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Effects of Suspended Sediment on Aquatic Organisms

A Literature Review and Database Effort

Paige M. Krupa, Alan J. Kennedy, Andrew D. McQueen,
and Justin L. Wilkens

September 2025



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Effects of Suspended Sediment on Aquatic Organisms

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Paige M. Krupa, Alan J. Kennedy, Andrew D. McQueen, and Justin L. Wilkens

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Abstract

The US Army Corps of Engineers (USACE) acknowledges that uncertainties and public perceptions regarding the effects of suspended sediment on aquatic organisms, particularly the concentration thresholds associated with harmful effects, present an ongoing challenge to its dredging mission. USACE is actively working to address these challenges through improved monitoring, research, and collaboration to support safer and more sustainable dredging practices. To help mitigate this uncertainty, 159 field- and laboratory-based studies describing the effects of sediment on aquatic organisms were reviewed and compiled in a database. No- and low-effect ecotoxicity data from this review were further analyzed to determine percentiles of effects data and species sensitivity distributions. The analysis indicated corals and freshwater crustaceans were most sensitive, followed by fish, while bivalves and marine crustaceans appeared to be the most tolerant of suspended sediment. This literature review provides a foundational framework for visualizing site-specific suspended sediment thresholds for effects concentrations associated with potential effects on aquatic species. It serves as a starting point for identifying critical data gaps for future research, layering in additional data, refining thresholds, and supporting more informed, site-specific decision-making moving forward.

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Preface

This study was conducted for the Dredging Operations and Environmental Research (DOER) program under Project RT23-07, “Next Gen Dredging/Water Quality Evaluation, Monitoring, and Sensing for Risk Management.” The navigation technical director was Dr. Matt Smith, US Army Engineer Research and Development Center–Coastal and Hydraulics Laboratory.

The work was performed by the Environmental Risk Assessment Branch of the Environmental Processes and Engineering Division, US Army Engineer Research and Development Center–Environmental Laboratory (ERDC-EL). At the time of publication, Mr. Jay Lindsay was branch chief; and Mr. Warren Lorentz was division chief. The deputy director of ERDC-EL was Dr. Brandon J. Lafferty, and the director was Dr. Edmond J. Russo Jr.

LTC Joshua M. Haynes was commander of ERDC, and Dr. Beth C. Fleming was the director.

1 Introduction

1.1 Background

Waterborne transportation in the United States is crucial to the economy, as evidenced by the over 2.2 billion short tons of commodities transported on the nation's waterways in 2020 (USACE 2021). As such, maintenance and capital improvements of waterways through dredging is necessary to enable shipping. This dredging mission falls largely under the purview of the US Army Corps of Engineers (USACE), which annually removes over 200 million yd³ of sediment from navigation channels at a cost exceeding \$2 billion (USACE 2021).*

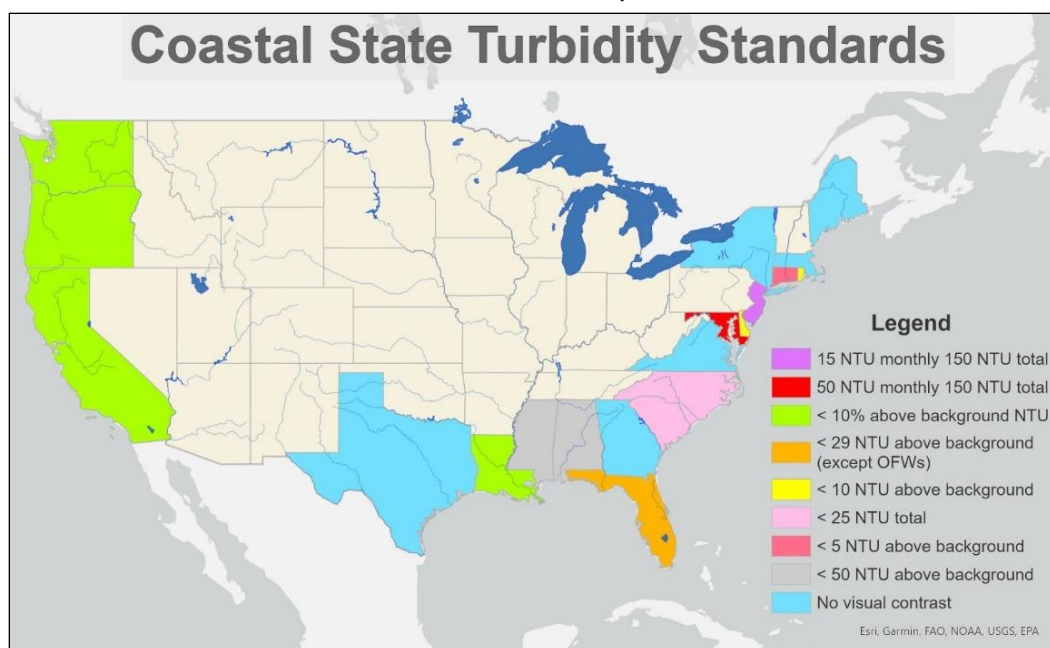
Due to the substantial scope of dredging activity, it is important to understand the ecological hazards of these operations. Although dredging activities have been reviewed for a number of different potential effects on aquatic organisms (e.g., Wenger et al. 2017), this review focuses on the potential effects of the resuspension of sediment, which refers to the incidental process by which sediment particles become suspended in the water column during dredging and related operations. Although dredging is intended to excavate and remove bedded sediment, a portion of the material is unintentionally dislodged and dispersed into the surrounding water due to mechanical disturbance, hydraulic forces, or vessel activity.

Previous review studies have sought to describe or quantify such impacts of suspended sediment on aquatic life; however, most of these studies are 20–30 years old (including Wilber and Clarke 2001; Anchor Environmental 2003; Newcombe and Jensen 1996; Newcombe and MacDonald 1991) or focus only on a single group of organisms (Tuttle and Donahue 2022; Zabarte-Maeztu et al. 2021; Kjelland et al. 2015; Erftemeijer et al. 2012; Courtice et al. 2022; Wenger et al. 2017). Given renewed focus on the potential for suspended sediments to impact sensitive aquatic species, there was a need for an updated review incorporating more recent studies and covering multiple groups of organisms to better inform resource managers of suspended sediment effects.

* For a full list of the spelled-out forms of the units of measure used in this document and their conversions, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52 and 345–47, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

In the United States, various state and local entities have enacted measures to protect organisms and the environment from negative effects of suspended sediment (Figure 1). As most state regulations and monitoring of dredging activity concern nephelometric turbidity units (NTUs), a water clarity measurement based on the scattering of light (USGS 2018), there is a disconnect between these turbidity standards and organism effects values reported in scientific literature because most suspended sediment toxicity studies report the effects to organisms from gravimetric (weight-based) methods such as suspended sediment or total suspended solids (in milligram per liter); turbidity and gravimetric measurements are not directly comparable and require a site-specific calibration to convert between the two units. As such, reporting site-specific information as suspended sediment concentrations as well as turbidity would be helpful to environmental specialists and other personnel interested in understanding possible impacts of suspended sediment to aquatic organisms at a particular site. For further discussion on discrepancies between turbidity and suspended sediment concentrations, refer to Kennedy et al. (2024). Other complications with state turbidity standards include a lack of consistency across states in terms of magnitude and whether these standards are based on elevation above background conditions (i.e., when there is no dredging). Additionally, there is a shortage of suitable studies to inform standards, including a lack of recent research looking at exposure-response effects; much of the current literature consists of older studies (20–60 years old), does not test an appropriate range of concentrations to determine scientifically defensible effect thresholds, or both. Consequently, turbidity standards could benefit from consideration of more relevant and recent studies to better protect aquatic life, while avoiding overly conservative assumptions that delay or hinder dredging operations.

Figure 1. Reported coastal state nephelometric turbidity unit (NTU) standards. (Reproduced from Kennedy et al. 2024, public domain, adapted from Clarke 2009, public domain, to confirm values.)



1.2 Objective

The objective of this study was to enhance current understanding of how suspended sediment concentrations induced by dredging potentially impact aquatic organisms through a literature review. This report also provides technical guidance for visualizing thresholds for effects concentrations associated with impacts on these organisms based on percentiles of no observed effect concentration (NOEC) and lowest observed effect concentration (LOEC) values.

1.3 Approach

A strategic literature review on suspended sediment effects to aquatic species was conducted. Although search terms and study selection were biased toward publications relevant to dredging operations in the United States, laboratory and field studies from greater than 20 countries with exposures designed to investigate various suspended sediment sources and scenarios (dredging, storm disturbances, erosion, turbid reef habitats, etc.) were incorporated into a database.

This literature review focused on the physical effects of suspended sediments. Impacts of contaminated sediments where effects could be

attributed to chemicals in the sediment rather than the sediment itself falls beyond the purview of this study. Both sediment from contaminated sites and sediment spiked with chemicals were excluded. Therefore, presence of contaminants is not expected to have confounded the data collected in this report. Section 4 provides relevant context to the NOEC/LOEC information by describing dredging conditions in the field.

2 Literature Review

2.1 Search Terms and Data Entry

A literature review was performed between 21 July 2023 and 31 December 2023 to gather data relevant to effect concentrations of noncontaminated suspended sediment on aquatic organisms. Relevant review papers (e.g., Anchor Environmental 2003; Wilber and Clarke 2001; Kjelland et al. 2015) were used as starting points to identify applicable studies. Further, searches were conducted on Google Scholar using terms such as “suspended sediment,” “total suspended solids,” “dredging,” or “turbidity” and “[organism name, e.g., fish, mollusk, coral]” as keywords. Data were entered into a spreadsheet (Microsoft Excel), capturing information including identifiers of the study (title, author, year, etc.), exposure conditions (unit [e.g., mg/L or NTU], exposure duration, sediment type, etc.), organism description (type [e.g., fish, crustacean, coral], species, life stage), and response data (end point, quantitative effect, NOEC or LOEC, etc.). A link to this database is provided in Appendix A. Table 1 explains differences between units reported in the database measuring sediment suspension or deposition.

Table 1. Explanation of different reporting units for measurement of suspended or deposited sediment.

Method	Reporting Unit	Example Standard Method(s)
Vacuum filtration	Total suspended solids (TSS)	USEPA 160.2 (USEPA 1983); American Public Health Association (APHA) 2540 (APHA 2023)
Gravimetric settling	Suspended sediment (SS) or suspended sediment concentration (SSC)	USEPA 160.2 (USEPA 1983); Gray et al. 2020 ^a
Turbidity	Nephelometric Turbidity Unit (NTU) ^b or Formazin Nephelometric Units (FNU) ^c	APHA 2130 (APHA 2023); ISO 7027 (ISO 2016); USEPA 180.1 (USEPA 1993)
Sediment thickness	Centimeters (cm) or millimeters (mm)	Refers to the vertical distance from the top of a sediment layer to the underlying surface (e.g., bedrock, test chamber).
Sediment loading	Milligram per centimeter squared (mg/cm ²)	The total mass of sediment that has accumulated or settled on a defined area, typically over a certain period of time (e.g., during a single storm, dredging operation, lab experiment).
Sedimentation rate	Milligram per centimeter squared per day (mg/cm ² /day)	Mass-based reflecting the amount of sediment settling over a known area during a specific period that is reflective of an ongoing process.

^a Description of comparability between TSS and SSC.

^b Measured via optical backscatter sensor or nephelometer; typically uses tungsten or LED as light source.

^c Typically used infrared light (860 nm) as light source.

As the goal of the database was to identify and include as many suspended sediment studies as time allowed, data down-selection and exclusion occurred later in the process when analyzing LOEC and NOEC data (Section 2.2). While these data were helpful to visualize toxicological trends, the output should not be considered comprehensive; due to the large amount of literature available, studies focusing on relevant units (suspended sediment in milligrams per liter), end points (survival, growth, reproduction) and with data available in a NOEC/LOEC format were prioritized for data entry into the database. The first edition of the database (Appendix A), upon which this literature review is based, contains over 150 studies and greater than 4,700 rows of data.

2.2 No Observable Effect Concentration (NOEC) and Lowest Observable Effect Concentration (LOEC) Identification and Data Exclusion

For this literature review effort, data entered into the database (Appendix A) were analyzed using percentiles of NOEC and LOEC values. Although NOEC and LOEC values were occasionally specifically stated as such by the authors, these values were typically identified by examining significant differences between treatment groups, indicated via figures or text of a publication; the NOEC represents the highest nonstatistically significant value reported for a treatment while the LOEC represents the first concentration in a treatment to have a statistically significant effect compared to the control. Note that for the purpose of this literature review, values were only designated as LOECs if the significant difference between the treatment and the control group was consistent with an exposure-response relationship (i.e., data was not categorized as a LOEC if a significant difference was observed at a lower concentration, but not at higher concentrations). Additionally, the NOEC was determined as the highest sediment concentration tested, regardless of whether that treatment group had a statistically significant effect. Due to method variations between studies and because the NOEC values in this literature review include data from studies that did not show statistically significant effects (i.e., no statistically significant effects at all concentrations tested), the percentiles for these NOEC values could be higher than the LOEC values (which only include studies with statistically significant effects). While the NOEC is strongly caveated for use in risk assessments (Beasley et al. 2015; Jager 2012; Warne and van Dam 2008; P. Chapman et al. 1996), it remains one of the most abundant end points reported in the literature; therefore, it is

not always possible to use more scientifically justifiable probabilistic alternatives (e.g., effect concentration and lethal concentration values, such as the effect concentration to impact 20% of test organisms [EC20] or the lethal concentration to kill 50% of test organisms [LC50]) when using reported effects data from older studies. Consequently, the following effects section (Section 3) focuses primarily on LOEC values, and NOEC values are included in Appendix C.

Studies were excluded from analysis if NOEC and LOEC values could not be determined, including if control and treatment groups were not clearly defined, if statistical tests or differences between treatment groups were not reported, and if an appropriate control group (i.e., treatment with no suspended sediment or turbidity added) was absent. Furthermore, only data that were in a consistent unit (i.e., milligrams per liter) or could be converted to this unit were included in the data analysis effort. As studies were frequently not in the consistent format required (i.e., data reported as LC50 values rather than NOEC/LOEC, units were turbidity (NTU) rather than milligrams per liter, etc.) and older studies often did not clearly indicate statistical differences between treatments, many of the data collected were excluded from NOEC/LOEC analysis (see Section 2.5).

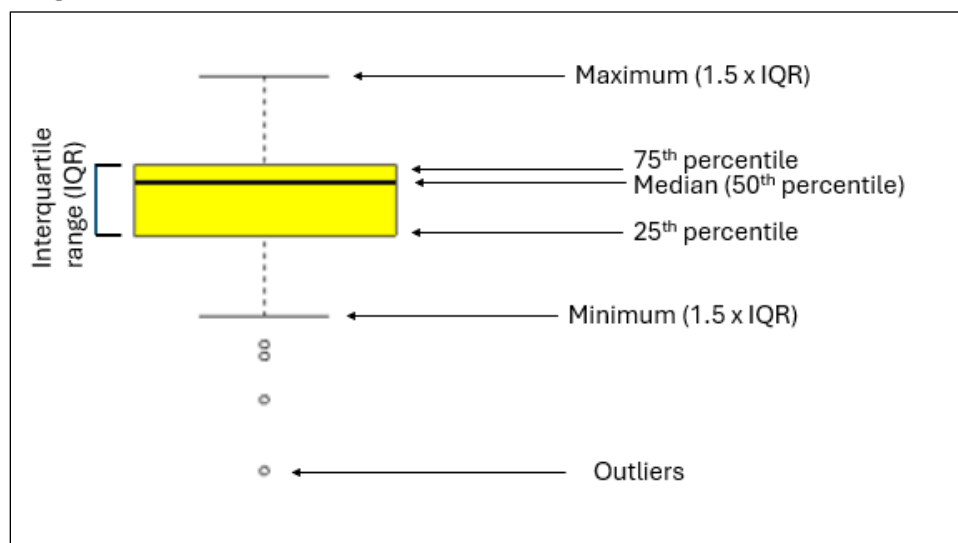
For the purposes of the data presentation in this report, non-apical endpoints (e.g., behavior, feeding, pumping, oxygen consumption, enzyme expression, hormones) were excluded due to the greater uncertainty and variability to predicting organism population level effects. However, these factors were retained in the database (Appendix A) and remain important considerations when evaluating the effects to biota, especially regionally important or threatened or endangered species. Data from approximately 70 studies matched these criteria, with 465 values for NOECs and 186 for LOECs, and were used to create the plots and calculate quartile ranges.

2.3 NOEC and LOEC Data Analysis and Visualization

NOEC and LOEC data from the Excel database were imported into R (v 4.0.3, RStudio) and used to generate box-and-whisker plots and determine 10th, 25th, 50th, and 75th percentiles. Figure 2 presents a visual explanation of how to interpret the box-and-whisker plots. Plots were generated for organism groups (e.g., fish, bivalves) with sufficient data. To reduce variation due to differences in test methods, data were further divided between acute (designated as less than or equal to 96 h) and chronic

(greater than 96 h), as well as lethal and sublethal end points. For this literature review, “lethal” data included survival and mortality-related end points, while sublethal end points included other end points that did not result in mortality during the exposure period (i.e., growth, development, hatching, reproduction, physiology/body condition, and tissue damage to the gill and epidermis).

Figure 2. Visual explanation of box-and-whisker plots used in this technical report.



Percentiles indicate the suspended sediment concentration for which the specified percent of LOEC or NOEC data points fall within. For LOEC values, this indicates the specified percent of observations (from studies with statistically significant differences only) in the database that were significantly impacted by suspended sediment concentration at that value. For example, a 25th LOEC percentile of 500 mg/L indicates that 25% of the end point data within the category (e.g., sublethal end points for freshwater fish) statistically significantly differed from the control group at a concentration of 500 mg/L suspended sediment. On the other hand, a 25th NOEC percentile of 500 mg/L represents that 25% of the exposure end point values from the highest treatment group with “no statistical effect” compared to the control group occurred at a concentration of 500 mg/L. NOEC values are typically more conservative than LOEC values, usually having lower suspended sediment concentrations for the percentiles.

While LOEC values are only from treatments that have a statistically significant difference from the control group, NOEC values in the database consist of data from exposures in which organisms were not significantly affected by sediment at all concentrations tested as well as data from

exposures with statistically significant differences between sediment concentrations. As a result, more data points are available for NOEC than for LOEC. Therefore, subtracting the number of LOEC values from the number of NOEC values for a category indicates the number of end points/exposures that were not affected by suspended sediment according to statistical analyses. This can be helpful to identify groups of organisms that were tolerant of suspended sediment (e.g., organisms that have a small LOEC sample size but a high NOEC sample size).

Although both freshwater and marine/estuarine fish and crustacean species were generally evaluated separately, freshwater and marine/estuarine data for bivalves were combined for analysis due to the limited studies included in the database for these organisms. Note that there was also a limited number of crustacean studies; however, differences in sensitivity between test species (primarily daphnids for freshwater and shrimp for marine/estuarine studies) made consolidating these groups impractical.

Additionally, species sensitivity distributions were generated with the US Environmental Protection Agency's (USEPA) *Species Sensitivity Distribution Generator* (USEPA 2017) using the apical LOEC end points as described previously. Species sensitivity distributions compare the sensitivity of different species by showing the proportion of species expected to be affected at specific concentrations of the stressor (i.e., suspended sediment in milligrams per liter for this literature review effort). Fifth percentile hazard quotients (HC5), the stressor intensity that is estimated to affect 5% of included taxa, were reported as the central tendency value (mean) and prediction intervals (Neter et al. 1990) at the proportion of 0.05. This study constructed species sensitivity distribution (SSD) curves consistent with USEPA (2017) methods using multiple taxonomic groups (e.g., fish, bivalves, freshwater crustaceans, etc.).

Note that these plots and percentiles do not distinguish or account for differences between study conditions, including sediment type, organism life stage, and particular end points. Although sediment type is an important consideration, due to small sample sizes (data was already sorted by NOEC/LOEC, organism type, exposure duration, and lethal/sublethal), data was not further divided by a simplified sediment type (i.e., sand, fine) in this report. Interested readers should refer to the database file (Appendix A) for more details on these factors.

Data included in plots and percentiles are limited to suspended sediment or similar measures (total suspended solids and so forth) reported in milligram per liter. Additionally, percentiles and plots are limited to organism groups with sufficient data (i.e., at least 3 exposure end point values that met the NOEC/LOEC quality criteria described previously), such as fish, bivalves, crustaceans, and corals. Suspended sediment impacts to seagrasses are discussed in Section 3.6; a few other groups of organisms are briefly discussed in Section 3.7.

2.4 Coral Data Extraction

While data for all other organism groups were entered into the database directly from research studies, the coral effects data were obtained from two comprehensive review papers (Table 5 in Erftemeijer et al. 2012; Supplementary file 3 [database] in Tuttle and Donahue 2022), that incorporated data from over 60 studies. In some cases, original publications were reviewed to supplement details not provided in the review paper. Additional information on how NOEC and LOEC data were incorporated from these studies are provided in Appendix B. Mortality, survival, bleaching extent, and tissue damage were classified as lethal end points, whereas sublethal end points were associated with growth, feeding, reproduction, photosynthesis, respiration, and mucus production. Only toxicological data reported in terms of directly defined suspended sediment concentrations (or shading equivalent to suspended concentrations) were used (i.e., shading, subsurface irradiance, and turbidity were excluded). Data points reporting increased survival were not included.

2.5 Data Gaps and Future Considerations

Although there is a substantial body of literature on suspended sediment impacts to aquatic organisms, there were a considerable number of studies that were not appropriate to include in the NOEC/LOEC analysis to inform the effects associated with dredged sediments based on the selection criteria (e.g., inconsistent units [NTU], unclear statistical significance, nonrepresentative end points, etc.). Thus, the figures and percentiles resulting from the literature review should not be considered comprehensive for all data available for suspended sediment impacts but rather they provide representative data to inform dredging risks and a framework to summarize and communicate data. Section 4 provides environmental context for the LOEC/NOEC data discussed.

While the database contains 150+ studies and greater than 4,700 rows of data (“data points”), most did not meet the specifications for the NOEC/LOEC data analysis described in Section 2.2 and were thus excluded from the plots and figures generated in this current literature review; 465 data points remained for NOEC and 186 for LOEC. Because of further division into categories—organism groups, lethal versus sublethal, exposure duration—fewer data points were available for each individual category. This especially pertained to lethal LOEC studies, which often had less than 5 data points available per category. Future database updates with additional studies to address data gaps would help resolve this issue.

This review had to rely on NOEC/LOEC data since these are among the most commonly reported toxicological end points, despite recognition that they are flawed measures of toxicity thresholds and probabilistic data representations would provide a better estimate of the safe versus harmful effects of suspended solids (Beasley et al. 2015; Warne and van Dam 2008). Usefulness of the NOEC/LOEC percentile plots and SSDs, as well as general comparisons between different studies, are complicated by the many variables that can differ between studies, including types of sediment used (grain size, field-collected sediments versus kaolin or similar clays), organism life stage, measured versus nominal exposure values, test conditions (temperature, dissolved oxygen, etc.), and suspension method. Additionally, percentiles for the NOEC and LOEC data can be skewed by studies that do not test a concentration gradient.

Many studies test only a control plus one or two treatments (i.e., presence or absence of sediment, or only testing a high, low, and control sediment concentrations), as these studies were not designed with the intention of providing information about threshold values, but rather presence or absence of an effect. Therefore, future studies could improve the quality of the reported dose response relationship data by improving the experimental design to capture more exposure concentrations (e.g., 5 exposures and control, per USEPA 2002) to decrease uncertainties in end points.

3 Effects of Suspended Sediment on Aquatic Organisms

3.1 Overview

Suspended sediments generally affect aquatic life in two ways: (1) effects related to a sediment's physical properties; or (2) through chemical effects, such as changes in pH, light penetration, dissolved oxygen, and other water quality parameters (Anchor Environmental 2003), with the former being the main focus of this review and database. Physical effects of suspended sediment to biota can further be divided into behavioral and physiological effects. Behavioral effects include avoidance or attraction to turbidity or sediment plumes as well as altered foraging, cover seeking, navigation/orientation, or alarm responses. Physiological impacts include changes in respiration or photosynthesis (e.g., shading), tissue damage (including to the gills and epidermis), smothering or burial, reduced hatching of eggs, reduced feeding or filtration rates, and abnormal development (Anchor Environmental 2003). Such impacts can result in mortality or reduced growth and reproduction, which in turn can lead to impacts on the population level.

Understanding the effects of suspended sediment to aquatic organisms can be complex because effects on biota are influenced by the interplay of numerous factors, including species or organism type, life stage, exposure concentration, duration and frequency of exposure, sediment physical properties (grain size, angularity, etc.), feeding habits (suspension feeding, filter feeding, etc.), habitat (epibenthic, pelagic, etc.), and presence of nutrients or contaminants, as well as temperature, oxygen availability, and other water quality conditions.

3.1.1 Box-And-Whisker Plots

Box-and-whisker plots can be a helpful method to visualize the sensitivity of different groups to suspended sediment; see Figure 2 for a diagram explaining how to interpret these graphs. For this literature review effort, we used these plots to compare sensitivity of different groups of organisms (i.e., fish, coral, bivalves, and crustaceans) for different exposure lengths (less than or equal to 96 h or greater than 96 h) and end points (lethal or sublethal). The box-and-whisker LOEC plots are provided in Figures 3–6 while the NOEC data are included in Appendix C.

Figure 3. Suspended sediment lowest observed effect concentration (LOEC) data compiled from the literature review effort for sublethal end points in exposures less than or equal to 96 h in duration. These values are not intended to be definitive or for legal or regulatory use. Instead, this lays out a process for summarizing toxicological data for important ecological receptors of concern.

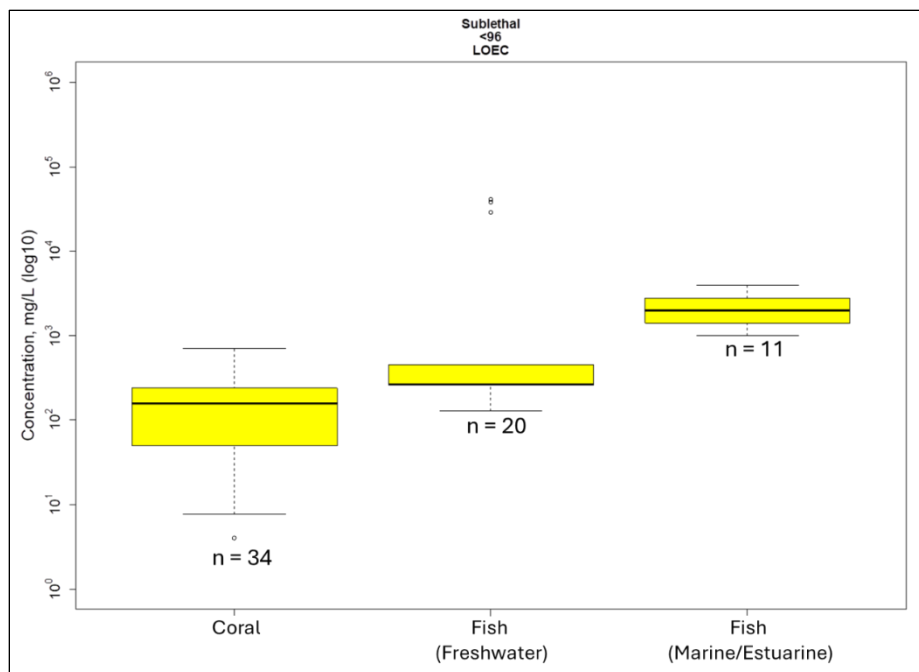


Figure 4. Suspended sediment LOEC data compiled from the literature review effort for lethal end points (i.e., survival, mortality) in exposures less than or equal to 96 h in duration.

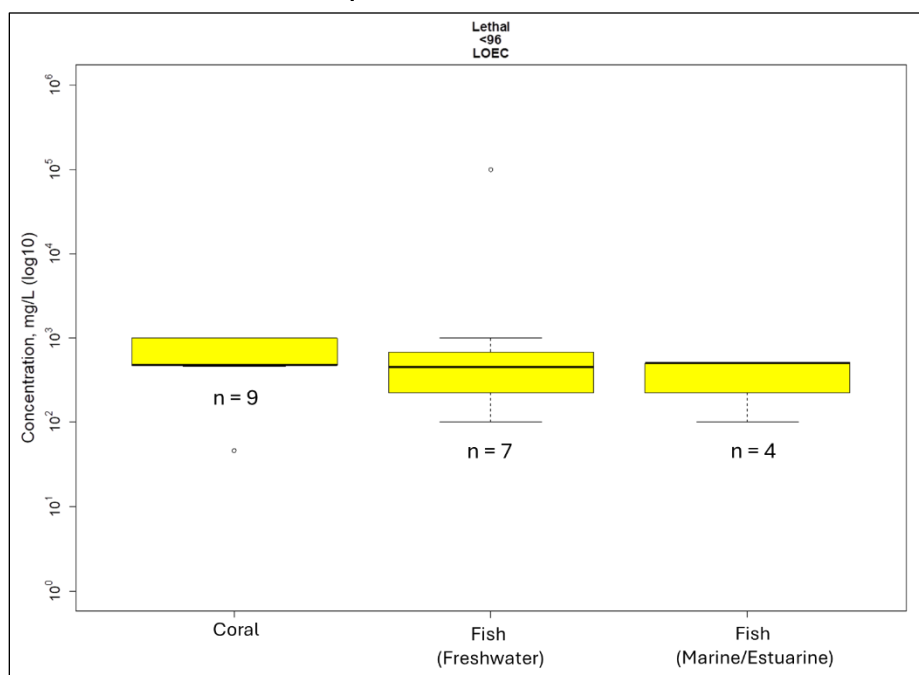


Figure 5. Suspended sediment LOEC data compiled from the literature review effort for sublethal end points in exposures greater than 96 h in duration.

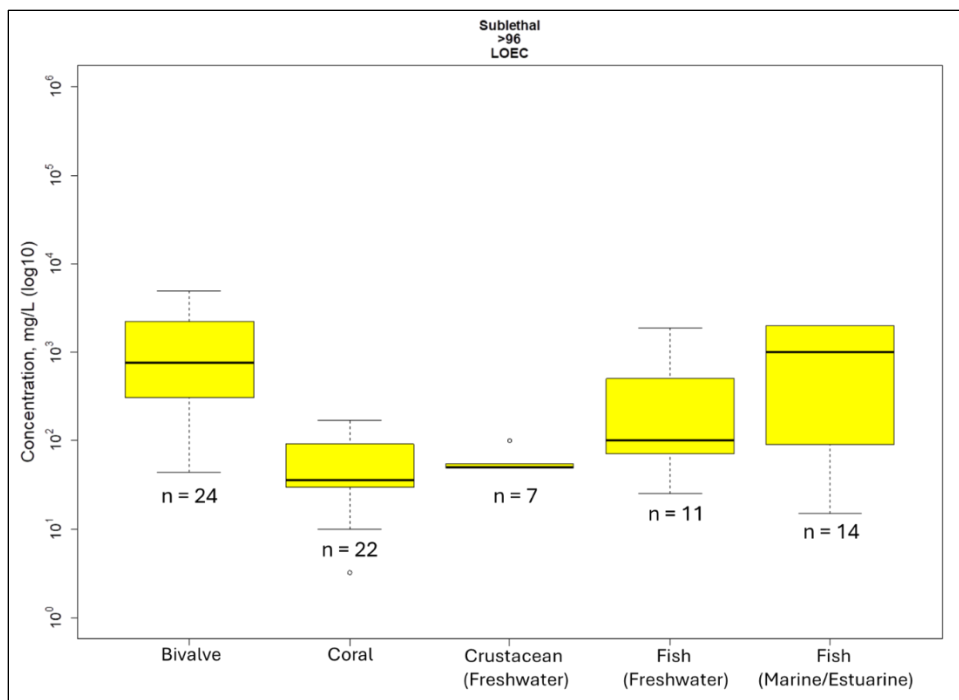
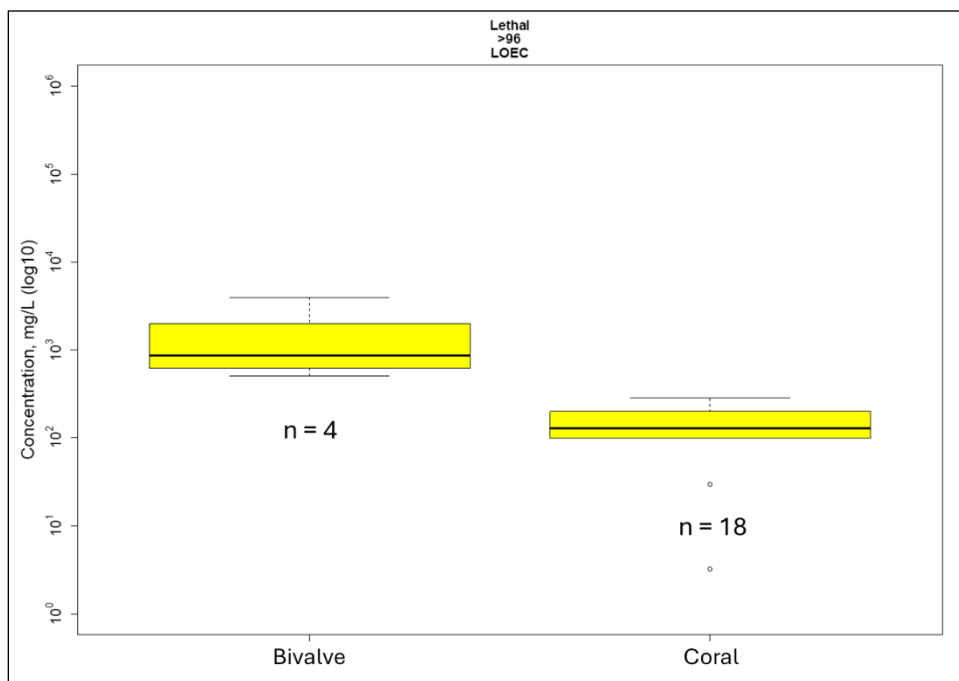


Figure 6. Suspended sediment LOEC data compiled from the literature review effort for lethal end points in exposures greater than 96 h in duration.



3.1.2 Species Sensitivity Distributions

Species sensitivity distributions are another tool that can be used to visualize differences in sensitivity between species. To demonstrate how these analyses can be used to evaluate sensitivity of different species to suspended sediment, species sensitivity distributions based off LOEC values are provided in Figures 7–10 (see Section 2.3 for an explanation of this analysis). The accompanying tables containing numerical values for the mean stressor intensity, number of observations, and proportion of taxa expected to be affected are provided in Appendix D. In the context of dredging projects, this approach could be helpful for visualizing what species may be vulnerable to suspended sediment levels expected from the dredging activity or for identifying species that would be expected to be more tolerant. For example, based off the SSD charts generated from the literature review (Figures 7–10), the most sensitive species to suspended sediment exposure include corals, fish, and freshwater crustaceans whereas bivalve species appear more tolerant. These analyses can also be used to predict how many species would be impacted by a particular sediment concentration, including the HC5, which represent the concentration that is estimated to affect 5% of included species.

Figure 7. Species sensitivity distribution (SSD) of lethal end point LOEC values for both freshwater and marine/estuarine species. Exposure duration was categorized as either greater than 96 h or less than 96 h. Several coral species affected at a mean of 199 mg/L (*Phyllangia americana*, *Scolymia cubensis*, *Isophyllia sinuosa*, *Cladocora arbuscula*, *Manicina areolata*, and *Stephanocoenia intersepta*) were combined into a single label (“Various corals, >96 hours”) (see Tables D-1 and D-2 for further information). The **solid black line** represents the central tendency of the data while the **dotted lines** represent the prediction intervals; these lines begin at the 0.05 proportion and thus indicate the HC5: 16 mg/L suspended sediment (CI: 4–66).

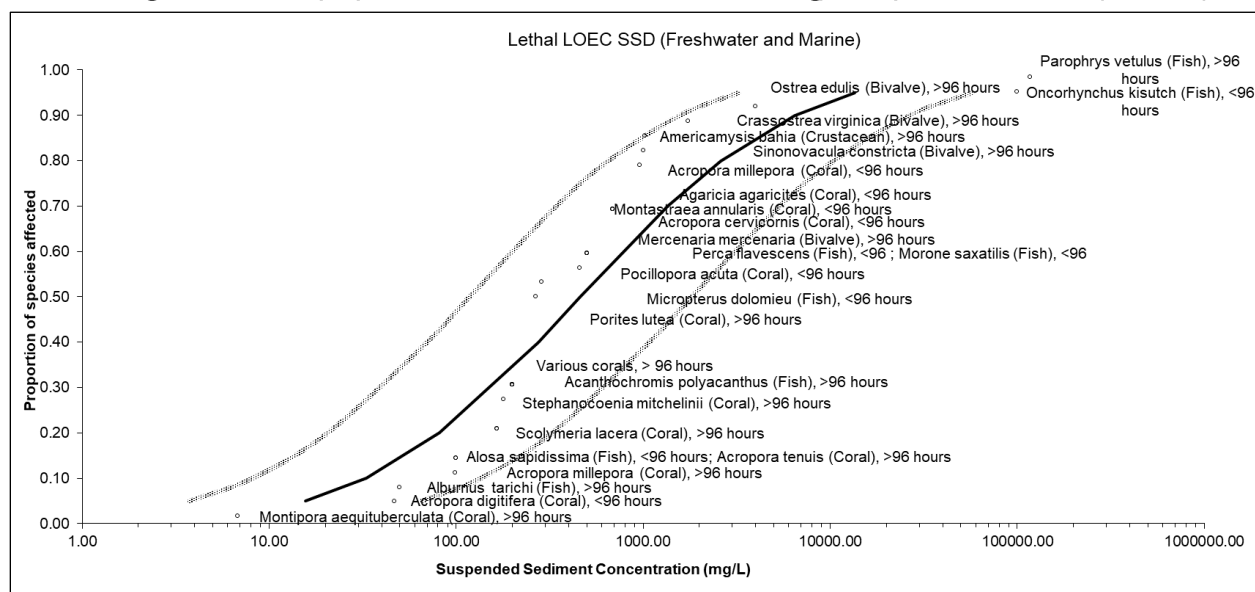


Figure 8. SSD of LOEC values for marine/estuarine species exposed to suspended sediment for greater than 96 h, for both lethal and sublethal end points. Some coral species were removed for ease of viewing (see Tables D-3 and D-4 for the complete species list as well as mean suspended sediment effect concentrations for the species). The **solid black line** represents the central tendency of the data while the **dotted lines** represent the prediction intervals; these lines begin at the 0.05 proportion and thus indicate the HC5: 6 mg/L suspended sediment (CI: 2–20).

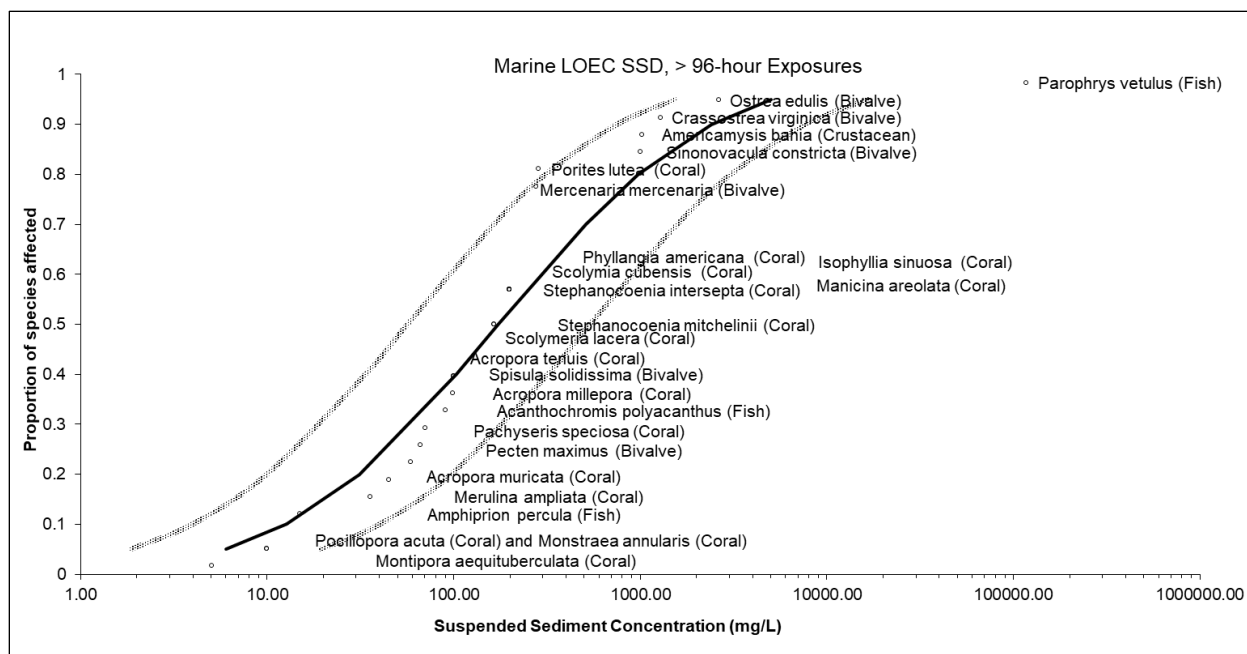


Figure 9. SSD of LOEC values for marine/estuarine species exposed to suspended sediment for less than or equal to 96 h, for both lethal and sublethal end points (see Table D-5 and D-6 for further information). The **solid black line** represents the central tendency of the data while the **dotted lines** represent the prediction intervals; these lines begin at the 0.05 proportion and thus indicate the HC5: 23 mg/L suspended sediment (CI: 8–63).

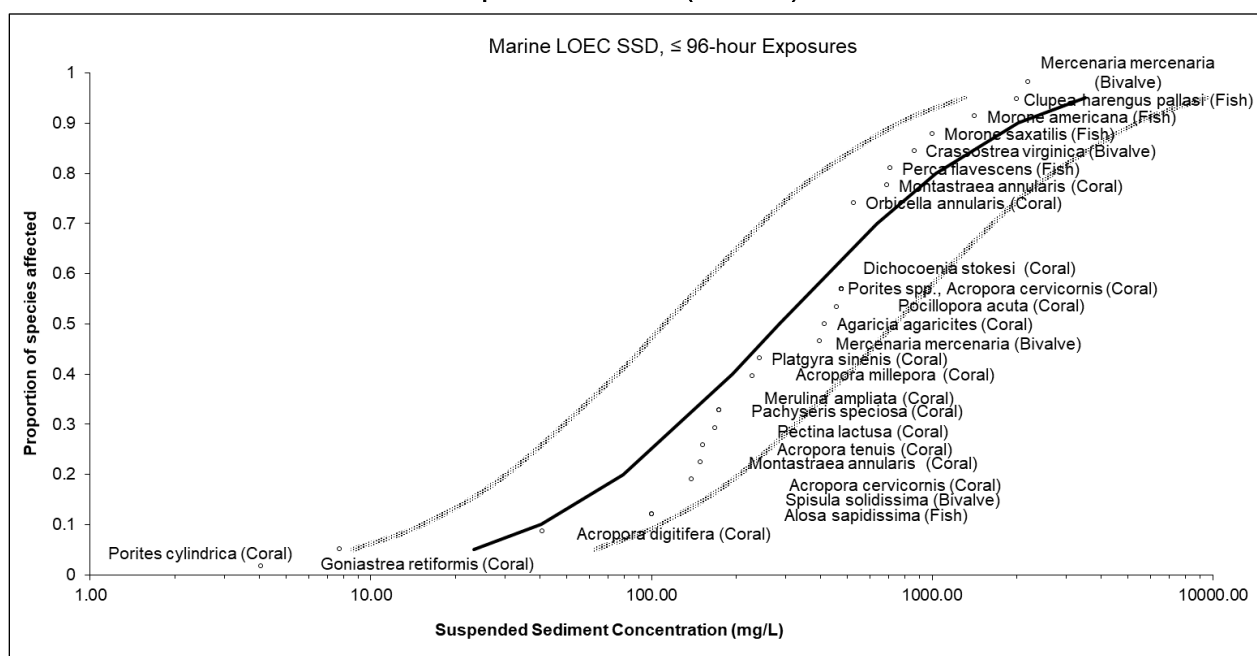
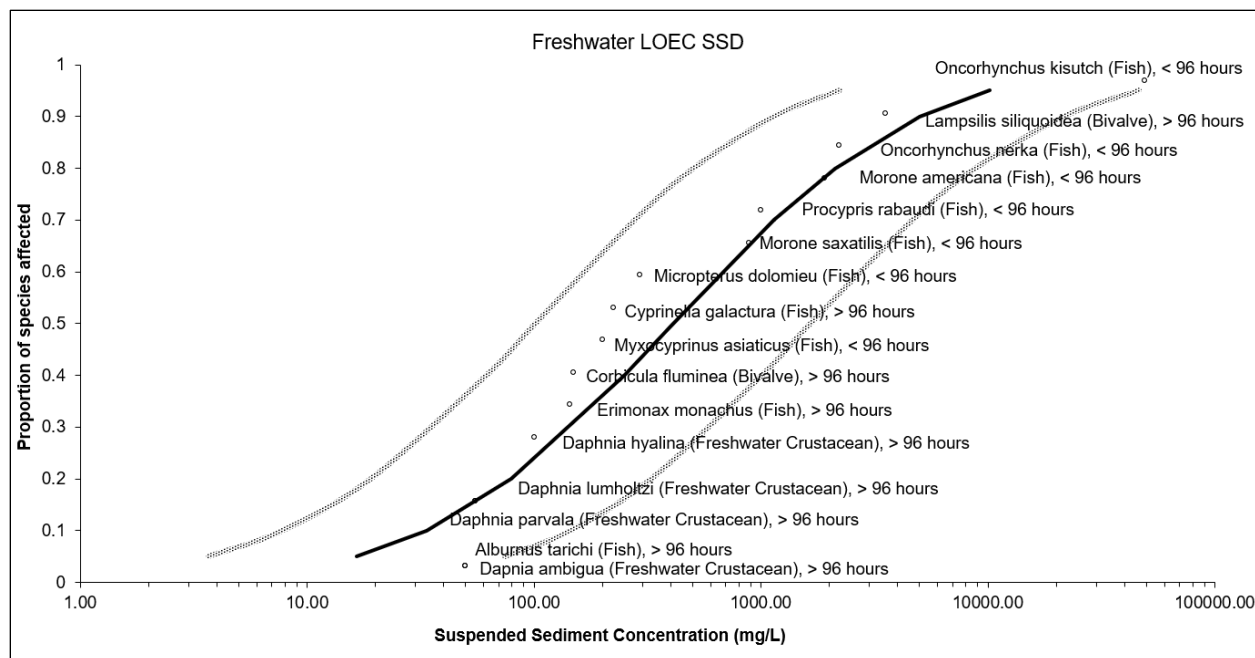


Figure 10. SSD of LOEC values for freshwater species exposed to suspended sediment for either less than or equal to 96 h or greater than 96 h, for both lethal and sublethal end points (see Table D-7 and D-8 for further information). The *solid black line* represents the central tendency of the data while the *dotted lines* represent the prediction intervals; these lines begin at the 0.05 proportion and thus indicate the HC5: 17 mg/L suspended sediment (CI: 4–75).



3.2 Fish

3.2.1 Overview

Adult fish are tolerant to high suspended sediment concentrations, often exceeding thousands of milligrams per liter before mortality occurs (Table A-4 from Anchor Environmental 2003). Perhaps except for the area within the immediate vicinity of a disturbance site, for instance, where a mechanical dredge bucket removes sediment, the conditions are such that the water could not support an unusually high suspended sediment load (e.g., 10,000 mg/L) over a long distance (i.e., greater than tens of meters) before settling. Younger fish, such as larva and juveniles, tend to be more sensitive to lower suspended sediment concentrations (e.g., less than 1,000 mg/L), which could occur during natural disturbances as well as near dredging operations (Cavanagh et al. 2014). Furthermore, larval fish may be more sensitive to suspended sediment than eggs, as they lack the egg's protective outer membrane (i.e., chorion; Isono et al. 1998). Tolerance to suspended sediment varies by species, with pelagic fish typically more sensitive than benthic species (Kjelland et al. 2015). Exposure length

is also an important consideration, with fish exhibiting greater sensitivity to longer exposures to suspended sediment (Table 2 and Table 3).

Table 2. Summary of LOEC percentile data from the literature review for studies pertaining to fish (suspended sediment concentration [SSC] in milligrams per liter).

Exposure	Percentile			
	10th	25th	50th	75th
≤96 h exposure				
Freshwater (Sublethal), <i>n</i> = 20	263	263	263	452
Freshwater (Lethal), <i>n</i> = 7	160	225	452	726
Marine/Estuarine (Sublethal), <i>n</i> = 3	1,200	1,500	2,000	3,000
Marine/Estuarine (Lethal), <i>n</i> = 4	220	400	500	500
>96 h exposure				
Freshwater (Sublethal), <i>n</i> = 11	50	75	100	500
Marine/Estuarine (Sublethal), <i>n</i> = 14	59	318	1,000	1,750

Note: *n* represents the sample size: the number of LOEC values that matched the selection criteria (see Section 2.2) and were used to calculate these percentiles; greater than 96 h lethal data not available (less than 2 LOEC values per organism group).

Table 3. Summary of LOEC percentile data from the literature review for studies pertaining to fish (SSC in milligrams per liter).

Exposure	Percentile			
	10th	25th	50th	75th
≤96 h exposure				
Freshwater (Sublethal), <i>n</i> = 46	110	133	452	485
Freshwater (Lethal), <i>n</i> = 21	200	221	500	528
Marine/Estuarine (Sublethal), <i>n</i> = 7	800	1,500	8,000	10,000
Marine/Estuarine (Lethal), <i>n</i> = 8	100	421	3,014	79,125
>96 h exposure				
Freshwater (Sublethal), <i>n</i> = 13	10	50	100	595
Marine/Estuarine (Sublethal), <i>n</i> = 25	45	500	1,000	1,500
Marine/Estuarine (Lethal), <i>n</i> = 3	54	68	90	35,045

Note: *n* represents the sample size: the number of LOEC values that matched the selection criteria (see Section 2.2) and were used to calculate these percentiles; greater than 96 h lethal data for freshwater fish not available (less than 2 studies per organism group).

Perhaps the most important exposure pathway of suspended sediment to fish is to the gill membranes, including gill damage, thickening, and clogging (Cavanagh et al. 2014). Particularly, suspended sediments can reduce the length of gill lamellae and thus reduce the gill surface area (Hess et al.

2017). Furthermore, suspended particles can harm the gill epithelium, which is the main location for oxygen uptake in most fish species (Hess et al. 2017). In response to suspended sediment, gills will often secrete mucous and grow more layers of cells on the lamellae (a condition called hyperplasia) to prevent and repair tissue damage (Hess et al. 2017). These structural changes increase the thickness of the gill epithelium and result in greater oxygen diffusion distances. Such increases in oxygen diffusion distances and reductions in gill surface area are expected to result in reduced oxygen uptake and gas exchange. However, the effects of these changes to gill structure appear to vary between species; while some species show reduced metabolic performance as one might expect, other species exhibited no decline in oxygen consumption rates despite these morphological changes to the gill structure (Cumming and Herbert 2016; Hess et al. 2017). Damage to the gill structure can also impede other important functions of this organ, including osmotic and ionic regulation and waste excretion (Evans et al. 2005).

Compared to more sessile species, fish are likely to be less susceptible to lethal effects of suspended sediment because they are mobile and can avoid areas of higher suspended sediment concentrations (e.g., dredging plumes) and can seek out areas of lower concentrations (Kjelland et al. 2015). Consequently, it is vital to comprehend sublethal effects on fish, including direct physical harm and tissue damage (especially to the gills), physiological adjustments (including increased metabolic activity and energy expenditure), reduced growth rate, and reproductive effects (Kjelland et al. 2015). Suspended sediment concentrations can also alter fish behavior, including changes in feeding, predator avoidance and reaction to stimuli, migration, orientation, and movement (Kjelland et al. 2015). Exposure to suspended sediment can induce primary stress responses in fish, resulting in increased blood levels of the stress hormone cortisol, which could impact growth rate, behavior, and disease resistance (Kjelland et al. 2015). Indirectly, suspended and deposited sediment could also harm fish populations through reduction of their food sources, including macrophytes, plankton, algae, and invertebrate prey.

High suspended sediment concentrations can negatively impact fish reproduction in several ways. Sediment-induced stress on breeding adults can affect gamete quality and quantity, delay ovulation, and result in lowered offspring survival (Kjelland et al. 2015) and can interfere with fertilization (Galbraith et al. 2006). Sediment cover can reduce hatching rate (Gatch et

al. 2020; R. Morgan et al. 1983) and can interfere with egg attachment to rocks and other substrate (Germano and Cary 2005). Furthermore, deposition of fine sediments on coarse substrates can result in decreased interstitial water flow in the sediment, which can inhibit oxygenation of the eggs and interfere with the expulsion of metabolic waste through the chorion (J. Chapman et al. 2014). While sediment deposition is harmful to demersal (settled) eggs, suspended sediment can also impact pelagic eggs by interfering with their buoyancy or oxygen supply (Isono et al. 1998).

Increased turbidity as a consequence of suspended sediment can also affect feeding behavior. These effects can differ depending on the size, habitat, and life history traits of particular fish (Kjelland et al. 2015). For example, in fish larvae, increased turbidity can increase visual contrast and thus aid prey capture (Utne-Palm 1999; Boehlert and Morgan 1985). Furthermore, increased turbidity levels can reduce the risk of predation for smaller fish, which in turn encourages increased foraging behavior in these fish (Wilber and Clarke 2001). For some species and life stages of fish, moderate turbidity may be ideal for prey capture; for example, Gregory and Northcote (1993) observed that juvenile Chinook salmon had the greatest prey capture in surface and benthic prey items at intermediate turbidity levels (35–150 NTU) rather than in clear water or at higher turbidity levels. On the other hand, light scattering or shading by suspended sediment particles often decreases visual acuity, interfering with foraging ability (Bruton 1985; Benfield and Minello 1996). Although most studies look at prey-capture at the surface or within the water column, decreased feeding ability with increasing suspended sediment concentrations have also been observed with the ability of fish to capture benthic organisms (Manning et al. 2013).

Although most laboratory studies attempt to characterize direct effects of sediment on fish, suspended sediments can also result in indirect effects on fish, which can be harder to quantify. For example, suspended and deposited sediment can result in loss of prey, changes to biochemical processes, and habitat alteration and loss (Wenger et al. 2017). However, all effects data from the literature must be put in context with concentrations and duration of exposure actually encountered in the field (see Section 4).

3.2.2 Summary of NOEC and LOEC Data

The 10th percentiles of LOEC values for lethal and sublethal end points (Table 2) were in the 160–1,200 mg/L range for exposures less than or

equal to 96 h and 50–60 mg/L range for greater than 96 h exposures (given sufficient sample sizes greater than 2); this suggests a conservative low effect threshold for the majority of fish species. For freshwater fish, effects quantiles were similar between sublethal and lethal end points, indicating decreased survival and sublethal impacts occur at similar suspended sediment concentrations (see Table 2); however, for marine/estuarine species this trend was not clear (with sublethal LOEC percentiles actually being higher than lethal percentiles), though this is likely due to a limited number of included data points. Additionally, there was a low number of chronic NOEC and LOEC data included in the analysis for fish, as many studies focused on end points not included in this current analysis, such as behavior, feeding, metabolic rate, and blood chemistry. Furthermore, there was a shortage of available studies focusing on lethal end points, with many papers being unsuitable for the NOEC/LOEC criteria for this current literature review effort (older studies with no statistical significance indicated, data reported as LC50 rather than NOEC/LOEC, turbidity (NTU) provided rather than milligrams per liter, and so forth).

In regard to greater than 96 h LOEC data for sublethal end points, marine/estuarine fish species and freshwater fish have a similar 10th percentile value, approximately 50 mg/L. Otherwise, marine/estuarine fish appear to be less sensitive to suspended sediment than freshwater species. Insufficient data were available for lethal data to compare between freshwater and marine species.

Based off the species sensitivity distributions generated from the LOEC dataset (see Figures 7–10), fish generally appear to be less or similarly sensitive than corals to suspended sediment, but more sensitive than bivalves and marine crustaceans. For freshwater species, *Alburnus tarichi*, a Cyprinid endemic to Lake Van in Turkey, was the most sensitive species of all organisms in the LOEC dataset (see Figure 10), with egg hatching and larval survival decreased at 50 mg/L in 7- and 14-week exposures (Atici et al. 2023). In terms of lethality for all freshwater and marine organisms, this species was also the third most sensitive overall (after two species of corals; see Figure 7). Two marine species, the American shad (*Alosa sapidissima*) and a damselfish (*Acanthochromis polyacanthus*), were also among the most sensitive species in terms of lethality, affected by 100 mg/L at less than 96 h and 180 mg/L at greater than 96 h, respectively (see Figure 7; Tables D-1 and D-2; Auld and Schubel 1978; Wenger et al. 2012).

3.3 Bivalves

3.3.1 Overview

The main effects of suspended sediments to bivalves include reduced respiration and feeding due to clogging of filtration mechanisms and mortality from smothering and burial (Berry et al. 2003). Adult bivalves respond to elevated suspended sediment concentrations by reducing net pumping/filtration rates and expelling excess filtered sediment particles as pseudofeces (Wilber and Clarke 2001). High suspended sediment concentrations can also interfere with bivalves' filtering ability and decrease the amount of algae consumed (Wilber and Clarke 2001). Elevated suspended sediment concentrations can decrease larval growth rates; for example, such reductions in growth were observed at suspended sediment concentrations of 400 mg/L for the quahog *Mercenaria mercenaria* and at 750 mg/L for oysters (Davis and Hidu 1969).

Overall, adult bivalves are tolerant to lethal effects of suspended sediment, with studies reporting no survival impacts in chronic exposures to suspended sediment concentrations as high as 60,000–100,000 mg/L (McFarland and Peddicord 1980; Wakeman et al. 1975). Larvae are more sensitive to sediment-induced mortality, with lethal effects occurring at levels as low as 500 mg/L during a 10-day suspended sediment exposure (Davis and Hidu 1969).

Low to moderate concentrations of suspended sediments may be beneficial to bivalves. Some suspended sediment can supplement bivalves' diet and enhance growth, but higher concentrations can dilute planktonic filtration and decrease food ingestion (Wilber and Clarke 2001). For example, concentrations less than 100 mg/L enhanced growth of larval quahog (Davis 1960; Huntington and Miller 1989) and concentrations up to 500 mg/L increased eastern oyster larval growth (Davis and Hidu 1969).

3.3.2 Summary of NOEC and LOEC Data

The mined data suggested that bivalves tended to be tolerant to suspended sediment in terms of lethal end points but were more sensitive to sublethal end points particularly in longer exposures. For example, the 10th percentile values of the greater than 96 h LOEC data suggests that most bivalves did not experience lethal effects at 575 mg/L or sublethal effects at 84 mg/L total suspended solids (TSS) (Table 4). For exposures less than or equal to 96 h, there was considerably more data available for NOEC than

LOEC, with only one LOEC value as compared to 16 NOEC data points for sublethal end points and 36 NOEC data points for lethal end points. This indicates that although multiple less than or equal to 96 h exposures were conducted with bivalves, they were rarely affected (based off a statistically significant difference from the control group) by suspended sediment for the included end points (survival, growth, and reproduction). See Figure 7, which shows the species sensitivity data for all lethal LOEC data points and indicates bivalves as being among the least sensitive organisms.

Table 4. Summary of LOEC and NOEC concentration percentile data from the literature review for studies pertaining to bivalves (SSC in milligrams per liter).

Exposure	Percentile			
	10th	25th	50th	75th
LOEC >96 h exposure				
Bivalve (Sublethal), <i>n</i> = 24	84	422	750	2,125
Bivalve (Lethal), <i>n</i> = 4	575	688	875	1,750
NOEC <96 h exposure				
Bivalve (Sublethal), <i>n</i> = 16	450	556	1,325	6,663
Bivalve (Lethal), <i>n</i> = 36	175	2,025	5,000	5,000
NOEC >96 h exposure				
Bivalve (Sublethal), <i>n</i> = 38	39	250	750	2,875
Bivalve (Lethal), <i>n</i> = 22	440	2,000	4,000	5,000

Note: *n* represents the sample size: the number of LOEC values that matched the selection criteria (see Section 2.2) and were used to calculate these percentiles; less than 96 h LOEC data were excluded due to small sample size (i.e., *n* ≤ 2).

Adult and juvenile bivalves were tolerant of suspended sediment, with significant effects observed primarily for growth. Of the four lethal LOEC values, all for exposures greater than 96 h, three of these were for larvae with a single value for adult/juveniles. However, these bivalves are still impacted by suspended sediment and often exhibit decreased pumping rates and reduced efficiency of filter-feeding (Wilber and Clarke 2001), two end-points that were excluded from the NOEC/LOEC percentiles and plots (see Section 2.2). In contrast, bivalve eggs and larvae are more sensitive to suspended sediment, with suspended sediment concentrations greater than or equal to 125 mg/L impacting embryonic development and greater than or equal to 500 mg/L reducing larval growth and larval survival in *Merccenaria mercenaria* and *Crassostrea virginica* (Davis and Hidu 1969).

As indicated in the SSDs, bivalves were among the least sensitive organisms in terms of lethality. Among marine species, bivalves tended to be less sensitive than corals, but similarly sensitive to fish (see Figures 8 and 9). Growth was the most sensitive end point in exposures greater than 96

h, with decreased growth reported in the quahog *Mercenaria mercenaria* at 44 mg/L (Bricelj et al. 1984; not shown in Figure 4 since it was averaged with other values for this species) and 66 mg/L in the scallop *Pecten maximus* (Szostek et al. 2013). In acute exposures less than or equal to 96 h, the Atlantic surf clam (*Spisula solidissima*) was the most sensitive bivalve species, with pseudofeces production affected at suspended sediment concentrations of 100 mg/L (Robinson et al. 1984).

3.4 Crustaceans

3.4.1 Overview

Fewer studies are available assessing the effects of suspended sediment on crustaceans as compared to other organisms such as fish, bivalves, and corals (Wilber and Clarke 2001). Of the approximately 150 studies captured in the database, only 10 focused on crustaceans. Estuarine/marine crustacean species are tolerant to lethal effects of suspended sediment in acute exposures (less than 2 weeks), with most mortality reported at concentrations greater than 10,000 mg/L, exceeding relevance to dredging activities (Wilber and Clarke 2001). Longer exposure times can result in greater mortality, such as the mortality at 1,000 mg/L in a 28-day exposure of the mysid shrimp (*Americamysis bahia*) to suspended sediment (Nimmo et al. 1982). However, other studies report no mortality in lobsters and shrimp at suspended concentrations of up to 20,000 mg/L for greater than 20 days (Peddicord 1980) and in isopods and crabs exposed to 100,000 mg/L sediment for 12 days (McFarland and Peddicord 1980). As such, uncontaminated suspended sediment concentrations from dredging or disposal operations are unlikely to harm these organisms (Peddicord 1980), while burial by deposited sediment likely presents a greater threat (Saluta et al. 2023). Freshwater daphnids, on the other hand, are much more sensitive to suspended sediment, perhaps due to their smaller size and more delicate body structures—suspended sediment concentrations of 50 mg/L have been observed to have negative effects on growth and reproduction (Kirk 1992; Soeken-Gittinger et al. 2009).

3.4.2 Summary of NOEC and LOEC Data

Overall, there was a limited amount of data for crustaceans, making comparison to other species groups difficult. In particular, there were no relevant LOEC data points for exposures less than 96 h. However, while marine/estuarine species (data predominantly available for shrimp and

crabs) appear largely tolerant of suspended sediment, freshwater species (primarily daphnids) are much more sensitive. Thus, the marine species sensitivity distributions show the single crustacean represented, *Americamysis bahia*, as one of the most tolerant species (see Figures 8 and 9) while the freshwater figure indicates daphnids as among the most sensitive species (see Figure 10).

For marine crustacean species, although there were insufficient data to calculate percentiles for NOEC data for exposures less than 96 h, the 10th percentile values of the chronic (greater than 96 h exposure) NOEC data indicate that the majority marine crustaceans did not experience mortality at 625 mg/L (Table 5). As most studies did not report adverse effects to marine/estuarine crustaceans, sufficient LOEC data points were not available for generation of LOEC percentiles. For example, LOEC data were only available from a single study, Nimmo et al. (1982), reporting reduced survival and reproduction in Mysid shrimp (*Americamysis bahia*) exposed to 1,000 mg/L suspended sediment for 28 days.

For freshwater crustacean species, the available data comprised mainly daphnids, which were among the most sensitive organisms to suspended sediment. However, it should be noted that this observation is based on sublethal chronic exposures greater than 96 h because there were insufficient NOEC and LOEC data for exposures less than or equal to 96 h. For sublethal exposures greater than 96 h, as the LOEC often occurred at the lowest concentration tested, the NOEC for the 10th–50th percentiles was nondetectable TSS (the control treatment) and the LOEC for the 10th–75th percentiles was 50–55 mg/L, the concentrations typically used for the lowest treatment concentration in the daphnid tests (Table 5). Sublethal end points, particularly reproduction, were tested more frequently than survival and other lethal end points. Consequently, there were no mortality LOEC data reported in the database, though NOEC data indicate juvenile crayfish survived 45-day exposures to 133 mg/L suspended sediment (Rosewarne et al. 2014) and *Daphnia* neonates survived 22-day exposures to 50 mg/L (Kirk 1992) and 6-day exposures to 100 mg/L suspended sediment (Rellstab and Spaak 2007).

Table 5. Summary of LOEC and NOEC concentrations percentile data from the literature review for studies pertaining to crustaceans (SSC in milligrams per liter).

Exposure	Percentile			
	10th	25th	50th	75th
LOEC >96 h exposure				
Crustacean, Freshwater (Sublethal), <i>n</i> = 7	50	50	50	55
NOEC >96 h exposure				
Crustacean, Freshwater (Sublethal), <i>n</i> = 11	<1	<1	<1	78
Crustacean, Freshwater (Lethal), <i>n</i> = 4	65	88	117	133
Crustacean, Marine/Estuarine (Lethal), <i>n</i> = 6	625	5,690	19,850	80,000

Note: *n* represents the sample size: the number of LOEC values that matched the selection criteria (see Section 2.2) and were used to calculate these percentiles; less than 96 h data for both NOECs and LOECs, as well as greater than 96 h data for marine crustaceans (NOEC: sublethal, LOEC: sublethal and lethal) were excluded due to small sample size (i.e., *n* ≤ 2).

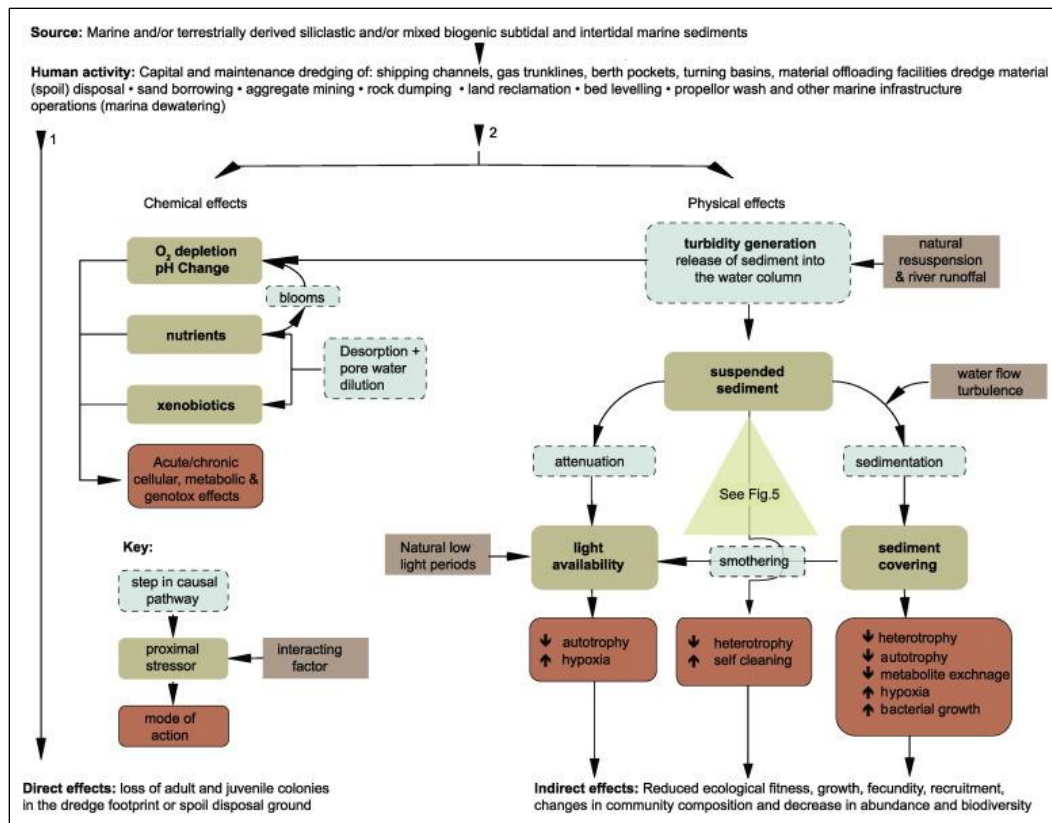
3.5 Corals

3.5.1 Overview

Suspended sediment, including plumes generated from dredging events, can result in harmful physical and chemical effects on corals, as illustrated in Figure 11. In addition to physical effects, suspension of anoxic benthic sediment can cause chemical effects by deoxygenating the overlying water, lowering the pH through the oxidation of iron monosulfide, and releasing nutrients into the water column (M. Morgan et al. 2001). The main physical effect of suspended sediment on corals is likely reduced light availability interfering with photosynthesis in symbiotic zooxanthellae algae (Erftemeijer et al. 2012; Bessell-Browne et al. 2017). Corals additionally obtain energy through heterotrophic tentacular suspension feeding; although sediment ingestion appears to be a normal feeding behavior for corals and low levels may be beneficial, high sediment loads can reduce ingestion rates as polyps may retract and cease feeding (R. Jones et al. 2016). Furthermore, elevated concentrations of suspended or deposited sediment can result in decreased larval survival and sexual recruitment by interfering with gamete fertilization and by making substrate unsuitable for larval settlement (Tuttle and Donahue 2022; Erftemeijer et al. 2012). Furthermore, sediment deposition can result in smothering (which can inhibit solute exchange) and tissue hypoxia (Erftemeijer et al. 2012; R. Jones et al. 2016). Sediment deposition can also impact corals by altering the substrate, as some species require specific substrate types or conditions for optimal survival and recruitment (NMFS 2020). Although it has been suggested that dredging makes corals more susceptible to disease (Pollock et

al. 2014), other studies caution that coral disease is not a suitable indicator for dredging effects (Stoddart et al. 2019; Gintert et al. 2019).

Figure 11. A conceptual model visualizing the effects of suspended sediment and turbidity upon coral through cause-effect pathways and likely physiological and ecological responses.
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Sensitivity of corals to suspended sediment varies by habitat, species, and growth forms, with tolerance limits for chronic exposures ranging from less than 10 mg/L for reefs relatively undisturbed by anthropogenic activities to greater than 100 mg/L for species from turbid marginal reefs (Erftemeijer et al. 2012). Sediment deposition is a particular concern, with sensitivity to sedimentation varying considerably by species and location. Erftemeijer et al. (2012) report ranges in effects from less than 10 mg/cm²/d to greater than 400 mg/cm²/d, with survival duration for sedimentation ranging from less than a day for the most sensitive species to longer than 14 days of complete burial for very tolerant species. Likewise, NMFS (2023) determined fine particle sedimentation depths of 0.5 cm or greater would inhibit coral recruitment (Section 3.3.1.2 of NMFS 2020).

Tuttle and Donahue (2022) created a database incorporating 45 studies dealing with sediment deposition effects on coral and 42 suspended sediment studies, using LOEC data and dose-response meta-analysis models to visualize effect thresholds on coral. However, rather than analyzing NOEC/LOEC data through percentiles as attempted in the current literature review or through other statistical analyses, LOEC data appear to simply be referenced in terms of minimum values (i.e., the lowest reported LOEC) for a particular end point, life stage, and so forth. Using this approach with LOEC values, called lowest-observed adverse-effect levels in the publication, Tuttle and Donahue (2022) state that concentrations of deposited sediment as low as 1 mg/cm²/day could harm corals, with larval settlement being the most sensitive end point. Similarly, suspended sediment concentrations at less than 10 mg/L could negatively impact corals (Tuttle and Donahue 2022). Local bleaching of adult coral was the most sensitive LOEC to suspended sediment, as this was reported at 3.2 mg/L in an acute 1-day exposure period (Table 6 in Tuttle and Donahue 2022). Studies investigating nonlethal end points have demonstrated physiological effects can occur rapidly, as evidenced by decreased photosynthesis after 1 h of exposure to suspended sediment and 12 h of deposited sediment.

Due to this approach of selecting minimum LOEC values, the thresholds presented in Tuttle and Donahue (2022) are very conservative, with the authors noting the values are more conservative than most species- and region-specific thresholds. Other studies indicate minimal effects to coral species, with sediment rates of less than 1 to approximately 180 mg/cm²/day (Rogers 1990; Weber et al. 2006; Chansang et al. 1992), as reported in Table S2 of Suedel et al. (2024).

Species sensitivity to suspended sediment and sediment deposition varied by growth form (i.e., branching, foliose, tabular, etc.), with free-living, branching, and massive corals tending to be tolerant of sedimentation, while laminar, plating, and tabular corals were much more sensitive (Erftemeijer et al. 2012). Additionally, Erftemeijer et al. (2012) found that corals were typically more sensitive to fine sediments than to coarse sediments.

Caution should be taken when considering laboratory data to regulatory effects thresholds, as sediment types and exposure regimes are often not relevant to environmental conditions. R. Jones et al. (2016) discusses several key issues when translating results of laboratory studies to dredging events in the field. Many laboratory studies do not specify particle size or

describe whether the sediment particles were kept in suspension over the course of the study (i.e., consistent exposure concentration for the duration of the study). Therefore, there are difficulties relating effects to sediment suspension or to deposition. Indeed, another review study could not find any laboratory studies that tested the effects of deposited and suspended sediment separately and together to disentangle the effects of these stressors (Tuttle and Donahue 2022). Furthermore, most laboratory studies are conducted in shallow containers and fail to replicate how light attenuation exponentially increases with depth in the field, such that only small reductions in light availability are observed in laboratory conditions even with high suspended sediment concentrations, whereas this decrease in light availability would be greater under field conditions (R. Jones et al. 2016). Therefore, due to practical limitations of some laboratory studies, they may fail to capture the effects on photosynthesis that would occur under a similar suspended sediment regime in the field. However, the failure of studies to compensate for light levels have suggested that corals are able to survive high suspended sediment concentrations for long periods of time given that light levels remain sufficient and sediment smothering does not occur, as evidenced in the study Cooper and Fabricius (2012), which saw no mortality in *Porites* coral exposed to suspended sediment concentrations of 20 mg/L for 56 days, and in Flores et al. (2012), which observed no mortality in *Acropora millepora* exposed to 30 mg/L sediment for 12 weeks.

Another frequent issue with laboratory studies discussed in R. Jones et al. (2016) concerns measuring sediment deposition. Sedimentation rates reported in field studies are usually measured with sediment traps. However, these sediment traps do not accurately quantify sedimentation rates, as they also capture particles that are only momentarily deposited and never actually settle. This is especially problematic in shallow, energetic environments typical of coral reefs. Consequently, sediment traps tend to greatly overestimate the amount of sediment deposited. For example, Field et al. (2013) found that net sedimentation rates (7–17 mg cm⁻²/day) measured using conventional sediment traps were higher than the (0.3–0.6 mg cm⁻²/day) rates measured with their rectangular SedPod. Similarly, Browne et al. (2012) used shallow trays that allowed sediment suspension to estimate net deposition rates at a location in the Great Barrier Reef over a year; the values they found (3–7 mg cm⁻²/day) were much lower than previously reported in the same area by Mapstone et al. (1992) (concentrations up to 364 mg cm⁻²/day with a mean of 44 mg cm⁻²/day).

Because laboratory studies often base their sediment application rates on observations from the field, these artificially high values from the field result in sediment rates selected for laboratory-based sediment deposition studies to be unrepresentative of all but the most extreme conditions encountered in the environment (R. Jones et al. 2016).

Furthermore, sediment types used in laboratory studies may not be directly relevant to those in dredging operations. For example, many studies look at the effects of sand, which tends to settle quickly, rather than silt and fines, which remain suspended longer in dredging plumes and are more susceptible to resuspension (R. Jones et al. 2016; Storlazzi et al. 2015). This can be problematic, because silt and clay particles are more likely to increase light attenuation than sand (Storlazzi et al. 2015). Similarly, substances such as silicon carbide that are often used in laboratory testing differ from natural sediment in terms of physical properties, including light scattering and adsorption, porosity, and specific gravity (R. Jones et al. 2016). As fine-grained particles remain suspended in the water column longer and have greater light scattering properties, they have greater impacts on coral photosynthesis, and consequently growth and survival, than do larger-grained particles.

3.5.2 Summary of NOEC and LOEC Data

Corals were among the most sensitive organisms to suspended sediment concentrations based on LOEC comparisons between coral literature (Erftemeijer et al. 2012 and Tuttle and Donahue 2022) and data compiled for fish, bivalves, and crustaceans; refer to Section 2 and Appendix B for a detailed explanation of how data was mined from these coral review studies and how these data differs from that extracted for the other groups of organisms. Additionally, corals were the most sensitive organism in all the marine species sensitivity distributions (see Figures 7–9).

Low concentrations of suspended sediment were shown to have negative effects on corals. For acute exposures less than 96 h, a timescale representative of typical dredging operations, corals were generally unaffected by suspended sediment concentrations less than 32 mg/L for sublethal end points and 376 mg/L for lethal end points, based on the respective 10th percentile values for LOECs (Table 6). Corals were even more sensitive to longer exposures (greater than 96 h), with 10th percentile values of 9 mg/L for sublethal end points and 22 mg/L for lethal end points. The most sensitive effects (less than 30 mg/L) were often observed with

exposure periods longer than those used for other organism groups (greater than 1,000 h) or with end points not included for the other organism groups (e.g., feeding end points), highlighting the importance of exposure duration on impacts to organisms. However, these extended exposure durations may also exceed dredging operation durations. Due to the low reported values for lethal and sublethal end points, actions to protect this more sensitive group from suspended sediment could be hypothesized to be protective of other organism groups.

Table 6. Summary of LOEC and NOEC percentile data from the literature review for studies pertaining to corals (SSC in milligrams per liter).

Exposure	Percentile			
	10th	25th	50th	75th
LOEC ≤96 h exposure				
Sublethal, <i>n</i> = 34	32	52	157	239
Lethal, <i>n</i> = 9	375	476	476	1000
LOEC >96 h exposure				
Sublethal, <i>n</i> = 22	10	31	36	92
Lethal, <i>n</i> = 18	22	99	133	199
NOEC ≤96 h exposure				
Sublethal, <i>n</i> = 80	<1	20	65	100
Lethal, <i>n</i> = 30	50	100	471	784
NOEC >96 h exposure				
Sublethal, <i>n</i> = 73	1	21	92	101
Lethal, <i>n</i> = 21	1	29	92	199

Note: *n* represents the sample size: the number of LOEC or NOEC values that matched the selection criteria (see Section 2.2) and were used to calculate these percentiles.

3.6 Seagrasses

3.6.1 Overview

Seagrasses serve many important roles in marine ecosystems, including creating structural habitat and serving as food for a great diversity of aquatic organisms, providing carbon storage, decreasing wave action, stabilizing fine sediment, and oxygenating sediment (Zabarte-Maeztu et al. 2021). However, these angiosperms are particularly vulnerable to dredging activity and other anthropogenic disturbances, as these plants usually grow in shallow, sheltered coastal waters, including estuaries, that are also ideal for port facilities and recreation. Suspended sediment can negatively affect these plants by reducing light penetration in the water column, thus interfering with photosynthesis. Sublethal instances of burial can result in decreased carbohydrate reserves and increased shoot mortality, leaf

turnover, vertical growth, and leaf length (Zabarte-Maeztu et al. 2021). Furthermore, if the sediment settles on the surfaces of leaves, this smothering can also inhibit photosynthetic activity, in addition to restricting metabolite exchange and increasing oxygen demand. These effects are exacerbated if complete burial of the seagrass occurs. Settled sediment can also harm these plants by intruding into the pore space of the native bottom sediment, reducing the porosity and permeability of the substrate. This lowered porosity, particularly if combined with organic enrichment (increased anthropogenic nutrient input), can result in anoxia and its associated toxins, including hydrogen sulfide (Zabarte-Maeztu et al. 2021). Increased nutrients can also promote growth of epiphytes and phytoplankton, reducing light availability for seagrasses. The ability of seagrass to survive burial events differs between species and is influenced by size (of leaves, rhizomes, roots, flowers, and fruits), with larger plants being more resistant to burial, as well as resource allocation and mobilization of carbon reserves throughout the clonal organism.

Note that effects data for seagrasses were not incorporated into the accompanying database (Appendix A) and thus were not used for NOEC and LOEC data analysis. For information on suspended sediment and deposition effects on seagrasses, refer to Zabarte-Maeztu et al. (2021) and its accompanying database.

3.6.2 Photosynthesis and Light Thresholds

For seagrasses and other organisms in which the primary negative effect of suspended sediment is interference with photosynthesis, rather than characterizing harm through suspended sediment concentration or TSS, impacts of suspended sediment could alternatively be measured or understood in terms of light availability (Erftemeijer and Lewis 2006). This includes determination of light thresholds that can cause negative impacts on the photosynthetic organism. For example, Chartrand et al. (2016) found negative effects on the growth and survival of the seagrass *Zostera muelleri capricorni* at light levels of 4–5 mol photons/m²/day and thus recommended a light threshold greater than 5 mol photons/m²/day to protect these seagrasses from adverse effects of suspended sediment from dredging activity. This light threshold of 6 mol photons/m²/day was later monitored alongside turbidity standards during dredging of a harbor. For a summary of critical thresholds for light availability reported from multiple studies dealing with several species of seagrasses, refer to Tables 1 and 2 and Figures 1 and 2 in Erftemeijer and Lewis (2006).

3.7 Other Organisms

The effects of suspended solids on other categories of organisms are also reported in the literature. Limited data exist for several other groups of organisms, including phytoplankton, zooplankton, benthic invertebrates, sponges, annelids, tunicates, and sea urchins. Because less information is available, data from these species were not used to generate plots and percentiles, and as such, was not prioritized in data collection for the database. Table 7 presents an overview of selected studies concerning such aquatic organisms.

Table 7. Overview of suspended sediment effects to other groups of aquatic organisms.

Organism Type	Exposure	Suspended Sediment Exposure Effects	Reference
Macroinvertebrates	Review paper on fine sediment effects	Suspended sediment effects include abrasion of body parts, clogging of gills and filter-feeding apparatus, and decreased algal food sources via light reduction	J. Jones et al. (2012)
Periphyton	Review paper on TSS effects	Increased growth at lower TSS concentrations (approximately 100 mg/L); decreased growth at higher TSS concentrations (approximately 200 mg/L)	P. Chapman et al. (2017)
Phytoplankton	Review paper on TSS effects	Flocculation and sinking, reduced light transmission and thus photosynthesis leading to reduced growth and productivity, increased growth and productivity due to increased nutrients, abrasion	P. Chapman et al. (2017)
Phytoplankton	Silicon dioxide (100–500 mg/L)	Decreased carbon uptake	Sherk et al. (1976)
Phytoplankton	Dredge material placement	Increased diatom biomass; increased abundance of harmful algal bloom species	Varkitzi et al. (2022)
Polychaete (<i>Neanthes succinea</i>)	200 h suspended kaolin exposure	High survival (LC10 of 7,000 mg/L)	McFarland and Peddicord (1980)
Sponges	Review paper on suspended sediment and sedimentation effects	Suspended sediment impacts include clogging; reduced pumping activity, feeding efficiency, and reproduction; increased juvenile mortality	Bell et al. (2015)
Tunicate (<i>Ascidia ceratodes</i>)	100 h suspended kaolin exposure	High survival (LC10 of 9,000 mg/L)	McFarland and Peddicord (1980)
Zooplankton	Review paper on TSS effects	Starvation (ingestion of sediment particles with no nutritional value), reduced food (phytoplankton) availability, refuge from fish in low light conditions, clogging of filter-feeding apparatus and digestive organs	P. Chapman et al. (2017)
Zooplankton	Mineral solids and natural sediments (50–1000 mg/L)	Increased time to maximum ingestion; reduced ingestion rate	Sherk et al. (1976)

Fewer studies are available describing the effects of suspended sediment on phytoplankton as compared to fish, corals, and bivalves. Oregon DEQ (2014) notes that although numerous studies demonstrate the relationship between light reduction caused by suspended sediments or turbidity to reduced photosynthetic activity and primary productivity in phytoplankton, few connect specific concentrations or turbidity levels to effects. Due to this limited amount of literature, phytoplankton values were not included in the database. Effects thresholds may be comparable to fish and bivalves, as Sherk et al. (1976) observed reduced carbon uptake in four species of phytoplankton exposed to sediment concentrations of 100–500 mg/L. However, the effects of suspended sediment may not always be detrimental to phytoplankton. Release of organic matter and minerals can positively affect phytoplankton by stimulating growth (Sherk et al. 1976), which could result in harmful algal blooms. For example, Varkitzi et al. (2022) observed an increase in diatom biomass and blooms of toxic diatom species associated with placement of dredged material at a disposal site, possibly due to increased phosphates.

Additional information on other groups of organisms can be found in review articles. For a review of how suspended and deposited sediments affect sponges, refer to Bell et al. (2015). However, it should be noted this review study does not include concentration thresholds or effect levels reported to induce responses. Information on suspended sediment effects thresholds known to impact periphyton, zooplankton, phytoplankton, and benthic invertebrates is discussed in P. Chapman et al. (2017). J. Jones et al. (2012) further describes the effects of fine sediments on macroinvertebrates.

4 Environmental Context

In toxicology, risk is calculated as $Risk = Hazard \times Exposure$. In this literature review, the effects data represents the hazard. To understand the risk suspended sediment poses to aquatic organisms, one must also consider the exposure, that is, the likelihood of organisms encountering these suspended sediment concentrations in the environment. With dredging and other anthropogenic activities, another important consideration is determining whether measured exposure concentrations are elevated above concentrations that naturally occur in the environment. As suspended sediment and turbidity levels are dependent on environmental conditions and thus vary between sites, site-specific reference data should be collected to represent a baseline that is unaffected by dredging activity. Exposure of aquatic organisms to suspended sediment during dredging activities is influenced by multiple factors, including the dredging method, sediment type, and environmental conditions. To provide environmental context for dredging, suspended sediment concentrations for various types of dredging activity, abbreviated from a table in NOAA 2025, are given in Table 8. For further information on suspended sediment concentrations associated with different dredging methods, refer to Appendix A of Anchor Environmental (2003) and NOAA (2025). Distance from the dredge is an important factor in measured suspended sediment concentrations, as TSS are highest near the dredge and decrease with distance. Sediment settles within 1–48 h after the dredging activity has stopped (NOAA 2025), but is dependent on sediment grain size, with large particles (greater than 250 μm [sand]) settling faster than smaller particles (less than 63 μm [silt and clay]). Dredging activities may represent chronic or acute exposures depending on the dredging method and duration as well as sediment characteristics.

Table 8. Total suspended solids (TSS) concentrations from dredging activities, condensed from the second table of NOAA (2025) (public domain).

Dredging Method	Total Suspended Solids (TSS) Concentration	Plume Extent and Sediment Settling
Hopper dredging	Near-field concentrations of 80–475 mg/L	SS plumes can extend up to 1,200 m. SS levels usually decrease exponentially with increasing time and distance from the active dredge due to settling and dispersion, quickly reaching ambient concentrations. The majority of SS resettle close to the dredge within one hour, although very fine particles be resuspended by ensuing peak ebb or flood currents.
Cutterhead dredging	Typically 11–282 mg/L, up to 550 mg/L adjacent to dredge	Elevated SS expected only in 300–500 m radius of elevated suspended sediment levels. Sediment is primarily at the bottom 1.8 m of the water column.
Mechanical dredging	Range from 105 mg/L in the middle of the water column to 445 mg/L near the bottom of the water column	Elevated SS concentrations at several hundreds of mg/L above background may be present in the immediate vicinity of the bucket dredge but would settle rapidly within a 730 m radius of the dredge.
Beach nourishment	About 34–64 mg/L	Since material is primarily coarse sands, plumes from the discharge should settle rapidly and not affect large areas. SS limited to an area approximately 1,640 ft (500 m) down current from the discharge pipe and settle within several hours after discharge cessation.
Off-shore disposal	Up to 500 mg/L within 250 feet of disposal vessel; 15–100 mg/L 300–2,000 m away	The SS is expected to decrease to background levels within 300–2,000 m of the placement site. TSS concentrations near the center of the plume created by the placement of dredged material have been observed to reach near background levels in 35–45 min.
Pile driving and removal	Up to 250 mg/L at 20 m from the plow; 43 mg/L within 200 m	Elevated levels of suspended sediment are predicted to return to ambient conditions within 24–48 h after plowing operations.

Note: SS = suspended sediment.

5 Conclusions and Recommendations

5.1 Conclusions

Suspended sediment exposures can pose risks to aquatic organisms. The risk to aquatic organisms during dredging scenarios depends on several factors, particularly exposure length (i.e., how long sediment in a certain location remains suspended) and concentration (influenced by distance from the dredge). The effects of suspended sediments vary among different groups of organisms, ranging from mortality to sublethal effects such as reduced growth, decreased reproduction, altered behavior, physiological and morphological changes, and diminished feeding efficiency. These data indicate corals and daphnids (planktonic crustaceans) are particularly sensitive to suspended sediment, while bivalves and marine crustaceans tend to be more tolerant. Exposure duration is an important consideration, with organisms showing greater sensitivity to longer and continuous exposures to suspended sediment. By providing a framework for visualizing thresholds of sediment effects concentrations associated with potential impacts on aquatic species, this report and accompanying database can be used to support site-specific sediment management decision-making.

5.2 Recommendations

The authors recommend that this database be periodically updated and expanded with future projects and funding opportunities. The current iteration of the database and associated literature review effort provide valuable information for understanding concentrations of suspended sediment reported to impact aquatic organisms in the context of dredging activity.

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Appendix A: Link to Sediment Effects Database

<https://doer.el.erdcdren.mil/sdSED.html>.

Appendix B: Data Extraction

No observed effect concentration (NOEC) and lowest observed effect concentration (LOEC) data for corals were collected from Supplementary file 3 (the database) from Tuttle and Donahue (2022) and Table 5 from Erftemeijer et al. (2012). When a study was included in both reviews, only the data from Tuttle and Donahue (2022) was included for data analysis to avoid duplication.

Tuttle and Donahue (2022) did not clearly indicate NOEC and LOEC data included in their database, so the following procedure was followed to extract data for this literature review effort.

First, the *Adverse effect of sediment?* column was referenced to check if there was a negative impact upon coral observed with the sediment concentrations used in the study. If “0” (indicating no effect) was entered, the highest value from each concentration series (for the same organism and time duration) were entered as a NOEC. If “1” (indicating an effect) was entered, further steps were taken to identify NOEC and LOEC data.

If an adverse effect was indicated, the next step was to identify the appropriate end point (indicated as a “response” in Tuttle and Donahue 2022). Note that while our database file contains unique responses/end points in their own row, in Tuttle and Donahue (2022), all responses for a treatment were included in the same Excel row. If only a single response was entered, the *Adverse effect of sediment?* column was used to identify NOEC and LOEC values, with NOEC being the highest value in a treatment with no effect (indicated as “0”) and LOEC being the lowest value with an effect (“1”). If multiple responses were provided, they were first designated as either lethal (mortality/survival, bleaching, necroses, tissue damage) or sublethal (other end points). All sublethal end points for a particular treatment were grouped together for reporting NOEC and LOEC values, unless otherwise noted; similarly, all lethal end points were grouped together for a particular treatment unless otherwise noted. Because the *Adverse effect of sediment?* column in Tuttle and Donahue (2022) reflects data for all end point responses for a particular treatment, the *binary response* or other columns as noted were used to distinguish NOEC/LOEC values for separate end points. For *Response 1*, the data was also included quantitatively in the column *Endpt_Quant* in our database. If multiple sublethal responses were found to be relevant for a row of data, these were

indicated as “Multiple” in the *Endpt* column and “Sublethal” in the *Endpt_Lethality* column, whereas multiple lethal responses were indicated as “Multiple” and Sublethal) in these columns.

Data from studies were excluded from NOEC/LOEC analyses for several reasons, including lack of clearly designated treatment or control groups, only testing a single sediment concentration, and adverse effects designated in the control group.

Appendix C: No Observed Effect Concentration (NOEC) Plots

Figure C-1. Suspended sediment no observed effect concentration (NOEC) data compiled from the literature review effort for sublethal end points in exposures less than or equal to 96 h in duration. These values are not intended to be definitive or for regulatory use. Instead, this lays out a process for summarizing toxicological data for important ecological receptors of concern. See Figure 2 for an explanation on how to interpret box-and-whisker plots.

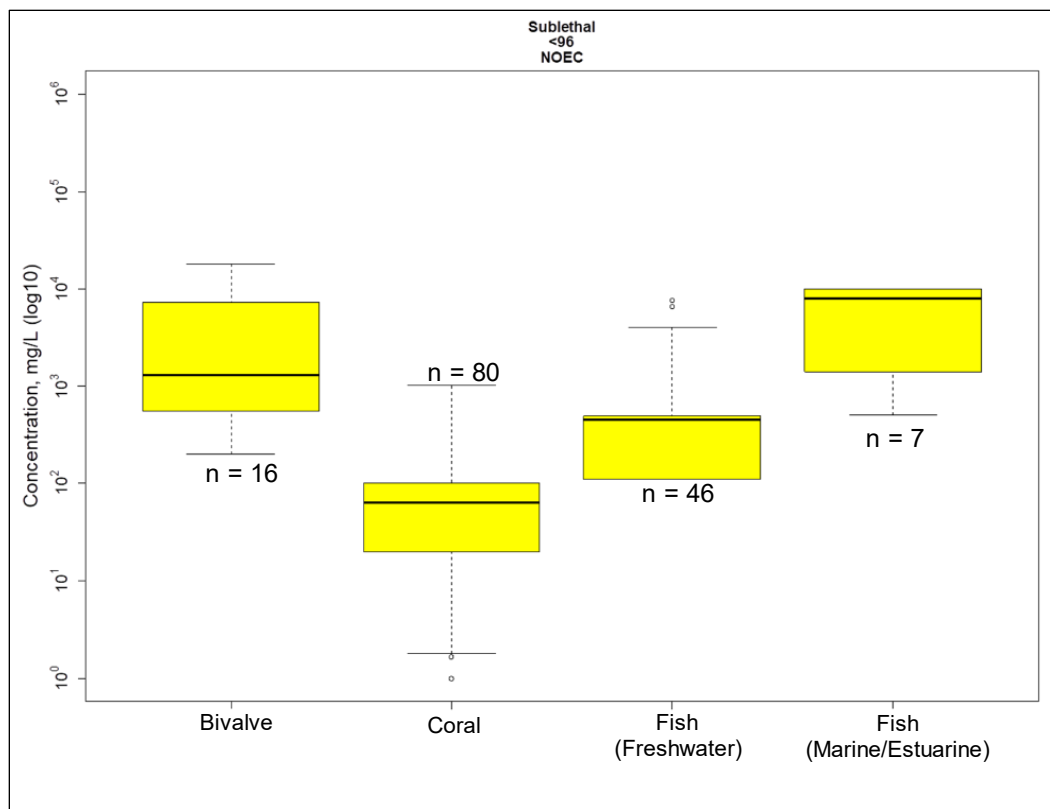


Figure C-2. Suspended sediment NOEC data compiled from the literature review effort for lethal end points in exposures less than or equal to 96 h in duration. These values are not intended to be definitive or for regulatory use. Instead, this lays out a process for summarizing toxicological data for important ecological receptors of concern. See Figure 2 for an explanation on how to interpret box-and-whisker plots.

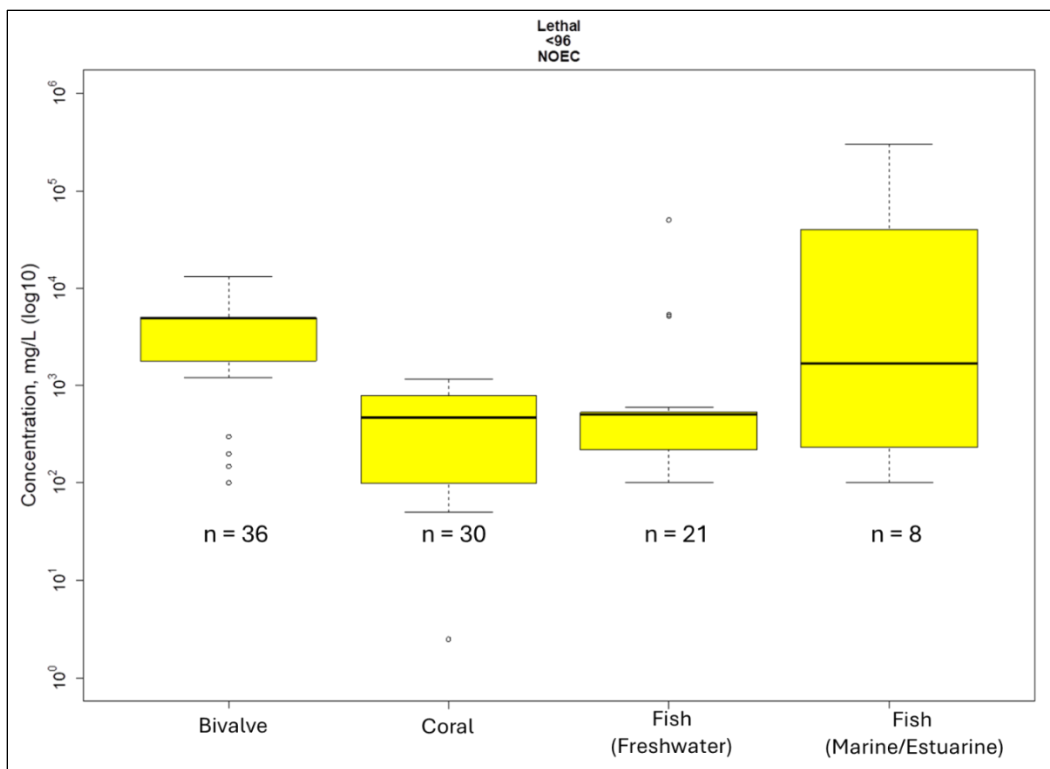


Figure C-3. Suspended sediment NOEC data compiled from the literature review effort for sublethal end points in exposures greater than 96 h in duration. These values are not intended to be definitive or for regulatory use. Instead, this lays out a process for summarizing toxicological data for important ecological receptors of concern. See Figure 2 for an explanation on how to interpret box-and-whisker plots.

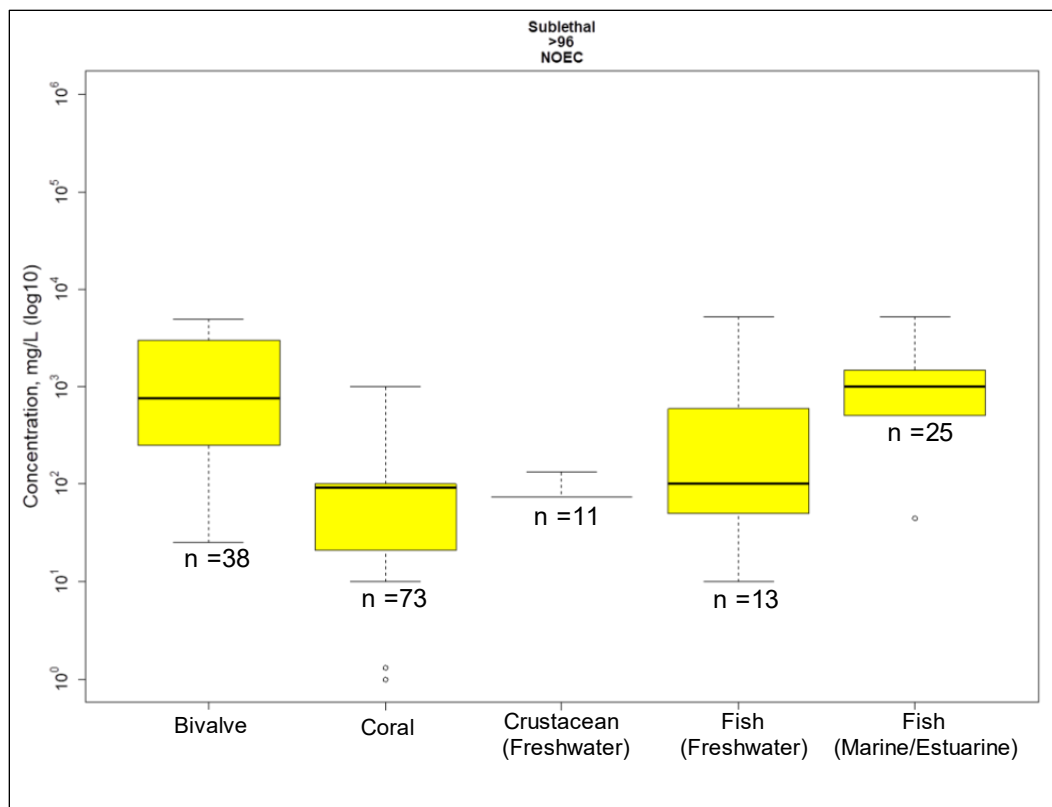
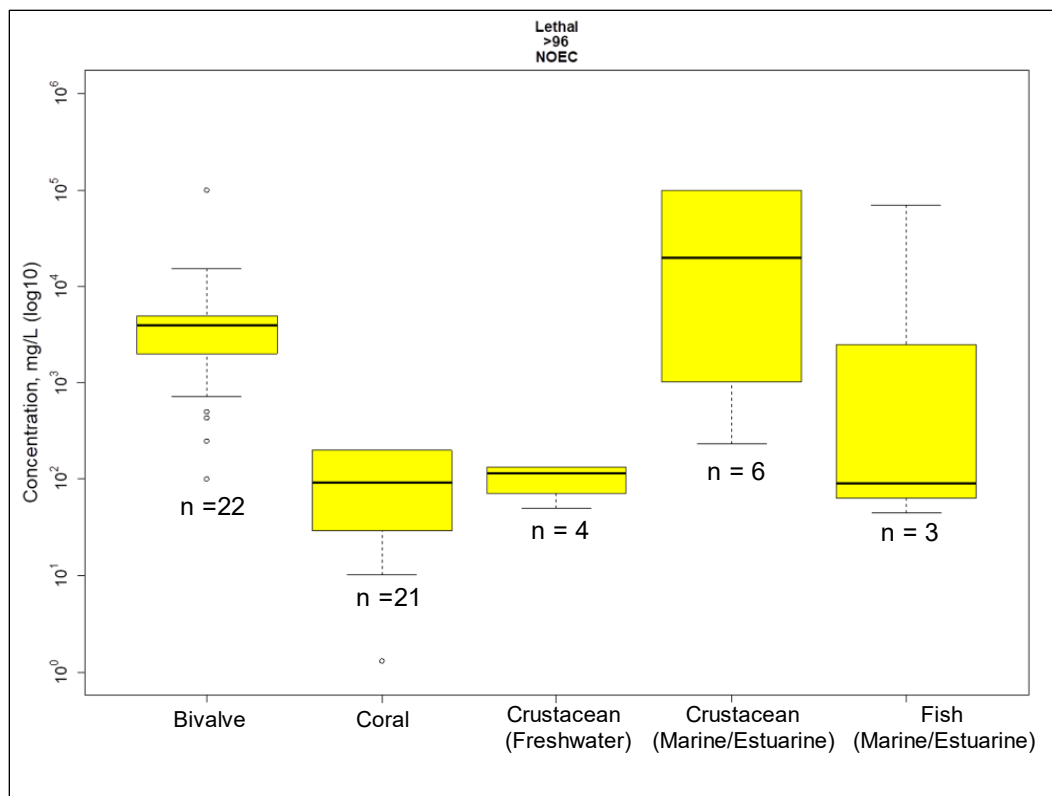


Figure C-4. Suspended sediment NOEC data compiled from the literature review effort for lethal end points in exposures greater than 96 h in duration. These values are not intended to be definitive or for regulatory use. Instead, this lays out a process for summarizing toxicological data for important ecological receptors of concern. See Figure 2 for an explanation on how to interpret box-and-whisker plots.



Appendix D: Species Sensitivity Distribution Tables

Table D-1. Species sensitivity distribution data for all species with lethal lowest observed effect concentration (LOEC) observations.

Taxa, exposure duration (hours)	Mean Stressor Intensity (mg/L)	Standard Deviation	Proportion Taxa	Number of Observations
<i>Montipora aequituberculata</i> (Coral), >96	7	0.56	2%	3
<i>Acropora digitifera</i> (Coral), <96	47	—	5%	1
<i>Alburnus tarichi</i> (Fish), >96	50	—	8%	2
<i>Acropora millepora</i> (Coral), >96	99	0.0043	11%	5
<i>Alosa sapidissima</i> (Fish), <96	100	—	15%	1
<i>Acropora tenuis</i> (Coral), >96	100	—	15%	1
<i>Stephanocoenia mitchelini</i> (Coral), >96	165	—	21%	1
<i>Scolymia lacera</i> (Coral), >96	165	—	21%	1
<i>Acanthochromis polyacanthus</i> (Fish), >96	180	—	27%	1
<i>Stephanocoenia intersepta</i> (Coral), >96	199	—	31%	1
<i>Scolymia cubensis</i> (Coral), >96	199	—	31%	1
<i>Phyllangia americana</i> (Coral), >96	199	—	31%	1
<i>Manicina areolata</i> (Coral), >96	199	—	31%	1
<i>Isophyllia sinuosa</i> (Coral), >96	199	—	31%	1
<i>Cladocora arbuscula</i> (Coral), >96	199	—	31%	1
<i>Micropterus dolomieu</i> (Fish), <96	267	0.30	50%	7
<i>Porites lutea</i> (Coral), >96	286	—	53%	1
<i>Pocillopora acuta</i> (Coral), <96	458	—	56%	1
<i>Perca flavescens</i> (Fish), <96	500	—	60%	1
<i>Morone saxatilis</i> (Fish), <96	500	—	60%	2
<i>Mercenaria mercenaria</i> (Bivalve), >96	500	—	60%	1
<i>Montastraea annularis</i> (Coral), <96	690	0.23	69%	2
<i>Agaricia agaricites</i> (Coral), <96	690	0.23	69%	2
<i>Acropora cervicornis</i> (Coral), <96	690	0.23	69%	2
<i>Acropora millepora</i> (Coral), <96	962	—	79%	1
<i>Sinonovacula constricta</i> (Bivalve), >96	1,000	—	82%	1
<i>Americamysis bahia</i> (Crustacean), >96	1,020	—	85%	1
<i>Crassostrea virginica</i> (Bivalve), >96	1,732	0.51	89%	2
<i>Ostrea edulis</i> (Bivalve), >96	4,000	—	92%	1
<i>Oncorhynchus kisutch</i> (Fish), <96	100,000	—	95%	1
<i>Parophrys vetulus</i> (Fish), >96	117,000	—	98%	1

Note: ">96" and "<96" refers to the exposure duration period in hours; "mean stressor intensity" refers to the mean suspended sediment concentrations in milligrams per liter that cause the specified effect in the indicated species; "proportion taxa" gives the estimate number of species expected to be affected at the mean stressor intensity value.

Table D-2. Proportion data for the species sensitivity distribution (SSD). Refer to USEPA (2017) for details regarding SSD calculations.

Proportion	Probit	Log Central Tendency	SSQ	Log Upper PI	Log Lower PI	Central Tendency	Upper PI	Lower PI
0.05	3.36	1.20	0.13	1.82	0.57	16 ^a	66 ^a	4 ^a
0.10	3.72	1.52	0.13	2.13	0.91	33	135	8
0.20	4.16	1.92	0.12	2.51	1.31	82	327	20
0.40	4.75	2.44	0.12	3.03	1.84	274	1,079	70
0.50	5.00	2.66	0.12	3.26	2.07	462	1,816	117
0.70	5.52	3.13	0.12	3.73	2.53	1,357	5,384	342
0.80	5.84	3.42	0.12	4.02	2.81	2,605	10,461	649
0.90	6.28	3.81	0.13	4.42	3.19	6,438	26,493	1,564
0.95	6.64	4.13	0.13	4.76	3.51	13,589	57,454	3,214

Note: SSQ = sum of squares; PI = prediction interval.

^aFifth percentile hazard quotient (HC5) and its respective prediction interval.

Table D-3. Species sensitivity distribution data for marine species with LOEC observations from greater than 96 h exposures for both sublethal and lethal end points.

Taxa	Mean Stressor Intensity (mg/L)	Standard Deviation	Proportion Taxa	Number of Observations
<i>Montipora aequituberculata</i> (Coral)	5	0.43	2%	5
<i>Pocillopora acuta</i> (Coral)	10	—	5%	1
<i>Montastraea annularis</i> (Coral)	10	—	5%	1
<i>Amphiprion percula</i> (Fish)	15	—	12%	1
<i>Merulina ampliata</i> (Coral)	36	—	16%	4
<i>Acropora muricata</i> (Coral)	45	—	19%	1
<i>Montipora verrucosa</i> (Coral)	59	—	22%	1
<i>Pecten maximus</i> (Bivalve)	66	—	26%	1
<i>Pachyseris speciosa</i> (Coral)	70	0.20	29%	7
<i>Acanthochromis polyacanthus</i> (Fish)	90	0.25	33%	4
<i>Acropora millepora</i> (Coral)	99	0.0043	36%	5
<i>Spisula solidissima</i> (Bivalve)	100	—	40%	1
<i>Montastraea annularis</i> (Coral)	100	—	40%	1
<i>Acropora tenuis</i> (Coral)	100	—	40%	2
<i>Stephanocoenia mitchelinii</i> (Coral)	165	—	50%	1
<i>Scolymia lacera</i> (Coral)	165	—	50%	1
<i>Stephanocoenia intersepta</i> (Coral)	199	—	57%	1
<i>Scolymia cubensis</i> (Coral)	199	—	57%	1
<i>Phyllangia americana</i> (Coral)	199	—	57%	1
<i>Manicina areolata</i> (Coral)	199	—	57%	1
<i>Isophyllia sinuosa</i> (Coral)	199	—	57%	1
<i>Cladocora arbuscula</i> (Coral)	199	—	57%	1

Table D-3 (cont.). Species sensitivity distribution data for marine species with LOEC observations from greater than 96 h exposures for both sublethal and lethal end points.

Taxa	Mean Stressor Intensity (mg/L)	Standard Deviation	Proportion Taxa	Number of Observations
<i>Mercenaria mercenaria</i> (Bivalve)	276	0.56	78%	7
<i>Porites lutea</i> (Coral)	286	—	81%	1
<i>Sinonovacula constricta</i> (Bivalve)	1,000	—	84%	1
<i>Americamysis bahia</i> (Crustacean)	1,020	—	88%	2
<i>Crassostrea virginica</i> (Bivalve)	1,285	0.35	91%	6
<i>Ostrea edulis</i> (Bivalve)	2,632	0.36	95%	4
<i>Parophrys vetulus</i> (Fish)	11,7000	—	98%	1

Note: “Mean stressor intensity” refers to the mean suspended sediment concentrations in milligrams per liter that cause the specified effect in the indicated species; “proportion taxa” gives the estimate number of species expected to be affected at the mean stressor intensity value.

Table D-4. Proportion data for the SSD. Refer to USEPA (2017) for details regarding SSD calculations.

Proportion	Probit	Log Central Tendency	SSQ	Log Upper PI	Log Lower PI	Central Tendency	Upper PI	Lower PI
0.05	3.36	0.78	0.09	1.29	0.27	6 ^a	20 ^a	2 ^a
0.10	3.72	1.10	0.09	1.61	0.60	13	40	4
0.20	4.16	1.49	0.08	1.99	1.00	31	97	10
0.40	4.75	2.02	0.08	2.51	1.53	104	320	34
0.50	5.00	2.24	0.08	2.73	1.75	174	538	56
0.70	5.52	2.71	0.08	3.20	2.21	509	1,584	163
0.80	5.84	2.99	0.09	3.49	2.49	973	3,061	309
0.90	6.28	3.38	0.09	3.89	2.87	2,393	7,689	745
0.95	6.64	3.70	0.09	4.22	3.18	5,030	16,548	1,529

Note: SSQ = sum of squares; PI = prediction interval.

^aFifth percentile hazard quotient (HC5) and its respective prediction interval.

Table D-5. Species sensitivity distribution data for marine species with LOEC observations from less than 96 h exposures for both sublethal and lethal end points.

Taxa	Mean Stressor Intensity (mg/L)	Standard Deviation	Proportion Taxa	Number of Observations
<i>Porites cylindrica</i> (Coral)	4	—	2%	1
<i>Goniastrea retiformis</i> (Coral)	8	—	5%	1
<i>Acropora digitifera</i> (Coral)	41	0.086	9%	6
<i>Spisula solidissima</i> (Bivalve)	100	—	12%	1
<i>Alosa sapidissima</i> (Fish)	100	—	12%	1
<i>Acropora cervicornis</i> (Coral)	139	0.66	19%	4
<i>Montastraea annularis</i> (Coral)	150	—	22%	1
<i>Acropora tenuis</i> (Coral)	152	0.42	26%	7
<i>Pectina lactusa</i> (Coral)	169	—	29%	1

Table D-5 (cont.). Species sensitivity distribution data for marine species with LOEC observations from less than 96 h exposures for both sublethal and lethal end points.

Taxa	Mean Stressor Intensity (mg/L)	Standard Deviation	Proportion Taxa	Number of Observations
<i>Pachyseris speciosa</i> (Coral)	174	—	33%	1
<i>Merulina ampliata</i> (Coral)	174	—	33%	1
<i>Acropora millepora</i> (Coral)	229	0.42	40%	7
<i>Platgyra sinensis</i> (Coral)	243	—	43%	1
<i>Mercenaria mercenaria</i> (Bivalve)	397	0.46	47%	3
<i>Agaricia agaricites</i> (Coral)	415	0.42	50%	3
<i>Pocillopora acuta</i> (Coral)	458	—	53%	1
<i>Porites furcata</i> (Coral)	476	—	57%	1
<i>Porites divaricata</i> (Coral)	476	—	57%	1
<i>Porites astreoides</i> (Coral)	476	—	57%	1
<i>Dichocoenia stokesi</i> (Coral)	476	—	57%	1
<i>Acropora cervicornis</i> (Coral)	476	—	57%	1
<i>Orbicella annularis</i> (Coral)	525	—	74%	1
<i>Montastraea annularis</i> (Coral)	690	0.23	78%	2
<i>Perca flavescens</i> (Fish)	707	0.21	81%	2
<i>Crassostrea virginica</i> (Bivalve)	867	0.94	84%	2
<i>Morone saxatilis</i> (Fish)	1,000	0.25	88%	7
<i>Morone americana</i> (Fish)	1,414	0.17	91%	4
<i>Clupea harengus pallasii</i> (Fish)	2,000	0.30	95%	3
<i>Mercenaria mercenaria</i> (Bivalve)	2,200	—	98%	1

Note: “Mean stressor intensity” refers to the mean suspended sediment concentrations in milligrams per liter that cause the specified effect in the indicated species; “proportion taxa” gives the estimate number of species expected to be affected at the mean stressor intensity value.

Table D-6. Proportion data for the SSD. Refer to USEPA (2017) for details regarding SSD calculations.

Proportion	Probit	Log Central Tendency	SSQ	Log Upper PI	Log Lower PI	Central Tendency	Upper PI	Lower PI
0.05	3.36	1.37	0.06	1.80	0.94	23 ^a	63 ^a	9 ^a
0.10	3.72	1.61	0.06	2.03	1.19	40	107	15
0.20	4.16	1.90	0.06	2.31	1.48	79	206	30
0.40	4.75	2.29	0.06	2.70	1.88	194	499	76
0.50	5.00	2.46	0.06	2.87	2.05	286	735	112
0.70	5.52	2.80	0.06	3.22	2.39	637	1,645	247
0.80	5.84	3.01	0.06	3.43	2.60	1,034	2,693	397
0.90	6.28	3.31	0.06	3.73	2.88	2,023	5,364	763
0.95	6.64	3.55	0.06	3.98	3.11	3,523	9,526	1303

Note: SSQ = sum of squares; PI = prediction interval.

^aFifth percentile hazard quotient (HC5) and its respective prediction interval.

Table D-7. Freshwater species sensitivity distribution data of LOECs for sublethal and lethal end points, including both exposures less than or equal to 96 h and greater than 96 h.

Taxa Exposure Duration (hours)	Mean Stressor Intensity (mg/L)	Standard Deviation	Proportion Taxa	Number of Observations
Daphnia ambigua (Freshwater Crustacean), >96	50	—	3%	4
Alburnus tarichi (Fish), >96	50	—	3%	4
Daphnia parvala (Freshwater Crustacean), >96	55	—	16%	1
Daphnia lumholtzi (Freshwater Crustacean), >96	55	—	16%	1
Daphnia hyalina (Freshwater Crustacean), >96	100	—	28%	1
Erimonax monachus (Fish), >96	144.269991	0.5507	34%	5
Corbicula fluminea (Bivalve), >96	150	—	41%	1
Myxocyprinus asiaticus (Fish), <96	200	—	47%	1
Cyprinella galactura (Fish), >96	223.606798	0.4943	53%	2
Micropterus dolomieu (Fish), <96	294.043768	0.1559	59%	20
Morone saxatilis (Fish), <96	890	—	66%	1
Procypris rabaudi (Fish), <96	1000	—	72%	1
Morone americana (Fish), <96	1900	—	78%	1
Oncorhynchus nerka (Fish), <96	2212.14104	1.7502	84%	2
Lampsilis siliquoidea (Bivalve), >96	3535.53391	0.2128	91%	2
Oncorhynchus kisutch (Fish), <96	49079.629	0.2784	97%	3

Note: “>96” and “<96” refers to the exposure duration period in hours; “mean stressor intensity” refers to the mean suspended sediment concentrations in milligrams per liter that cause the specified effect in the indicated species; “proportion taxa” gives the estimate number of species expected to be affected at the mean stressor intensity value.

Table D-8. Proportion data for the SSD. Refer to USEPA (2017) for details regarding SSD calculations.

Proportion	Probit	Log Central Tendency	SSQ	Log Upper PI	Log Lower PI	Central Tendency	Upper PI	Lower PI
0.05	3.355	1.219	0.138	1.873	0.565	16.565 ^a	74.728 ^a	3.672 ^a
0.1	3.718	1.527	0.130	2.163	0.891	33.651	145.387	7.789
0.2	4.158	1.900	0.123	2.519	1.281	79.383	330.007	19.096
0.4	4.747	2.398	0.119	3.006	1.791	250.115	1013.130	61.747
0.5	5.000	2.613	0.119	3.220	2.006	410.002	1657.850	101.397
0.7	5.524	3.057	0.121	3.670	2.444	1140.462	4678.793	277.989
0.8	5.842	3.326	0.125	3.948	2.704	2117.602	8866.415	505.755
0.9	6.282	3.699	0.132	4.339	3.058	4995.427	21812.359	1144.043
0.95	6.645	4.006	0.140	4.666	3.346	10147.943	46387.771	2219.998

Note: SSQ = sum of squares; PI = prediction interval.

^aFifth percentile hazard quotient (HC5) and its respective prediction interval.

Abbreviations

APHA	American Public Health Association
DEQ	Department of Environmental Quality
EC20	Effect concentration to impact 20% of test organisms
FNU	Formazin Nephelometric Units
HC5	Fifth percentile hazard quotient
ISO	International Organization for Standardization
LC50	Lethal concentration to kill 50% of test organisms
LOEC	Lowest observed effect concentration
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOEC	No observed effect concentration
NTU	Nephelometric turbidity unit
PI	Prediction interval
SS	Suspended sediment
SSC	Suspended sediment concentration
SSD	Species sensitivity distribution
SSQ	Sum of squares
TSS	Total suspended solids
USACE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
USGS	US Geological Survey

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