudson River (Vinhateiro et al. 2013). The model predicted sediment conditions under both flood and ebb tide conditions. Under mean flood tide conditions, a sediment plume of over 200 mg/L extends 50 feet from the plow site and covers an area of 0.05 acres of riverbed. Under mean ebb tide condition, a sediment plume of over 200 mg/L extends 17 feet from the plow site and covers an area of 0.025 acres of riverbed. Under peak flood and ebb conditions, sediments are dispersed, lowering the concentrations of sediment in the water column and producing an elongated sediment plume. This is in contrast to a slack tide. At slack tide, the sediment plume is smaller and more concentrated.

The model was also able to predict the maximum expected sediment concentration throughout the jet plowing process. Suspended sediment concentrations of 50 mg/L are expected to occur a maximum of 1,470 feet from the plow, whereas concentrations at or above 200 mg/L are expected to occur a maximum of 312 feet from the plow. The elevated concentrations of 200 mg/L or above are expected to be limited to 10-13 feet off the bottom with concentrations rapidly declining to about 10 mg/L or less 16-26 feet off bottom (Vinhateiro et al. 2013). Finally, the model predicted the sediment concentration levels and their durations as the jet plow passes a fixed point. Concentrations of 200 mg/L or higher are not expected to remain at one location for longer than two hours. After 12 hours, suspended sediment concentrations created by the jet plow are expected to be below 10 mg/L. After 24 hours, they are expected to return to background levels.

Sediment deposition results from the jet plowing process. The model predicted that, on average, sediment deposition of over 0.04 inches (1 mm) would extend 100 to 300 feet on either side of the cable route, although in some places this deposition level was seen as far as 950 feet from the cable route. In other areas, this depth is increased to 0.08 inches. This generally occurs along the path of jet plow and extending out as far as 300 feet.

A similar modeling effort was completed by ASA for the oceanic environment at an alternative site for wind turbines as part of the Cape Wind project. This modeling effort predicted suspended sediment and deposition levels associated with placing the wind farm in an alternative location (9 km southwest of Tuckernuck Island) to provide comparisons with the original project site on Horseshoe Shoal in Nantucket Sound (Swanson and Isaji 2006). The project involves laying a series of cables to connect wind turbine generators to an electric service platform as well as two cables connecting the electric service platform to shore. The cables would be laid in a manner similar to that described for the Hudson River power cable installation, injecting pressurized seawater into the substrate to fluidize the sediments along the cable route.

The results of the SSFATE model for this project provided similar results to those for the Hudson River in that suspended sediment concentration levels were typically predicted to be about 50 mg/L, with some areas peaking at 500 mg/L in the bottom portion of the water column (Swanson and Isaji 2006). Concentrations of approximately 100 mg/L were expected to last about two hours or less, but one area on the route lasted about six hours. Sediment deposition predictions seemed a bit higher for this area than for the Hudson River project with thicknesses of one to five mm (0.04 to 0.2 inches) occurring in the area a few hundred meters from the cable route. Deposition thicknesses adjacent to the cable route were predicted to be quite a bit higher, measuring up to 20 mm (0.8 inches).

Pile Installation and Removal

The installation of piles for projects, such as bridge construction, has the potential to generate suspended sediment levels that are above ambient. However, these increases are expected to be only slightly above ambient levels and in much smaller amounts than suspended sediment levels generated from activities such as dredging. When considering suspended sediments generated from pile installation and removal, the scope of the project should be considered as well as proximity to ESA-listed species and their habitats. Smaller projects with fewer piles would likely generate lower amounts of total suspended sediments.

Limited information on suspended sediments generated from pile driving activities is available. In much of the literature reviewed, the general consensus is that pile driving activities generate relatively small levels of suspended sediments by causing local increases in turbidity in the project area. These levels were found to quickly return to ambient levels (Ocel 2014). According to the Environmental Impact Statement (EIS) completed for the Tappan Zee Bridge replacement project, suspended sediments generated from pile driving are estimated at 40% of levels generated by dredging. This is based on suspended sediment monitoring from the San Francisco-Oakland Bay Bridge East Span Seismic Safety Project, which is the most comprehensive and applicable project for generating these estimates (FHWA 2012). This equates to suspended sediment concentrations of approximately 2 mg/L above ambient conditions (FHWA 2012).

In general, suspended sediment levels associated with pile driving are believed to produce concentrations t approximately 5 – 10 mg/L above ambient levels (FHWA 2012). These low levels are not likely to generate a reaction from fish species. In the case it does, the reaction will be slight in terms of alarm response (e.g., temporary sporadic swimming).

Similarly, turbidity monitoring associated with the driving of six test piles in the Columbia River was conducted in 2011 near two proposed pier locations for a new bridge (Coleman 2011). Over 130 turbidity casts were made under ambient and pile driving conditions and at various depths and distances away from the activity. The data indicated that pile driving activities did not significantly change turbidity levels. Natural fluctuations in ambient turbidity levels far outweighed the turbidity impacts generated from these pile driving activities (Coleman 2011).

Barrier Removals, Culvert Replacement Projects, and Cofferdams

There is a general absence of information regarding the levels of suspended sediments generated from in-water construction activities, including those associated with barrier removal, culvert replacement, and dewatering of cofferdams. According to the EIS completed for the Tappan Zee Bridge replacement project, installation of sheet piles for cofferdams is expected to generate 30% of TSS generated by dredging (FHWA 2012). This is equivalent to suspended sediment concentrations of approximately 1.3 mg/L above ambient (FHWA 2012). As described for the pile driving calculations, these levels were based on monitoring resuspended sediment levels associated with dredging and in-water construction activities conducted as part of the San Francisco-Oakland Bay Bridge East Span Seismic Safety Project. Cofferdams may also be used in barrier removal projects such as dam removals and culvert replacements.

Direct measurement was not provided for cofferdam dewatering (pumping water out of the area). However, FWHA (2012) believed that suspended sediment levels generated in the immediate vicinity of the dredges (clamshell dredges with closed buckets) used for construction access channels would be 50 to 100 mg/L above ambient with levels significantly lower for other activities, including cofferdam dewatering and pile driving. Additionally, FWHA (2012) estimated that pier installation activities, including pile driving and dewatering, could generate suspended sediments on the order of 2 mg/L above ambient.

Barrier removal has the potential to add suspended sediments to the downstream riverine environment. Activities include cofferdam construction and removal, access road construction, and, if needed, removal of sediments that have accumulated behind the barrier. Sediments become trapped behind the barrier and once the impounded water is released, it can rush downstream, carrying sediments with it. Maine has best management practices in use to reduce resuspended sediment during barrier removals. These are discussed in more detail below under "Best Management Practices."

INFORMATION NEEDS FOR CONSULTATIONS THAT CONSIDER TURBIDITY AND SUSPENDED SEDIMENT EFFECTS

When analyzing the effects of turbidity and suspended sediments on listed species and their habitats, a biologist must consider a number of factors. These include characteristics of the environment, how the addition of turbidity and sediment stressors could change the environment, and the possible impacts these changes could have on the species present (including their prey and habitat). A biologist should review, when available, the species present in the action area (including relevant life stages) and relevant abundance, function of the habitat to the listed species (e.g., spawning area, overwintering area, critical habitat area), substrate type, suspended sediment type/sedimentation type (if sediment is being deposited), depth of the project, ambient hydrological conditions, prey species present, and details about the project activity (i.e., timing, scope, etc.). We note that some of this information may not be available (e.g., ambient hydrological conditions) but would be helpful to include if it is.

The biologist should request the details from the action agency to improve the assessment of potential effects on listed species and their habitat. Table 12 lists recommended or suggested information for the action agency to provide and/or to be considered by the biologist completing the section 7 consultation, noting that it may not be feasible for the action agency to provide all of the requested information.

Table 12: Guidance for section 7 biologists on information that could be requested from the action agency and considered during a consultation.

Details on the activity type/cause of stressor	Dredging • Dredge type • Description of the dredge (e.g., open vs. closed bucket for clamshell dredge) • Description of planned modifications or operational controls to reduce resuspended sediment and/or turbidity associated with the activity (e.g., dredge modifications) • Depending on dredge type, will overflow be allowed (e.g., hopper dredging)? • Description of the disposal area's physical environment (e.g., currents, vessel activity, etc.) • Description of substrate to be dredged • Specifics of dredged material disposal (e.g., location, distance from dredging, method of disposal) • Listed species observation protocols (e.g., use of an observer, what occurs if ESA-listed species are observed)
	Jetting or Jet Plowing • Details of the operation of the jet plow • Description of how sediment will be moved and where it will be placed (e.g., will it be taken to another location or pushed to the side of the trench)
	Pile Installation • Details on the scope and duration of the project • Details on the piles to be installed (e.g., number per day, total number, pile diameter, pile type, duration to install each pile) • Details on pile installation method (e.g., drilling, vibratory hammer, impact hammer, jetting) • Substrate type in project area • Proposed mitigation measures to reduce turbidity/suspended sediments (e.g., soft start technique, turbidity curtain)

	Dam/Barrier Removals and Culvert Replacements
	• Details on the scope and duration of the project
	• Use of cofferdams
	    o Number of proposed cofferdams to be used
	    o Details on installation method
	    o Proposed mitigation measures to reduce turbidity/suspended sediments
	• Proposed mitigation measures to reduce turbidity/suspended sediments from dam removal activities (e.g., erosion control plan)

Description of the project environment	• Size and location of the project area(s), including depth and width • Description of the physical environment (currents, tides, vessel activity, river/canal depth and width, etc.) • Time of year that the activity will take place, including whether the timing will overlap with known spawning seasons for listed fish • Planned duration of the project or activity (daily and total duration) • Description of the substrate (type, size) affected by the project's activity and expected amount of substrate affected, moved, resuspended, etc. • Ambient TSS and turbidity conditions of the action area, pre-activity (which may allow for comparisons to be made) • Reports, if available, of TSS associated with the project activity if it has been done in the past, in a similar area, or using the equipment that will be used for the project

ESA-listed Species Considerations	• Listed species (of all life stages) that may be present in the area during the period proposed for the activity, including expected abundance and expected behavioral activities • Description of listed species' use of the area planned for the project or activity (e.g., critical habitat, spawning ground, nursery ground, overwintering area, etc.)
Potential Effects on Listed Species	• Compare project information with threshold and turbidity/suspended sediment exposure information

SUMMARY: THRESHOLDS AND CONSIDERATIONS FOR RESPONSES OR ADVERSE EFFECTS

Listed Fish

After reviewing the available literature on the effects of turbidity and suspended sediments on salmon and sturgeon species, we conclude that species' behavioral and physiological responses vary greatly. Further, studies on this topic vary in their approach, species studied, sediment concentrations and particle sizes tested, and exposure durations. This makes it difficult to draw conclusions and establish workable thresholds for species found in this region. We have set thresholds based on our review of the literature, taking into account the sensitivity of these listed species and other environmental factors that can affect them at any given time (Table 13). We expect, based on the information presented in this document, that effects to Atlantic salmon and sturgeon resulting from exposure to suspended sediments at or below these levels will be insignificant or discountable.

Table 13: Total suspended sediment (TSS) thresholds for each life stage for Atlantic salmon and Atlantic and shortnose sturgeon. Note that the threshold levels represent total sediment exposure, in which baseline sediment concentration levels are factored into this threshold. Therefore, baseline and TSS levels generated from the project combined should not exceed these thresholds.

<table>
<tr><th>Species</th><th>Life Stage</th><th>Exposure Duration</th><th>Threshold (total suspended sediments)</th></tr>
<tr><td rowspan="5">Atlantic Salmon</td><td rowspan="3">Adults / Juveniles</td><td>Threshold one: ≤ 3 hours</td><td>≤ 1,000 mg/L</td></tr>
<tr><td>Threshold two: ≤ 24 hours</td><td>≤ 50 mg/L</td></tr>
<tr><td>Threshold three: ≤ 144 hours (6 days) after the first 24 hours of exposure</td><td>≤ 10 mg/L</td></tr>
<tr><td rowspan="2">Eggs/Larvae[1] (TSS and sediment deposition)</td><td>Avoid spawning habitat (Oct 1 – July 14)</td><td>0 mg/L outside of July 15 – Sept 30</td></tr>
<tr><td>Operate within specified work window (July 15 – Sept 30)</td><td>See above limits for adults/juveniles</td></tr>
<tr><td colspan="4">[1]The work window suggested to minimize impacts to migrating juvenile and adult Atlantic salmon and eggs/larvae within spawning habitat is July 15 through September 30. However, the section 7 biologist must consider the location and project type, as salmon may not always be present. Species presence depends on the ability of salmon to access the habitat from the ocean or direct stocking of fish from a hatchery. Therefore, it is possible that much of the available spawning habitat is vacant.</td></tr>
<tr><td rowspan="4">Atlantic and shortnose sturgeon</td><td>Adults / Juveniles</td><td>14 days</td><td>≤ 1,000 mg/L</td></tr>
<tr><td rowspan="3">Eggs/larvae (TSS and sediment deposition)</td><td>Project occurs outside periods for which spawning, egg incubation, and larval rearing occurs (no sturgeon life stages present)</td><td>Review project to ensure is not altered such that it becomes unsuitable for spawning, egg incubation, or larval rearing</td></tr>
<tr><td rowspan="2">Project occurs within the periods for which spawning, egg incubation, and larval rearing occurs (sturgeon life stages present)</td><td>Parameter a: ≤ 50 mg/L above ambient; no sediment deposition</td></tr>
<tr><td>Parameter b: Work windows [1]; no sediment deposition</td></tr>
<tr><td colspan="4">[1]Parameter b allows section 7 biologists the flexibility to apply work windows to activities that 1) cannot reduce suspended sediments to levels approaching 50 mg/L above ambient; 2) would require exposure durations longer than 24 hours; or 3) may damage spawning, egg incubation, and/or rearing habitat such that these habitats would be unsuitable for sturgeon.</td></tr>
</table>

While taking into account the thresholds in Table 13, biologists should also consider additional factors (environmental or human-caused) that may cause stress to the animal and modify the thresholds (e.g., lower them) or parameters, if necessary. For example, both salmonid and sturgeon species prefer specific temperature and dissolved oxygen ranges. Changes to these ranges, especially higher temperatures and lower dissolved oxygen levels, can cause stress to the fish and possibly lead them to seek other, more preferable habitat. Adding sediments to the water column in an already stressful environment could affect fish species at lower TSS levels than when these other conditions are not present. Additionally, suspended sediments in the water absorb sunlight, raising the temperature of the water. This could lead to declines in dissolved oxygen levels as warm water holds less oxygen than cold water. In these cases, it may be wise to lower the suspended sediment threshold levels to avoid further harmful impacts.

Listed Sea Turtles and Whales

ESA-listed whales and sea turtles could potentially be affected by turbidity and suspended sediments. However, the literature lacks studies on the kinds of effects and thresholds for effects where behavioral or physiological responses would be observed in these species. As such, we have not set behavioral, sub-lethal, or lethal effects thresholds for sea turtles or whales for exposure to turbidity or suspended sediments. The open ocean environment experiences turbulence on a daily basis, and suspended sediments generated from projects occurring in this environment are likely to rapidly disperse and settle due to waves and currents. Further, the ocean environment is exposed to other stochastic conditions such as storms that could raise TSS levels temporarily. Suspended sediments generated from oceanic projects are likely to be relatively small when compared to normal oceanic conditions and periodic storms.

Direct impacts to sea turtles or whales from TSS could include an inability to forage or find prey resulting from a potential decrease in visual acuity. Vision reductions could also contribute to separation of mother/calf pairs and to increased risk of predation. These species are highly mobile and likely to avoid sediment plumes and to find forage in other areas, if foraging grounds are temporarily disturbed.

Prey

Characterizing thresholds for effects to prey species is very difficult as there are limited studies available, the results vary, and a wide variety of prey species could be consumed by listed species in the Greater Atlantic Region. Generally, the temporary suspension of sediments from projects such as dredging or jet plowing should not alter predator-prey relationships, as any effects should be short-term. Any inhibitions to feeding for listed species due to the presence of suspended sediments should be temporary as animals will likely move to another area or begin foraging again once the sediments have settled. Generally, adult bivalves seem tolerant to suspended sediments (Wilber and Clarke 2001). Sturgeon species, both shortnose and Atlantic, feed on benthic worms such as polychaetes, although they do not exclusively feed on this prey item. Hinchey et al. (2006) reported negative effects to the tube-dwelling spionid polychaete, *Stresblospio benedicti*, from sediment deposition. In this case, sediment depth and sediment type affected this species. Similar to fish species' exposure to suspended sediments, if prey species face prolonged exposure (e.g., chronic), we expect negative effects to occur. However, these chronic effects are not expected to result from projects that involve activities such as dredging, jet plowing, or pile installation. We do not believe that long-term impacts would result to prey species based on the scope of projects thus far conducted in the Greater Atlantic Region.

Sediment deposition in the open ocean has the potential to bury benthic organisms and change the composition of the substrate (Johnson et al. 2008). It is believed that sediments suspended during sediment deposition fall out of the water column, returning to ambient conditions in approximately 1-4 hours. However, turbidity associated with the plume may remain longer, especially near the bottom and if the particles are very fine. The ability of benthic communities of plants and animals to recolonize after disturbance from sediment deposition depends on the particle size and composition and how this differs from the original substrate. Additionally, species responses vary depending on sensitivity to suspended sediments or foraging strategies. For example, sight-feeding fish species tend to leave these areas while others will move into these turbid areas (Johnson et al. 2008).

We cannot set turbidity/suspended sediment thresholds for prey species at this time as there are many factors to consider, effects likely vary by species, and some of the species co-exist. This makes it very difficult to establish thresholds that would work for all species. Section 7 biologists should: 1) consider what, if any, prey species for the listed species will be in the project area; 2) determine the possible effects (even general ones) that these species may experience from suspended sediments (taking into account ambient versus project-generated suspended sediment concentration levels, exposure durations, mobility and life stages of the prey species present, etc.); and 3) examine the availability of other equally or more suitable foraging areas close by. Modifications to the project area and/or timing may be warranted to help alleviate impacts resulting from presumed damage to prey species and reductions in potential foraging opportunities.

Habitat (including Critical Habitat)

Unfortunately, no published studies indicate levels at which habitat becomes unsuitable for fish species because of turbidity or suspended sediments. Sediment deposition onto important spawning habitat could create issues for fish as sediment deposits could make the habitat unsuitable for spawning activities and incubating eggs. When white perch eggs were buried (he bottom half or less of the egg) under 0.45 mm of sediment, significant mortalities did not occur, and approximately 80% of the eggs hatched (Morgan et al. 1973). The eggs of this species were used because they are adhesive and demersal, similar to the eggs of salmon and sturgeon. Similar tests have not been conducted for Atlantic salmon or sturgeon eggs, but these results indicate that even slight burial can cause at least some mortality. The loss of hard, clean substrate through sediment deposition could reduce the availability of important nursery habitats and cause changes in the ability of these habitats to support prey species that are important to ESA-listed fish.

When considering the effects of turbidity and suspended sediments on ESA-listed species, biologists must take into account a number of factors. These include the location, time of year, habitat type, prey species present, and the potential for the activity to harm prey species or their habitats. For example, dredging activities may remove prey species or alter habitat such that different prey species have the opportunity to come into the area.

Atlantic Salmon Critical Habitat

Suspended sediments can affect all Atlantic salmon critical habitat PCEs, which were described above in reference to five life stages, but do not affect all of the essential features associated with each PCE. The most sensitive stages to suspended sediments are the adult spawning and embryo and fry development stages. In this case, sediments have the potential to change the substrate that is an important essential feature for these life stages. We generally establish work windows outside of the adult spawning and embryo and fry developmental periods to help mitigate the occurrence of activities that can affect sediment concentration levels in spawning habitat and during these sensitive development phases. However, section 7 biologists should first carefully consider if these life stages are likely to be present in the project area before placing restrictions on the activities.

Suspended sediments could also hamper visibility for various Atlantic salmon life stages when searching for cover, foraging, or migrating upstream or downstream. Suspended sediments may negatively affect parrs since this life stage feeds on drifting prey that could be less visible or sediments could be mistaken for prey. High TSS can also cause alarm reactions and area avoidance that could delay important migrations for adults and smolts. Further, suspended sediments may alter interactions between Atlantic salmon and other fish species within the river system. For predatory fish, suspended sediments may provide an advantage of cover or increased stealth when hunting.

Proposed Atlantic Sturgeon Critical Habitat and General Sturgeon Habitat

In proposing critical habitat for Atlantic sturgeon DPSs (Gulf of Maine, New York Bight, and Chesapeake Bay), NMFS noted the possibility of special management needed for the protection of the physical and biological features associated with reproduction and recruitment. Relevant to this paper, this includes dredging which could alter spawning habitat, but suspended sediment or turbidity are not necessarily the concern. Rather, sediment deposition and substrate removal are the primary areas of concern from a critical habitat standpoint.

While it is important to consider impacts to sturgeon habitats when fish are present, we must also consider the effects of turbidity and suspended sediments to these habitats when fish are not expected to be present. Additionally, other factors may affect the suitability of habitat in the future. For example, a project occurring in or near spawning habitat but outside the spawning period during which suspended sediments settle out and fill in cobble areas with fine sediments could reduce the suitability of this habitat in the future for spawning sturgeon.

To reduce impacts to sturgeon sand their habitats from turbidity and suspended sediments, the location and timing of projects must be considered with river and substrate characteristics as well as other environmental conditions that could cause sturgeon to aggregate in and/or utilize specific locations. We do not make turbidity/suspended sediment threshold recommendations for sturgeon habitat because it is difficult to quantify the possible effects to habitat from turbidity or suspended sediments as a variety of physical, biological, and environmental factors must be considered. Section 7 biologists should make qualitative assessments of effects to habitat.

Right Whale Critical Habitat and Loggerhead DPS Critical Habitat (Sargassum)

We do not believe turbidity or suspended sediments will have effects on the physical and biological features of North Atlantic right whale critical habitat. NMFS identified four activities that may require special management due to their potentially negative effects on the essential features of right whale foraging habitat, including zooplankton fisheries, sewage outfalls, oil and gas exploration and development, and global climate change. None of these includes concerns related to turbidity or suspended sediment that could affect the essential features of foraging habitat.

In addition, we do not believe it will have an effect on *Sargassum* habitat or the PCEs that support this habitat for the Northwest Atlantic loggerhead sea turtle DPS. NMFS identified five activities that may require special management due to their potentially negative effects on the essential features of loggerhead sea turtle *Sargassum* habitat, including commercial *Sargassum* harvesting, oil and gas activities, vessel operations that result in the disposal of trash and wastes, ocean dumping (e.g., debris, toxins), and global climate change (NMFS 2014). None of these activities generates suspended sediments or causes sedimentation.

BEST MANAGEMENT PRACTICES FOR AVOIDING OR REDUCING EFFECTS

Best Management Practices to Reduce Impacts from Dredging

A number of methods and best management practices (BMPs) have been developed to reduce the environmental impact associated with resuspended sediment occurring from dredging activities. Two of these methods, silt curtains and gunderbooms, aid the containment of sediment particles during dredging activities.

Silt Curtains and Gunderbooms

Silt curtains are made of flexible plastic material with an upper portion that floats. The lower portion is weighted to keep it open in the water column. They are placed around an in-water activity, allowed to unroll into the water, and anchored or weighted to keep them in place. While silt curtains can theoretically come within two feet of the seafloor or be considered full-depth, this is often impossible due to currents and the impermeability of the curtains. Since the curtains typically only extend 10-12 ft. below the surface, they are only effective at reducing dredging-related sediment resuspension at the surface, not at the bottom where concentrations are higher. Silt curtains are not useful in high-energy areas or when they must be constantly opened and closed for access to the dredge site. They should only be used when currents are two knots or less (Anchor Environmental 2003).

Other turbidity barriers are similar to silt curtains but are made of permeable fabric that allows water to pass through while trapping sediments. As such, they are made to extend from the surface to the seafloor, giving the widest range of coverage from resuspended sediment. However, these curtains are more expensive than silt curtains and can become clogged with silt (Anchor Environmental 2003). This likely depends on the type of screen being used.

For projects that will employ the use of silt curtains and other turbidity barriers, section 7 biologists should consider if it would be necessary to first inspect that area to ensure listed species are not trapped in the enclosed area prior to commencement of the activity.

Operational Controls and Measures

A number of operator-controlled measures and techniques can be employed during dredging activities to help reduce the amount of sediment that is resuspended in the water column. Anchor Environmental (2003) provides examples of operational controls for mechanical, hydraulic, and hopper dredges as well as barges. Operational control measures are low-cost and relatively simple to implement. However, they have the potential to slow down the activity, reducing efficiency.

Additionally, there are “best practice” techniques that can help reduce sedimentation. These, adapted from Anchor Environmental (2003), are summarized in Table 14.

Table 14: Best Management Practices for Dredging (largely adapted from Anchor Environmental (2003))

	Control Measure	Control Measure Description
Mechanical Dredges	Increase cycle time	Longer cycle times lower the speed at which the bucket is pulled up through the water column, reducing sediment loss. It also reduces the speed at which the bucket is lowered to the seafloor and impacts the bottom, thus requiring more sediment bites to remove the project material, which could increase sedimentation at the bottom.
	Eliminate multiple bites	When a clamshell dredge takes multiple bites, it loses sediment each time it is opened. Sediments are released higher into the water column each time the bucket is raised, opened, and lowered.
	Eliminate bottom stock-piling	Stockpiling silty sediment on the bottom has the potential to increase the amount of sediment that is resuspended into the water column.
Hydraulic Dredges	Reduce cutterhead rotation speed	Slowing the cutterhead speed on a hydraulic dredge can reduce the amount of sediment that is cast aside before it enters the pipeline. This is usually effective for maintenance projects or in areas with loose, fine grain sediment.
	Reduce swing speed	Typical swing speeds are 5-30 ft/min. The dredge head should not swing at speeds that stir up sediments faster than the hydraulic flow can handle. The proper balance will minimize resuspension.
	Eliminate bank undercutting	Cutting into a bank with a cutterhead dredge causes the bank to cave and release large amounts of material. This can overload the suction capacity of the pipe intake and increase the amount of suspended sediment. A BMP is to conduct maximum equal lifts of sediment that are 80% or less of the cutterhead diameter.
Hopper Dredges and Barges	Reduce or eliminate hopper overflow	This reduces the amount of sediment that is released into the water column when hoppers or barges are allowed to overflow. This, however, may reduce the efficiency of the operation.
	Lower hopper fill level	Lowering the hopper fill levels during rough conditions will minimize sediment loss during material transport to the disposal site.
	Use a recirculation system	This system can recirculate overflowing sediments from hoppers back to the draghead.
	Draghead operation	Turn off suction pumps until draghead is in contact with the bottom.
Specialty Dredges	Pneuma pump	This pump is usually used for fine-grained sediment and allows for up to 90% of the slurry to consist of solids, all while minimizing the turbidity associated with the dredge activity.
	Closed or environmental bucket	These dredge buckets are specially designed to reduce or eliminate suspended solids-related turbidity near the dredging activity.
	Large capacity dredges	These larger dredges carry more sediment, reducing vessel traffic impacts by allowing fewer transports to the disposal site and reducing impacts from resuspended sediments at the disposal site.
	Precision dredging	This uses specialized tools and techniques to dredge only the specific material identified. This requires modification to the operation to select for materials within specific boundaries or dredging in thin layers.
General Best Practices for All Dredge Types	Be aware of tides	Suspend dredging activities when tidal fluctuations are highest and currents are strongest.
	Work within a specific time window	Dredging activities should occur when listed species are not present. While this does not reduce sedimentation, it reduces the chance for species to be affected by the activity.

A combination of techniques and modifications may be needed to reduce or eliminate sedimentation and turbidity impacts. Determining the appropriate approach requires knowledge of the dredge site (e.g., site characteristics, sediment type and size, etc.) and the listed species and life stages that may be present.

Best Management Practices to Reduce Impacts from Jetting/Jet Plowing

Jet plowing uses water pressure to fluidize the sediments within the trench it is digging. It allows sediments to resettle into the trench rather than dispersing them into the water column, which is more environmentally friendly than dredging for the burial of cables in a freshwater or marine environment. While there is the potential for the resuspension of some sediments, these are minor and settle quickly along the trench route (CHPE 2012).

Best Management Practices to Reduce Impacts from Pile Driving or Pile Removal

For the installation of piles, we did not find any BMPs during our literature review. For the removal of piles, Oregon State Marine Board (2012) identified a number of BMPs to help reduce the resuspension of sediments. These include:

- Vibratory extraction to help reduce friction between the pile and the sediments
- Use of a crane or excavator to pull the pile out of the sediment (the entire pile should be removed)
- Slow removal to minimize sediment suspension into the water
- Work during low tide or low water
- Proper containment of sediments associated with the removed pile to prevent introduction of those sediments to the water column
- Collect floating debris associated with pile removal
- If a pile breaks, it should be cut off at least one foot below the mudline

Best Management Practices for Barrier Removals, Culvert Replacement Projects, Cofferdams, and Land-Based Projects

Most dam removals and culvert replacements have occurred in Maine. These open up stream passage for Atlantic salmon but have the potential for resuspended sediments downstream. Other land-based construction projects occurring in riparian habitats also have the potential to release sediments into water bodies. Maine's Department of Environmental Protection developed a list of BMPs to help reduce the amount of sediment released downstream of in-water construction activities or added to a body of water from land-based construction activities. State agencies, including Maine, have erosion and sedimentation control laws to reduce the introduction of sediments, pollutants, and contaminants to waterbodies. In Maine, an erosion control plan must be developed prior to construction.

Below are some examples of techniques that can be used to reduce and prevent sediments from entering waterbodies or from being released downstream of a construction site:

- Use of land-based stabilization methods and buffers to reduce erosion and sedimentation (ME DEP 2015)
    - Land grading and slope protection
    - Vegetative buffers
    - Mulching

- Straw/hay bales
    - Silt fences
- Conduct the project in sequences/phases rather than opening up an entire area at one time (ME DEP 2015)
- Disperse storm-water runoff away from stream channels (ME DEP 2015)
- Stream diversion activities include methods for reducing re-entry of sediments into the waterbody (ME DEP 2015)
- Use of sediment basins to collect soil and runoff during construction activities to prevent them from entering waterbodies (good for larger sediments)
- Dam removals (Graber et al. 2011)
    - Slowly drain the impoundment (reduces sediment release downstream)
    - Removal of sediments that have assembled behind the dam if necessary
    - Stabilize sediment behind the dam through active revegetation and bioengineering
- Cofferdams
    - During dewatering, pump sediment-laden water through a filter bag and dispose of filter bag at an upland site (MDEQ 2015; ME DOT 2015)
    - Reflood the cofferdam gradually to minimize the amount of resuspended sediments when the cofferdam is breached (ME DOT 2015)

Sources for the erosion and sediment control BMPs provided by the Maine Department of Environmental Protection (DEP) can be found on their website (http://www.maine.gov/dep/land/erosion/escbmps/). The following references can be obtained there: Sediment Barriers (B-1), Land Grading and Slope Protection (C-1), Vegetated Buffers (C-5), and Temporary Stream Diversion (F-1). Additionally, information was obtained from the dam project manager's guide (Graber et al. 2011).

SUMMARY

Turbidity and suspended sediments have the potential to affect ESA-listed species in this region, and our research has shown that listed fish, especially the early life stages (eggs and larvae), are more sensitive to these stressors than sea turtles or large whales. Several factors support this determination. These include the complex life histories of Atlantic salmon, shortnose sturgeon, and Atlantic sturgeon, exposure to riverine as well as marine environments, their anatomy and physiology (e.g., gills are sensitive to fine sediments, direct physical effects from suspended sediments, stress effects), and sensitivity to other water quality parameters (e.g., dissolved oxygen, pH, temperature) that can increase their sensitivity to suspended sediments. Much of the literature reviewed was not focused on t other salmonid species (although there have been a number of useful studies involving Atlantic salmon) and freshwater and estuarine fish not listed under the ESA. These studies are used as surrogates because of the similar life histories of the fish studied to the ESA-listed fish. When developing thresholds for suspended sediment exposure concentrations and exposure durations for sediment-generating activities, we considered this information as well as other external factors that can influence Greater Atlantic Region fish species responses to suspended sediment concentrations above ambient conditions. We believe these thresholds are appropriately conservative from a species standpoint and will be workable for an action agency.

We were unable to generate exposure thresholds for listed large whales and sea turtles. To date, research focused on examining the effects of TSS and turbidity on whales and turtles is largely non-existent. Therefore, we qualitatively considered effects to vision, stress levels, communication, predation, prey, and habitat. We suggest that section 7 biologists consider these factors when consulting on projects that would occur in large whale or sea turtle habitats.

The project activities that could generate suspended sediments considered include dredging, jet plowing, pile installation/removal, and dam/barrier removal. After reviewing the information available on these activities, sufficient measures and best management practices are available to reduce suspended sediments generated from these projects to levels at or below the thresholds provided in this paper for Atlantic salmon and sturgeon species. At these thresholds, effects on Atlantic salmon and sturgeon will be insignificant as the effects will be temporary and will not significantly disrupt normal behaviors.

It is important that biologists consider the life stages and habitats (including critical habitat) where proposed activities will occur. Early life stages are much less tolerant to suspended sediments and sediment deposition than juvenile and adult life stages. These earlier stages are unable to avoid this stressor because of limited mobility. We have built flexibility into the suspended sediment exposure thresholds to account for sensitive life stages and habitats of listed fish species. Biologists should consider the location of the proposed project relative to species habitat (e.g., upstream, downstream) and ambient conditions (e.g., temperature, dissolved oxygen) to determine whether these may contribute added stress to fish. Added stress may reduce their tolerance to suspended sediments or turbidity above the ambient levels of the immediate environment.

ANNOTATED BIBLIOGRAPHY

1. Anchor Environmental 2003. Literature review of effects of resuspended sediments due to dredging operations. Prepared for Los Angeles Contaminated Sediments Task Force, Los Angeles, California. 140 p.

   This document provides a literature review of the effects of resuspended sediments resulting from dredging activities. This review was prepared to assist a California-based task force in the development of a Contaminated Sediment Management Strategy and help them determine the need for controlling the level of resuspended sediment that occurs due to dredging activities. The article provides solid comparisons of hydraulic and mechanical (most commonly used) dredges, the two most commonly used dredges. It includes measures of resuspension rates and concentrations associated with each based on published literature. It also describes a number of water quality parameters (e.g., turbidity, TSS, light transmission, chemicals) and how they are measured.

2. Hayes DF. 1986. Environmental effects of dredging technical notes. U.S. Army Engineer Waterways Experiment Station, Environmental Laboratory. EEDP-09-1. 7 p.

   This Technical Note provides a brief description of sediment concentration levels generated by cutterhead, hopper (with and without overflow), and clamshell (open and closed bucket) dredges. This information is based on field tests conducted at a variety of undisclosed sites.

We know that Savannah River, Grays Harbor, and the St. Johns River were used based on the graphics and information provided:

3. Newcombe CP, Jensen JOT. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16: 693-727.

   This paper uses previously published studies on responses of salmonids and other fishes to suspended sediments to model biological responses to sediment concentrations and duration of exposure. Figures 1B through 4B from this paper are provided in the white paper as a reference for modeled responses of adult and juvenile salmonids as a group, adult salmonids and juvenile salmonids individually, and eggs and larvae of salmonids and non-salmonids combined to varying levels of sediment concentrations and exposure durations. Responses range from minor alarm reactions to 80-100% mortality according to severity of ill effect scores. Table A.1 at the end of the paper provides a summary of the data used and the published literature references for each.

4. O'Connor WCK, Andrew TE. 1998. The effects of siltation on Atlantic salmon, *Salmo salar* L. embryos in the River Bush. Fisheries Management and Ecology 5: 393-401.

   This paper describes a laboratory and river experiment involving varying concentration levels of fine sediment (0.063 – 1 mm) and their effect on the survival of Atlantic salmon alevin. In the laboratory, 100% alevin mortality was observed at 25% fine sediment concentration levels. In the field, alevin survival varied between the 15 incubators placed in the river. No fine sediments were added to these incubators, as they were allowed to experience natural levels of sedimentation influx. None of the field incubators experienced fine sediment levels as high as 25%. The highest percentage was approximately 17% fine sediment.

5. Parsley MJ, Popoff ND, Romine JG. 2011. Short-term response of subadult white sturgeon to hopper dredge disposal operations. North American Journal of Fisheries Management 31(1): 1-11.

   This article provides behavioral information on white sturgeon responses to hopper dredge disposal activities in the Columbia River. Seven animals were tagged and their movements analyzed for 24 hours prior to, during, and after disposal activities. Six out of seven tagged fish stayed near the disposal operation and site and, in fact, seemed to be slightly attracted to the site. Only one fish moved away from the disposal site but remained in the core area. The overall conclusion of this particular study was that, for subadult white sturgeon, there was no change in rate of movement, a slight increase in core area, and no change in depth use when disposal activities were occurring. While there was a slight increase in fish activity (thought to result from the fish investigating a potential food source that may have been present in the suspended sediments), there was no change in the core area occupied. The authors indicate that additional studies should be done on very small juveniles as well as larger adults. This is one of the only studies found on effects to sturgeon from dredging activities.

6. Robertson MJ, Scruton DA, Gregory RS, and Clarke KD. 2006. Effect of suspended sediment on freshwater fish and fish habitat. Canadian Technical Report of Fisheries and Aquatic Sciences 2644. 37 p.

   This is literature review on the effects of suspended sediments on freshwater fish and their habitat. Brief information is provided within the paper itself on the various subjects that were reviewed. These include effects on fish eggs/larvae, physiological effects on fish, effects on fish foraging and growth, effects on primary producers and aquatic plans, effects on invertebrates, behavioral effects on fish, effects on fish habitat (spawning and overwintering), and effects on fish abundance and community structure. Appendix 1 at the end of the paper provides a severity of effects table using the species and literature cited.

7. Wilber DH, Clarke, DG. 2001. Biological effects of suspended sediments: a review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries. North American Journal of Fisheries Management 21(4): 855-875.

   This article provides a summary of a number of studies completed on various aquatic species and the biological effects to these species from suspended sediments associated with dredging activities. The authors generally used the response categories (none, behavioral, sub-lethal, and lethal) described by Newcombe and Jensen (1996) when categorizing the effects sediment concentration levels and exposure durations. Graphic depictions of effects to the species groups are portrayed, capturing effects, concentration levels, and exposure durations. Additionally, Table A.1 at the end of the paper provides a summary of the literature used for their review and the associated references.

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