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DRAFT AQUATIC LIFE AMBIENT ESTUARINE/MARINE WATER QUALITY CRITERIA FOR COPPER - 2016

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AMBIENT ESTUARINE/MARINE WATER QUALITY CRITERIA FOR
COPPER - 2016

(CAS Registry Number 7440-50-8)

July 2016

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER
OFFICE OF SCIENCE AND TECHNOLOGY
HEALTH AND ECOLOGICAL CRITERIA DIVISION
WASHINGTON, D.C.

NOTICES

This document provides information for states and tribes authorized to administer a water quality standards program, to consider in adopting water quality standards under the Clean Water Act (CWA), to protect aquatic life from toxic effects of copper in estuarine/marine environments. Under the CWA, states and tribes are to adopt water quality criteria to protect designated uses. State and tribal decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from these criteria when appropriate. While this document contains EPA's scientific recommendations regarding ambient concentrations of copper in estuarine/marine environments that protect aquatic life, it does not substitute for the CWA or EPA's regulations; nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, states, tribes, or the regulated community, and might not apply to a particular situation based upon the circumstances. EPA may change this document in the future. This document has been approved for publication by the Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency.

FOREWORD

Section 304(a) (l) of the Clean Water Act, 33 U.S.C. § 1314(a)(1), directs the Administrator of the Environmental Protection Agency to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including ground water. This document is EPA's new recommended ambient water quality criteria (AWQC) for the protection of aquatic life based upon consideration of available information relating to effects of copper on estuarine/marine organisms, and consideration of independent external peer review and EPA workgroup comments.

The term "water quality criteria" is used in two sections of the Clean Water Act: section 304(a)(l) and section 303(c)(2). The term has different meanings in each section. In section 304, the term represents a non-regulatory, scientific assessment of ecological and human health effects. The criteria presented in this document are such a scientific assessment of ecological effects. In section 303(c), the term water quality criteria refer to criteria adopted by a state or authorized tribe as part of their legally-binding water quality standards. Criteria in water quality standards establish the maximum acceptable pollutant concentrations in ambient waters protective of the state's designated uses. States and authorized tribes may adopt water quality criteria in their water quality standards that have the same numerical values as EPA's recommended section 304(a)(1) criteria. However, states and authorized tribes may decide to adopt water quality criteria different from EPA's section 304 recommendations to reflect local environmental conditions and human exposure patterns. Alternatively, states and authorized tribes may use different data and assumptions than EPA in deriving numeric criteria that are scientifically defensible and protective of designated uses. It is not until their adoption as part of state or tribal water quality standards and approved by EPA (or in limited instances promulgated by EPA) under section 303(c) that criteria become applicable water quality standards for Clean Water Act purposes. Information to assist the states and authorized tribes in modifying the recommended criteria presented in this document is contained in the Water Quality Standards Handbook (U.S. EPA 2014). This handbook and additional information on the development of water quality standards and other water-related programs of this agency have been developed by the Office of Water.

This document does not establish or affect legal rights or obligations. It does not establish a binding norm and cannot be finally determinative of the issues addressed. Agency decisions in any particular situation will be made by applying the Clean Water Act and EPA regulations on the basis of specific facts presented and scientific information then available.

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EXECUTIVE SUMMARY

Guidance documents containing aquatic life criteria recommendations for copper (Cu) have been updated and published by EPA over the past 30 years as new science becomes available (e.g., U.S. EPA 1980, 1984, 1986a, 1995a, 1996, 2003, 2007). EPA's most recent 2007 updated recommended criteria for copper only provided an update for freshwater organisms, and differed from EPA's previous metals criteria in that the biotic ligand model (BLM) (Di Toro et al. 2001) addressed the metal availability to organisms. The complexing ligands in water compete with the biotic ligand for metals and other cations in the water. Unlike the empirical toxicity to water hardness relationships, which EPA used to establish copper criteria prior to 2007, the BLM explicitly accounts for individual water quality variables, is not linked to a particular correlation amongst the variables, and can address variables that are not a factor in the hardness relationship. EPA did not update estuarine/marine criteria in 2007 because a saltwater BLM had not been sufficiently developed and tested at that time.

This document utilizes the recently developed saltwater BLM to provide updated BLM-based acute and chronic water quality criteria (WQC) for copper that are applicable to both estuarine and marine waters. This saltwater BLM includes a new characterization of copper binding to natural organic matter (NOM) in estuarine/marine systems and considers the binding of copper to the surface membranes of embryo-larval stages of several sensitive marine invertebrates. Development of the saltwater BLM for copper is detailed in Chadwick et al. (2008).

EPA is developing the recommended ambient WQC for copper in estuarine/marine waters pursuant to its authority under §304(a)(1) of the Clean Water Act (CWA). EPA developed the copper aquatic life criteria using peer reviewed methods and data that EPA determined to be acceptable for their derivation as described in U.S. EPA's "*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*" (Guidelines) (Stephan et al. 1985). This update includes the evaluation of data submitted in support of the registration of copper-containing pesticides that were reviewed by EPA's Office of Pesticide Programs and studies reported in the open literature.

The resulting recommended ambient WQC indicate that estuarine/marine aquatic organisms would have an appropriate level of protection if the 1-hour average and four-day average dissolved copper concentrations do not respectively exceed the acute and chronic criteria concentrations calculated by the saltwater BLM more than once every three years on average. For the 2016 draft acute criteria, EPA has changed the duration to 1 hour from the 24 hours EPA recommended in the 2003 draft copper criteria for estuarine/marine organisms and the 2007 recommended freshwater copper criteria. EPA made this change to the 2016 criteria to reflect the acute criteria duration recommended in EPA's Guidelines (see **Section 4.1.2**). Because this updated WQC relies on the BLM, the numeric WQC change accordingly in response to changes in water quality parameters (i.e., temperature, salinity, dissolved organic carbon and pH). At an example pH of 8.0, temperature of 22°C, DOC of 1.0 mg/L and salinity of 32 ppt, the 2016 acute criterion magnitude is 2.0 µg/L copper (lowered to protect the commercially important red abalone *Haliotis rufescens*), and the chronic criterion magnitude is 1.3 µg/L copper. Additional examples at different water chemistry conditions are provided in Appendix I.

This document provides guidance to states and authorized tribes to consider in adopting water quality standards under the CWA to protect estuarine/marine aquatic life from the acute and chronic effects of copper. Under the CWA, states and authorized tribes may adopt these WQC into water quality standards to protect designated uses. While this document constitutes EPA's scientific recommendations regarding ambient concentrations of copper, this document does not substitute for the CWA or EPA's regulations, nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, states, authorized tribes, or the regulated community, and it might not apply to a particular situation based upon the circumstances. State and tribal decision-makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance when appropriate.

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ACRONYMS

ACR	Acute-Chronic Ratio
ALC	Aquatic Life Criteria
BL	Biotic Ligand
BLM	Biotic Ligand Model
CCC	Criterion Continuous Concentration
CF	Conversion Factors
CHESS	Chemical Equilibria in Soils and Solutions
CMC	Criterion Maximum Concentration
CWA	Clean Water Act
DIC	Dissolved Inorganic Carbon
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
EC_{50}/EC_{20}	Effect concentration to 50%/20% of the test population
ELS	Early Life Stage
EPA	Environmental Protection Agency
FACR	Final Acute-Chronic Ratio
FAV	Final Acute Value
FCV	Final Chronic Value
FFDCA	Federal Food, Drug and Cosmetic Act
FIAM	Free Ion Activity Model
FQPA	Food Quality Protection Act
GDCI	Generic Data Call-In
GMAV	Genus Mean Acute Value
GMCV	Genus Mean Chronic Value
GSIM	Gill Surface Interaction Model
HA	Humic Acid
IC_{50}	Inhibition Concentration where effect is inhibited 50% compared to control organism
LA_{50}	Lethal Level of Accumulation at 50% effect level
LC_{50}	Lethal Concentration to 50% of the test population
LOAEC	Lowest Observed Adverse Effect Concentration
LOEC	Lowest Observed Effect Concentration
MATC	Maximum Acceptable Toxicant Concentration (geometric mean of NOEC and LOEC)
MDR	Minimum Data Requirements
Me:BL	Metal-Biotic Ligand Complex
MSE	Mean Square Error
NASQAN	National Stream Quality Accounting Network
NOAEC	No Observed Adverse Effect Concentration
NOEC	No Observed Effect Concentration
NOM	Natural Organic Matter
PLC	Partial Life-Cycle
RED	Reregistration Eligibility Decision
SMAV	Species Mean Acute Value
SMCV	Species Mean Chronic Value
SSD	Species Sensitivity Distribution
TSS	Total Suspended Solids
WER	Water-Effect Ratio
WET	Whole Effluent Toxicity
WHAM	Windermere Humic Aqueous Model
WQC	Water Quality Criteria

1 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is developing ambient water quality criteria (WQC) for copper (Cu) for the protection of aquatic life in estuarine/marine waters through its authority under §304(a)(1) of the Clean Water Act (CWA). Over the past 30 years the EPA has published a number of guidance documents containing aquatic life criteria recommendations for copper (U.S. EPA 1980, 1984, 1986a, 1995a, 1996, 2003, and 2007). The most recent 2007 updated recommended WQC document only provided an update for freshwater criteria, and differed from EPA's previous metals criteria primarily with regard to how metal availability to organisms is addressed. EPA based previous criteria recommendations on empirical relationships between toxicity and water hardness. In the 2007 freshwater acute and chronic recommended criteria, EPA instead used the biotic ligand model (BLM) (Di Toro et al. 2001). The BLM is based on the premise that: (1) toxicity is related to the amount of metal bound to a biochemical site (the biotic ligand); and (2) binding is related to the total dissolved metal and complexing ligand concentrations in water. The biotic ligand is a binding site on biological membranes which is associated with the mechanism of toxicity in the organism. Some ligands and cations complex with metals in water, while other elements compete for binding sites on the biotic ligand with the uncomplexed, bioavailable metals in water. Unlike the empirical hardness relationships, the BLM explicitly accounts for a broader range of water quality variables, including variables that are not a factor in the hardness relationship. The BLM is not linked to a particular correlation amongst these variables.

EPA's current recommended estuarine/marine criteria for copper are based on data for 33 species representing 26 genera (U.S. EPA 1995a). EPA last updated the estuarine/marine criteria as draft in 2003 and were derived without normalization of the available toxicity data. EPA based the draft 2003 acute criterion on Species Mean Acute Values (SMAVs) for 52 species in 44 genera (34 invertebrates and 18 fish species), with mussels, oysters and the summer flounder identified as the most sensitive species. Chronic saltwater tests were available only for the sheepshead minnow, *Cyprinodon variegatus* in the 2003 draft document. Sufficient toxicity data were available to fulfill requirements to calculate an acute estuarine/marine criterion using a species sensitivity distribution (SSD), as described in EPA's Guidelines (Stephan et al. 1985). The Final Acute Value (FAV) and Criterion Maximum Concentration (CMC) were lowered to be protective of the commercially and recreationally important mussel, *Mytilus*. Data were not sufficient to calculate the chronic estuarine/marine criterion using a SSD, and therefore Acute-Chronic Ratios (ACRs) were used to derive the 2003 draft criterion.

EPA did not update the estuarine/marine criteria at the time of the 2007 release of the BLM-based freshwater criteria because the saltwater BLM had not been sufficiently developed or tested. This has now been addressed and details about the development of the saltwater version of the copper BLM were published in Chadwick et al. (2008). The saltwater BLM for copper includes a new description of copper binding to natural organic matter (NOM) represented by dissolved organic carbon (DOC) in the model. DOC is an analytical measurement used to quantify NOM in marine systems, and considers copper binding to the biological membranes of embryo-larval stages of several sensitive marine invertebrates. The chemical properties of NOM in saltwater and freshwater are similar as NOM from either medium can strongly affect the chemistry and bioavailability of copper to aquatic biota. However, the distribution of binding sites for NOM in marine waters differs enough from those in freshwater that a new BLM model was developed for saltwater. This document utilizes an updated version of the saltwater BLM, which was originally published in Chadwick et al. (2008), to provide BLM-based water quality criteria for copper that are applicable to both estuarine and marine waters. Although the original development of the BLM (Chadwick et al. 2008) focused on several sensitive marine invertebrates, application of the model to the development of estuarine/marine WQC required changes to the model to account for additional species over a wider range of copper concentrations.

The present document contains EPA's criteria recommendations for the protection of aquatic life in ambient estuarine/marine water from both acute and chronic toxic effects of copper. EPA updated the estuarine/marine WQC provided in this document in accordance with methods outlined in the Agency's "*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*" (EPA Guidelines) (Stephan et al. 1985). This document describes scientifically defensible water quality criteria values for copper in estuarine/marine waters pursuant to CWA §304(a)(1), derived utilizing best available data in a manner consistent with the EPA Guidelines and reflecting the latest available scientific information and best professional scientific judgments of toxicological effects. Once finalized, these criteria will supersede EPA’s previously published recommendations for copper in estuarine/marine water.

This criteria document provides updated guidance to states and authorized tribes to adopt water quality standards under the CWA to protect estuarine/marine aquatic life from copper. Under the CWA, states and authorized tribes adopt WQC to protect designated uses. Although this document constitutes EPA’s scientific recommendations regarding ambient concentrations of copper in estuarine/marine waters, it does not substitute for the CWA or EPA’s regulations, nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, states, authorized tribes, or the regulated community, and might not apply to a particular situation based on the circumstances. State and tribal decision makers retain the discretion in adopting approaches, on a case-by-case basis, that differ from this guidance when appropriate.

2 PROBLEM FORMULATION

Problem formulation provides a strategic framework to develop water quality criteria by providing an overview of a chemical's sources and occurrence, fate and transport in the environment, and toxicological characteristics and factors affecting toxicity. A problem formulation uses this information to develop a conceptual model and identify the most relevant chemical properties and endpoints for evaluation. The structure of the problem formulation developed for copper in estuarine/marine waters is consistent with U.S. EPA's Guidelines for Ecological Risk Assessment (U.S. EPA 1998) and the approach used by EPA for pesticide effects assessment (U.S. EPA 2004).

Since copper is a registered pesticide in the United States, EPA issued Registration Standards in 1986 for copper sulfate (U.S. EPA 1986a) and in 1987 for Group II copper compounds (U.S. EPA 1987). As a result, Generic Data Call-In (GDCI) notices were issued to registrants in 1987 and 1993. The GDCI notices required registrants to submit ecological fate/effects studies and product chemistry/residue and avian toxicity studies for various copper compounds as part of the 40 CFR Part 158 data necessary to support reregistration (U.S. EPA 2010a). In further support of reregistration, and as required by FIFRA and the Federal Food, Drug and Cosmetic Act (FFDCA) and amended by the Food Quality Protection Act (FQPA), EPA completed the copper Reregistration Eligibility Decision (RED). The RED was signed in July 2006 and was published, along with supporting documents, for public comment in August 2006. The revised RED, which addressed the public comments, is available online (U.S. EPA 2009).

2.1 Overview of Copper Sources and Occurrence

Copper is a naturally occurring element in the earth's crust, with concentrations typically ranging from 55 to 70 mg/kg (Nriagu 1979). U.S. soil levels commonly range from 1 to 40 mg/kg and average around 9 mg/kg (Tisdale et al. 1985). Copper ranks 14th in relative abundance amongst all elements and is typically found combined with other minerals in the form of oxides, carbonates and sulfides (CDA 2003; Chemicool 2012). The highest copper concentrations are found in basaltic igneous rocks (averaging approximately 90 mg/kg), while much lower concentrations (averaging 4 mg/kg) are found in sedimentary limestones (CDA 2003).

Copper is commonly found in aquatic systems as a result of both natural and anthropogenic sources (Nriagu 1979). Natural sources of copper to aquatic systems include geological deposits, weathering and erosion of rocks and soils and volcanic activity (Kious and Tilling 1996). It is estimated that, on average, approximately 68% of the copper released to surface waters originates from these sources (ATSDR 1990). Naturally occurring copper concentrations have been reported to range from 0.03 to 0.23 µg/L in surface seawaters (Bowen 1985). In a review paper, Kennish (1998) reported copper concentrations ranging from 0.3 to 3.8 µg/L in estuarine waters and from 0.1 to 2.5 µg/L in coastal waters of the United States.

Copper concentrations in estuarine environments receiving anthropogenic inputs can range from background to more than 15 µg/L, and concentrations in impacted coastal waters have been reported to range from 0.5 to 2.6 µg/L (International Copper Association 2003). It should be noted, however, that much of the quantitative metals data for samples collected from natural waters prior to the mid-1970s are considered inaccurate due to contamination from sampling methods or containers.

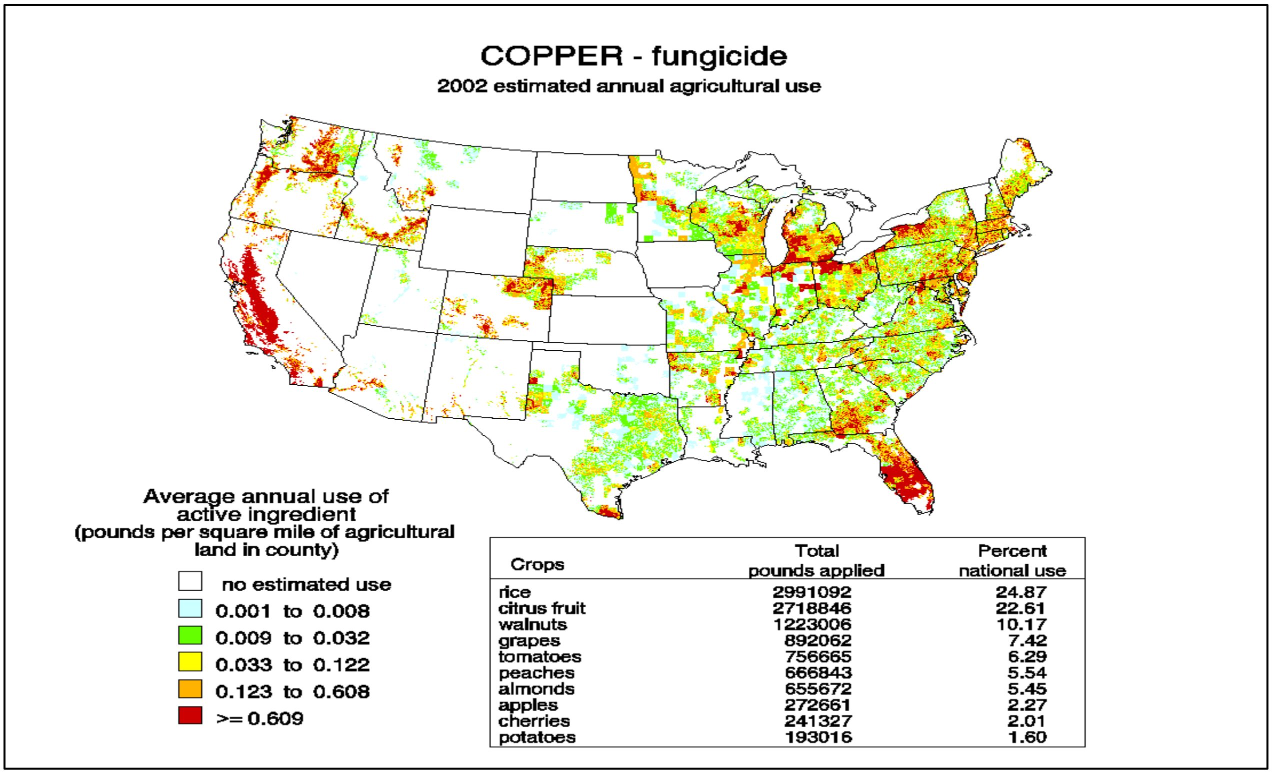
Elevated concentrations of copper in the aquatic environment can result from both natural sources, such as from the erosion of soils, and from numerous anthropogenic point and nonpoint sources. The following discussion provides a description of some of the most notable anthropogenic sources.

A broad range of mining/resource extraction activities can represent a source of copper to the aquatic environment via both permitted discharges from active mines and uncontrolled releases from abandoned mines. Abandoned mines are a notable source of copper due to acid mine drainage, which solubilizes and transports a broad range of metals, including copper, to adjacent waterbodies. Copper mining activities can, in particular, represent a source of copper to the environment, with the majority of both historic and ongoing copper mining activity in the U.S. occurring in Arizona, Utah, New Mexico, Nevada and Montana (CDA 2012). EPA estimated that mining has impacted headwater streams in more than 40 percent of watersheds in the western United States (U.S. EPA 1994b, 2012a).

Copper is widely used in pesticides and elevated concentrations of copper in the environment can result from the application and use of registered pesticides. The first copper-containing pesticide registration was issued in 1956. Currently, there are 19 copper compounds that have active food use registrations (12 for agricultural uses and 7 for antimicrobial uses) and that are subject to tolerance reassessment and registration review (U.S. EPA 2010a).

Copper is widely used as a broad-spectrum bactericide, fungicide, antimicrobial, herbicide, algaecide, and molluscicide for a variety of agricultural, commercial and urban purposes. Marketed trade names include Kocide, CuproFix, Basicop, K-Tea, Cutrine Ultra and Triangle. In 2002, for example, it was estimated that approximately 106 million pounds of copper was applied nationwide as an agricultural fungicide (**Figure 1**). Primary applications were to rice (25%), citrus fruit (23%), walnuts (10%) and grapes (7%), with lesser amounts used on tomatoes, peaches, almonds, apples, cherries, and potatoes (U.S. EPA 2010a).

As pesticidal products, copper-containing compounds are also applied directly to aquatic systems to control algae, cyanobacteria, aquatic weeds, leeches, mollusks and tadpole shrimp (TDC Environmental 2004; U.S. EPA 2010a). Antimicrobial pesticide uses include wood preservatives including surface and pressure treatments, architectural and antifoulant paints, algae resistant roofing shingles, human drinking water treatment, and other material preservatives. Urban uses include application to control algae and moss in lawns, algae in outdoor swimming pools, and root growth in sewage and irrigation systems.



Crops	Total pounds applied	Percent national use
rice	2991092	24.87
citrus fruit	2718846	22.61
walnuts	1223006	10.17
grapes	892062	7.42
tomatoes	756665	6.29
peaches	666843	5.54
almonds	655672	5.45
apples	272661	2.27
cherries	241327	2.01
potatoes	193016	1.60

Figure 1. Copper Usage Data for Agriculture.
(Source: http://water.usgs.gov/nawqa/pnsp/usage/maps/show_map.php?year=02&map=m5011, accessed on May 25, 2010).

Copper is an essential micronutrient for plant growth and agricultural fertilizers and biosolids containing copper are applied to bolster deficient soils and increase crop yields (CDA 2003; University of Minnesota 2009). Copper is also used as a feed supplement for cattle and other livestock to prevent a deficiency that can make cattle less responsive to vaccines and more susceptible to disease (Oregon State University 2011), and to improve weight gain. Other agricultural uses include copper sulfate in dairy cattle foot baths to control hairy heel warts (Jokela et al. 2010), which can introduce copper to the environment.

A number of other industries have been identified as sources of copper to the environment, including leather and leather product manufacturers, metal fabricators, and electrical equipment manufacturers, amongst others (Patterson et al. 1998; CDA 2003; TDC Environmental 2004). Copper is also released to the environment from the burning of fossil fuels (oil, diesel and coal) and wood (CDA 2003).

Urban runoff from the numerous and unrelated upland sources can cumulatively represent an important anthropogenic source of copper to surface water. In addition to the uses already discussed, sources of copper to runoff include copper roofs and gutters, chromate copper arsenate (CCA) treated wood[1], automotive brake pads and tailpipe emissions, asphalt, coolant leaks and construction erosion. Storm water runoff is estimated to contribute approximately 2% of the total copper released to waterways (ASTDR 1990) compared to 68% contributed from soils through natural weathering and disturbance (Georgopoulis et al. 2001). However, in a study of copper sources to the San Francisco Bay, urban runoff was estimated to contribute approximately 53 percent of the copper loading to the Bay (45,000 to 47,000 pounds per year; TDC Environmental 2004).

In estuarine and marine waters, and to lesser extent freshwater environments, antifouling paints and coatings (also known as Antifouling Systems or AFS's) are pesticidal products used to protect boat/ship hulls, underwater surfaces, buoys and barges, while CCA-impregnated timbers are used for the decking and pilings of boat docks and marine structures. Antifouling paints and coatings are intended to retard the growth of algae, weeds, and other encrusting organisms such as barnacles and mussels on the underwater portion of vessel hulls and underwater surfaces. These encrusting organisms can foul hulls and other underwater surfaces, increasing corrosion and drag, reducing safety and maneuverability, decreasing fuel efficiency and economy, and lengthening transit times (WHOI 1952). The development of antifouling paints and coatings has a long history, as mariners have tried for centuries to keep vessel hulls free from barnacles and other fouling growth (Thomas and Brooks 2010). In the late 1950s and early 1960s, antifouling paint formulations using tributyltin (TBT) were introduced and proved to be excellent at preventing hull fouling. However, restrictions on the use of TBT-based compounds due to severe environmental impacts opened the market for manufacturers to develop new biocides for use on vessels (Kiaune and Singhasemanon 2011). Alternative metals, including copper and zinc, are currently used as substitutes for TBT.

The most common form of copper used in antifouling paints and coatings is cuprous oxide, which acts as a preventative biocide by leaching into the water. Most marine antifouling paints contain 40 to 70 percent cuprous oxide by weight. Since cuprous oxide is comprised of 89 percent copper by weight, typical cuprous oxide marine antifouling paints are 36 to 62 percent copper by weight (TDC Environmental 2004). Although not as common, copper thiocyanate and

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[1] In December 2003, chromated arsenicals manufacturers voluntarily discontinued manufacturing chromated arsenicals-treated wood products for homeowner uses (U.S. EPA 2010b)

copper hydroxide are also used as biocides in antifouling paints and coatings. Copper thiocyanate has the advantage of being compatible with aluminum. The contribution of copper to receiving waters from copper thiocyanate and copper hydroxide paints is small relative to biocides containing cuprous oxide (TDC Environmental 2004).

Antifouling paints and coatings applied to vessel hulls represent one of the most commonly identified sources of copper in marinas. A number of studies have been done to estimate the loading of copper from these paints and coatings. EPA estimated that copper loading from the use of these biocides in California's Lower Newport Bay, which harbors approximately 10,000 boats, contributed more than 62,000 pounds of copper annually through passive leaching and underwater hull cleaning (U.S. EPA 2002). This release could account for as much as 80 percent of the copper input into the Lower Newport Bay. Although this may represent an extreme case, based on the high number and density of boats that are docked and the minimal water circulation and flushing of the harbor, it illustrates the potential significance of antifouling paints and coatings as a source of copper to the aquatic environment.

The U.S. Navy and private researchers conducted two copper source loading studies for the San Diego Bay in the late 1990s (Johnson et al. 1998; PRC Environmental Management, Inc.1997). Both studies concluded that antifouling paints and coatings accounted for the majority of dissolved copper loading to the bay. The San Diego Regional Water Quality Control Board estimated that passive leaching and the underwater hull cleaning of the 2,400 boats berthed in the Shelter Island Yacht Basin marina collectively contribute 98 percent of the copper discharged to the basin (Singhasemanon et al. 2009). Approximately 95 percent of the 1.8 pounds of copper estimated to be released by each boat per year is believed to leach from antifouling paints and coatings while boats are moored at the dock, while the remaining five percent is believed to be released during underwater hull cleaning activities (TDC Environmental 2004).

Copper leaching from vessel hulls represents a potential water quality concern in ports throughout the United States, including ports in the Chesapeake Bay, Port Canaveral and Indian River Lagoon in Florida, and various harbors in Washington State (Carson et al. 2009). In addition to AFS, antifouling paint particles are generated during boat maintenance and from abandoned structures and ships. These particles have the potential to leach metals more rapidly due to the increased surface area and also may be consumed by benthic invertebrates (Turner 2010).

As presented in EPA's *Study of Discharges Incidental to Normal Operation of Commercial Fishing Vessels and Other Non-Recreational Vessels Less than 79 Feet* (U.S. EPA 2010b), elevated levels of copper were found in the ambient water associated with a number of harbors and marinas (**Table 1**). A recent study of AFS biocides in California marinas found dissolved copper concentrations ranging from 0.1-18.4 μg/L in the water, which are similar to the range of concentrations reported in U.S. EPA (2010b). Concentrations were significantly higher in salt- and brackish water marinas than in freshwater marinas (Singhasemanon 2008).

Case Study: Mass Balance for Sources of Copper to the San Francisco Bay

There is a long history of investigation of copper sources to the San Francisco Bay and surrounding area, where copper has been a pollutant of concern since the late 1980s. The 1989 designation of the lower South San Francisco Bay as impaired by copper (listing under §303(d) of the CWA) caused government agencies and businesses to make a significant investment in copper source identification andreduction measures. These activities created a wealth of information on copper releases to surface waters and greatly expanded the understanding of options to prevent or reduce copper releases to San Francisco Bay.

Copper Sources in Urban Runoff and Shoreline Activities (TDC Environmental 2004) was prepared for the Clean Estuary Partnership to summarize available information about the sources of copper in urban runoff that is released directly into the Bay from shoreline activities. Marine antifouling paint and copper algaecides applied to shoreline lagoons were included in the evaluation of direct release sources. The report did not address discharges from industrial or municipal wastewater treatment plants or non-urban copper sources, such as sediment erosion from open space, agricultural pesticide use, mine drainage, and reservoir releases. These were not considered to be significant sources of copper to urban runoff or from shoreline activities.

Nine categories of copper sources were found to have the potential to make a significant contribution to copper levels in the San Francisco Bay Area via urban runoff and releases from shoreline activities. These sources are listed below, ordered from highest to lowest based on the estimated magnitude of loading:

- Marine antifouling coatings
- Vehicle brake pads
- Architectural copper
- Copper pesticides (including shoreline algaecides) and CCA-treated wood
- Industrial copper uses
- Copper air emissions
- Soil erosion
- Copper in domestic water discharged to storm drains
- Vehicle fluid leaks and dumping

In theory, there are thousands of potential sources for copper in urban runoff and shoreline activities. Additional information characterizing sources of copper is summarized in *Diffuse Sources of Environmental Copper in the United States* (CDA 2003).

Table 1. Ambient Dissolved Copper Concentrations Reported for Coastal Harbors and Marinas.

Location	**Ambient Water Copper Dissolved (µg/L)**
Baltimore (Fort McHenry), MD	18.7
Baltimore (Fells Point), MD	24.2
Gloucester, MA	<5[a]
New Bedford, MA	<5[a]
Philadelphia, PA	<5[a]
Havre de Grace, MD	<5[a]
Pensacola, FL	1.8
Gulf Breeze, FL	3.1
Lafitte, LA	3
Bayou La Batre, AL	4.3
Pass Christian, MS	4
Slidell, LA	2.4
Convent, LA	2.4
Sitka SB, AK	<5[a]
Sitka, AK	<5[a]

[a] Limit of detection
(Source: U.S. EPA 2010b).

Monitoring in the Southern California Bight demonstrated that sediment from marinas throughout southern California had consistently elevated copper levels compared to surrounding waters (Bay et al. 2000). Surveys around the United States routinely find elevated copper concentrations in marina and harbor sediments relative to other areas with less vessel traffic or shoreline activities (NOAA 1994; U.S. EPA 1999).

2.2 Environmental Fate and Transport of Copper in the Aquatic Environment

Elemental copper, atomic number 29, is a reddish solid with a molecular weight of 63.546 g/mol. Copper has a density of 8.94 g/mL at 20°C, a melting point of 1,083°C and is insoluble in water. Copper naturally occurs as two stable isotopes (^{63}Cu and ^{65}Cu) along with numerous unstable radioisotopes. Being a metallic element, copper will not break down and continues to cycle in the environment after it is released (Eisler 1998).

Copper exists in four oxidation states: Cu^0, Cu^+, Cu^{2+}, and Cu^{3+}. The cupric ion (Cu^{2+}) oxidation state is the form of copper generally encountered in water. Elemental copper (Cu^0) is slightly soluble in dilute ammonia and is not oxidized in water, cuprous copper (Cu^+) is only found in water when complexed (oxides, hydroxides and ligands), and trivalent copper (Cu^{3+}) does not occur naturally. The pH of the medium and presence of other chemical species usually controls which forms of Cu^{+} or Cu^{2+} are found (ATSDR 1990; Eisler 1998). In oxic natural waters with neutral pH and above, the free cupric (Cu^{2+}) ion is generally a minor species (Stumm and Morgan 1981). The cupric ion instead generally reacts with inorganic and organic chemicals in solution and in suspension, and forms moderate to strongly complexed solutes and precipitates with the numerous inorganic and organic constituents of natural waters (e.g., carbonate, phosphate, and organic materials). An overview of the chemistry of copper in aqueous systems is provided in **Figure 2** (U.S. EPA 2010a).

Copper hydroxide, copper carbonate and cupric ion are the dominant copper species in seawater (U.S. EPA 1980). This is in contrast to freshwater, where cupric salts (chloride, nitrate and sulfate) are generally highly soluble and where solubility decreases under reducing conditions and is modified by water pH, temperature and hardness. Copper flux from estuarine/marine sediments is influenced by the presence of ligands in the sediment pore waters. In a study of two contrasting types of organic rich estuarine sediments from the Chesapeake Bay, it was determined that most of the total dissolved copper fluxing from these sediments would be complexed by ligands during the sediment-water exchange, and these sediments will influence the copper speciation in overlying waters when these ligands are released (Skrabal et al. 2000). Due to the complexation of the copper from the pore waters, only a small fraction of the copper is exchanged as an organic species (the most bioavailable form) (Skrabal et al. 2000), indicating that the geochemistry of copper from estuarine/marine sediments is an important determinant of the fate and transport of copper to aquatic organisms.

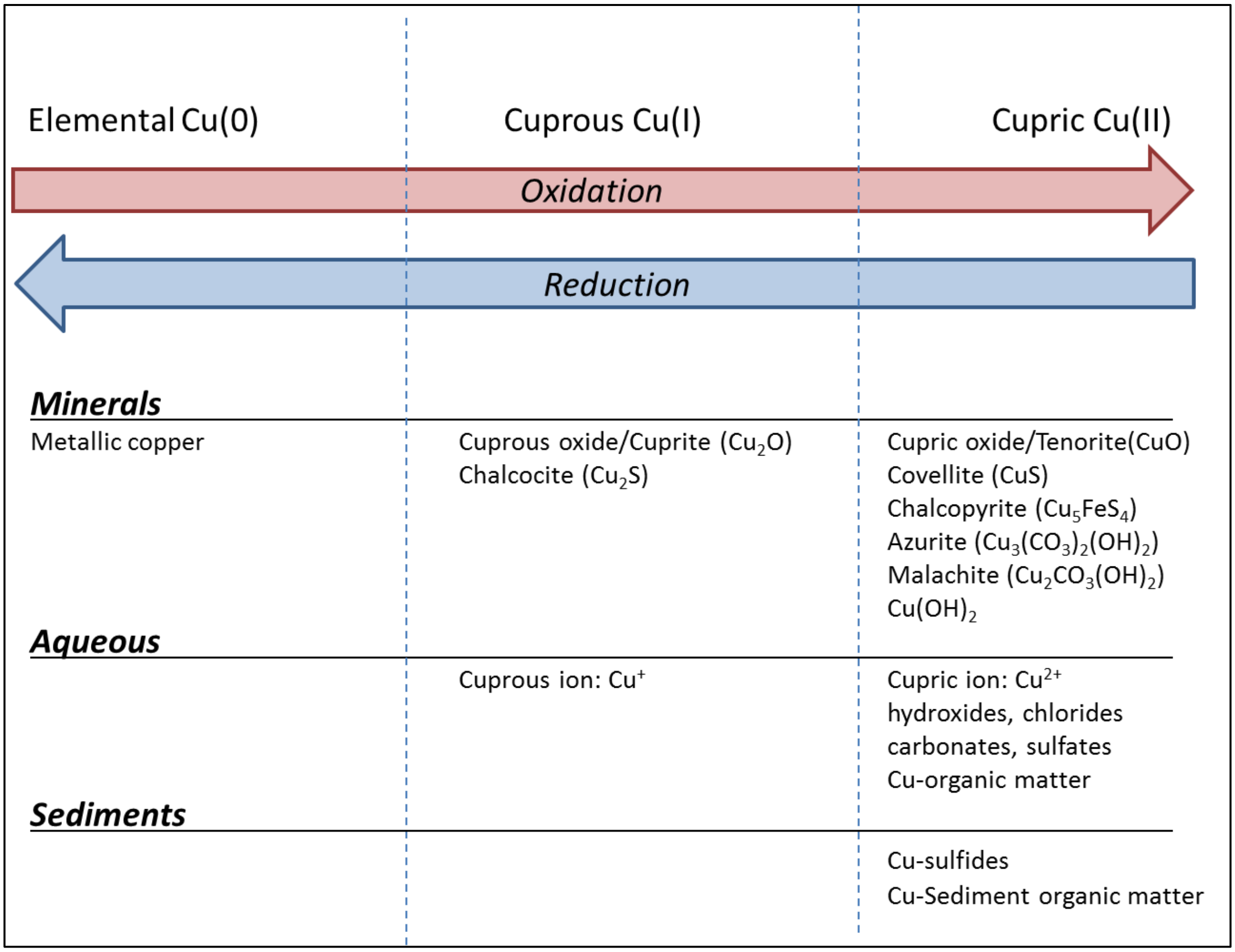


Figure 2. Environmental Bridging Chemical Species for Copper (Cu) Minerals and Complexes.

2.3 Overview of Copper Toxicity

Copper is a micronutrient for organisms at low concentrations and is recognized as essential to virtually all plants and animals (Kapustka et al. 2004). It is also a key atom in the oxygen carrying protein (hemocyanin) of some invertebrates. However, it can become toxic to some forms of aquatic life at elevated concentrations. The specific mode of toxic action depends on the organism. In bacteria, fungi and algae, excess copper causes disruption of cell membrane integrity and the subsequent leakage of the cell contents (Borkow and Gabbay 2005). In mollusks, copper alters the normal function of peroxidase enzymes and surface epithelia, often producing peroxidation products that lethally disrupt vital functions of membranes and cells (Cheng 1979). In the mussel, *Mytilus galloprovincialis*, elevated copper concentrations have been found to interfere with Ca^{+2} homeostasis in the gill, and disrupt Na/K ATPase and Ca^{+2}

ATPase activities (Viarengo et al. 1996). Copper also affects the gills of crabs, reducing hemocyanin-oxygen affinity in these organisms. Hansen et al. (1992) attributed copper exposed crab (*Carcinus maenas*) mortality to reduced oxygen transport and subsequent tissue hypoxia, with reductions in the activities of regulatory enzymes of ATP-synthesizing pathways.

In marine fish, copper adversely affects osmoregulatory processes, ATP-synthesizing pathways and ion transport across the gills, and causes oxidative stress damage. The osmotic balance maintained by the gastrointestinal tract and gills in marine teleost fish is disrupted when elevated copper levels inhibit water absorption by the gut (active uptake of Na^+ and Cl^-) and/or the secretion of Na^+ and Cl^- by the gills (inhibition of branchial Na^+/K^+-ATPase) (Marshall and Grosell 2005; Stagg and Shuttleworth 1982). Excretion of nitrogenous waste by teleost fish can also be impacted by copper, with elevated plasma ammonia concentrations observed in seawater-acclimated rainbow trout exposed to 400 µg/L copper (Wilson and Taylor 1993). In contrast, marine elasmobranchs retain nitrogenous compounds for osmoregulatory purposes, and exposure of spiny dogfish (*Squalus acanthias*) to 1,000 µg/L copper resulted in a loss of plasma urea (De Boeck et al. 2007). Dodoo et al. (1992) observed inhibited calcium transport in juvenile flounder (*Paralichthys sp*.) exposed to copper, and speculated that it was caused by copper interference with gill chloride cells.

Copper can also induce cellular oxidative stress, through the formation of reactive oxygen species (ROS), inhibition of antioxidant enzymes, alteration of the mitochondrial electron-transfer chain, or depletion of cellular glutathione (Shukla et al. 1987; Freedman et al. 1989; Stohs and Bagchi 1995; Rau et al. 2004; Wang et al. 2004). Oxidative stress is normally mitigated with cellular antioxidant mechanisms, but prolonged exposure to elevated copper concentrations can exhaust these defenses, and may result in the oxidation of DNA (strand break), lipids (impaired cell membrane permeability) and proteins (Grosell 2012). ROS neutralization includes antioxidant enzymes such as catalase, glutathione peroxidase and reductase, and Cu/Zn superoxide dismutase. Detoxifying mechanisms include the induction of metallothioneins and heat shock protein 70 (Sato and Bremner 1993; McDuffee et al. 1997; Evans and Halliwell 2001). In summary, excessive copper concentrations compromise normal cell functions by disrupting osmoregulation and ion flow, inhibiting enzymes and ATP-driven pumps, and inducing oxidative stress, resulting in cell toxicity from oxidative damage and disruption of cell homeostasis, and leading to changes in internal pH balance, membrane potential, and osmosis (Okocha and Adedeji 2012).

Copper concentrations typically build up in tissues at the site of exposure, such as the gill surface and gut tract wall (Chevreuil et al. 1995). Copper is then transferred via circulation to other tissues and organs, with the liver and kidney typically accumulating high concentrations relative to muscle tissues (Grosell 2012). Although copper bioaccumulates in some aquatic species, there does not appear to be a consistent relationship between body burden and toxicological effect (Meyer et al. 2005; DeForest and Meyer 2015). This inconsistent relationship between whole body tissue concentration and toxic effect may be related to specific organs and/or tissues where the accumulation is occurring. Therefore, it may not be accurately quantified by whole body tissue residue analysis, and/or the metabolic bioavailability of copper in tissues.

Since copper is an important trace nutrient, some organisms may have mechanisms for maintaining homeostasis, such as detoxification, making it more difficult to study the relationship between body burden and toxic effect. Detoxification mechanisms in aquatic organisms, including the formation and activation of antioxidants, metallothionein, glutathione, and heat shock proteins (McGeer et al. 2011) effectively sequester the metal in a detoxified form, thereby allowing the organism to accumulate elevated levels of copper before displaying a toxic response. While the amount of detoxified metal that an aquatic organism can accumulate is theoretically unlimited, an organism will only experience toxic effects once the concentration of metabolically required metal is exceeded (Rainbow 2002; Rainbow and Smith 2013). Under natural conditions, most accumulated copper in tissues is expected to exist in a detoxified state, which may explain the poor relationship between whole body tissue residue concentrations and toxic effect observed in tested aquatic invertebrates and fish (Rainbow 2002).

An additional consideration is the potential for copper in aquatic prey items (e.g., invertebrates) to adversely affect higher trophic level organisms, such as fish and aquatic-dependent wildlife via dietary exposure. This exposure pathway does not show a consistent dose-response relationship because the bioavailability of copper to top predators differs substantially among prey species that are consumed (U.S. EPA 1993). Further, there are numerous different prey types and amounts eaten by each predator, thus complicating the estimate of a safe dose to higher trophic level organisms (this and other uncertainties are discussed in **Section 4.3.1**).

Overall, however, the risk to higher trophic level species is considered low because researchers have found that copper generally does not accumulate or biomagnify in aquatic food chains (Lewis and Cave 1982; Suedel et al. 1994). The evaluation of effects from the direct exposure of organism tissues (e.g., gills and other biological membranes) to copper in water is therefore considered more applicable to the development of criteria for aquatic life and was the focus of the development of criteria for estuarine/marine aquatic life.

The toxicity of copper to aquatic life is related primarily to the activity of the cupric ion, and possibly to some hydroxy complexes (Allen and Hansen 1996; Andrew 1976; Andrew et al. 1977; Borgmann and Ralph 1983; Chakoumakos et al. 1979; Chapman and McCrady 1977; Dodge and Theis 1979; Howarth and Sprague 1978; Pagenkopf 1983; Petersen 1982; Rueter 1983). Examples of the response of organisms to cupric ion activity, and limited exceptions, are reviewed by Campbell (1995). Any changes in water quality that would be expected to decrease free copper ion activity also would be expected to decrease copper bioavailability and resulting toxicity. For example, increases in pH, alkalinity, and NOM (as represented by DOC) would all tend to decrease copper bioavailability and be associated with increased copper LC_{50} values. The following section discusses in detail the characterization of water quality parameters and their effect on bioavailability.

2.4 Overview of Historic and BLM Criteria Development Methods

Early national recommended aquatic life criteria for copper (U.S. EPA 1980, 1984, 1995a, 1996, 2003) considered bioavailability effects for freshwater organisms based on water hardness by incorporating linear regression equations into the criterion-calculation procedure to account for the decreasing acute and chronic toxicity of copper to freshwater biota with increasing water hardness. Temperature did not vary significantly for tests with most species, pH values were often not reported or were highly variable, and alkalinity and DOC were rarely reported. Accordingly, freshwater criteria for copper, and those for several other metals, were established as functions of water hardness alone. However, the regression coefficients for hardness did not only reflect how hardness affected copper toxicity. Hardness was instead a surrogate for other co-varying water quality parameters that were not included in the regression analyses and the criteria based on hardness alone did not explicitly account for the modifying effects of these other water parameters.

An alternate approach that has been proposed to predict metal toxicity is to (1) identify the bioavailable form(s) of the metal; (2) analyze or calculate the concentration(s) of the bioavailable form(s) in the exposure water; and (3) predict the toxicity based on an empirical relationship between the biological response and the concentration(s) of the bioavailable forms (Santore et al. 2001). This approach only requires the direct measure or calculation (using a geochemical-speciation model) of the free metal ion (Cu^{2+}) concentration, which is the bioavailable-fraction of copper in water. The concentration of Cu^{2+} has been demonstrated to be an accurate indicator of acute toxicity, as characterized by trends in the LC_{50} values, even in the presence of varying levels of inorganic or organic ligands, which can complex with copper and alter the Cu^{2+} concentration (e.g., Borgmann 1983; Santore et al. 2001). This approach, however, loses accuracy when other cations are present in water that can interact with biota. For example, the LC_{50} of Cu^{2+} increases significantly as the concentration of Ca^{2+} (a major component of water hardness) increases (Campbell 1995; Meyer et al. 1999). This trend indicates that the concentration of cupric ion alone is not always sufficient to predict toxicity.

In general, there is no universally constant bioavailable fraction of a metal that can be identified by chemical analyses (Meyer et al. 2002). The interactions amongst the key abiotic components in exposure water must be considered in conjunction with the interactions of those key abiotic components directly with biota. Metal bioavailability may also be modified by competitive interactions at the biotic ligand (i.e. biological membranes of toxic interaction). Increased sodium and calcium concentrations, for example, can reduce the binding of copper to physiologically active binding sites and can thereby reduce copper bioavailability. Cation competition also has an effect on the complexation of copper by DOC, and this interaction will partially offset competitive interactions that occur at the biotic ligand. The complex interactions of Cu^{2+} with dissolved components, suspended particles, and biota therefore must be simultaneously considered in order to accurately predict copper toxicity.

The chemical speciation of copper in natural waters and explanatory power of the free copper ion in characterizing copper toxicity were first recognized more than 30 years ago (Anderson and Morel 1978; Sunda and Gillespie 1979; Sunda and Guillard 1976; Sunda and Lewis 1978; Zitko et al. 1973). These concepts were eventually formalized in models that linked metal chemistry and biological effects, such as the gill surface interaction model (GSIM) (Pagenkopf 1983) and the free ion activity model (FIAM) (Morel 1983). Playle and others demonstrated that copper binding to fish gills can be modeled using a chemical speciation approach (Playle et al. 1993a, 1993b). MacRae and others demonstrated that copper binding on the gill shows a dose-response relationship with mortality (MacRae et al. 1999). Although early models showed remarkable utility, several critical issues remained. Perhaps most notably, and until recently, few models could predict metal chemistry in the presence of NOM over a range of environmental conditions (Bergman and Dorward-King 1997). A considerable amount of information about metals speciation in the environment has since become available and computing techniques have been further developed to simulate metal speciation (e.g., Nordstrom et al. 1979). These early efforts, however, laid the foundation for the development and use of the BLM to predict adverse effect levels of metals as a function of site-specific water chemistry (Di Toro et al. 2001). A more comprehensive review of these historical developments is presented in Paquin et al. (2002).

The BLM is a metal bioavailability model that considers chemical and physiological effects information for metals in aquatic environments and was originally developed for freshwater settings (Di Toro et al. 2001; Paquin et al. 2002; Santore et al. 2001). The approach was first presented to EPA's Science Advisory Board in 1999 where it received a generally favorable response (U.S. EPA 1999, 2000). Like the FIAM and GSIM, the BLM is based on a description of the chemical speciation of metals in aqueous systems (**Figure 3**). Chemical speciation is simulated as an equilibrium system that includes the complexation of inorganic ions and NOM. The chemical system for the original freshwater BLM was simulated by the chemical equilibria in soils and solutions (CHESS) model (Santore and Driscoll 1995), including a description of metal interactions with NOM based on the Windermere humic aqueous model (WHAM) (Tipping 1994). A significant advantage of the NOM chemistry developed for WHAM is that reactions and parameter values were developed by simultaneously considering numerous NOM samples and numerous metals. A chemical description was needed specifically characterizing chemical speciation for the saltwater BLM, but the basic principles of metal speciation are similar to those established by the development of the models used for the original freshwater BLM (Chadwick et al. 2008).

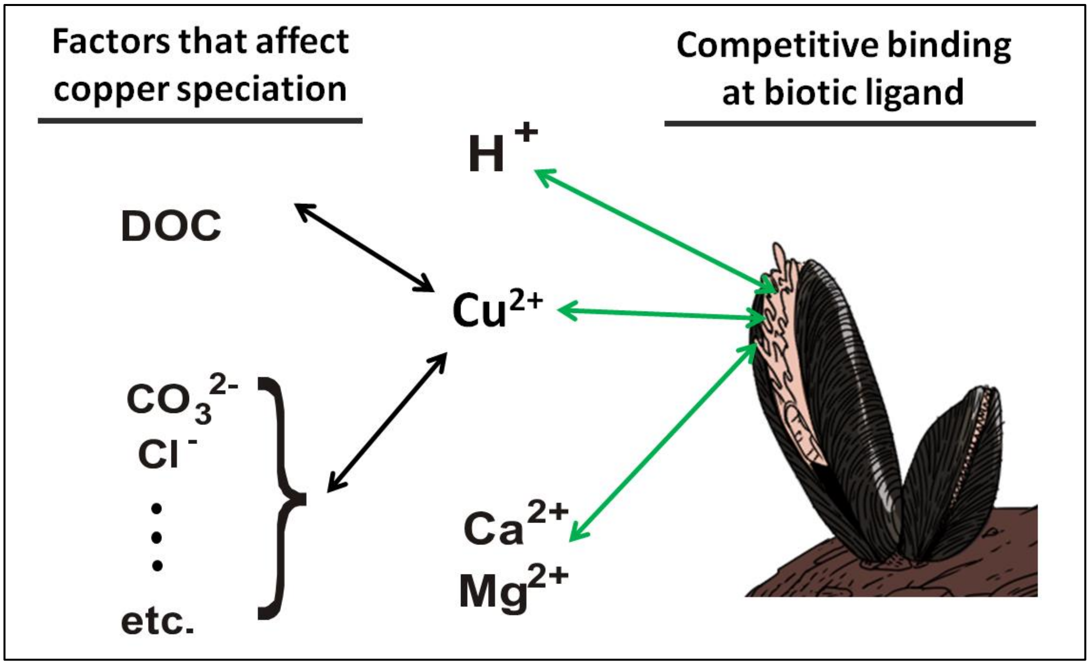


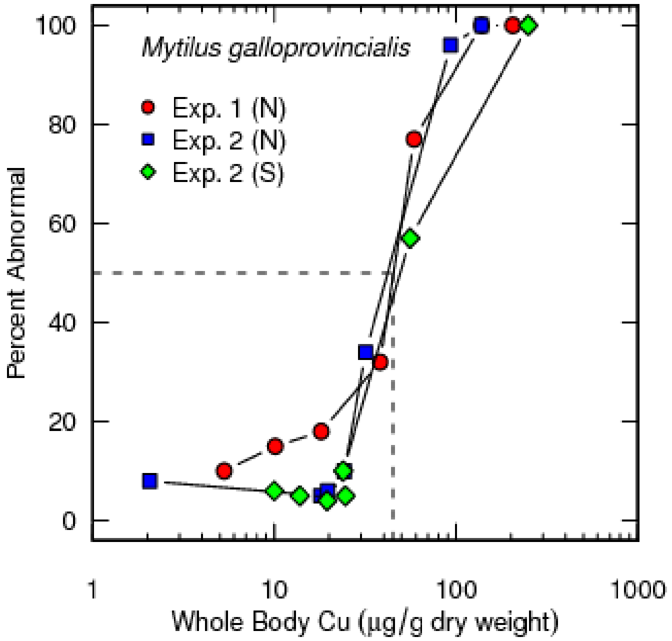
Figure 3. Conceptual Diagram Showing Relationship between Chemical Speciation, Metal Binding at Biotic Ligand (BL) Sites, and Competition at These BL Sites for Other Cations. (Adapted from Santore et al. 2001).

In addition to considering chemical speciation, the BLM also includes reactions that describe the chemical interactions of copper and other cations with physiologically active sites, termed biotic ligands (BLs). BLs correspond to the proximate site of action of toxicity in aquatic organisms and can be present on any biological membrane. The model parameters define the degree of interaction based on binding affinity characteristics measured in gill-loading experiments. The BL is represented by a characteristic binding site density and conditional stability constant for each of the dissolved chemical species with which it reacts. Predictions of metal toxicity are made by assuming that the dissolved metal LC_{50}, which varies with water chemistry, is always associated with a fixed critical level of metal binding with the BL. This fixed level of metal-biotic ligand (Me:BL) accumulation at 50 percent mortality has been referred to as the "lethal accumulation 50%" (LA_{50}), but since the BLM can also apply to sub-lethal endpoints, this parameter has been more generically termed "critical accumulation." Copper accumulation on the BL is characterized by a rapid and reversible chemical interaction with binding sites on biological membranes, and is not in any other way similar to accumulation that results from uptake within the organism. It is assumed to be constant, regardless of the chemical characteristics of the water (Meyer et al. 1999, 2002). This combination of reactions that describe aqueous metal speciation and organism interactions allows the BLM to predict copper toxicity to a variety of organisms over a variety of water quality conditions (Santore et al. 2001).

The saltwater BLM for copper was developed from independent datasets that could be used to characterize copper speciation, surficial copper binding to membranes, and toxicity (Chadwick et al. 2008). The chemistry model used to represent interactions between copper and dissolved organic matter (DOM, usually measured as DOC) included four discrete ligands and was calibrated to titration results with over 60 water samples. The calibrated model was then validated using an additional dataset that was similar in breadth (>60 titrations). The established relationship between free copper, dissolved copper, and DOC in marine waters was demonstrated to describe the range of copper concentrations that bracketed anticipated marine criteria values that would be protective of sensitive marine invertebrates (Chadwick et al. 2008). The development effort included calibration and validation steps. Extensive datasets from San Diego Bay and Pearl Harbor were used in the analysis. Subsets of the data from each site were assigned as calibration or validation data. Calibration data were used in the parameterization of the model, while the validation data were only used to test overall goodness of fit (Chadwick et al. 2008). Validation was performed by comparison with chemical speciation data (i.e., free copper ion), and measured copper toxicity to sensitive marine invertebrates.

Binding constants for copper and other cations to the BL for the saltwater BLM were developed from data reported by Rosen et al. (2008), which included copper accumulation data for both *Mytilus galloprovincialis* and *Strongylocentrotus purpuratus.* These accumulation data were measured in short-term exposures designed to quantify copper interactions with the surficial membranes of embryolarval forms of these marine organisms and should not be equated with whole-body accumulation in more well-developed life stages, which may represent uptake and incorporation of copper in the tissue of multiple organs. The dose-response (percent abnormal) curves for different water samples having different DOC levels differed from each other when the exposure was characterized only on the basis of dissolved copper. However, a single dose-response curve can characterize copper toxicity in these different samples when exposure is expressed as embryo-larvae whole body copper concentrations (**Figure 4**). The ability of a single relationship between accumulation and toxicity in different samples indicates that the surficial copper binding to cell membranes (which can be measured as whole body accumulation in embryolarval forms of these organisms) on the larval life stages is directly related to the copper bound to the site of toxic action. The resulting saltwater BLM is thus demonstrated to consistently simulate accumulated copper using a single model representation for both *M. galloprovincialis* and *S. purpuratus*, as shown in **Figure 5**.

An advantage of the BLM is that most of the parameters are invariant for different organisms, despite the complexity of the modeling framework. All of the thermodynamic constants used to simulate inorganic and organic chemical equilibrium reactions are determined by characteristics of the metal and the available ligands. As such, the constants do not change for simulations involving different organisms. This is an important consideration in the development of the BLM. In a recent review, Erickson (2013) cautioned against the introduction of additional parameters that weaken the mechanistic framework of the model. In particular, Erickson cautioned about inferring accumulation-based effects from toxicity measurements. In the development of the marine copper BLM, the critical accumulation for several sensitive organisms were taken from direct measurements (**Figure 4**) rather than inferred from toxicity data. These measurements confirmed several assumptions made during the development of the freshwater model. First, that the same accumulation model (and hence the same BL parameters) could be used to describe accumulation to different organisms [for example *Mytilus* in **Figure 4 (Panel A)** and *Strongylocentrotus* in **Figure 4 (Panel B**)]. Second, that the difference in sensitivity between these organisms is due to different critical accumulation levels (vertical dashed lines in **Figure 4**). The critical accumulation, therefore, is the only model parameter that is needed to account for differences in organism sensitivity.



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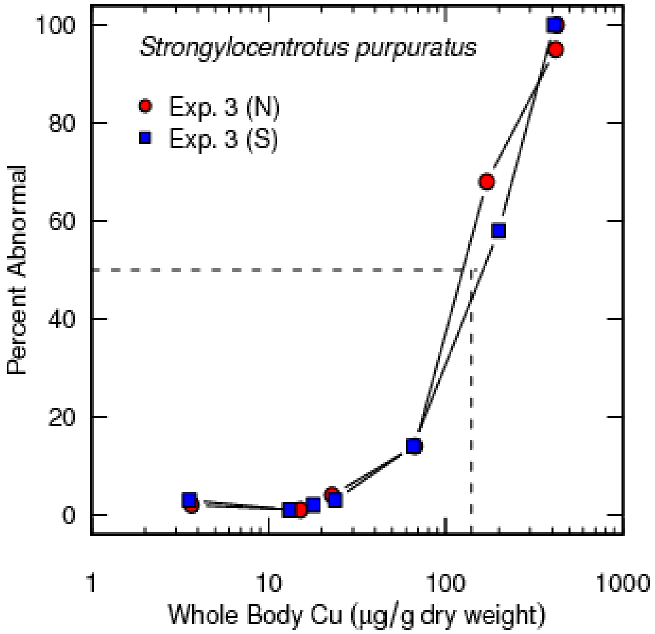

B

Figure 4. Percent Abnormal Cells in Test Waters with Different Composition (primarily DOC) for *M. galloprovincialis* (Panel A) and *S. purpuratus* (Panel B).

(Samples collected from different areas are labeled with the sample identifier (N or S). Values collapse into a single dose response when compared with measured copper accumulation). (Chadwick et al. 2008).

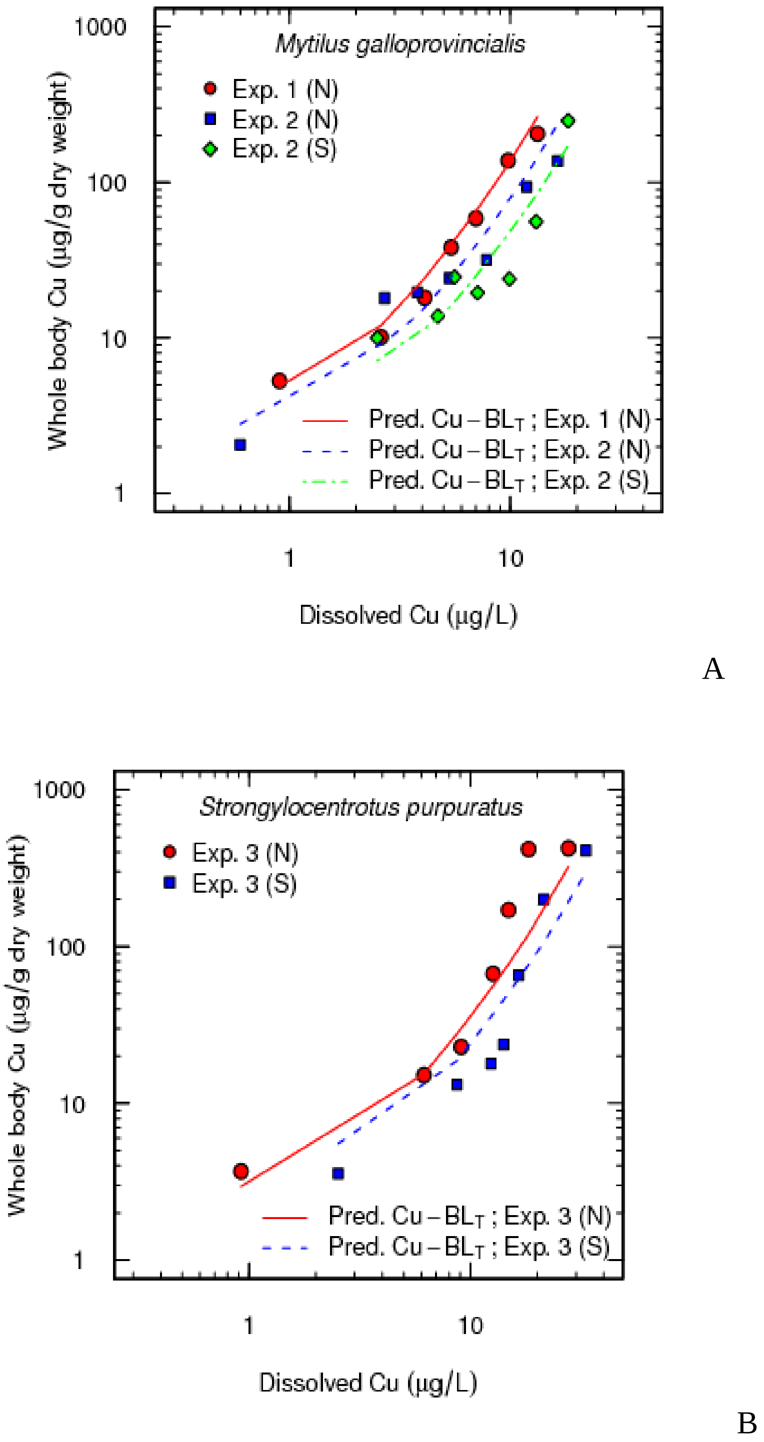

Figure 5. Predicted Copper Binding to BL Sites on Cell Membranes (solid lines) by the Saltwater BLM for Copper with a Single Set of Parameters Compared with Measured Copper Accumulation for Embryo-larval Stages of *M. galloprovincialis* (Panel A) and *S. purpuratus* (Panel B).

(Samples collected from different areas are labeled with the sample identifier (N or S). (Chadwick et al. 2008).

Toxicity data were used to evaluate the critical accumulation values for *M. galloprovincialis* and *S. purpuratus* and to predict EC_{50} values for these two organisms. Coupled with the toxicity data, the BLM can predict how much dissolved copper is associated with critical accumulation in waters of varying composition, and how toxicity changes in response to changes in key environmental variables, such as DOC. The resulting model can predict toxicity to both *M. galloprovincialis* and *S. purpuratus* over a wide range of conditions for waters from different geographic regions (**Figure 6**).

Accumulation values that were available for *M. galloprovincialis* and *S. purpuratus* were not available for other organisms having toxicity data. To incorporate other organisms into the BLM, water effect concentrations (ECs) were extrapolated for the biological species for which accumulation data are not available. This is the same approach as was used for the BLM-based copper criteria for fresh water (U.S. EPA 2007). The general procedure used for the freshwater criteria development was to normalize all available toxicity data to selected water chemistry values, calculate criteria values at these conditions, and then use the normalization procedure to compute criteria at other water chemistry conditions. With this approach, the BL parameter values developed from *M. galloprovincialis* and *S. purpuratus* accumulation measurements are assumed to be constant for other sensitive marine invertebrates. This approach has been shown to work well when used to predict copper effect levels for other freshwater organisms (U.S. EPA 2007). The same accumulation model was first used to evaluate the critical accumulation for the additional organisms, and then used to predict effect levels. It was determined that 94% of all predictions were within a factor of two of the measured EC_{50} (**Figure 7**).

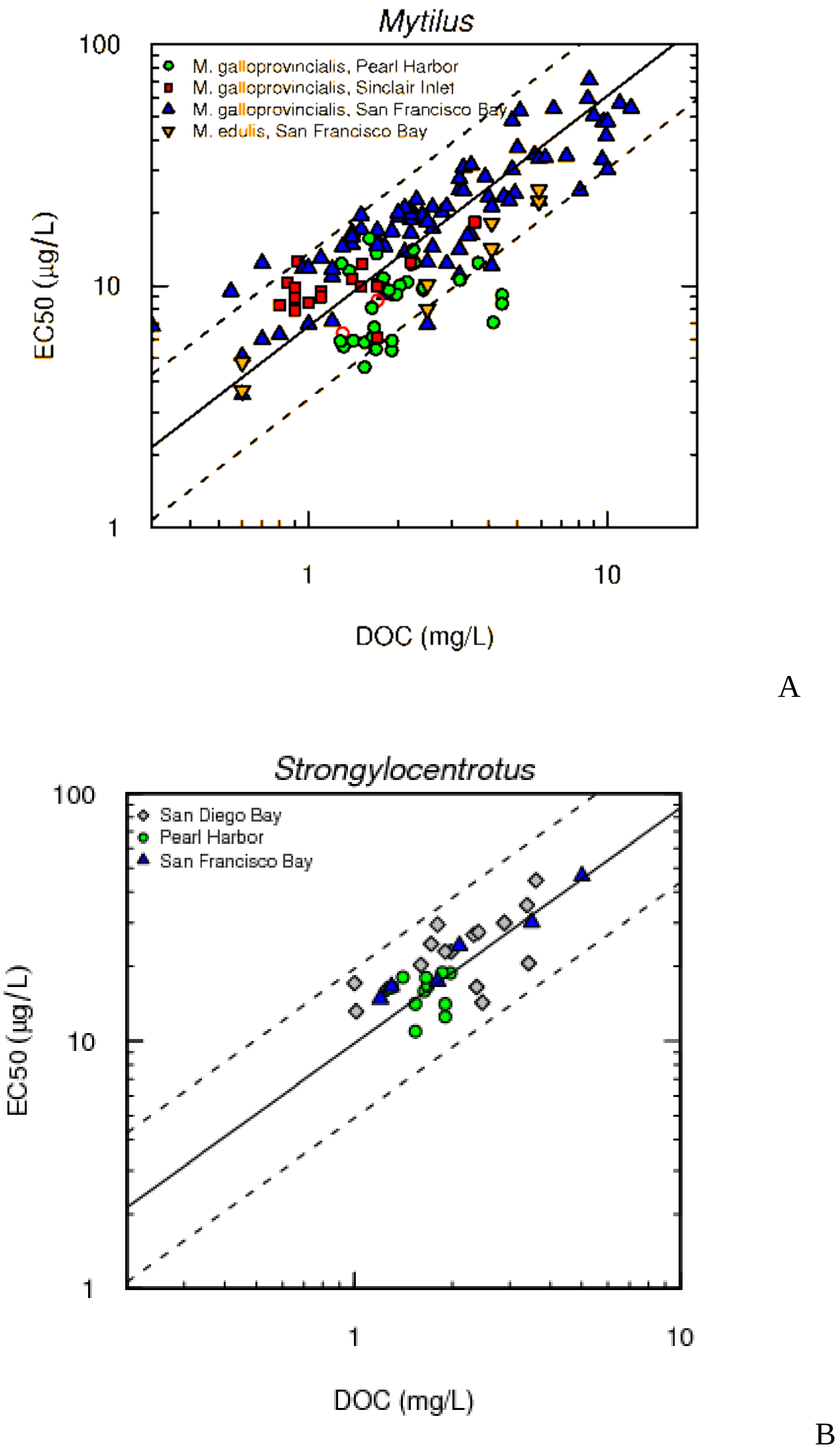

Figure 6. Predicted Copper Toxicity by the Saltwater BLM for Copper (solid lines) in Response to Changing DOC from a Variety of Estuarine and Marine Sites Compared with Measured Copper Toxicity for Embryo-larval Stages of *M. galloprovincialis* (Panel A) and *S. purpuratus* (Panel B).

(Dashed lines indicate plus or minus a factor of two around the solid line. Variation within these boundaries represents the variability of replicate toxicity tests).

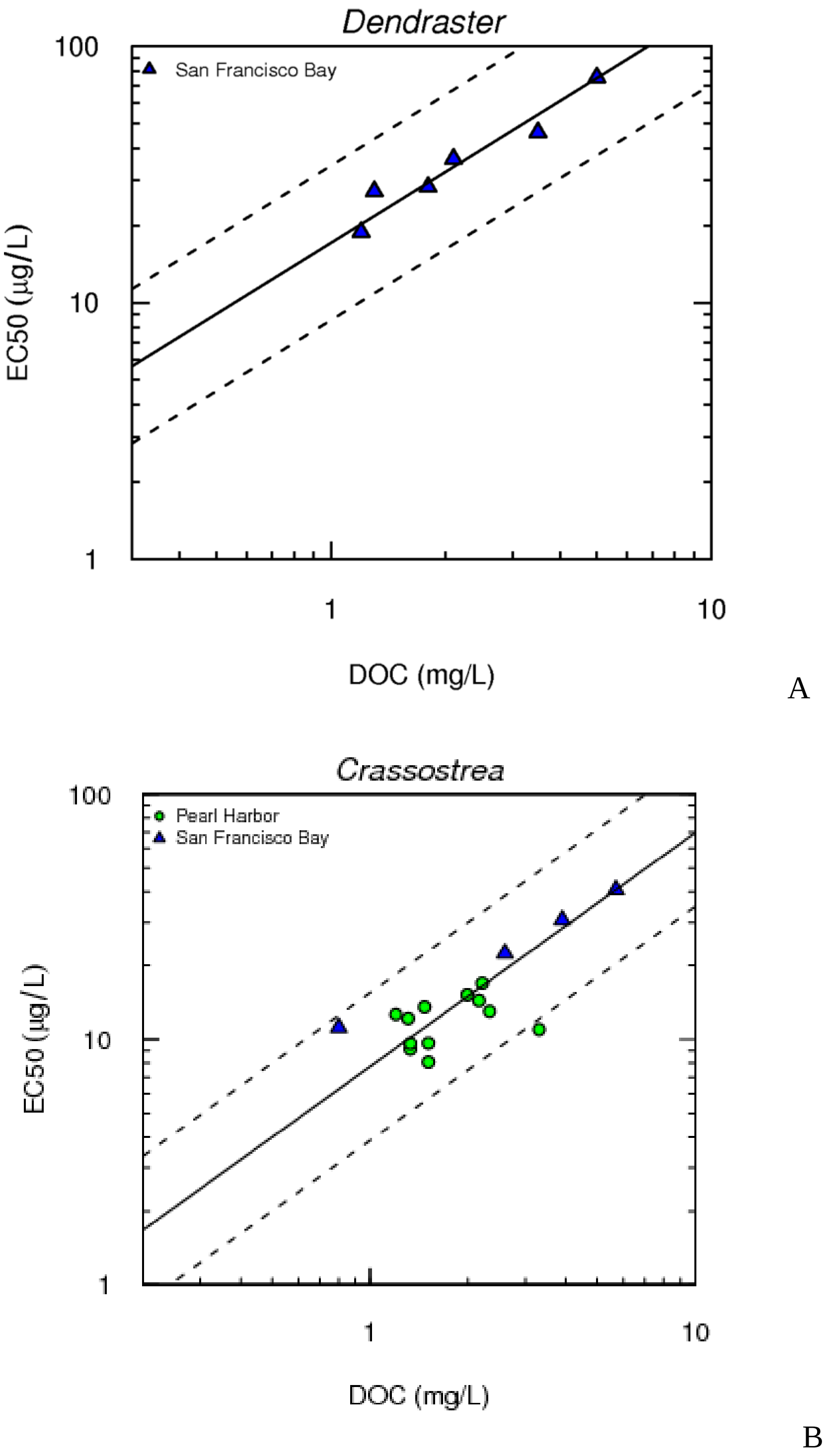

Figure 7. Predicted Copper Toxicity by the Saltwater BLM for Copper (solid lines) in Response to Changing DOC from a Variety of Estuarine and Marine Sites Compared with Measured Copper Toxicity for Embryo-larval Stages of *Dendraster* (Panel A) and *Crassostrea* (Panel B).

(Dashed lines indicate plus or minus a factor of two around the solid line. Variation within these boundaries represents the variability of replicate toxicity tests).

While many of the concepts and conditions applicable to the freshwater BLM for copper also apply to estuarine/marine waters, there are some differences. First, the concentrations of all ions in saltwater are much higher than in freshwater (Morel and Hering 1983). Second, in waters with constant salinity, the ionic composition is well defined and consistent so the likelihood that changes in ionic composition could result in observable bioavailability effects is lower than for freshwater (Stumm and Morgan 1981). Although water samples from estuaries may be collected across a range of salinities, toxicity tests with copper are typically conducted with embryo-larval stages of sensitive marine invertebrates such as *Mytilus* or *Crassostrea* (Arnold et al. 2010a; Rosen et al. 2005). Available toxicity data indicate that the early life stages of these bivalve molluscs are amongst the most sensitive marine organisms to copper (U.S. EPA 1995a; Table 3). However, the early life stages of these species have a narrow range of salinity tolerance. When used to test copper toxicity in estuarine samples, standard procedures therefore require that the salinity of test solutions be increased to full marine salinity (e.g., 30 to 32 ppt; U.S. EPA 1995a). Although it is expected that cation competition plays a role in determining metal bioavailability along salinity gradients, the effects of salinity on copper bioavailability are absent in the majority of toxicity data sets that are available, due to the standard practice of adjusting samples to full strength salinity. In tests where estuarine samples have been salted up to marine salinity, the potential effects of variable salinity on copper toxicity have been eliminated, leaving only DOC as the primary toxicity modifying factor (such as in **Figure 6** and **Figure 7**).

Recent tests with sensitive invertebrates capable of tolerating a wide range of salinities have shown that the same bioavailability relationships involving pH, DOC, and salinity also apply in estuarine conditions when tested over a range of salinities (Arnold et al. 2010b, 2010c; Cooper et al. 2012; Hall et al. 1997, 2008). These studies have shown that copper bioavailability is reduced at high salinity, which is consistent with effects predicted by the saltwater BLM for copper. For example, Arnold et al. (2010c) found that EC_{50}s for *Brachionus plicatilis* ranged from less than 40 µg/L at a salinity of 5 ppt, to approximately 70 µg/L at a salinity of 30 ppt. Similar results were reported by Cooper et al. (2012) for *B. plicatilis*. The overall results from Cooper et al. (2012) suggest that both salinity and DOC are important in estuarine samples and the combined effects are consistent with predictions by the saltwater BLM. Increasing salinity was also shown to have variable effects to the polychaete *Hediste* (Ozoh 1992a,b). In exposures with sediment, the effect of salinity on copper toxicity was small and variable depending on the temperature, while in water-only exposures there was a reduction in copper bioavailability with increasing salinity similar to that seen in rotifers (Ozoh 1992a,b). The saltwater BLM for copper is therefore considered predictive of copper effects to sensitive estuarine invertebrates.

2.5 Conceptual Model

A conceptual model characterizes relationships between human activities, stressors and ecological effects on the assessment endpoints identified for evaluation (U.S. EPA 1998). The conceptual model links exposure characteristics with the ecological endpoints important for the development of management goals. Under the CWA, these management goals are established by states and tribes as designated uses of waters of the United States (for example, the protection of aquatic life). In deriving aquatic life criteria, U.S. EPA is developing acceptable thresholds for pollutants that, if not exceeded, are expected to be protective of aquatic life. A state and/or tribe may implement these criteria by adopting them into their respective water quality standards.

The conceptual model depicted in **Figure 8** provides a broad overview of how aquatic organisms could be exposed to copper in the estuarine/marine environment. As depicted in **Figure 8** and discussed in **Section 2.1**, copper enters the environment from both natural and anthropogenic sources. The environmental fate properties of copper indicate that weathering and erosion of natural sources and inputs from a variety of anthropogenic sources represent potential mechanisms that can transport copper from these sources to surface water (TDC Environmental 2004; U.S. EPA 2010a). The model also depicts exposure pathways for potential biological receptors (e.g., non-target aquatic animals) and potential attribute changes (e.g., reduced survival, growth and reproduction) in those receptors due to copper exposure. The conceptual model diagram (**Figure 8**) depicts where the BLM predicts how water quality parameters (especially DOC) influence the uptake/gill or integument exposure pathway. Copper also has the potential for adsorption to sediment and to bioaccumulate in aquatic organism tissues. There is accordingly the potential for the exposure of benthic organisms to copper in sediment (pore water) and the potential for the exposure of carnivorous mammals and birds via the consumption of aquatic invertebrates and fish that have accumulated copper (terrestrial effects were not assessed). Aquatic toxicity assessments assume anthropogenic exposure occurs primarily as a result of direct release/discharge to surface water and/or following partitioning from sediment to surface water. The transport and leaching of copper from groundwater to surface water is assumed to be negligible (U.S. EPA 2010a).

The conceptual model is intended to provide a broad overview of how aquatic organisms can potentially be exposed to copper. Transport mechanisms and exposure pathways are not considered in the derivation of aquatic life criteria. Derivation of criteria instead focuses on the effects of copper on survival, growth and reproduction of aquatic organisms based on its presence in the aquatic environment. However, the pathways, receptors, and attribute changes depicted in **Figure 8** may be helpful for states and authorized tribes as they adopt criteria into standards and need to evaluate potential exposure pathways affecting designated uses.

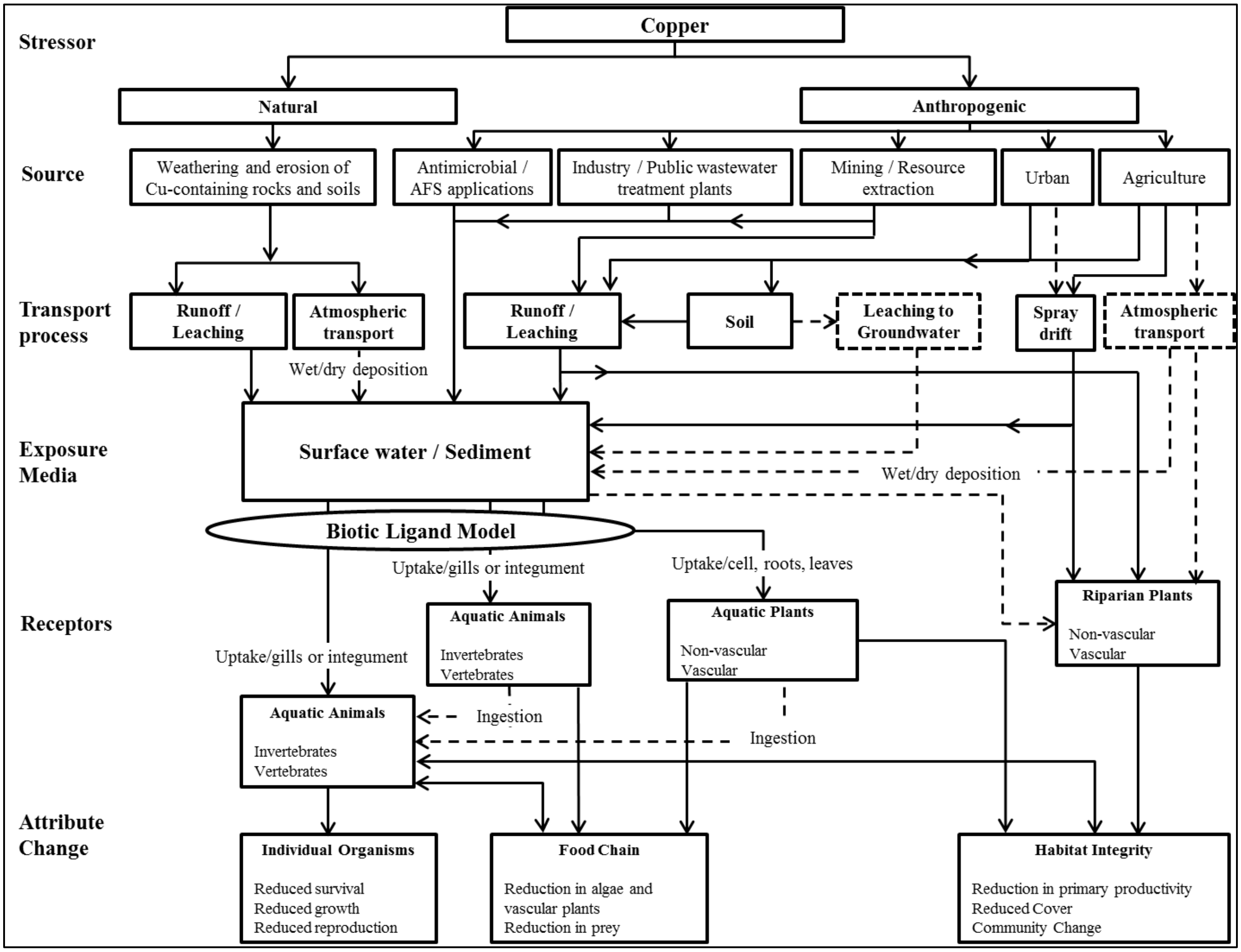

Figure 8. Conceptual Model for Copper Effects on Aquatic Organisms.
(Dotted arrows indicate exposure pathways that have a low likelihood of contributing to ecological risk).

2.6 Assessment Endpoints

Assessment endpoints are defined as the explicit expressions of the environmental values to be protected and are comprised of both the ecological entity (e.g., a species, community, or other entity) and the attributes or characteristics of the entity to be protected (U.S. EPA 1998). Assessment endpoints may be identified at any level of organization (e.g., individual organism, population, community). In context of the CWA, aquatic life criteria for toxic substances are typically determined based on the results of toxicity tests with aquatic organisms, for which adverse effects on growth, reproduction or survival are measured. This information is aggregated into a species sensitivity analysis that characterizes an impact to the aquatic community. Criteria are designed to be protective of the vast majority of aquatic organisms in an aquatic community (i.e., approximately the 95th percentile of tested aquatic organisms representing the aquatic community). Assessment endpoints consistent with the criteria developed in this document are summarized in **Table 2.**

2.7 Measurement Endpoints

Assessment endpoints require one or more measures of ecological effect, which are termed "measurement endpoints." Measurement endpoints are the measures of ecological effect used to characterize or quantify changes in the attributes of an assessment endpoint or changes in a surrogate entity or attribute, in this case a response to chemical exposure. Toxicity data are used as measures of direct and indirect effects on representative biological receptors. The selected measures of effect for the development of aquatic life criteria encompass changes in the growth, reproduction, and survival of aquatic organisms.

The toxicity data used for development of the aquatic life criteria depend on the availability of applicable toxicity test outcomes, the acceptability of test methodologies, and an in-depth evaluation of the acceptability of each specific test, as performed by the U.S. EPA per its Guidelines (1985). Measurement endpoints for the development of aquatic life criteria are derived using acute and chronic toxicity studies for representative test species, which are then quantitatively and qualitatively analyzed, as described in the Analysis Plan below. Measurement endpoints considered for each assessment endpoint in this criteria document are summarized in **Table 2**. The following sections discuss toxicity data requirements for the fulfillment of these measurement endpoints.

Table 2. Summary of Assessment Endpoints and Measures of Effect Used in Criteria Derivation.

Assessment Endpoints for the Aquatic Community	Measures of Effect
Survival, growth, biomass, and reproduction of fish and invertebrates (estuarine/marine)	Acute: LC_{50}, EC_{50} Chronic: EC_{20}, MATC (only used when an EC_{20} could not be calculated for the genus)
Maintenance and growth of aquatic plants from standing crop or biomass (estuarine/marine)	LOEC, EC_{20}, EC_{50}, IC_{50}, reduced growth rate, cell viability, calculated MATC

MATC=Maximum acceptable toxicant concentration (geometric mean of NOEC and LOEC)
NOEC=No observed effect concentration
LOEC=Lowest observed effect concentration
LC_{50}=Lethal concentration to 50% of the test population
EC_{50}/EC_{20}=Effect concentration to 50%/20% of the test population
IC_{50}=Concentration of copper at which some effect is inhibited 50% compared to control organism

2.7.1 Overview of Toxicity Data Requirements

U.S. EPA has specific data requirements to assess the potential effects of a stressor on an aquatic ecosystem and develop 304(a) aquatic life criteria under the CWA. To develop 304(a) criteria for estuarine/marine aquatic life under CWA, EPA typically requires the following:

- Acute toxicity test species data from a minimum of eight diverse taxonomic groups as follows:
    - two families in the phylum Chordata
    - a family in a phylum other than Arthropoda or Chordata
    - a family from either Mysidae or Peneidae
    - three other families not in the phylum Chordata (may include Mysidae or Penaeidae, whichever was not used above)
    - any other family

- Chronic toxicity test data (longer-term survival, growth, or reproduction) are generally required for a minimum of three taxa, with at least one chronic test being from an acutely-sensitive species. Acute-chronic ratios can be calculated with data for species of aquatic animals from at least three different families if the following data requirements are met:
    - at least one is a fish
    - at least one is an invertebrate
    - at least one is an acutely sensitive saltwater species (the other two may be freshwater species)

2.7.2 **Measures of Effect**

Acute measures of effect

The acute measures of effect used for organisms in this document are the LC_{50}, EC_{50}, and IC_{50}. LC stands for "Lethal Concentration" and an LC_{50} is the concentration of a chemical that is estimated to kill 50 percent of the test organisms. EC stands for "Effective Concentration" and the EC_{50} is the concentration of a chemical that is estimated to produce a specific effect in 50 percent of the test organisms. IC stands for "Inhibitory Concentration" and the IC_{50} is the concentration of a chemical that is estimated to inhibit some biological process (i.e. growth, etc.) by 50 percent compared to a control.

Chronic measures of effect

The endpoints for chronic measures of exposure are the NOEC, LOEC, MATC and EC_{20}. The NOEC (i.e., "No-Observed-Effect-Concentration") is the highest test concentration at which none of the observed effects were statistically different from the control. The LOEC (i.e., "Lowest-Observed-Effect-Concentration") is the lowest test concentration at which observed effects is statistically different from the control. The Maximum Acceptable Toxicant Concentration (MATC) is the calculated geometric mean of the NOEC and LOEC. The EC_{20}, which represents a 20 percent effect/inhibition concentration, is a low level of effect that is generally significantly different from the control treatment.

Data available for measuring effect

Effect data for copper were obtained from studies published in the open literature and identified in a search of the ECOTOXicology database (Available online at: https://cfpub.epa.gov/ecotox/). ECOTOX is a source of high quality toxicity data for aquatic life, terrestrial plants, and wildlife. The database was created and is maintained by the EPA, Office of Research and Development, National Health and Environmental Effects Research Laboratory's Mid-Continent Ecology Division. The latest comprehensive literature search for this document was conducted in April 2016.

Following initial identification with the ECOTOX database search, a further evaluation of available data was performed by EPA to determine test acceptability. The amount of toxicity testing data available for any given pollutant varies significantly, depending primarily on whether it has raised any significant environmental issues and, in the case of a pesticide, how long it has been registered. Appendix A of *Quality Criteria for Water 1986* (U.S. EPA 1986b) provides an in-depth discussion of the minimum data requirements and data quality requirements for aquatic life criteria development.

As discussed above, the assessment endpoints for aquatic life criteria are based on the growth, reproduction, and survival of the assessed taxa, while the specific measures of effect are provided by the acute and chronic toxicity data (**Table 2**). The toxicity endpoints derived from these data are expressed as the geometric means of acute values for all species of the same genus (GMAVs) or geometric means of the chronic values for all species of the same genus (GMCVs). GMAVs and GMCVs are used in the applicable species sensitivity distributions of the available aquatic community data to derive the acute and chronic aquatic life criteria.

Table 3 provides a summary of the data used to fulfill the minimum data requirements (MDR) outlined in the EPA Guidelines (Stephan et al. 1985) for derivation of the estuarine/marine acute criterion for copper. It also provides a summary of the number of families, genera, and species with acceptable acute and chronic toxicity data. There are a total of seven phyla in the acute copper toxicity database representing 63 families, 78 genera, and 89 species. The copper toxicity dataset far exceeds the MDRs for derivation of an estuarine/marine acute criterion. Acceptable estuarine/marine copper chronic values are available for only two species, the euryhaline rotifer, *Brachionus plicatilis* (Arnold et al. 2010b) and the sheepshead minnow, *Cyprinodon variegatus* (Hughes et al. 1989). Consistent with U.S. EPA's Guidelines, freshwater toxicity data were therefore integrated into the derivation of the chronic criterion. Data that were determined to have acceptable quality and to be useable in the derivation of water quality criteria as described in U.S. EPA's Guidelines for the derivation of acute and chronic criteria are presented in **Appendix Table A-1** and **Appendix Table B-1**, respectively.

Table 3. Summary Table of Acceptable Toxicity Data Used to Meet the Minimum Data Requirements in EPA's Guidelines and Count of Phyla, Families, Genera and Species.

Family Minimum Data Requirement (Estuarine/Marine)	**Acute Phylum / Family / Genus**	**Chronic Phylum / Family / Genus**
Family in the phylum Chordata	Chordata / Atherinopsidae / Menidia	Chordata / Cyprinodontidae / Cyprinodon
Family in the phylum Chordata	Chordata / Sciaenidae / Leiostomus	-
Either the Mysidae or Penaeidae family	Arthropoda / Mysidae / Americamysis	-
Family in a phylum other than Arthropoda or Chordata	Mollusca / Mytilidae / Mytilus	Rotifera / Brachionidae / Brachionus
Family in a phylum other than Chordata	Rotifera / Brachionidae / Brachionus	-
Family in a phylum other than Chordata	Echinodermata / Diadematidae / Diadema	-
Family in a phylum other than Chordata	Cnidaria / Aiptasiidae / Aiptasia	-
Any other family	Arthropoda / Crangonida / Crangon	-

Dash (-) indicates requirement not met (i.e., no acceptable data).

	Estuarine/Marine Acute			**Estuarine/Marine Chronic**		
Phylum	**Families**	**GMAVs**	**SMAVs**	**Families**	**GMAVs**	**SMAVs**
Annelida	4	5	5	-	-	-
Arthropoda	23	31	34	-	-	-
Chordata	18	21	24	1	1	1
Cnidaria	1	1	1	-	-	-
Echinodermata	5	5	6	-	-	-
Mollusca	11	14	18	-	-	-
Rotifera	1	1	1	1	1	1
Total	**63**	**78**	**89**	**2**	**2**	**2**

2.8 Analysis Plan

Although the BLM-based approach for copper in estuarine/marine waters has now been developed for use in place of the former, non-BLM-based approach, the updated criteria derivations in this document are still based on the principles set forth in EPA's Guidelines (Stephan et al. 1985). Therefore, it is useful to review how the Guidelines are applied.

During CWA §304(a) criteria development, U.S. EPA reviews and considers all relevant toxicity test data. Information available for all relevant species and genera are reviewed to identify: (1) data from acceptable tests that meet data quality standards; and (2) whether the acceptable data meet the MDRs as outlined in U.S. EPA's Guidelines (Stephan et al. 1985; U.S. EPA 1986b). The taxa represented by the different groups comprising the MDRs are comprised of taxa with different ecological, trophic, taxonomic and functional characteristics in aquatic ecosystems, and are intended to be a representative subset of the diversity within a typical aquatic community. Although the aquatic life criteria process is based on selected toxicity endpoints from the most sensitive species tested, the criteria derived may not necessarily reflect the most sensitive species existing in a specific environment. If plants are more sensitive than vertebrates and invertebrates, plant criteria are developed if sufficient data are available to support its derivation.

Application of the saltwater BLM to the derivation of the estuarine/marine Final Acute Value is analogous to procedures already described in EPA's criteria for metals criteria using empirical hardness regressions. For these hardness-dependent metals criteria, LC_{50}s at various hardness levels are normalized to a selected hardness using the regression slopes. Similarly, the acceptable acute and chronic data are normalized to the selected water chemistry conditions using the BLM, and then the criteria are derived according to the Guidelines. The values presented below are relative only to the selected water chemistry for comparison purposes. The saltwater BLM-based criteria will in some cases be more stringent and in other cases less stringent than the previous criteria, depending on specific water conditions used with the BLM. As there is not a single criterion value to use for comparison purposes, it will only be possible to provide illustrative examples of each situation.

2.8.1 Acute Criterion Derivation

As recommended by the Guidelines, acute criteria are based on a species sensitivity distribution (SSD) comprised of genus mean acute values (GMAVs), which are calculated from species mean acute values (SMAVs) for available and acceptable data. SMAVs are calculated using the geometric mean for all acceptable toxicity tests for a given species (e.g. all tests for *Mytilus edulis*). If only one test is available, the SMAV is that test value by default. GMAVs are then calculated using the geometric means of all SMAVs within a given genus (e.g. all SMAVs for the genus Mytilus - *Mytilus edulis*, *Mytilus galloprovincialis*).

The estuarine/marine acute criterion is based on the Final Acute Value (FAV). The FAV is determined by first ordering the GMAVs by rank from most sensitive (Rank 1) to least sensitive (Rank *N*) for linear regression analysis. The regression analysis is typically driven by the four most sensitive genera reflecting the lowest GMAVs in the sensitivity distribution, based on the need to interpolate or extrapolate (as appropriate) to the 5th percentile of the distribution represented by the tested genera. The FAV represents a hypothetical genus more sensitive than 95 percent of representative genera. Consistent with EPA's Guidance, because more than 59 GMAVs were available for copper, the FAV was derived from the four GMAVs that have cumulative probabilities closest to the 5th percentile toxicity value for all the tested genera. The acute criterion, defined as the Criterion Maximum Concentration (CMC), is then calculated by dividing the FAV by two, which is intended to provide an acute criterion protective of nearly all individuals in the distribution (Stephan et al. 1985). The FAV may be lowered to protect recreationally or commercially important species.

As discussed above, acute toxicity test data must be available for species from a minimum of eight genera with a specified minimum required taxonomic diversity as established by the MDRs. The diversity of tested species required by the MDRs is intended to ensure the protection of various components of an aquatic ecosystem. Although the aquatic life criteria derivation process relies on selected toxicity endpoints from the sensitive species tested, it does not necessarily mean that the selected toxicity endpoints reflect the sensitivity of the most sensitive species existing within a given habitat. The intent of the eight MDRs is instead to serve as a representative sample of the aquatic community, with the MDRs representative of the different ecological, trophic, taxonomic and functional differences observed in the natural aquatic ecosystem. Use of the SSD method where the criteria values are based on the four most sensitive taxa is reflective of the whole distribution, representing a censored statistical approach that improves estimation of the lower tail when the shape of the whole distribution is uncertain.

2.8.2 Chronic Criterion Derivation

A chronic criterion is typically determined by one of two methods. If MDRs are met with acceptable chronic test data available for all eight families, then the chronic criteria can be derived using the same method as for the acute criteria, employing chronic values (e.g., EC_{20}) estimated from acceptable toxicity tests. In cases where less chronic data are available, but where there are at least three chronic tests from taxa that also have appropriate acute toxicity data, the chronic criterion can be derived by determining an appropriate acute-chronic ratio (ACR). The ACR is a way of establishing a relationship between the acute and chronic toxicities of a chemical to aquatic organism. ACRs can be used to derive chronic criteria with data for species of aquatic animals provided that the MDR of at least three species is met and that:

- at least one species is a fish
- at least one species is an invertebrate
- at least one species is an acutely sensitive estuarine/marine species (the other two species data may be freshwater or estuarine/marine, as appropriate, for the derivation).

ACRs are calculated by dividing the acute toxicity test values by a “paired” chronic test value. Tests for a chemical are considered paired when they are conducted by the same laboratory, with the same test organism and with the same dilution water. A chronic criterion is not derived if there is more than a ten-fold difference amongst ACRs and if there is no clear trend related to species sensitivity (Stephan et al. 1985). If these criteria are met, the Final Acute-Chronic Ratio (FACR) may be the geometric mean of the available ACRs or an individual ACR (or combination therefore), based on the most sensitive taxa. The Final Chronic Value (FCV) is then estimated by dividing the FAV by the FACR. This serves as the basis for the chronic criterion. The FCV then may be lowered if necessary to protect recreationally or commercially important species.

2.8.3 BLM Evaluation

Use of the BLM to predict the bioavailability and toxicity of copper to estuarine/marine organisms under site-specific conditions is a significant modification from the previous criteria derivation methodology, which used no relationships (e.g., salinity) to adjust the criteria. As detailed in **Section 2.4**, the BLM is based on the premise that toxicity is related to metal bound to a biochemical site (the biotic ligand) and that binding is related to total dissolved metal concentrations and complexing ligands in the water, with the BLM explicitly accounting for individual water quality variables that affect bioavailability and toxicity. This document utilizes the recently developed saltwater BLM to provide an updated BLM-based water quality criterion that is applicable to marine and estuarine waters.

Table 4 summarizes the water quality input parameters required for the freshwater and marine copper BLMs. As shown in **Table 4**, the saltwater BLM for copper has relatively few input parameters, compared with the freshwater BLM.

Table 4. Water Quality Input Parameters for the Freshwater and Saltwater Versions of the BLM.

Freshwater BLM Input Parameters	Saltwater BLM Input Parameters
Temperature	Temperature
pH	pH
DOC	DOC
Calcium	Salinity
Magnesium	
Sodium	
Potassium	
Sulfate	
Chloride	
Alkalinity	
Sulfide	

Because the ionic composition of marine water is relatively constant (Turekian 1968), all of the cations, anions, and alkalinity are estimated from salinity. The major dissolved ions in seawater (Cl, Na, Mg, SO_4, Ca, K, HCO_3), and used in toxicity tests, are present in constant ratios. Individual ion concentrations can therefore be easily calculated from a known salinity or from the known concentration of a single ion (Pilson 1998). The defined and consistent ionic composition of saltwater is what reduces the needed input parameters for the copper saltwater BLM to just temperature, pH, DOC, and salinity. Approximating the ionic content of variable salinity samples in this way assumes that the freshwater component mixing with the marine water is devoid of ions. Actual freshwaters mixing into estuaries will, of course, have variable ionic content. The deviation from this simplified assumption and the actual chemistry of the estuary will depend on how ionically rich the freshwater is, and how far upstream the estuary (i.e., to how low a salinity level) the estimation is used. It is clear, however, that to the extent that the actual ionic content is different, it will always be higher than the estimate, and therefore the estimate will always be conservative. Despite the reduction in the number of parameters needed, much of the currently available aquatic toxicity literature for metals does not include the measurement or reporting of all key BLM input parameters. Additional data were therefore obtained from the authors, additional measurements were made in relevant water sources, or input parameters were estimated when necessary to fill in these data gaps. As with any modeling effort, however, the reliability of the BLM-derived accumulation and toxicity values for this project are subject to the limitations of the input measurements and estimation procedures described above.

The criteria presented herein are the agency's best estimate of maximum concentrations of copper to protect most estuarine/marine aquatic organisms from any unacceptable short- or long-term effects. Results of such intermediate calculations such as SMAV and chronic values are specified to four significant figures to prevent rounding errors in subsequent calculations and the number of places beyond the decimal point does not reflect the precision of the value.

3 EFFECTS ANALYSES FOR AQUATIC ORGANISMS

3.1 Summary of Acute Studies

The acute criterion or CMC was calculated according to the procedure described in the following section. The reported acute toxicity values (LC_{50}s or EC_{50}s) determined to be acceptable for use in criteria development (summarized in **Appendix Table A-1**) and individual test water chemistry parameters were first used to calculate lethal accumulation values (LA_{50}s). The LA_{50}s represent the critical threshold concentrations at the biotic ligand that result in acute toxicity and were used to normalize toxicity values (e.g., LC_{50}s) to a standard water condition (**Appendix Table A-1**, footnote e). As used here, "normalization" refers to the procedure by which all of the measured effect levels were adjusted, via use of the BLM, to predict effect concentrations that would have been expected in the selected water chemistry (see **Section 3.3**). LA_{50}s were determined by running the saltwater BLM in speciation mode (see BLM User's Guide)[2]. The resulting normalized effect concentrations were then used to calculate the Species Mean Acute Values (SMAVs), Genus Mean Acute Values (GMAVs), and the Final Acute Value (FAV) according to EPA's Guidelines procedure. These values are relevant (for comparison purposes across species) only at the selected water chemistry values specified, but are used to allow the BLM model to predict the FAV and criteria in any water chemistry condition. Data that were identified during the review, but that were not considered to be acceptable and not included in the criteria calculations are listed in **Appendix Table E-1**.

Acceptable data on the acute effects of copper on estuarine/marine species were available for 89 species representing 78 genera (**Table 5**). BLM-normalized (at the selected water chemistry) SMAVs ranged from 3.944 µg/L for the most sensitive species, the red abalone, *Haliotis rufescens*, to 81,550 µg/L for the least sensitive species, the amphipod *Corophium volutator*. Molluscs were among the most sensitive species, with *H. rufescens*, *Mytilus edulis* and *M. galloprovincialis*, having three of the five lowest SMAVs. The other two of five lowest SMAVs were for the copepod, *Tigriopus californicus*, and the purple sea urchin, *Strongylocentrotus purpuratus* (Arnold et al. 2010a; City of San Jose 1998; Dinnel et al. 1989;

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[2] The saltwater BLM has the same two prediction modes (speciation and toxicity) as the freshwater model. The speciation mode is only used in the context of a data processing step and is not a mode that is needed or publicly available in the software distributed for calculating estuarine/marine criteria.

O’Brien et al. 1988; Rosen et al. 2008). Invertebrates, including molluscs, were generally more sensitive than fish, representing 19 of the 20 lowest GMAVs (**Table 5**).

Table 5. Ranked Estuarine/Marine Genus Mean Acute Values.
(All values were normalized to select water chemistry conditions, see **Section 3.3**).

Rank	Genus Mean Acute Value (µg/L)	Genus	Species	Species Mean Acute Value (µg/L)
78	81,550	*Corophium*	Amphipod, *Corophium volutator*	81,550
77	43,694	*Rangia*	Clam, *Rangia cuneata*	43,694
76	>33,000	*Opsanus*	Gulf toadfish, *Opsanus beta*	>33,000
75	31,716	*Limulus*	Horseshoe crab, *Limulus polyphemus*	31,716
74	>29,733	*Gammarus*	Amphipod, *Gammarus duebeni*	>29,733
73	8,976	*Callinectes*	Blue crab, *Callinectes sapidus*	8,976
72	8,863	*Micropogonias*	Atlantic croaker, *Micropogonias undulatus*	8,863
71	8,423	*Rivulus*	Mangrove killifish, *Rivulus marmoratus*	8,423
70	4,898	*Mugil*	Striped mullet, *Mugil cephalus*	4,898
69	4,428	*Centropomus*	Fat snook, *Centropomus parallelus*	4,428
68	4,145	*Lagodon*	Pinfish, *Lagodon rhomboides*	4,145
67	3,715	*Nitokra*	Copepod, *Nitokra spinipes*	3,715
66	3,690	*Boleophthalmus*	Mud-skipper, *Boleophthalmus sp.*	3,690
65	3,014	*Litopenaeus*	Whiteleg shrimp, *Litopenaeus vannamei*	3,014
64	2,590	*Palaemonetes*	Grass shrimp, *Palaemonetes pugio*	2,590
63	2,512	*Terapon*	Thornfish, *Terapon jarbua*	2,512
62	2,492	*Emerita*	Sand crab, *Emerita analoga*	2,492
61	2,163	*Palaemon*	Decapod, *Palaemon elegans*	2,163
60	2,057	*Amphiascoides*	Copepod, *Amphiascoides atopus*	2,057

Rank	Genus Mean Acute Value (µg/L)	Genus	Species	Species Mean Acute Value (µg/L)
59	1,675	*Eurythoe*	Polychaete, *Eurythoe complanata*	1,675
58	1,672	*Sphaeroma*	Isopod, *Sphaeroma serratum*	1,672
57	1,538	*Crepidula*	Gastropod, *Crepidula convexa*	1,105
			Gastropod, *Crepidula fornicata*	2,141
56	1,534	*Archosargus*	Sheepshead, *Archosargus probatocephalus*	1,534
55	1,416	*Turbo*	Whelk, *Turbo coronatus*	1,416
54	1,089	*Planaxis*	Grooved snail, *Planaxis sulcatus*	1,089
53	1,058	*Penaeus*	Tiger shrimp, *Penaeus monodon*	1,058
52	875.7	*Trachinotus*	Pompano, *Trachinotus carolinus*	875.7
51	730.8	*Carcinus*	Shore crab, *Carcinus maenas*	730.8
50	646.9	*Perna*	Asian green mussel, *Perna viridis*	646.9
49	623.4	*Hediste*	Polychaete, *Hediste* (*Nereis*) *diversicolor*	623.4
48	611.0	*Cymatogaster*	Shiner perch, *Cymatogaster aggregata*	611.0
47	589.5	*Ophionereis*	Bristle star, *Ophionereis dubia*	589.5
46	556.3	*Fundulus*	Mummichog, *Fundulus heteroclitus*	556.3
45	515.7	*Allorchestes*	Amphipod, *Allorchestes compressa*	515.7
44	512.2	*Cyprinodon*	Leon Springs pupfish, * *Cyprinodon bovinus*	778.0
			Sheepshead minnow, *Cyprinodon variegatus*	337.2
43	445.6	*Oncorhynchus*	Coho salmon, * *Oncorhynchus kisutch*	445.6
42	350.2	*Mercenaria*	Hard clam, *Mercenaria mercenaria*	350.2
41	341.6	*Balanus*	Barnacle, *Balanus amphitrite*	139.7
			Barnacle, *Balanus eburneus*	835.4
40	260.8	*Farfantepenaeus*	Pink shrimp, *Farfantepenaeus duorarum*	260.8

Rank	Genus Mean Acute Value (µg/L)	Genus	Species	Species Mean Acute Value (µg/L)
39	255.4	*Crangon*	Shrimp, *Crangon crangon*	255.4
38	229.9	*Morone*	Striped bass, *Morone saxatilis*	229.9
37	222.9	*Loligo*	Squid, *Loligo opalescens*	222.9
36	190.6	*Leiostomus*	Spot, *Leiostomus xanthurus*	190.6
35	185.0	*Atherinops*	Topsmelt, *Atherinops affinis*	185.0
34	130.1	*Echinogammarus*	Amphipod, *Echinogammarus olivii*	130.1
33	112.8	*Neanthes*	Polychaete, *Neanthes arenaceodentata*	112.8
32	106.8	*Metapenaeus*	Shrimp, *Metapenaeus sp.*	106.8
31	106.4	*Pseudopleuronectes*	Winter flounder, *Pseudopleuronectes americanus*	106.4
30	101.2	*Pseudodiaptomus*	Copepod, *Pseudodiaptomus coronatus*	101.2
29	99.77	*Tisbe*	Copepod, *Tisbe furcata*	99.77
28	87.98	*Hydroides*	Polychaete, *Hydroides elegans*	87.98
27	85.48	*Orchomenella*	Amphipod, *Orchomenella pinguis*	85.48
26	82.57	*Americamysis*	Mysid, *Americamysis bahia*	96.60
			Mysid, *Americamysis bigelowi*	70.57
25	75.27	*Elasmopus*	Amphipod, *Elasmopus rapax*	75.27
24	72.63	*Aiptasia*	Sea anemone, *Aiptasia pallida*	72.63
23	64.47	*Menidia*	Inland silverside, *Menidia beryllina*	46.01
			Atlantic silverside, *Menidia menidia*	85.97
			Tidewater silverside, *Menidia peninsulae*	67.73
22	64.20	*Scorpaenichthys*	Cabezon, *Scorpaenichthys marmoratus*	64.20
21	53.80	*Anaitides*	Polychaete, *Anaitides maculata*	53.80
20	35.72	*Cancer*	Dungeness crab, *Cancer magister*	35.72

Rank	**Genus Mean Acute Value (µg/L)**	**Genus**	**Species**	**Species Mean Acute Value (µg/L)**
19	32.60	*Neomysis*	Mysid, *Neomysis mercedis*	32.60
18	28.37	*Homarus*	Lobster, *Homarus americanus*	28.37
17	28.35	*Spisula*	Surf clam, *Spisula solidissima*	28.35
16	23.03	*Mya*	Softshell clam, *Mya arenaria*	23.03
15	23.03	*Brachionus*	Rotifer, *Brachionus plicatilis*	23.03
14	22.44	*Eurytemora*	Copepod, *Eurytemora affinis*	22.44
13	16.49	*Dendraster*	Sand dollar, *Dendraster excentricus*	16.49
12	16.40	*Acartia*	Copepod, *Acartia clausi*	21.86
			Copepod, *Acartia tonsa*	12.31
11	15.35	*Argopecten*	Bay scallop, *Argopecten irradians*	15.35
10	13.85	*Arbacia*	Sea urchin, *Arbacia punctulata*	13.85
9	12.58	*Diadema*	Long-spined sea urchin, *Diadema antillarum*	12.58
8	12.38	*Mulinia*	Coot clam, *Mulinia lateralis*	12.38
7	10.29	*Strongylocentrotus*	Green sea urchin, *Strongylocentrotus droebachiensis*	13.29
			Purple sea urchin, *Strongylocentrotus purpuratus*	7.971
6	10.10	*Crassostrea*	Pacific oyster, *Crassostrea gigas*	11.94
			Eastern oyster, *Crassostrea virginica*	8.537
5	9.572	*Holmesimysis*	Mysid, *Holmesimysis costata*	9.572
4	9.153	*Haliotis*	Black abalone,* *Haliotis cracherodii*	21.24
			Red abalone, *Haliotis rufescens*	3.944
3	8.848	*Paralichthys*	Summer flounder, *Paralichthys dentatus*	8.848
2	7.847	*Tigriopus*	Copepod, *Tigriopus californicus*	7.847
1	5.577	*Mytilus*	Blue mussel, *Mytilus edulis*	4.238

Rank	Genus Mean Acute Value (µg/L)	Genus	Species	Species Mean Acute Value (µg/L)
			Mediterranean mussel, *Mytilus galloprovincialis*	7.338

[a] From **Appendix Table A-1**.
* Listed species.

3.2 Summary of Chronic Studies

Acceptable estuarine/marine copper chronic values are available for only two species, the euryhaline rotifer, *Brachionus plicatilis* (Arnold et al. 2010b) and the sheepshead minnow, *Cyprinodon variegatus* (Hughes et al. 1989) (**Appendix Table B-1**). These chronic toxicity values were obtained from a multigeneration life-cycle test with the rotifer, and a flow-through early life stage (ELS) test with the sheepshead minnow. Copper concentrations were measured in the test chambers of both tests. As for the acute values, the chronic values presented below are BLM-normalized and are relevant (for comparison purposes across species) only at the selected water chemistry values specified, but are used to allow the BLM model to predict the criteria in any water chemistry condition.

The static multigeneration life cycle test with the rotifer, conducted by Arnold et al. (2010b), was used to develop an acute-chronic ratio for the species (**Table 6**). Neonates were exposed to seven copper concentrations in artificial seawater for 96 hours (Note: due to the life history of this short-lived organism, this duration represents a chronic exposure). The intrinsic rate of rotifer population increase was negatively affected (37% decrease) at 10.3 µg/L dissolved copper, but not at 6.1 µg/L, with a MATC value of 7.927 µg/L. The authors reported an EC_{20} of 10.9 µg/L dissolved copper, or 13.23 µg/L once BLM normalized. Dividing the 48-hr LC_{50}s from this study by the EC_{20} resulted in an ACR of 1.229 (13.4 µg/L/10.9 µg/L) when the rotifers were not fed in the acute test, and an ACR of 1.908 (20.8 µg/L /10.9 µg/L) when the rotifers were fed in the acute test (**Appendix Table B-2**).

The ELS test with sheepshead minnow did not provide concentration-response data and regression analysis could not be done. In the 28-day ELS test, growth was reported to be a more sensitive endpoint than mortality, and the chronic value for growth was 249 µg total Cu/L (or 226.8 µg dissolved Cu/L). The BLM normalized MATC is 204.1 µg/L dissolved copper.

Dividing the 96-hr LC_{50} from this study by the 28-day chronic value (368/249 µg/L) resulted in an ACR of 1.475 (**Appendix Table B-2**).

Table 6. Ranked Estuarine/Marine Genus Mean Chronic Values with Species Mean Acute-Chronic Ratios.

(All values were normalized to select water chemistry conditions, see **Section 3.3**).

Rank	Genus Mean Chronic Value (µg/L)	Genus	Species	Species Mean Chronic Value (µg/L)[a]	ACR
2	204.1	*Cyprinodon*	Sheepshead minnow, *Cyprinodon variegatus*	204.1	1.475
1	13.23	*Brachionus*	Rotifer, *Brachionus plicatilis*	13.23	1.229 / 1.908 fed

[a] From **Appendix Table B-1**.

Other chronic toxicity data deemed unacceptable for quantitative use in the criteria derivation (**Appendix Table E-1**), but generally considered to be representative were evaluated to determine ACRs for additional species for purposes of comparison. A 28-day LC_{50} of 56 µg/L was reported for the polychaete, *Neanthes arenaceodentata* (Pesch and Hoffman 1982), which yields an ACR of 2.298 when divided into the SMAV of 128.7 µg/L. Pesch et al. (1979) reported an EC_{50} of 5.8 µg/L for reduced growth for the bay scallop, *Argopecten irradians*, based on exposure to copper for 42 days. Division of the SMAV (25.01 µg/L) by this value gives an ACR of 4.312. Data for these two additional invertebrate species, although not used quantitatively in the criteria derivation, are consistent with and generally support the lower (<2) ACRs given for the rotifer and sheepshead minnow.

3.3 Summary of BLM Water Quality Input Parameters

Table 7 summarizes the selected water quality input parameters used for the saltwater BLM normalization. The designation of these parameters is not in and of itself important other than to define a consistent set of conditions to which to normalize all the data. The LC_{50} and EC_{50} values presented in **Appendix Table A-1** were standardized to these specified water chemistry conditions (see footnote “e”). The reported chemistry for each individual study is presented in **Appendix Table H-1** and summary statistics of all the test conditions are provided in **Appendix Table H-2**. Likewise, the estuarine/marine chronic values in **Appendix Table B-1** are normalized to the same specified water chemistry conditions. These inputs were standardized in order to perform calculations with a consistent set of parameters and to ensure the selection of these parameters does not affect either the rank order of the species sensitivity distribution or the resulting criteria calculations (Di Toro et al. 2001). Following normalization of the data presented in **Appendix Table A-1**, the BLM can be used to calculate an FAV which accounts for changes to any variable included in the model (i.e., temperature, pH, salinity, and DOC). DOC is typically the most important variable because pH tends to have limited variation in marine water, while salinity and temperature have a lesser effect on copper bioavailability than does DOC.

Table 7. Water Quality Input Parameters Used for Saltwater BLM-Normalization.

Saltwater BLM Input Parameters	Saltwater BLM Input Value
Temperature	22°C
pH	8
DOC	1.0 mg/L
Salinity	32 ppt

3.4 Bioaccumulation

Copper bioaccumulates in aquatic organisms, although increased accumulation through trophic levels in aquatic food chains (i.e., biomagnification) is not usually observed (Lewis and Cave 1982; Suedel et al. 1994). Total uptake generally depends on the environmental copper concentration, exposure route and the duration of exposure (McGeer et al. 2000). Bioconcentration Factors (BCFs) typically vary with the bioavailable concentration of copper in water, with higher BCFs occurring at lower copper concentrations (McGeer et al. 2003; U.S. EPA 2010a). Some of the highest reported BCFs for copper are for marine and freshwater bivalves (Hamelink et al. 1994). Copper bioavailability and toxicity is promoted by oxine and other lipid soluble synthetic organic chelators in marine ecosystems (Bryan and Langston 1992). In marine sediments, bioavailability is altered by increased acid volatile sulfide (AVS) content (Casas and Crecelius 1994), and ligand concentration (Skrabal et al. 2000). A more detailed discussion of bioaccumulative factors is provided in the Effects Characterization (**Section 4.3**).

3.5 Toxicity to Aquatic Plants

No acceptable estuarine/marine copper toxicity tests are available for algal or aquatic vascular plant species for which the concentrations of test material were measured. Therefore, a

Final Plant Value (FPV) could not be determined. Effects on aquatic plants are discussed qualitatively in the Effects Characterization (**Section 4.4**).

3.6 The National Estuarine/Marine Criteria for Copper

3.6.1 Acute Criterion Calculation

Acceptable acute toxicity values are available for 89 species representing 63 taxonomic families (**Table 3**). The ranked GMAVs are presented in **Figure 9** and the ranked SMAVs and summaries of acute toxicity test data for individual species are shown in **Figure 10** for comparison. Because more than 59 GMAVs were available for copper, the FAV was derived from the four GMAVs that have cumulative probabilities closest to the 5th percentile toxicity value for all the tested genera. The 5th percentile of the species sensitivity distribution, equivalent to the FAV, was estimated as 9.138 µg/L (**Table 8**) (Note: the FAV changes with respect to the conditions at the site, and the values represented below only apply to the selected conditions in **Table 7**). For previous estuarine/marine criteria, the FAV was lowered to protect commercially and recreationally important mussel species. For these data, a value that is protective of commercially and recreationally important species would involve lowering the FAV to the SMAV for *Haliotis rufescens*, which is the lowest SMAV amongst commercially and recreationally important species with a value of 3.944 µg/L. The calculated FAV was therefore lowered to the SMAV for *H. rufescens* and the CMC was set to this lowered FAV divided by two (3.944/2=2.0 µg/L) (**Table 8**).

Table 8. Estuarine/Marine Water Final Acute Value (FAV) and Criteria Calculations.
(All values were normalized to select water chemistry conditions see **Section 3.3**).

N	Rank[b]	Genus	GMAV	ln(GMAV)	$\ln(\mathrm{GMAV})^2$	P=R/(N+1)	sqrt(P)
78	5	*Holmesimysis*	9.572	2.26	5.10	0.063	0.252
	4	*Haliotis*	9.153	2.21	4.90	0.051	0.225
	3	*Paralichthys*	8.848	2.18	4.75	0.038	0.195
	2	*Tigriopus*	7.847	2.06	4.24	0.025	0.159
	Sum:			**8.71**	**19.00**	**0.177**	**0.831**

S^2 = 4.575
L = 1.734
A = 2.212
FAV (calculated) = 9.138
FAV (*H. rufescens* lowered) = 3.944
CMC[a] = **2.0**

Where, S=slope, L=intercept, A=ln(FAV); and FAV=final acute value

[a] When the temperature=22°C, pH=8, DOC=1.0 mg/L, and salinity=32 ppt.

[b] According to the Guidelines, ranks 2-5 are used in the calculation of the FAV (Stephan et al. 1985).

The recommended CMC of 2.0 µg/L is specific for the seawater chemistry specified in **Table 7**, which consists of the following physical and chemical parameter assumptions: temperature=22°C, pH=8, DOC=1.0 mg/L and salinity=32 ppt. The BLM analysis can be adjusted to incorporate different physical and chemical parameters to be protective of aquatic life under varied conditions (see **Appendix I**).

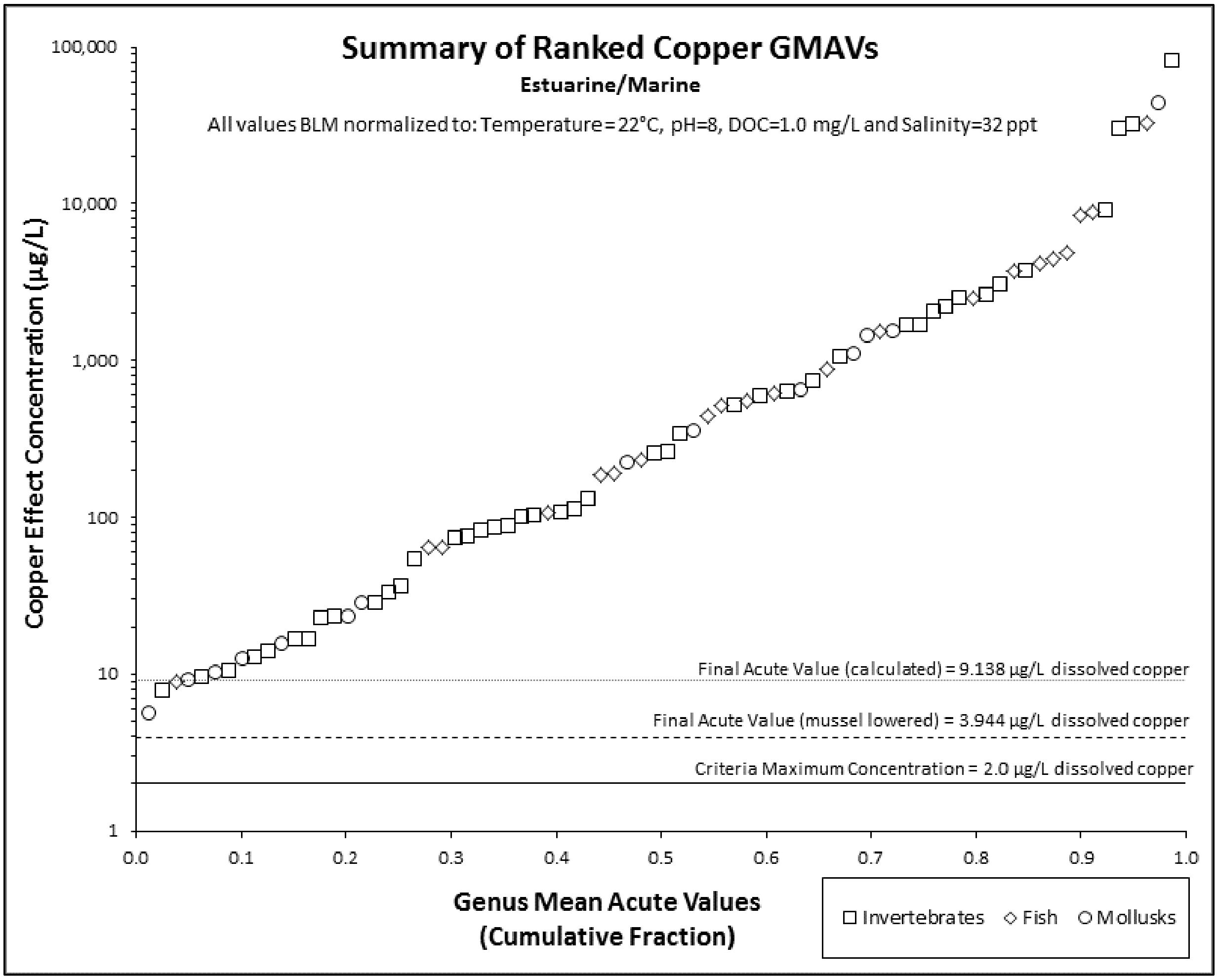

Figure 9. Ranked Estuarine/Marine GMAVs.

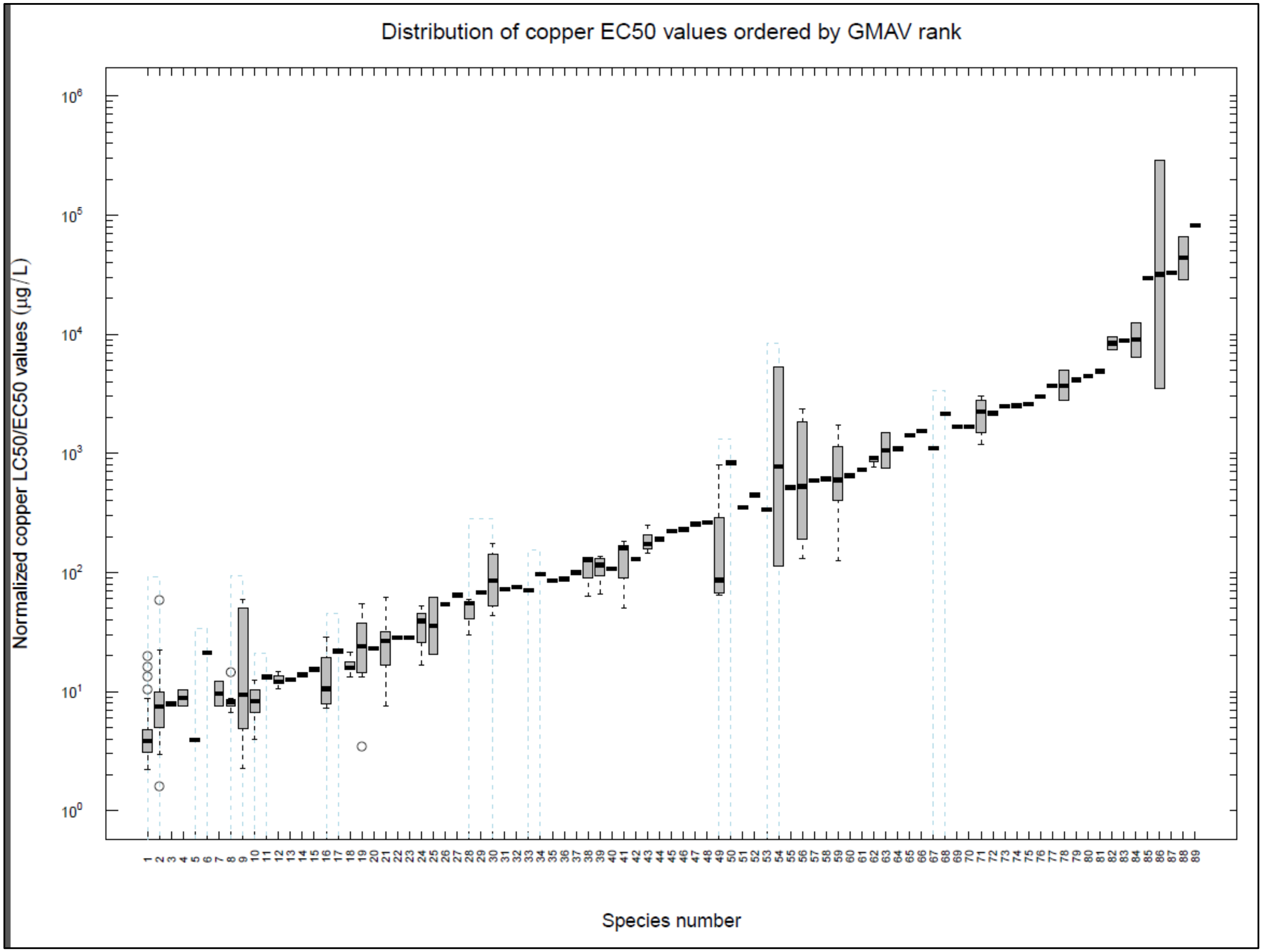

Figure 10. Reported Dissolved Cu LC_{50}s Ranked by the Geomean of the Normalized Cu Values (i.e., SMAVs).

(For each species, the box shows the range from the 25th to the 75th percentile of the available BLM normalized EC_{50}s, and the geometric mean SMAV is shown by the horizontal line within the box. The whiskers show the maximum and minimum values, exclusive of outlier points. Outliers are shown as individual symbols. Test species are identified on the x-axis labels using species numbers listed in **Appendix Table G-1**).

3.6.2 **Chronic Criterion Calculation**

The Criterion Continuous Concentration (CCC) can be derived either from chronic values if the MDRs are met, or from the FAV divided by a FACR (Stephan et al. 1985). Since estuarine/marine chronic values are available for only two species and the MDR is not met, the FAV divided by the FACR was used to determine the CCC.

Two valid estuarine/marine ACRs are available for copper (**Table 6**). The sheepshead minnow, *Cyprinodon variegatus*, is a relatively insensitive estuarine/marine water species on an acute basis, with a GMAV falling at approximately the midway point of sensitivity of all the tested estuarine/marine genera (Rank 44), while the rotifer *Brachionus plicatilis* is more sensitive, with a GMAV falling within the lower quarter of the all tested species (Rank 15) (**Table 5**). The lowest estuarine/marine acute values are from tests with embryos and larvae of molluscs and embryos of summer flounder, which are also likely to be the most sensitive life stages of these species. Although estuarine/marine ACRs are not available for these sensitive species, ACRs are available for the most acutely sensitive freshwater species tested to date for copper (**Appendix Table B-2**).

Individual ACRs varied amongst studies ranging from <1 (0.142) for *Ceriodaphnia dubi*a (Harmon et al. 2003) to 191.6 for the snail, *Campeloma decisum* (Arthur and Leonard 1970). Species mean ACRs ranged from 1.229 for the rotifer, *B. plicatilis* to 171.2 for the freshwater snail, *C. decisum*. The Guidelines outline four primary ways to combine ACRs to calculate an appropriate FACR.

- If the species mean acute-chronic ratios seems to increase or decrease as the SMAV increases, the Final Acute-Chronic Ratio should be calculated as the geometric mean of the acute-chronic ratios for species whose SMAVs are close to the Final Acute Value.

- If no major trend is apparent and the acute-chronic ratios for a number of species are within a factor of ten, the Final Acute-Chronic Ratio should be calculated as the geometric mean of all the species mean acute-chronic ratios available for both freshwater and saltwater species.

- For acute tests conducted on metals and possibly other substances with embryos and larvae of barnacles, bivalve molluscs, sea urchins, lobsters, crabs, shrimp, and abalones, it is probably appropriate to assume that the acute-chronic ratio is 2. Thus, if the lowest available SMAVs were determined with embryos and larvae of such species, the Final Acute-Chronic Ratio should probably be assumed to be 2, so that the Final Chronic Value is equal to the Criterion Maximum Concentration.

- If the most appropriate species mean acute-chronic ratios are less than 2.0, and especially if they are less than 1.0, acclimation has probably occurred during the chronic test. Because continuous exposure and acclimation cannot be assured to provide adequate protection in field situations, the Final Acute-Chronic Ratio should be assumed to be 2, so that the Final Chronic Value is equal to the Criterion Maximum Concentration.

Since the available ACRs are not within a factor of 10, and because a relationship is evident between acute sensitivity and ACRs, the FACR was calculated as the geometric mean of the ACRs for species with SMAVs close to the FAV, and that have taxonomically related marine species. The FACR of 3.022 was calculated as the geometric mean of the genus mean ACRs for five sensitive freshwater genera, *Ceriodaphnia* (3.268), *Daphnia* (4.057), *Oncorhynchus* (3.630), *Acipenser* (5.757) and *Cottus* (2.075), along with the two estuarine/marine genus mean ACRs for *Cyprinodon* (raised to 2.0) and *Brachionus* (raised to 2.0) (**Appendix Table B-2**). The final chronic value (FCV) for copper at the selected water chemistry (**Table 7**) is the FAV of 3.944 μg/L (lowered to protect *H. rufescens*) divided by the FACR and equals 1.3 μg/L Cu. The CCC, which is equivalent to the FCV, is lower than the two acceptable GMCVs available for copper (**Figure 11**) at the specified chemistry.

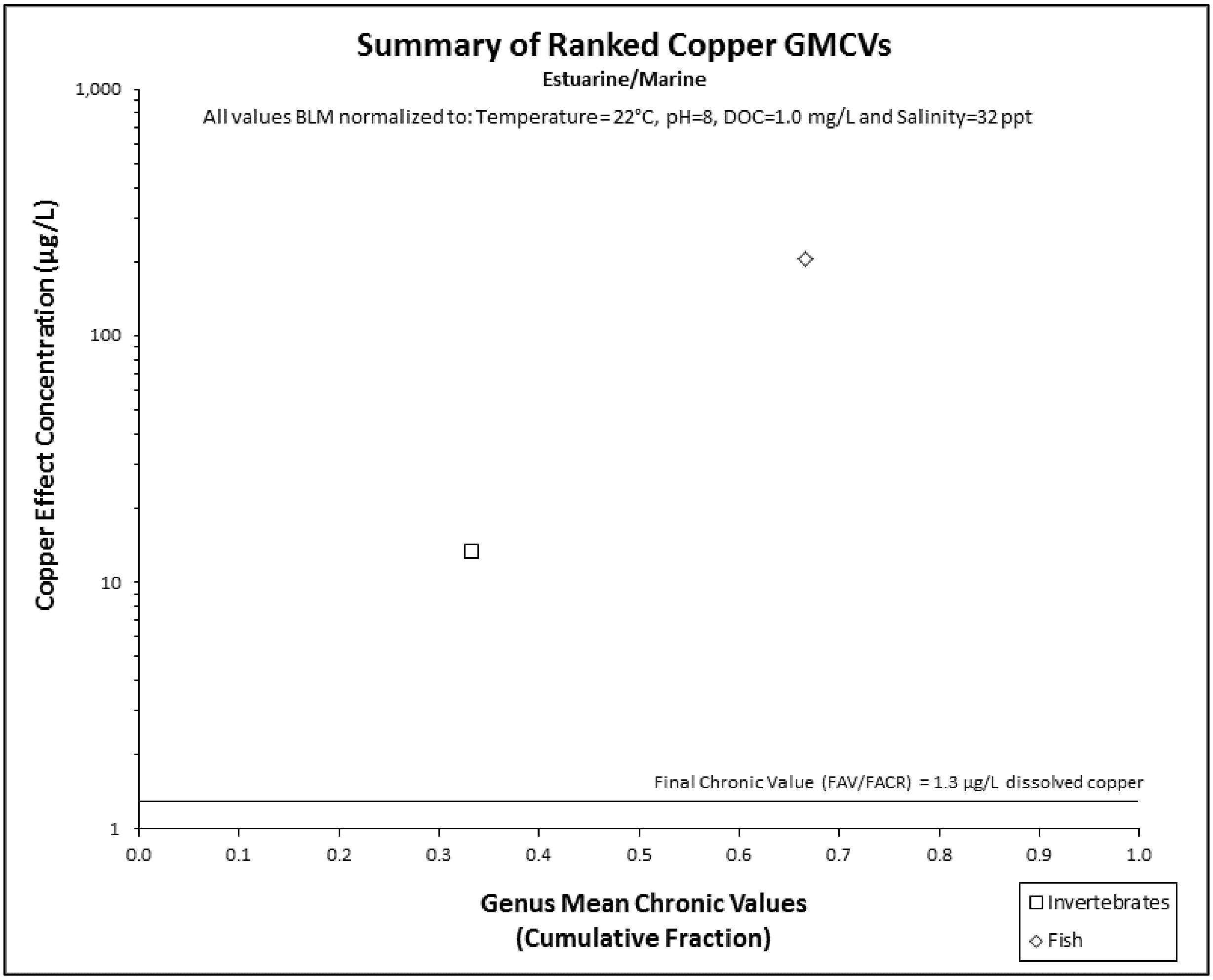

Figure 11. Ranked Estuarine/Marine GMCVs.

3.7 Summary of National Criteria

The resulting recommended ambient WQC indicate that estuarine/marine aquatic organisms would have an appropriate level of protection if the 1-hour average and four-day average dissolved copper concentrations do not respectively exceed the acute and chronic criteria concentrations calculated by the saltwater BLM more than once every three years on average. For the 2016 acute criteria, EPA has changed the duration to 1 hour from the 24 hours EPA applied in the 2003 draft copper criteria document and the 2007 freshwater copper criteria document. EPA made this change to the 2016 criteria to reflect the acute criteria duration recommended in the Guidelines (see **Section 4.1.2**). The WQC numeric values will change in response to changes in water quality parameters (i.e., temperature, salinity, dissolved organic carbon and pH).

For example, at the selected water chemistry conditions chosen for BLM-normalization (temperature=22°C, pH=8, DOC=1.0 mg/L and salinity=32 ppt), the resulting recommended ambient WQC indicate that estuarine/marine aquatic organisms would have an appropriate level of protection if the 1-hour average dissolved copper concentration does not exceed 2.0 µg/L more than once every three years on average, and if the four-day average dissolved copper concentration does not exceed 1.3 µg/L more than once every three years on average. There may be an exception, however, if a locally important species is more sensitive.

The BLM can be used to adjust criteria values to be protective under different temperature, pH, DOC, and salinity conditions. For example, when the site conditions are changed to assume a temperature=20°C, pH=8, DOC=4.0 mg/L and salinity=15 ppt (which may be typical conditions for an estuary with moderate DOC concentrations), the resulting CMC and CCC are 7.1 and 4.7 µg/L, respectively. **Appendix I** provides a discussion of temperature, pH, DOC and salinity conditions expected to occur in estuarine and marine waters around the United States, a discussion of environmental variables affecting each of these conditions, and additional examples of numeric criteria values for copper depending on selected water quality inputs.

3.8 Identification of Data Gaps for Aquatic Organisms

3.8.1 Chronic Toxicity Data for Estuarine/Marine Animals

Limited acceptable chronic copper toxicity data are available for estuarine/marine animal species. Studies are available for only two estuarine/marine animal species, as discussed in **Section 3.2**. The FCV is therefore based on the use of a FACR. The FACR assumes that the relationship between acute and chronic toxicity for each species is constant. Acceptable ACRs are averaged across taxa to calculate the final overall relationship between the acute and chronic toxicity values. Since freshwater ACRs are used to bolster the calculation of the FACR, due to only two estuarine/marine genus-level ACRs being available, this creates an additional uncertainty in the estuarine/marine FCV.

3.8.2 Chronic Toxicity Data for Aquatic Vascular Plants and Algae

Acceptable toxicity data are limited for aquatic vascular plants and algae for which the concentrations of test material were measured. Accordingly, the available plant data did not meet the MDRs established in the Guidelines to support the derivation of a plant-based value (**Appendix Table C-1**). However, analysis of the toxicity data that are available for estuarine/marine plant species, which is discussed in **Section 4.4**, suggests that a chronic criterion value that is protective of estuarine/marine animals would also be protective of aquatic plants (see **Section 4.4**).

3.8.3 BLM Uncertainties and Performance

The BLM used to update the estuarine/marine copper criteria employs equilibrium reactions for copper and other anions/cations using a single and simple type of surface ligand to characterize the effects of all physical and chemical exposure conditions on toxicity. As such, the model is a simplified and approximate representation of a complex set of chemical reactions and transfers that are involved with environmental copper eliciting toxicity. As already noted, cation effects may involve mechanisms in addition to competition for a surface ligand. Further, the microenvironment at the gill surface and other biological membranes of toxic interaction for juvenile and adult fish might change copper speciation, but the most sensitive organisms to which the criteria are applicable (and likely to determine the FAV) are embryo-larval life stages of invertebrates that do not have a gill microenvironment. Finally, because the biotic ligand refers to specific binding sites in the organism, accumulation measurements taken from digests of whole embryonic stages, or based on bulk gill tissue could include metal in addition to that bound to the biotic ligand, including metal that has been taken up and transported by the cell or organ.

Despite the uncertainties described in this section, the BLM provides a reasonable mechanistic framework for the well-established effects of copper speciation, explicitly addressing the relative bioavailability of different copper species. It also includes a plausible mechanism that allows the effects of cations to be addressed and uses a comprehensive model for calculating the concentrations of various copper species. Even if the mechanistic descriptions are incomplete, this model allows the major empirical effects of complexing ligands and competing cations to be described in a more comprehensive and reasonable fashion than other approaches (U.S. EPA 2007).

4 EFFECTS CHARACTERIZATION

The Effects Characterization section evaluates the potential effects of copper on estuarine/marine aquatic life based on available test data and describes additional lines of evidence that were not used directly in the criteria calculations, but which support the 2016 aquatic life criteria values. This section also provides a summary of uncertainties and assumptions, and explanations for decisions about the acceptability and use of data in the effects assessment. Finally, this section describes substantive differences between the 2003 draft copper ALC and the 2016 update, based on incorporation of the latest scientific information.

All acceptable acute and chronic values used to derive criteria are presented in **Appendix Table A-1** and **Appendix Table B-1**, respectively. Studies that were determined to be scientifically sound, but not meeting with screening guidelines for inclusion in criteria calculations are presented in **Appendix Table E-1**. Studies that were not used qualitatively or quantitatively in the criteria development and the reason they were not used are provided in **Appendix Table F-1**.

4.1 Estuarine/Marine Acute Toxicity Data

Acceptable acute toxicity data are available for 89 estuarine/marine species representing 78 genera. These data were used to support the development of an estuarine/marine acute criterion.

Aquatic invertebrates are more acutely sensitive to copper than fish in the marine environment. Amongst the ten most sensitive genera to copper, nine are invertebrates and are primarily represented by bivalves and echinoderms. BLM-normalized SMAVs for copper range from 3.944 to 81,550 µg/L. The most sensitive genus is the mussel *Mytilus*, followed by the copepod, *Tigriopus*, with BLM-normalized GMAVs of 5.577 and 7.847 µg/L, respectively. The two most tolerant genera were the amphipod, *Corophium*, and the clam, *Rangia*, with BLM-normalized GMAVs of 81,550 and 43,694 µg/L, respectively (**Table 5**).

Several studies were identified as not meeting screening guidelines for inclusion in criteria calculations (**Appendix Table E-1**), but showed similar ranges of toxicity for a number of the most sensitive species (Note: the values below were BLM-normalized to the same water quality parameters in **Table 7**). Manley et al. (1984) reported a 72-hr LOEC of 4.258 µg/L copper to *Mytilus edulis*, which is similar to the GMAV for the genus (5.577 µg/L). Similarly, Fitzpatrick et al. (2008) observed increased abnormal larval development of *Mytilus trossulus* embryos exposed to 4.623 µg/L copper for 48 hours. The Pacific oyster, *Crassostrea gigas,* was investigated by several authors and acute effect levels were observed at concentrations ranging from 1.890 to 65.90 µg/L copper for embryos exposed from one to three days, which is similar to the SMAV of 11.94 µg/L for the species (Brooks et al. 2007; Harrison et al. 1981; Worboys et al. 2002). Eisler (1977) reported a 7-day LC_{50} of 16.22 µg/L copper for the soft-shell clam *Mya arenaria,* which is close to the GMAV of 23.03 µg/L reported for this species.

For fish, Anderson et al. (1994) reported 7-day LC_{50}s for topsmelt, *Atherinops affinis*, larva that ranged from 25.46 to 78.71 µg/L copper. Pacific herring embryos, *Clupea harengus pallasi*, non BLM-normalized acute effect levels ranged from 33 to 900 µg/L copper (Rice and Harrison 1978). A 4-day LC_{50} of >164.4 µg/L copper was reported for larva of the sheepshead minnow, *Cyprinodon variegates* (Hutchinson et al. 1994). Cobia, *Rachycentron canadum*, 4-day LC_{50}s ranged from 25.75 to 130.1 µg/L copper (Dung et al. 2005). The acute effect levels observed for all these species are similar to the BLM-normalized GMAV (64.20 µg/L copper) reported for the cabezon, *Scorpaenichthys marmoratus,* which was the second most sensitive fish species (Rank 22, **Table 5**) with acceptable acute data.

4.1.1 **Uncertainty in the Estuarine/Marine FAV Calculation**

A number of uncertainties are associated with calculation of the FAV as described in the Guidelines (Stephan et al. 1985), and include use of limited data for a species or genus, application of safety factors, and extrapolation of laboratory data to the field. There are a number of cases in the acute database where only one acute test is used to determine the SMAV, and subsequently the GMAV is based on the one acute test. In this situation, species variability within a particular genus is unknown. The GMAV is still valid, in spite of absence of these additional data.

The final step in the acute criteria derivation process is to divide the FAV by a safety factor of 2 to yield the CMC. The CMC is set as equal to half of the FAV to represent a low level of effect for the fifth percentile genus, rather than a 50% effect. This adjustment factor was derived from an analysis of 219 acute toxicity tests with a variety of chemicals (see 43 FR 21506-21518 for a complete description) where mortality data were used to determine the highest tested concentration that did not cause mortality greater than that observed in the control (or between 0 and 10%). Application of this safety factor is justified because that concentration represents minimal acute toxicity to the species.

Application of water-only laboratory toxicity tests to develop water quality criteria to protect aquatic species is a basic premise of the Guidelines, supported by the requirements of a diverse assemblage of eight families and the protection of 95 percent of all species. Confirmation has been reported by a number of researchers (Clements and Kiffney 1996; Clements et al. 2002; Mebene 2006; Norgberg-King and Mount 1986), thereby indicating that on the whole, extrapolation from the laboratory to the field is a scientifically valid and protective approach for aquatic life criteria development.

4.1.2 **Acute Criteria Duration**

For the 2016 acute estuarine/marine copper criteria, EPA has changed the duration to 1-hour from the 24 hours EPA applied in the 2003 draft copper criteria document and the 2007 freshwater copper document. EPA made this change to the 2016 criteria to reflect the acute criteria duration recommended in the Guidelines. Both the 2003 and 2007 copper criteria documents used a 24-hour duration, but did not detail the rationale for this duration, and EPA has further examined this issue as part of the 2016 criteria update.

EPA revised the acute duration in this document to be consistent with the more protective 1-hour duration, which is generally supported by and consistent with the Guidelines. The Guidelines, for example, states the following:

> *"For the CMC the averaging period should again be substantially less than the lengths of the tests it is based on, i.e., substantially less than 48 to 96 hours. One hour is probably an appropriate averaging period because high concentrations of some materials can cause death in one to three hours. Even when organisms do not die within the first hour or so, it is not known how many might have died due to delayed effects of this short of an exposure. Thus it is not appropriate to allow concentrations above the CMC to exist for as long as one hour. The durations of the averaging periods in national criteria have been made short enough to restrict allowable fluctuations in the concentration of the pollutant in the receiving water and to restrict the length of time that the concentration in the receiving water can be continuously above a criterion concentration."* (Stephan et al. 1985, page 5)

> …*"the one-hour average should never exceed the CMC."* (Stephan et al. 1985, page 6)

Additional information supporting the 1-hour averaging period is presented in the *Technical Support Document for Water Quality-based Toxics Control* (U.S. EPA 1991) which states:

> *"For acute criteria, EPA recommends an averaging period of 1-hour. That is, to protect against acute effects, the 1-hour average exposure should not exceed the CMC. The 1-hour acute averaging period was derived primarily from data on response time for toxicity to ammonia, a fast-acting toxicant. The l-hour averaging period is expected to be fully protective for the fastest-acting toxicants, and even more protective for slower-acting toxicants."* (U.S. EPA 1991, page 35)

The frequency of allowed exceedances is once in three years on average, as recommended in the Guidelines (Stephan et al. 1985). This is based on the ability of aquatic ecosystems to recover from criteria exceedances, which will depend in part on the magnitude and duration of the exceedance(s).

4.2 Estuarine/Marine Chronic Toxicity Data

Data for only two estuarine/marine species are suitable for derivation of a chronic criterion. Suitable data are available for the rotifer, *Brachionus plicatilis* (BLM-normalized SMCV=13.23 µg/L dissolved Cu) and the sheepshead minnow, *Cyprinodon variegatus* (BLM-normalized SMCV=204.1 µg/L dissolved Cu).

Several studies that were identified as not meeting with screening guidelines for inclusion in criteria calculations reported chronic sublethal effects of copper on estuarine/marine invertebrates (**Appendix Table E-1**). The following data are BLM-normalized, unless noted. Three scleractinian coral species along with their algal symbionts were exposed to three measured copper concentrations for five weeks under flow-through conditions (Bielmyer et al. 2010). The authors reported reduced growth chronic values of 14.69, >20.31 and <4.04 µg/L copper (not BLM-normalized) for *Acropora cervicornis*, *Montastraea faveolata* and *Pocillopora damicornis*, respectively. Pesch et al. (1979) reported reduced growth for the bay scallop, *Argopecten irradians*, after exposure to 3.681 µg/L copper for 42-days. Gill alterations were observed by Frias-Espericueta et al. (2008a) in juvenile whiteleg shrimp, *Litopenaeus vannamei*, after exposure to 80.61 µg/L copper for 28 days. The 26 to 28-day LC_{50}s for the polychaete worms, *Cirriformia spirabranchia* and *Neanthes arenaceodentata,* ranged from 25.53 to 35.97 µg/L copper (Milanovich et al. 1976; Pesch and Hoffman 1982; Pesch and Morgan 1978). Channeled whelk, *Busycon canaliculatum*, Mediterranean mussel, *Mytilus galloprovincialis*, and quahog clam, *Mercenaria*, 28- to 77-day LC_{50} effect levels ranged from 25 to 470 µg/L copper (not BLM-normalized) (Bat et al. 2013; Betzer and Yevich 1975; Shuster and Pringle 1968).

Limited chronic data are available for estuarine/marine fish species. Lacoue-Labarthe et al. (2010) exposed cuttlefish (*Sepia officinalis*) eggs to four unmeasured copper concentrations for 50 days and reported a hatchling weight NOEC and LOEC of 2.3 and 23 µg/L (not BLM-normalized), respectively. Several authors (Engel et al. 1976; Swedmark and Granmo 1981) conducted 14-day exposures for different species and reported copper not BLM-normalized LC_{50} effect levels of 10 µg/L for the Atlantic cod, *Gadus morhua*, 150 µg/L for the pinfish, *Lagodon rhomboids*, 160 µg/L for the spot, *Leiostomus xanthurus*, 210 µg/L for the Atlantic croaker, *Micropogonias undulates*, and 610 µg/L for the Atlantic menhaden, *Brevoortia tyrannus*. Although the exposure periods were shorter than typically used for chronic studies, these data indicate response concentrations that are generally similar to the chronic effect level reported by Hughes et al. (1989) for sheepshead minnow, *Cyprinodon variegatus* (BLM-normalized SMCV=204.1 µg/L dissolved Cu), which was the only estuarine/marine fish for which acceptable chronic toxicity data were available.

4.2.1 Uncertainty in the Estuarine/Marine FCV Calculation

In addition to the uncertainties described above for the acute criteria derivation (**Section 4.1.1**) and identification of data gaps (**Section 3.8.1**), the estuarine/marine FCV calculation is also influenced by the estimation of chronic values with MATC methods. The estimation of chronic values with an EC_{20} regression analysis is preferred over the use of MATCs because MATCs are highly dependent on the concentrations tested and can therefore potentially bias the chronic value either higher or lower than the EC_{20}. Point estimates also provide additional information that is difficult to determine with an MATC, such as a measure of effect level across a range of tested concentrations. A MATC was used to determine the chronic value for the sheepshead minnow, whereas an EC_{20} was estimated for the rotifer.

4.3 Bioaccumulation

Bioconcentration factors (BCFs) for copper in estuarine/marine water are provided in **Appendix Table D-1**. In estuarine/marine water, the polychaete worms, *Phyllodoc maculate*, *Neanthes arenaceodentata* and *Eudistylia vancouveri*, had copper BCFs of 2,500, 2,950 and 1,006, respectively (McLusky and Phillips 1975; Pesch and Morgan 1978; Young et al. 1979). BCFs for six species of estuarine/marine bivalve molluscs range from 790 for the soft-shell clam, *Mya arenaria* (Shuster and Pringle 1968), to 57,000 for the Pacific oyster, *Crassostrea gigas* (Han and Hung 1990). Similarly, Shuster and Pringle (1968) found that the eastern oyster, *Crassostrea virginica*, could concentrate copper to levels 27,800 times greater than ambient water concentrations during a 140-day continuous exposure to 25 µg/L copper. Even though the tissue of the oyster became bluish-green, mortalities were only slightly greater than in the controls. There are no BCF data for estuarine/marine fish or crustaceans meeting the data quality objectives required for inclusion in Appendix Table D-1 of this document.

4.3.1 **Uncertainty with Copper Exposure Routes**

Aquatic organisms can accumulate copper from both aqueous and dietary exposure routes. The relative importance of each, however, is dependent upon the species. The filter feeding oyster *Crassostrea gigas* was found to accumulate more copper from ambient water than from phytoplankton food items (Ettajani et al. 1992), as did the suspension feeding cockle, *Cerastoderma edule* (Absil et al. 1996). Guo et al. (2013) exposed the abalone, *Haliotis discus hannai*, for eight weeks to either aqueous or dietary copper and observed that substantially more copper was accumulated in muscle tissue from the water exposure (10.8 fold increase) than the macroalgae diet (2.0 fold increase). Similar copper absorption efficiency or accumulation levels from water and diet were observed by Absil et al. (1994) for the sediment-dwelling bivalve, *Macoma balthica* (efficiencies ranged from 71-87% in aqueous exposures and from 78-90% in foodborne exposures), and by Long and Wang (2005) for the marine target fish, *Terapon jarbua* (approximately two-fold increase for both). Pinho et al. (2007) also observed similar waterborne and waterborne plus dietborne copper accumulation for the copepod *Acartia tonsa*, irrespective of the salinity level (5, 15 and 30 ppt). Although accumulation decreased as salinity increased, no significant differences were observed between the exposure routes at each salinity exposure (from approximately 6.5 to 11.5 fold increases). Copper burdens in blackhead seabream *Acanthopagrus schlegelii schlegelii* intestine and liver after aqueous exposure (130 and 110 µg/g dw, respectively) were comparable to those after dietary exposure (140 and 95 µg/g dw, respectively) (Dang et al. 2012). In contrast, Bielmyer et al. (2005a) found significantly higher copper accumulation in the intestine and liver of saltwater-acclimated hybrid striped bass (*Morone chrysops* x *Morone saxatilis*) exposed to dietary copper (approximately 8-fold and 2-fold increases, respectively) than those exposed to aqueous copper (no significant increases). In summary, the primary route of copper accumulation varies among species, with no consistent pattern.

The specific tissues/organs affected in an aquatic organism are also dependent on the exposure route. Several authors have postulated that copper speciation influences exposure route and the subsequent tissues and organs affected (Henry et al. 2012; Martins et al. 2011; Wang and Fisher 1996). Bivalve molluscs and crustaceans primarily accumulate dissolved metals across the gills, and particulate forms within the gut. In crustaceans, aqueous metals can be adsorbed to the body surface or taken up internally by ingestion, passive diffusion, or facilitated transport (Wang and Fisher 1998). For example, dissolved copper adsorbs onto the chitosan exoskeleton of pelagic and benthic crustaceans (Henry et al. 2012; Hook and Fisher 2001), or inert chitin surfaces of insects (Hare 1992), where it is rendered unavailable to interfere with internal metabolic processes. In contrast, ingested copper can accumulate into internal tissues potentially interfering with a variety of metabolic and reproductive processes (Hook and Fisher 2001). Copper assimilated from food is stored in the soft tissue of oysters (Amiard-Triquet et al. 1992). Lobsters accumulate aqueous copper primarily in their gills (Canli and Furness 1993), with most of the dietary copper deposited in the digestive gland (Chou et al. 1987).

In marine fish, uptake of dissolved copper is either by the gills or the intestinal tract, and is sometimes influenced by ambient water and dietary levels (Grosell 2012). Accumulation of dissolved copper by the gills can be by either passive (diffusion) or active (pump) transport (Neff 2002). Aqueous accumulation of copper via intestinal tissues is due to the ingestion of seawater for osmoregulatory purposes (Grosell et al. 2003, 2004). Fish exposed to metals in the presence of food initially absorb copper in the intestinal tract and to some degree the stomach, and subsequently transfer it to other tissues via the circulatory system (Wood et al. 2012). Water-borne copper primarily accumulated in the gill of the skate, *Raja erinacea*, and the sculpin, *Myoxocephalus octodecemspinosus* (Gosell et al. 2003). However, Blanchard and Grosell (2005) exposed the killifish, *Fundulus heteroclitus*, to aqueous copper at different salinities and observed the highest accumulations in the liver, gill and intestine. In comparison, dietary copper (as copper contaminated oysters) accumulated mainly in the intestine and to some extent the gill of the killifish, *Fundulus heteroclitus* (Blanchard et al. 2009).

In an effort to determine the most toxic exposure route, three studies have compared the adverse effects of copper to marine organisms exposed separately to both aqueous and dietary copper. Bielmyer et al. (2005a) exposed saltwater-acclimated (15 ppt salinity) hybrid striped bass (*Morone chrysops* x *Morone saxatilis*) to dietary (571 to 1013 µg Cu/g), aqueous (22 to 44 µg Cu/L) and dietary plus aqueous copper concentrations for 42 days. None of the exposures scenarios had significant growth effects when compared to controls, although the authors noted that the dietary copper exposed fish had significant liver and intestinal copper accumulation. Conversely, Lauer and Bianchini (2010) observed exposure route differences when a copepod (*Acartia tonsa*) was exposed for six days to either dietary, aqueous or dietary plus aqueous copper concentrations at three different salinities (5, 15, 30 ppt). The copepods were exposed to three concentrations of aqueous copper, fed diatoms that were exposed to three aqueous concentrations of copper for 24 hours, or a combination of both. Pulsed exposures lasted 12 hours each day over the six-day experiment, after which the copepods were transferred to clean media and allowed to reproduce for 24 hours. The water only exposure was the most toxic exposure route, with reduced egg production EC_{50}s of 9.9, 36.8 and 48.8 µg/L dissolved copper, followed by the dietary plus aqueous exposure with EC_{50}s of 40.1, 63.7 and 109.9 µg/L dissolved copper at 5, 15 and 30 ppt, respectively. The diet only exposures exhibited the least effect, with a maximum of 43 percent reduction in reproduction regardless of exposure concentration or test salinity. A similar toxicological difference in exposure routes was observed in a 28-day study of juvenile blackhead seabream (*Acanthopagrus schlegelii schlegelii*) that was either fed a contaminated diet of copper or exposed to only copper in seawater. When based on similar estimated influx rates, the aqueous exposure was more toxic (31 percent mortality) than the diet only exposure (<10 percent mortality) (Dang et al. 2012).

Several other investigators examined the toxic effects of dietary copper exposures to marine organisms. Roberts et al. (2006) observed reduced survival of juvenile amphipods (*Peramphithoe parmerong*) fed a contaminated macroalgae that was cultured in a spiked solution containing 100 µg/L copper for 30 days. However, spiked solutions of up to 300 µg/L copper had no effect on the growth of survivors. Juvenile grey mullet (*Chelon labrosus*) fed a high-Cu diet of 2,400 µg/g dry weight for 67 days did not experience any mortality, but growth rate was reduced by 43 percent (Baker et al. 1998). Sea urchins (*Lytechinus variegatus*) fed two copper containing formulated diets (36 or 144 µg Cu/g) over twelve weeks had no significant difference in mortality, total diameter and total dry weight compared to the controls that were fed 12 µg Cu/g (Powell et al. 2010). Similarly, no death was observed when juvenile rock fish (*Sebastes schlegeli*) were fed one of four copper diets (50, 100, 250, 500 µg/g) for 60 days, but the specific growth rates for weight and length were reduced at 100 µg Cu/g and 250 µg Cu/g, respectively (Kang et al. 2005; Kim and Kang 2004). Lin et al. (2008) fed juvenile grouper (*Epinephelus malabaricus*) copper diets with eight different copper concentrations ranging from 0.11 to 20.05 µg Cu/g for eight weeks. Weight gain and feed efficiency was significantly greater in diets containing 4.37 and 6.56 µg Cu/g, but was less in diets with ≤1.66 or ≥11.03 µg Cu/g. Survival in all exposures was ≥80 percent with no dose-response observed amongst treatments. No mortality was observed when adult male crabs (*Neohelice granulata*) were fed copper dosed algae (300 µg Cu/g) twice a week for five weeks. However, it should be noted that the exposure regime was equivalent to mean weekly doses of 6 µg Cu/g per crab (Sabatini et al. 2009).

Bielmyer et al. (2006b) exposed adult copepods (*Acartia tonsa*) to four copper-enriched diatom diets for seven days at a salinity of 30 ppt. The authors reported the 7-day reproductive EC_{20} as 22.3 µg Cu/g dry weight, or 1.2 µg Cu/L (the lowest diatom medium exposure concentration). In contrast, Lauer and Bianchini (2010) observed a diet-only 6-day reproductive EC_{20} of 23 µg Cu/g dry weight at a salinity of 30 ppt, or 40.1 µg Cu/L based on the diatom culture medium. In addition, they reported waterborne reproductive EC_{20}s ranging from 8.3 to 27.4 µg Cu/L. A review by Deforest and Meyer (2015) compared the results of these two studies and noted the following study design differences which may explain why the waterborne copper effect levels are different: 1) the dilution water in the Lauer and Bianchini (2010) study had a higher DOC level; 2) two different species of diatoms were used; 3) the diatoms were exposed for seven days in the Bielmyer et al. (2006b) study versus only 24 hours; and 4) the feeding regimes differed between the two studies. In addition, the Bielmyer et al. (2006b) study had unacceptable control survival (<80 percent) for a chronic test, which suggests that the test organisms may have been subjected to stresses other than copper during the exposure. So, while the 1.2 µg Cu/L effect concentration from the Bielmyer et al. (2006b) appears to be low, it may not be representative of the copper water effect concentration to this species. And as discussed earlier in **Section 2.3**, the apparent lack of aquatic food chain biomagnification (Lewis and Cave 1982; Suedel et al. 1994) reduces the risk to higher trophic level predators including aquatic dependent wildlife.

Understanding the toxicological link between accumulated metal tissue levels and the observation of adverse effects remains difficult to characterize, and therefore has received considerable interest in recent years (Adams et al. 2011; Mebane 2006; Wood et al 2012). The poorly understood link between copper tissue levels and corresponding adverse effects is in part due to the various mechanisms utilized by different species to detoxify and/or sequester copper, thereby rendering it biologically unavailable. A well-known and widespread copper detoxification mechanism is the production of metal binding proteins (e.g., metallothioneins) by a number of invertebrates and fish in response to a metal exposure. Adams et al. (2011) noted that aquatic organisms contain a diverse array of homeostatic mechanisms that are both metal- and species-specific, and therefore the risk to the aquatic organism could not be determined by whole-body tissue residue levels for metals, further suggesting tissue-based copper criteria may not accurately reflect ecotoxicological effects of copper under real-world exposure scenarios at the national-level. Thus, it is unclear if the copper accumulated in a specific fish organ is bioavailable or sequestered. Therefore, the link between total copper tissue levels and adverse effects is difficult to quantify since the majority of accumulated copper may be in a detoxified form.

4.4 Effects on Aquatic Plants

Data are available on the toxicity of copper to 26 species of estuarine/marine aquatic plants; however, these data were not used quantitatively in this effects assessment because they did not meet the MDRs established in the Guidelines to support the derivation of a plant-based value (**Appendix Table C-1)**. The species for which toxicity data are available encompass several classes of aquatic plants, inclusive of microalga, cyanobacterium, diatoms, dinoflagellates, green and red alga, and two species of kelp. The following data are not BLM normalized. A copper concentration of 60 µg/L copper caused a 50% decrease in photosynthesis in the giant kelp, *Macrocystis pyrefera* (Clendenning and North 1959), whereas a 21-day exposure to 5 µg/L copper reduced gametophyte development rate in the kelp, *Laminaria saccharina* (Chung and Brinkhuis 1986). Zhu et al. (2011) reported a 7-day growth rate LOEC of 50 µg/L copper for the brown alga, *Hizikia fusiformis*, and the less sensitive green seaweed, *Ulva* *pertusa*, had a chlorophyll fluorescence EC_{50} of 711 µg/L copper (Kumar et al. 2009). Growth reduction in the red alga, *Champia parvul*a, occurred in both the tetrasporophyte and female plants exposed to copper concentrations of 4.6 and 4.7 µg/L copper, respectively (Steele and Thursby 1983). Another red algal species, *Ceramium tenuicorne*, had a 7-day growth EC_{50} of 6.4 µg/L copper. Dinoflagellates were equally sensitive to copper with growth rate reductions occurring at concentrations that ranged from 5 to 12,740 µg/L copper, with most reductions occurring at concentrations <50 µg/L copper. Diatoms were also sensitive to copper, with the most sensitive species, *Thalassiosira aestevallis*, having reduced growth at 19 µg/L copper with a 3-4 day exposure period (Hollibaugh et al. 1980).

The most sensitive plant effect concentrations were BLM-normalized to the same water chemistry to allow comparison to the FCV. All of the normalized values were greater than the FCV except a static, unmeasured 4-day IC_{50} for reduced growth of 0.8320 µg/L dissolved copper for the golden/brown flagellate (*Isochrysis sp*.) (Garr 2012). Saifullah (1978) reported a BLM normalized growth LOEC of 2.257 µg/L copper for two dinoflagellates (*Prorocentrum micans* and *Scrippsiella faeronense*) at 8 and 5 days, respectively. The red alga, *Champia parvula*, had BLM-normalized effect concentrations that ranged from 2.078 to 6.159 µg/L based on reduced growth and reproduction (Steele and Thursby 1983). Giant kelp, *Macrocystis pyrifera*, exposed to measured copper for 19-20 days using renewal procedures exhibited reduced sporophyte production at a BLM-normalized concentration of 4.552 µg/L copper (Anderson et al. 1990). The most sensitive effect concentration of 0.8320 µg/L copper reported by Garr (2012) was based on nominal concentrations and, as recommended by the Guidelines (Stephan et al. 1985), cannot be used to calculate a FPV. Since the majority of the other values show sensitivity to copper that is similar to animals, a chronic criterion that protects estuarine/marine animals should also protect plants.

4.5 Protection of Endangered Species

The estuarine/marine dataset for copper is extensive for the evaluation of acute toxicity, but few data are available for the evaluation of chronic toxicity. Only limited data are available for species that are Federally-listed as threatened or endangered by the NOAA National Marine Fisheries Service. Summaries are provided here of data that are available for listed species and demonstrate that, based on the best and most current available data, the draft copper criteria in this 2016 update are protective of threatened or endangered species.

4.5.1 Acute Toxicity Data for Listed Species

There are only three endangered and/or threatened estuarine/marine species that have acceptable acute toxicity data. The black abalone, *Haliotis cracherodii*, was tested as an adult in an acute static-renewal exposure with a BLM-normalized value of 21.24 µg/L copper (Martin et al. 1977). The genus *Haliotis* was the fourth most sensitive genus with the embryo non-endangered abalone species *H. rufescens* with a BLM-normalized value of 3.944 µg/L copper. The endangered/threatened Coho salmon smolt (*Oncorhynchus kisutch*) was the 43rd most sensitive genera tested and had a BLM-normalized value of 445.6 µg/L copper. The Leon Springs pupfish, *Cyprinodon bovinus*, had a BLM-normalized SMAV of 778.0 µg/L copper, with the genus ranking 44th.

4.5.2 Chronic Toxicity Data for Listed Species

There is no threatened and/or endangered estuarine/marine species with acceptable or other chronic toxicity data for copper.

4.6 Comparison of Draft 2003 and 2016 Criteria Values

New acute data for estuarine/marine species have been added to the 2016 update. A total of 78 genera are used to derive the estuarine/marine CMC of 2.0 µg/L in the 2016 update (when selected water chemistry values were used for BLM normalization) in comparison to the 44 genera used for the 2003 draft criteria, which resulted in a CMC of 3.1 µg/L (**Table 9**). The draft 2003 acute criterion is more stringent than the current recommended 1995 criterion of 4.8 µg/L, because of additional data for sensitive organisms (U.S. EPA 1995a, 2003). The 2016 update uses the BLM to incorporate the interaction and effect of water physical and chemical parameters (pH, temperature, salinity and DOC) that affect the bioavailability of copper to aquatic organisms. Thus, the numeric water quality criteria values derived from the BLM are dependent upon site-specific water quality parameters. The updated BLM-based WQC will in some cases be more stringent and in other cases less stringent than the previous criteria (which are not adjusted based on water chemistry condition). As there is not a single WQC value to use for comparison purposes, the values presented in **Table 9** are illustrative only at the selected water chemistry values used for BLM-normalization (**Table 7**).

The four most sensitive genera with available data were used to calculate the CMC in the 2003 draft document (because n<59 GMAVs), while the second to fifth more sensitive genera are used in the 2016 update (because n≥59 GMAVs). The CMC reported in U.S. EPA 1995a, 2003 (draft), and this 2016 (draft) document were lowered to protect commercially important aquatic species, *Mytilus edulis*, *Mytilus sp.* and *H. rufescens*, respectively. The approximately 35 percent decrease in the 2016 CMC relative to the 2003 draft CMC is primarily due to the use of the BLM model and the default selected water quality parameters, and the additional genera used to calculate the new CMC including the following: amphipods (*Allorchestes, Echinogammarus, Gammarus* and *Orchomonella*), barnacle *Balanus*, mussel *Perna*, crabs (*Callinectes* and *Emerita*), horseshoe crab *Limulus*, bristle star *Ophionereis*, copepods (*Nitokra* and *Tisbe*), decapod *Palaemon*, gastropods (*Crepidula*, *Planaxis* and *Turbo*), shrimps (*Farfantepenaeus, Metapenaeus*, *Litopenaeus*, *Palaemonetes* and *Penaeus*), hard clam *Mercenaria*, isopod *Sphaeroma*, sea urchins (*Arbacia* and *Diadema*), polychaetes (*Eurythoe* and *Hydroides*), rotifer *Brachionus*, sand dollar *Dendraster*, sea anemone *Aiptasia*, Gulf toadfish *Opsanus*, mud-skipper *Boleophthalmus*, fat snook *Centropomus* and thornfish *Terapon.*

One new estuarine/marine species with acceptable chronic data, the rotifer, *Brachionus plicatilis*, was included in the 2016 update. The addition of this species, along with sheepshead minnow data, which was included in the 2003 draft document, results in a total of two species with chronic values and ACRs. (Note: the chronic value used in the 1995 ALC from Lussier et al. 1985 for the mysid, *Americamysis bahia,* is no longer considered valid because of poor control survival). The 2016 CCC of 1.3 µg/L copper was derived from division of the FAV of 3.944 µg/L by the FACR of 3.022, which is less than the 1995 CCC of 3.1 µg/L (FAV of 9.625 µg/L divided by an FACR of 3.127), and the 2003 draft CCC of 1.9 µg/L (FAV of 6.188 µg/L divided by an FACR of 3.23) at the selected water chemistry conditions. As noted for the acute criterion, the lower CCC presented in the 2016 update relative to the previous criteria reflects use of the BLM that incorporates water physical and chemistry interactions that affect the bioavailability of copper to aquatic organisms.

Table 9. Comparison of the Four Most Sensitive Taxa Used to Calculate the Estuarine/Marine FAV and CMC in the 2003 Draft Copper Document and 2016 Update.

2003 Draft Copper Estuarine/Marine FAV and CMC			2016 Copper Update Estuarine/Marine FAV and CMC (at selected chemistry conditions)		
Species	**SMAV (µg/L)**	**GMAV [Rank] (µg/L)**	**Species**	**SMAV (µg/L)**	**GMAV [Rank] (µg/L)**
			Mysid, *Holmesimysis costata*	9.572	9.572 [5]
Sea urchin, *Strongylocentrotus purpuratus*	12.81	12.81 [4]	Black abalone, *Haliotis cracherodii*	21.24	9.153 [4]
Summer flounder, *Paralichthys dentatus*	12.66	12.66 [3]	Red abalone, *Haliotis rufescens*	3.944	
Eastern oyster, *Crassostrea virginica*	14.49	12.60 [2]	Summer flounder, *Paralichthys dentatus*	8.848	8.848 [3]
Pacific oyster, *Crassostrea gigas*	10.96		Copepod, *Tigriopus californicus*	7.847	7.847 [2]
Blue mussel, *Mytilus edulis*	21.50	11.53 [1]	Blue mussel, *Mytilus edulis*	4.238	5.577* [1]
Mussel, *Mytilus sp.*	6.19		Mediterranean mussel, *Mytilus galloprovincialis*	7.338	
Number of GMAVs	44		Number of GMAVs	78	
FAV (calculated)	12.34		FAV (calculated)	9.138	
CMC (calculated)	6.170		CMC (calculated)	4.6	
Lowered FAV[a]	6.188		Lowered FAV[b]	3.944	
Recommended CMC	**3.1**		Recommended CMC	**2.0**[c]	

* Not used to calculate CMC since number of GMAVs ≥59.

[a] Dissolved copper final acute value (FAV) was lowered from 12.34 to 6.188 to protect *Mytilus sp*.

[b] Dissolved copper final acute value (FAV) was lowered from 9.138 to 3.944 to protect *Haliotis rufescens*.

[c] When Temperature=22°C, pH=8, DOC=1.0 mg/L, and Salinity=32 ppt.

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Appendix A Acceptable Estuarine/Marine Acute Toxicity Data

Appendix Table A-1. Acceptable Estuarine/Marine Acute Toxicity Data.

Species	Organism Age, Size or Lifestage	Method[a]	Chemical[b]	Reported LC_{50}/EC_{50} (total µg/L)[c]	Reported LC_{50}/EC_{50} (dissolved µg/L)[d]	BLM Data Label	BLM Normalized LC_{50}/EC_{50} (µg/L)[e]	Species Mean Acute Value (µg/L)[f]	Reference
Sea anemone, *Aiptasia pallida*	-	R, M	N	148	134.5	12	**72.63**	72.63	Main et al. 2010
Rotifer, *Brachionus plicatilis*	Neonate, 0-3 hr	S, M	N	-	13.4	50	**16.55**	-	Arnold et al. 2010b
Rotifer, *Brachionus plicatilis*	Neonate, 0-3 hr	S, M	N	-	20.8	51	**26.58**	-	Arnold et al. 2010b
Rotifer, *Brachionus plicatilis*	Neonate, <4hr	S, M	N	-	<12.80	53	**<34.12**	-	Arnold et al. 2010c
Rotifer, *Brachionus plicatilis*	Neonate, <4hr	S, M	N	-	<12.60	54	**<31.66**	-	Arnold et al. 2010c
Rotifer, *Brachionus plicatilis*	Neonate, <4hr	S, M	N	-	<12.90	55	**<29.67**	-	Arnold et al. 2010c
Rotifer, *Brachionus plicatilis*	Neonate, <4hr	S, M	N	-	<12.50	56	**<26.19**	-	Arnold et al. 2010c
Rotifer, *Brachionus plicatilis*	Neonate, <4hr	S, M	N	-	10.1	57	**20.41**	-	Arnold et al. 2010c
Rotifer, *Brachionus plicatilis*	Neonate, <4hr	S, M	N	-	119.1	58	**57.15**	-	Arnold et al. 2010c
Rotifer, *Brachionus plicatilis*	Neonate, <4hr	S, M	N	-	173.4	59	**54.09**	-	Arnold et al. 2010c
Rotifer, *Brachionus plicatilis*	Neonate, <4hr	S, M	N	-	80.7	60	**58.41**	-	Arnold et al. 2010c
Rotifer, *Brachionus plicatilis*	Neonate, <4hr	S, M	N	-	45.5	61	**30.52**	-	Arnold et al. 2010c
Rotifer, *Brachionus plicatilis*	Neonate, 0-2 hr	S, M	-	-	27.7	745	**62.17**	-	Saunders 2012
Rotifer, *Brachionus plicatilis*	Neonate, 0-2 hr	S, M	-	-	23.3	746	**29.42**	-	Saunders 2012
Rotifer, *Brachionus plicatilis*	Neonate, 0-2 hr	S, M	-	-	11.2	747	**8.347**	-	Saunders 2012
Rotifer, *Brachionus plicatilis*	Neonate, 0-2 hr	S, M	-	-	19.7	748	**31.19**	-	Saunders 2012
Rotifer, *Brachionus plicatilis*	Neonate, 0-2 hr	S, M	-	-	46.8	749	**17.47**	-	Saunders 2012
Rotifer, *Brachionus plicatilis*	Neonate, 0-2 hr	S, M	-	-	48.9	750	**8.115**	-	Saunders 2012

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Rotifer, *Brachionus plicatilis*	Newly hatched, <6 hr	S, M	S	42.07	38.24	760	**8.034**	-	Tait 2013
Rotifer, *Brachionus plicatilis*	Newly hatched, <6 hr	S, M	S	49.44	44.94	761	**21.89**	-	Tait 2013
Rotifer, *Brachionus plicatilis*	Newly hatched, <6 hr	S, M	S	62.28	56.61	762	**7.599**	-	Tait 2013
Rotifer, *Brachionus plicatilis*	Newly hatched, <6 hr	S, M	S	46.07	41.88	763	**8.182**	-	Tait 2013
Rotifer, *Brachionus plicatilis*	Newly hatched, <6 hr	S, M	S	25.1	22.82	764	**16.92**	-	Tait 2013
Rotifer, *Brachionus plicatilis*	Newly hatched, <6 hr	S, M	S	21.16	19.23	765	**15.25**	-	Tait 2013
Rotifer, *Brachionus plicatilis*	Newly hatched, <6 hr	S, M	S	58.15	52.86	766	**26.75**	-	Tait 2013
Rotifer, *Brachionus plicatilis*	Newly hatched, <6 hr	S, M	S	26.82	24.38	767	**43.03**	-	Tait 2013
Rotifer, *Brachionus plicatilis*	Newly hatched, <6 hr	S, M	S	35.52	32.29	768	**29.01**	23.03	Tait 2013
Polychaete, *Anaitides maculata*	-	S, U	S	120	100.6	505	**53.80**	53.80	McLusky and Phillips 1975
Polychaete, *Eurythoe complanata*	Immature, 1.0 g	S, U	-	1,300	1,089	170	**1,675**	1,675	Marcano et al. 1996
Polychaete, *Hediste (Nereis) diversicolor*	-	S, U	S	200	167.6	193	**125.3**	-	Jones et al. 1976
Polychaete, *Hediste (Nereis) diversicolor*	-	S, U	S	445	372.9	194	**792.4**	-	Jones et al. 1976
Polychaete, *Hediste (Nereis) diversicolor*	-	S, U	S	480	402.2	195	**726.9**	-	Jones et al. 1976
Polychaete, *Hediste (Nereis) diversicolor*	-	S, U	S	410	343.6	196	**403.9**	-	Jones et al. 1976
Polychaete, *Hediste (Nereis) diversicolor*	Juvenile	R, U	N	357	299.2	197	**505.9**	-	Ozoh 1992a
Polychaete, *Hediste (Nereis) diversicolor*	Juvenile	R, U	N	357	299.2	198	**475.6**	-	Ozoh 1992a
Polychaete, *Hediste (Nereis) diversicolor*	Juvenile	R, U	N	247	207.0	199	**177.4**	-	Ozoh 1992a

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Polychaete, *Hediste (Nereis) diversicolor*	Juvenile	R, U	N	307	257.3	200	**279.7**	-	Ozoh 1992a
Polychaete, *Hediste (Nereis) diversicolor*	Juvenile	R, U	N	400	335.2	201	**485.9**	-	Ozoh 1992a
Polychaete, *Hediste (Nereis) diversicolor*	Juvenile	R, U	N	462	387.2	202	**597.2**	-	Ozoh 1992a
Polychaete, *Hediste (Nereis) diversicolor*	Juvenile	R, U	N	375	314.3	203	**386.0**	-	Ozoh 1992a
Polychaete, *Hediste (Nereis) diversicolor*	Juvenile	R, U	N	362	303.4	204	**340.1**	-	Ozoh 1992a
Polychaete, *Hediste (Nereis) diversicolor*	Juvenile	R, U	N	480	402.2	205	**539.9**	-	Ozoh 1992a
Polychaete, *Hediste (Nereis) diversicolor*	Juvenile	R, U	N	512	429.1	206	**602.1**	-	Ozoh 1992a
Polychaete, *Hediste (Nereis) diversicolor*	Juvenile	R, U	N	360	301.7	207	**302.0**	-	Ozoh 1992a
Polychaete, *Hediste (Nereis) diversicolor*	Juvenile	R, U	N	500	419.0	208	**508.2**	-	Ozoh 1992a
Polychaete, *Hediste (Nereis) diversicolor*	Adult	R, U	N	402	336.9	209	**660.1**	-	Ozoh 1992b
Polychaete, *Hediste (Nereis) diversicolor*	Adult	R, U	N	724	606.7	210	**1,718**	-	Ozoh 1992b
Polychaete, *Hediste (Nereis) diversicolor*	Adult	R, U	N	339	284.1	211	**389.5**	-	Ozoh 1992b
Polychaete, *Hediste (Nereis) diversicolor*	Adult	R, U	N	776	650.3	212	**1,533**	-	Ozoh 1992b
Polychaete, *Hediste (Nereis) diversicolor*	Adult	R, U	N	723	605.9	213	**1,286**	-	Ozoh 1992b
Polychaete, *Hediste (Nereis) diversicolor*	Adult	R, U	N	725	607.6	214	**1,192**	-	Ozoh 1992b
Polychaete, *Hediste (Nereis) diversicolor*	Adult	R, U	N	900	754.2	215	**1,539**	-	Ozoh 1992b
Polychaete, *Hediste (Nereis) diversicolor*	Adult	R, U	N	754	631.9	216	**1,127**	-	Ozoh 1992b
Polychaete, *Hediste (Nereis) diversicolor*	Adult	R, U	N	870	729.1	217	**1,262**	-	Ozoh 1992b
Polychaete, *Hediste (Nereis) diversicolor*	Adult	R, U	N	890	745.8	218	**1,302**	-	Ozoh 1992b
Polychaete, *Hediste (Nereis) diversicolor*	Adult	R, U	N	763	639.4	219	**988.6**	-	Ozoh 1992b

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Polychaete, *Hediste (Nereis) diversicolor*	Adult	R, U	N	825	691.4	220	**1,016**	-	Ozoh 1992b
Polychaete, *Hediste (Nereis) diversicolor*	-	R, U	-	921.5	772.2	221	**569.7**	623.4	Mouneyrac et al. 2003
Polychaete, *Neanthes arenaceodentata*	Adult	F, M	N	77	69.99	469	**50.01**	-	Pesch and Morgan 1978
Polychaete, *Neanthes arenaceodentata*	Adult	F, M	N	200	181.8	470	**158.3**	-	Pesch and Morgan 1978
Polychaete, *Neanthes arenaceodentata*	-	F, M	N	222	201.8	472	**181.1**	112.8	Pesch and Hoffman 1982
Polychaete, *Hydroides elegans*	Larva	R, U	S	100	83.8	230	**87.98**	87.98	Bao et al. 2011
Black abalone, *Haliotis cracherodii*	Adult	R, U	S	50	41.9	187	**21.24**	21.24	Martin et al. 1977
Red abalone, *Haliotis rufescens*	Adult	R, U	S	65	54.47	189	27.77[g]	-	Martin et al. 1977
Red abalone, *Haliotis rufescens*	Larva	S, U	S	114	95.53	190	49.87[g]	-	Martin et al. 1977
Red abalone, *Haliotis rufescens*	Embryo	S, M	C	8.8	8	191	**3.944**	3.944	Hunt et al. 1989
Whelk, *Turbo coronatus*	2.36 cm, 7.42 g	R, U	S	3,790	3,176	577	**1,416**	1,416	Kidwai and Ahmed 1999
Gastropod, *Crepidula convexa*	Juvenile	R, U	C	325	272.4	114	**1,105**	1,105	Untersee and Pechenik 2007
Gastropod, *Crepidula fornicata*	Larva	R, U	C	636.3	533.2	116	**2,141**	2,141	Untersee and Pechenik 2007
Grooved snail, *Planaxis sulcatus*	1.92 cm, 1.38 g	R, U	S	1,010	846.38	507	**1,089**	1,089	Kidwai and Ahmed 1999
Blue mussel, *Mytilus edulis*	Juvenile, 15.8 mm	R, U	C	122	-	333	72.69[g]	-	Nelson et al. 1988

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Blue mussel, *Mytilus edulis*	Embryo	S, U	S	5.8	4.86	331	**2.445**	-	Martin et al. 1981
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	8.92	8.11	334	**4.181**	-	TOXSCAN, Inc. 1991a
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	8.19	7.44	335	**3.851**	-	TOXSCAN, Inc. 1991b
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	8.29	7.54	336	**3.843**	-	TOXSCAN, Inc. 1991c
Blue mussel, *Mytilus edulis*	Embryo	R, M	S	13.1	12.5	337	**8.719**	-	Science Applications International Corporation 1993
Blue mussel, *Mytilus edulis*	Embryo	R, M	S	14.1	14.1	338	**10.40**	-	Science Applications International Corporation 1993
Blue mussel, *Mytilus edulis*	Embryo	R, M	S	12.2	11.3	339	**7.863**	-	Science Applications International Corporation 1993
Blue mussel, *Mytilus edulis*	Embryo	R, M	S	12.8	11.9	340	**8.265**	-	Science Applications International Corporation 1993
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	7.16	5.95	341	**3.524**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	5.85	5.21	342	**3.059**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	5.03	5.05	343	**3.022**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	3.82	3.75	344	**2.230**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	5.86	5.45	345	**3.204**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	4.7	3.8	346	**2.241**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	6.42	4.97	347	**2.949**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	6.22	5.72	348	**3.355**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	6.21	5.84	349	**3.423**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	5.87	5.44	350	**3.187**	-	City of San Jose 1998

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Blue mussel, *Mytilus edulis*	Embryo	S, M	S	5.4	4.75	351	**2.797**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	6	5.1	352	**3.053**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	9.05	8.3	353	**4.912**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	6.92	5.34	354	**3.138**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	7.19	5.02	355	**2.946**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	5.56	4.39	356	**2.548**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	8.48	7.5	357	**4.434**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	7.36	6.79	358	**3.995**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	7.85	5.29	359	**3.090**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	8.02	6.82	360	**3.989**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	9.5	7.81	361	**4.649**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	7.29	5.59	362	**3.270**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	8.93	6.35	363	**3.792**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	4.54	3.94	364	**2.316**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	S	4.73	3.9	365	**2.315**	-	City of San Jose 1998
Blue mussel, *Mytilus edulis*	Embryo	S, M	N	-	3.52	369	**7.142**	-	Arnold et al. 2008
Blue mussel, *Mytilus edulis*	Embryo	S, M	N	-	4.66	370	**5.259**	-	Arnold et al. 2008
Blue mussel, *Mytilus edulis*	Embryo	S, M	N	-	21.6	371	**4.284**	-	Arnold et al. 2008
Blue mussel, *Mytilus edulis*	Embryo	S, M	N	-	25.2	372	**4.907**	-	Arnold et al. 2008
Blue mussel, *Mytilus edulis*	Embryo	S, M	N	-	8.03	373	**4.057**	-	Arnold et al. 2008

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Blue mussel, *Mytilus edulis*	Embryo	S, M	N	-	9.9	374	**4.552**	-	Arnold et al. 2008
Blue mussel, *Mytilus edulis*	Embryo	S, M	N	-	14	375	**4.048**	-	Arnold et al. 2008
Blue mussel, *Mytilus edulis*	Embryo	S, M	N	-	17.5	376	**4.665**	-	Arnold et al. 2008
Blue mussel, *Mytilus edulis*	Embryo, 4 hr post fert	S, M	S	17.46	17.83	366	**13.350**	-	CH2M Hill 1999b
Blue mussel, *Mytilus edulis*	Embryo, 4 hr post fert	S, M	S	22.81	21.35	367	**16.11**	-	CH2M Hill 1999b
Blue mussel, *Mytilus edulis*	Embryo, 4 hr post fert	S, M	S	27.37	26.1	368	**19.88**	4.238	CH2M Hill 1999b
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	8.3	380	**5.606**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	8.1	381	**5.471**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	9.5	382	**15.94**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	6	383	**10.08**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	6.9	384	**6.984**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	7.1	385	**5.993**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	9.4	386	**4.761**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	6.8	387	**22.14**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	12.4	388	**17.88**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	21.7	389	**8.459**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	25	390	**7.919**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	19.1	391	**8.415**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	21.3	392	**21.65**	-	Arnold 2005

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Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	19.4	393	**13.13**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	19.3	394	**9.315**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	18.9	395	**8.705**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	17	396	**17.25**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	20.1	397	**10.19**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	27.8	398	**8.809**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	17.3	399	**6.740**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	16.3	400	**4.713**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	19.4	401	**4.266**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	30.9	402	**9.499**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	19.6	403	**8.275**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	14.7	404	**14.90**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	20.3	405	**13.75**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	20.7	406	**9.538**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	16.8	407	**8.958**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	16.4	408	**16.64**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	17.8	409	**12.04**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	15.3	410	**9.116**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	16.9	411	**10.07**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	12.4	412	**12.55**	-	Arnold 2005

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Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	18.2	413	**8.782**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	24.2	414	**5.001**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	13.8	415	**6.655**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	14.5	416	**8.158**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	16.7	417	**11.29**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	24.8	418	**3.085**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	20.1	419	**7.274**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	19.2	420	**9.731**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	22.4	421	**7.567**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	50.5	422	**5.686**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	23.3	423	**5.901**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	22.7	424	**10.01**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	14.2	425	**8.459**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	30.3	426	**6.397**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	16.5	427	**7.597**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	21.1	428	**8.224**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	14.5	429	**6.385**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	23.4	430	**5.266**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	18.4	431	**7.457**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	19.7	432	**9.075**	-	Arnold 2005

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Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	21.1	433	**12.60**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	33.3	434	**3.502**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	21.3	435	**7.443**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	14	436	**7.089**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	30.2	437	**3.043**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	11.1	438	**3.501**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	14.8	439	**10.72**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	13	440	**11.98**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	71	441	**8.327**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	24.8	442	**7.663**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	17.1	443	**11.57**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	16.6	444	**12.03**	-	Arnold 2005
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	52.9	295	**10.60**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	59.4	296	**7.044**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	47.9	297	**5.029**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	48.2	298	**10.26**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	54	299	**8.348**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	47.8	300	**4.867**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	19.6	301	**13.37**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	34.4	302	**4.797**	-	Arnold et al. 2006

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Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	56.8	303	**5.261**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	15.9	304	**11.60**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	33.8	305	**5.555**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	20	306	**10.21**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	22.5	307	**4.874**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	54.4	308	**4.614**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	14.7	309	**8.814**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	16.1	310	**4.820**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	41.6	311	**4.273**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	11.8	312	**11.95**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	11.7	313	**9.874**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	12.3	314	**4.296**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	-	-	14.1	315	**4.464**	-	Arnold et al. 2006
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	9.7	316	**1.614**	-	Arnold et al. 2007
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	8.6	317	**21.80**	-	Arnold et al. 2007
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	7.5	318	**58.07**	-	Arnold et al. 2007
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	5.13	446	**7.443**	-	Arnold et al. 2008
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	3.56	447	**3.602**	-	Arnold et al. 2008
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	30.6	448	**6.329**	-	Arnold et al. 2008
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	21.7	449	**3.847**	-	Arnold et al. 2008

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Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	12.2	450	**6.503**	-	Arnold et al. 2008
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	6.91	451	**3.164**	-	Arnold et al. 2008
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	20.2	452	**6.206**	-	Arnold et al. 2008
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	11.5	453	**3.053**	-	Arnold et al. 2008
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	S	-	6.36	454	**4.824**	-	Rosen et al. 2008
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	S	-	8.68	455	**5.051**	-	Rosen et al. 2008
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	6.28	456	**8.040**	-	Arnold et al. 2010a
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	14.4	457	**5.646**	-	Arnold et al. 2010a
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	28.2	458	**7.341**	-	Arnold et al. 2010a
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	34.8	459	**6.205**	-	Arnold et al. 2010a
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	10.9	460	**9.118**	-	Arnold et al. 2010a
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	21	461	**10.06**	-	Arnold et al. 2010a
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	31.6	462	**9.065**	-	Arnold et al. 2010a
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	N	-	37.2	463	**7.459**	-	Arnold et al. 2010a
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo, 4 cell	S, M	N	-	12.66	319	**11.87**	-	DePalma et al. 2011
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo, 4 cell	S, M	N	-	22.72	320	**6.452**	-	DePalma et al. 2011
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo, 4 cell	S, M	N	-	19.01	321	**8.304**	-	DePalma et al. 2011
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo, 4 cell	S, M	N	-	20.67	322	**6.237**	-	DePalma et al. 2011
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo, 4 cell	S, M	N	-	16.04	323	**9.176**	-	DePalma et al. 2011
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo, 4 cell	S, M	N	-	20.45	324	**6.781**	-	DePalma et al. 2011

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Mediterranean mussel, *Mytilus galloprovincialis*	Embryo, 4 cell	S, M	N	-	31.58	325	**4.646**	-	DePalma et al. 2011
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo, 4 cell	S, M	N	-	30.96	326	**9.895**	-	DePalma et al. 2011
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo, 4 cell	S, M	N	-	15.96	327	**10.27**	-	DePalma et al. 2011
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo, 4 cell	S, M	N	-	31.19	328	**4.748**	-	DePalma et al. 2011
Mediterranean mussel, *Mytilus galloprovincialis*	20-39 mm	S, U	S	1,670	1,399	730	2,285[g]	-	Bat et al. 2013
Mediterranean mussel, *Mytilus galloprovincialis*	40-59 mm	S, U	S	1,450	1,215	731	1,946[g]	-	Bat et al. 2013
Mediterranean mussel, *Mytilus galloprovincialis*	60-79 mm	S, U	S	1,180	988.8	732	1,529[g]	-	Bat et al. 2013
Mediterranean mussel, *Mytilus galloprovincialis*	50-80 mm	S, U	S	800.0	670.4	733	944.8[g]	-	Bat et al. 2013
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	C	-	8.9	769	**4.345**	-	Fabbri et al. 2014
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	C	-	8.7	770	**4.258**	-	Fabbri et al. 2014
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	C	-	12.2	752	**4.321**	-	Deruytter et al. 2015
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	C	-	10.1	753	**8.568**	-	Deruytter et al. 2015
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	C	-	13.4	754	**3.556**	-	Deruytter et al. 2015
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	C	-	4.1	755	**7.452**	-	Deruytter et al. 2015
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	C	-	13.6	756	**2.946**	-	Deruytter et al. 2015
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	C	-	10.3	757	**3.734**	-	Deruytter et al. 2015
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	C	-	11.0	758	**3.990**	-	Deruytter et al. 2015
Mediterranean mussel, *Mytilus galloprovincialis*	Embryo	S, M	C	-	5.0	759	**3.385**	7.338	Deruytter et al. 2015
Asian green mussel, *Perna viridis*	Juvenile, 1.6 cm, 0.12 g	R, M	C	-	500.0	771	**646.9**	646.9	Rajkumar 2012

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Bay scallop, *Argopecten irradians*	Juvenile, 21.2 mm	R, U	C	29	24.30	32	**15.35**	15.35	Nelson et al. 1988
Pacific oyster, *Crassostrea gigas*	Adult, 13-17 cm	F, M	S	560.00	-	88	662.0[g]	-	Okazaki 1976
Pacific oyster, *Crassostrea gigas*	Embryo	S, U	C	11.5	9.640	89	**4.918**	-	Coglianese and Martin 1981
Pacific oyster, *Crassostrea gigas*	Embryo	S,M	C	12.06	10.96	90	**6.871**	-	Harrison et al. 1981
Pacific oyster, *Crassostrea gigas*	Embryo	S, M	C	12	10.91	93	**12.88**	-	Knezovich et al. 1981
Pacific oyster, *Crassostrea gigas*	Embryo	S, U	S	5.3	4.440	94	**2.237**	-	Martin et al. 1981
Pacific oyster, *Crassostrea gigas*	Embryo	S, M	Copper	25.8	23.45	96	**50.05**	-	S.R. Hansen & Associates 1992
Pacific oyster, *Crassostrea gigas*	Embryo	S, M	Copper	30.5	27.72	97	**59.35**	11.94	S.R. Hansen & Associates 1992
Eastern oyster, *Crassostrea virginica*	Embryo	S, U	C	15.1	12.65	106	**6.699**	-	MacInnes and Calabrese 1978
Eastern oyster, *Crassostrea virginica*	Embryo	S, U	C	18.7	15.67	107	**8.284**	-	MacInnes and Calabrese 1978
Eastern oyster, *Crassostrea virginica*	Embryo	S, U	C	18.3	15.34	108	**8.110**	-	MacInnes and Calabrese 1978
Eastern oyster, *Crassostrea virginica*	Embryo	S, M	N	-	11.2	109	**14.40**	-	Arnold et al. 2010a
Eastern oyster, *Crassostrea virginica*	Embryo	S, M	N	-	22.4	110	**8.791**	-	Arnold et al. 2010a
Eastern oyster, *Crassostrea virginica*	Embryo	S, M	N	-	30.7	111	**7.994**	-	Arnold et al. 2010a
Eastern oyster, *Crassostrea virginica*	Embryo	S, M	N	-	40.7	112	**7.259**	8.537	Arnold et al. 2010a
Coot clam, *Mulinia lateralis*	Embryo	R, M	S	25.2	21	286	**14.84**	-	Science Applications International Corporation 1993
Coot clam, *Mulinia lateralis*	Embryo	R, M	S	19.1	14.9	287	**10.49**	-	Science Applications International Corporation 1993

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Coot clam, *Mulinia lateralis*	Embryo	R, M	S	18.4	17.3	288	**12.12**	-	Science Applications International Corporation 1993
Coot clam, *Mulinia lateralis*	Embryo	R, M	S	18.6	16.9	289	**11.70**	-	Science Applications International Corporation 1993
Coot clam, *Mulinia lateralis*	Embryo	R, M	S	18.9	19.3	290	**13.49**	-	Science Applications International Corporation 1993
Coot clam, *Mulinia lateralis*	Embryo	R, M	S	18.4	17.4	291	**12.09**	12.38	Science Applications International Corporation 1993
Clam, *Rangia cuneata*	-	S, U	S	8,000	6,704	526	**66,022**	-	Olson and Harrel 1973
Clam, *Rangia cuneata*	-	S, U	S	7,400	6,201	527	**28,918**	43,694	Olson and Harrel 1973
Surf clam, *Spisula solidissima*	Juvenile, 15.9 mm	R, U	C	51	42.74	536	**28.35**	28.35	Nelson et al. 1988
Hard clam, *Mercenaria mercenaria*	Larva, 160-180 µm	S, U	S	398.2	333.7	274	**350.2**	350.2	Becerra-Huencho 1984
Softshell clam, *Mya arenaria*	38-49 mm, 3.6-6.0 g	S, U	C	39	32.68	293	**23.03**	23.03	Eisler 1977
Squid, *Loligo opalescens*	Post-hatch larva	S, M	C	309	280.9	243	**222.9**	222.9	Dinnel et al. 1989
Copepod, *Pseudodiaptomus coronatus*	-	S, U	C	235.4	197.3	509	**127.8**	-	Gentile 1982
Copepod, *Pseudodiaptomus coronatus*	-	S, U	-	138	115.6	510	**62.64**	-	Gentile and Cardin 1982
Copepod, *Pseudodiaptomus coronatus*	Adult	S, U	C	235.4	197.3	511	**129.5**	101.2	Lussier and Cardin 1985
Copepod, *Eurytemora affinis*	-	S, U	C	928.0	-	151	1,361[g]	-	Gentile 1982

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Copepod, *Eurytemora affinis*	-	S, U	-	526.0	-	152	632.5[g]	-	Gentile and Cardin 1982
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	R, M	N	30.6	27.82	153	**14.27**	-	Sullivan et al. 1983
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	R, M	N	31.1	28.27	154	**14.50**	-	Sullivan et al. 1983
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	R, M	N	28.7	26.09	155	**13.36**	-	Sullivan et al. 1983
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	R, M	N	7.5	6.82	156	**3.453**	-	Sullivan et al. 1983
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	R, M	N	33.7	30.63	157	**15.74**	-	Sullivan et al. 1983
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	S, M	C	-	69.4	158	**22.99**	-	Hall et al. 1997
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	S, M	C	-	71	161	**28.51**	-	Hall et al. 2008
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	S, M	C	-	104	162	**54.19**	-	Hall et al. 2008
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	S, M	C	-	67.6	163	**44.69**	-	Hall et al. 2008
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	S, M	C	-	58.1	164	**45.39**	-	Hall et al. 2008
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	S, M	C	-	76.2	165	**37.25**	-	Hall et al. 2008
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	S, M	C	-	108	166	**34.92**	-	Hall et al. 2008
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	S, M	C	-	111	167	**24.40**	-	Hall et al. 2008
Copepod, *Eurytemora affinis*	Nauplii, 24 hr	S, M	C	-	166	168	**23.81**	22.44	Hall et al. 2008
Copepod, *Acartia clausi*	-	S, U	C	48.80	40.89	1	**21.15**	-	Gentile 1982
Copepod, *Acartia clausi*	-	S, U	-	52.00	43.58	2	**22.59**	21.86	Gentile and Cardin 1982
Copepod, Acartia tonsa	-	S, U	C	17	14.25	4	**8.367**	-	Sosnowski and Gentile 1978
Copepod, Acartia tonsa	-	S, U	C	55	46.09	5	**28.36**	-	Sosnowski and Gentile 1978

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Copepod, Acartia tonsa	-	S, U	C	31	25.98	6	**13.31**	-	Sosnowski and Gentile 1978
Copepod, Acartia tonsa	-	S, U	-	17	14.25	7	**7.262**	-	Gentile and Cardin 1982
Copepod, Acartia tonsa	Mixed ages	R, M	C	-	41.80	734	609.2[g]	-	Monteiro et al. 2013
Copepod, Acartia tonsa	Mixed ages	R, M	C	-	67.40	735	533.7[g]	-	Monteiro et al. 2013
Copepod, Acartia tonsa	Mixed ages	R, M	C	-	108.7	736	470.8[g]	12.31	Monteiro et al. 2013
Copepod, *Amphiascoides atopus*	Adult, female	S, M	C	334.24	303.8	737	**1,192**	-	Caramujo et al. 2012
Copepod, *Amphiascoides atopus*	Adult, female	S, M	C	538.67	489.7	738	**1,905**	-	Caramujo et al. 2012
Copepod, *Amphiascoides atopus*	Adult, female	S, M	C	741.83	674.3	739	**2,614**	-	Caramujo et al. 2012
Copepod, *Amphiascoides atopus*	Adult, female	S, M	C	857.19	779.2	740	**3,017**	2,057	Caramujo et al. 2012
Copepod, *Tigriopus californicus*	Egg/Embryo	R, U	N	229	191.9	557	108.6[g]	-	O'Brien et al. 1988
Copepod, *Tigriopus californicus*	Nauplii, Stage 1	R, U	N	76	63.69	558	31.78[g]	-	O'Brien et al. 1988
Copepod, *Tigriopus californicus*	Nauplii, Stage 2	R, U	N	19	15.92	559	**7.847**	-	O'Brien et al. 1988
Copepod, *Tigriopus californicus*	Nauplii, Stage 3	R, U	N	159	133.24	560	69.79[g]	-	O'Brien et al. 1988
Copepod, *Tigriopus californicus*	Nauplii, Stage 4	R, U	N	184	154.19	561	82.66[g]	-	O'Brien et al. 1988
Copepod, *Tigriopus californicus*	Nauplii, Stage 5	R, U	N	261	218.72	562	129.6[g]	-	O'Brien et al. 1988
Copepod, *Tigriopus californicus*	Nauplii, Stage 6	R, U	N	305	255.59	563	161.9[g]	-	O'Brien et al. 1988
Copepod, *Tigriopus californicus*	Copepodite, Stage 1	R, U	N	375	314.25	564	218.7[g]	-	O'Brien et al. 1988
Copepod, *Tigriopus californicus*	Copepodite, Stage 2	R, U	N	496	415.65	565	322.7[g]	-	O'Brien et al. 1988
Copepod, *Tigriopus californicus*	Copepodite, Stage 3	R, U	N	413	346.09	566	250.9[g]	-	O'Brien et al. 1988

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Copepod, *Tigriopus californicus*	Copepodite, Stage 4	R, U	N	394	330.2	567	234.7[g]	-	O'Brien et al. 1988
Copepod, *Tigriopus californicus*	Copepodite, Stage 5	R, U	N	394	330.2	568	234.7[g]	-	O'Brien et al. 1988
Copepod, *Tigriopus californicus*	Adult	R, U	N	762	638.56	569	557.4[g]	7.847	O'Brien et al. 1988
Copepod, *Tisbe furcata*	Newborn nauplii	R, M	S	-	178	571	**99.77**	99.77	Bechmann 1994
Copepod, *Nitokra spinipes*	Adult	S, U	C	1,800	1,508	478	**2,781**	-	Bengtsson 1978
Copepod, *Nitokra spinipes*	-	S, U	C	2,100	1,760	772	**4,961**	3,715	Ytreberg et al. 2010
Barnacle, *Balanus amphitrite*	Nauplii, Stage 2	S, U	S	145	121.5	44	**64.73**	-	Qiu et al. 2005
Barnacle, *Balanus amphitrite*	Nauplii, Stage 4	S, U	S	156	130.7	45	**70.50**	-	Qiu et al. 2005
Barnacle, *Balanus amphitrite*	Nauplii, Stage 6	S, U	S	213	178.5	46	**105.6**	-	Qiu et al. 2005
Barnacle, *Balanus amphitrite*	Nauplii, Stage 2	S, U	S	720	603.4	741	**791.1**	139.7	Prato et al. 2012
Barnacle, *Balanus eburneus*	Nauplii, Stage 2	S, U	S	750	628.5	742	**835.4**	835.4	Prato et al. 2012
Mysid, *Americamysis bahia*	24 hr	F, M	N	181	164.5	16	**96.60**	-	Lussier et al. 1985
Mysid, *Americamysis bahia*	2-30 hr	R, M	S	209	164.0	17	153.7[h]	-	Science Applications International Corporation 1993
Mysid, *Americamysis bahia*	Juvenile, <24 hr	R, U	C	72.32	60.60	18	32.34[h]	-	Cripe 1994
Mysid, *Americamysis bahia*	<48 hr	S, M	-	110	99.99	19	99.37[h]	-	Ho et al. 1999
Mysid, *Americamysis bahia*	<48 hr	S, M	-	250	227.3	20	189.0[h]	-	Ho et al. 1999
Mysid, *Americamysis bahia*	<48 hr	S, M	-	360	327.2	21	39.29[h]	96.60	Ho et al. 1999

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Mysid, *Americamysis bigelowi*	24 hr	F, M	N	141	128.2	23	**70.57**	70.57	Gentile 1982
Mysid, *Holmesimysis costata*	<3 d	S, M	C	27	24.54	223	**12.08**	-	Hunt et al. 1989
Mysid, *Holmesimysis costata*	Juvenile, 3 d	S, M	C	17	15.45	224	**7.588**	9.572	Martin et al. 1989
Mysid, *Neomysis mercedis*	Neonate, >5 d	F, M	S	28.27	25.7	474	**16.73**	-	Brandt et al. 1993
Mysid, *Neomysis mercedis*	Juvenile, >15 d	F, M	S	87.58	79.61	475	**52.85**	-	Brandt et al. 1993
Mysid, *Neomysis mercedis*	Juvenile, >15 d	F, M	S	63.7	57.9	476	**39.19**	32.60	Brandt et al. 1993
Isopod, *Sphaeroma serratum*	-	S, U	S	1,980	1,659	534	**1,672**	1,672	Bat et al. 1999a
Amphipod, *Corophium volutator*	Adult, 4-7 mm	S, U	S	20,740	17,380	79	**81,550**	81,550	Bat et al. 1998
Amphipod, *Echinogammarus olivii*	-	S, U	S	250	209.5	137	**130.1**	130.1	Bat et al. 1999a
Amphipod, *Gammarus duebeni*	Adult, 60-90 mg	R, U	C	>10,000	>8,380	185	**>29,733**	>29,733	Moulder 1980
Amphipod, *Allorchestes compressa*	-	F, M	S	480	436.3	14	**515.7**	515.7	Ahsanullah et al. 1988
Amphipod, *Elasmopus rapax*	Juvenile, 0.54 mm	R, U	S	78	65.36	141	**75.57**	-	Bao et al. 2008
Amphipod, *Elasmopus rapax*	Juvenile	R, U	S	77	64.53	142	**74.97**	75.27	Bao et al. 2011
Amphipod, *Orchomenella pinguis*	Adult	R, U	-	179.8	150.7	773	**85.48**	85.48	Bach et al. 2014

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Pink shrimp, *Farfantepenaeus duorarum*	Post-larva, 3-5 d	R, U	C	393.3	329.6	503	**260.8**	260.8	Cripe 1994
Tiger shrimp, *Penaeus monodon*	Post-larva	R, U	C	660	553.1	743	**746.8**	-	Kumar 2012
Tiger shrimp, *Penaeus monodon*	Post-larva, Stage 12	R, M	C	-	950.0	774	**1,498**	1,058	Rajkumar 2012
Whiteleg shrimp, *Litopenaeus vannamei*	1.2 cm	R, U	C	37,000	4,200	239	**3,014**	3,014	Frias-Espericueta et al. 2003
Shrimp, *Metapenaeus sp.*	2.45 cm, 3.905 g	R, U	S	220	184.36	276	**106.8**	106.8	Kidwai and Ahmed 1999
Decapod, *Palaemon elegans*	-	S, U	S	2,520	2,112	487	**2,163**	2,163	Bat et al. 1999a
Grass shrimp, *Palaemonetes pugio*	Embryo, 9 d	S, U	C	860.3	720.9	489	**2,590**	2,590	Rayburn and Fisher 1999
Shrimp, *Crangon crangon*	Larva, 1-3 d	S, U	S	330	276.5	85	**255.4**	255.4	Connor 1972
Lobster, *Homarus americanus*	Larva stage 1, 24 hr	S, U	N	48	40.22	226	**28.37**	28.37	Johnson and Gentile 1979
Dungeness crab, *Cancer magister*	Larva	S, U	S	49	41.06	68	**20.60**	-	Martin et al. 1981
Dungeness crab, *Cancer magister*	Zoea	S, M	C	96	87.26	69	**61.93**	35.72	Dinnel et al. 1989
Blue crab, *Callinectes sapidus*	Juvenile, 8.3 cm	R, M	C	-	337.2	65	**6,403**	-	Martins et al. 2011
Blue crab, *Callinectes sapidus*	Juvenile, 8.3 cm	R, M	C	-	3,365	66	**12,583**	8,976	Martins et al. 2011
Shore crab, *Carcinus maenas*	Larva, 1-3 d	S, U	S	600	502.8	71	**730.8**	730.8	Connor 1972

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Sand crab, *Emerita analoga*	Immature, 8-10 mm	S, U	C	2,000	1,676	144	**2,492**	2,492	Valdovinos and Zuniga 2002
Horseshoe crab, *Limulus polyphemus*	Embryo, Stage 20, Sandy Hook	R, U	S	2,000	1,676	775	**3,473**		Botton et al. 1998
Horseshoe crab, *Limulus polyphemus*	Embryo, Stage 20, Delaware Bay	R, U	S	171,000	143,298	776	**289,605**		Botton et al. 1998
Horseshoe crab, *Limulus polyphemus*	Larva, Sandy Hook	R, U	S	637,000	533,806	777	1,066,174[g]	31,716	Botton et al. 1998
Bristle star, *Ophionereis dubia*	0.14 g	R, U	S	960	804.48	483	**589.5**	589.5	Kidwai and Ahmed 1999
Sea urchin, *Arbacia punctulata*	Embryo	S, M	S	30	27	778	**13.85**	13.85	Nelson et al. 2010
Green sea urchin, *Strongylocentrotus droebachiensis*	Embryo	S, M	C	21	19.09	538	**13.29**	13.29	Dinnel et al. 1989
Purple sea urchin, *Strongylocentrotus purpuratus*	Embryo	S, M	C	6.3	5.73	543	**3.966**	-	Dinnel et al. 1989
Purple sea urchin, *Strongylocentrotus purpuratus*	Embryo	S, M	S	14.38	13.52	547	**8.030**	-	City of San Jose 1998
Purple sea urchin, *Strongylocentrotus purpuratus*	Embryo	S, M	S	15.05	12.77	548	**7.593**	-	City of San Jose 1998
Purple sea urchin, *Strongylocentrotus purpuratus*	Embryo	S, M	S	-	14.3	549	**5.768**	-	Rosen et al. 2008
Purple sea urchin, *Strongylocentrotus purpuratus*	Embryo	S, M	N	-	14.8	550	**12.41**	-	Arnold et al. 2010a
Purple sea urchin, *Strongylocentrotus purpuratus*	Embryo	S, M	N	-	24.3	551	**11.66**	-	Arnold et al. 2010a
Purple sea urchin, *Strongylocentrotus purpuratus*	Embryo	S, M	N	-	30.2	552	**8.661**	-	Arnold et al. 2010a
Purple sea urchin, *Strongylocentrotus purpuratus*	Embryo	S, M	N	-	46.4	553	**9.320**	7.971	Arnold et al. 2010a
Sand dollar, *Dendraster excentricus*	Embryo	S, M	C	33	30	125	**21.43**	-	Dinnel et al. 1989

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Sand dollar, *Dendraster excentricus*	Embryo	S, M	N	-	18.9	129	**15.89**	-	Arnold et al. 2010a
Sand dollar, *Dendraster excentricus*	Embryo	S, M	N	-	36.4	130	**17.57**	-	Arnold et al. 2010a
Sand dollar, *Dendraster excentricus*	Embryo	S, M	N	-	46.2	131	**13.31**	-	Arnold et al. 2010a
Sand dollar, *Dendraster excentricus*	Embryo	S, M	N	-	>75.80	132	**>15.32**	16.49	Arnold et al. 2010a
Long-spined sea urchin, *Diadema antillarum*	Adult, ~1 yr	F, M	S	-	25	134	**12.58**	12.58	Bielmyer et al. 2005b
Coho salmon, *Oncorhynchus kisutch*	Smolt, 132 mm	F, M	C	601	546.3	481	**445.6**	445.6	Dinnel et al. 1989
Mangrove killifish, *Rivulus marmoratus*	4-6 week	F, M	S	-	1,250	529	**7,419**	-	Lin and Dunson 1993
Mangrove killifish, *Rivulus marmoratus*	4-6 week	F, M	S	-	1,610	530	**9,563**	8,423	Lin and Dunson 1993
Leon Springs pupfish, *Cyprinodon bovinus*	0.42 g	S, U	S	1306	1094.4	781	**5,304**		Sappington et al. 2001; Dwyer et al. 2005; Mayer et al. 2008
Leon Springs pupfish, *Cyprinodon bovinus*	0.42 g	S, U	S	>204	>171.0	782	**>114.1**	778.0	Sappington et al. 2001; Dwyer et al. 2005; Mayer et al. 2008
Sheepshead minnow, *Cyprinodon variegatus*	Larva, >24 hr	F, M	S/C	368	334.5	120	**337.2**	-	Hughes et al. 1989
Sheepshead minnow, *Cyprinodon variegatus*	Juvenile, 0.24 g	S, U	S	630	527.9	779	1,946[h]	-	Sappington et al. 2001; Dwyer et al. 2005; Mayer et al. 2008
Sheepshead minnow, *Cyprinodon variegatus*	Juvenile, 0.24 g	S, U	S	>204	>171.0	780	>114.1[h]	337.2	Sappington et al. 2001; Dwyer et al. 2005; Mayer et al. 2008
Mummichog, *Fundulus heteroclitus*	2.7 g	S, U	S	3,100	2,598	172	10,647[g]	-	Dorfman 1977
Mummichog, *Fundulus heteroclitus*	2.7 g	S, U	S	2,000	1,676	173	3,452[g]	-	Dorfman 1977

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Mummichog, *Fundulus heteroclitus*	2.7 g	S, U	C	2,300	1,927	174	7,401[g]	-	Dorfman 1977
Mummichog, *Fundulus heteroclitus*	2.7 g	S, U	C	400	335.2	175	386.2[g]	-	Dorfman 1977
Mummichog, *Fundulus heteroclitus*	4-6 week	F, M	S	-	1,690	176	10,040[g]	-	Lin and Dunson 1993
Mummichog, *Fundulus heteroclitus*	7 d	R, M	S	~360.00	~327.20	178	**578.9**	-	Grosell et al. 2007
Mummichog, *Fundulus heteroclitus*	7 d	R, M	S	~640.00	~581.80	179	**1,837**	-	Grosell et al. 2007
Mummichog, *Fundulus heteroclitus*	7 d	R, M	S	>937.00	>851.70	180	**>2,345**	-	Grosell et al. 2007
Mummichog, *Fundulus heteroclitus*	7 d	R, M	S	~500.00	~454.50	181	**476.9**	-	Grosell et al. 2007
Mummichog, *Fundulus heteroclitus*	7 d	R, M	S	~340.00	~309.10	182	**190.8**	-	Grosell et al. 2007
Mummichog, *Fundulus heteroclitus*	7 d	R, M	S	294	267.25	183	**130.6**	556.3	Grosell et al. 2007
Topsmelt, *Atherinops affinis*	Larva, 8 d	S, M	C	288	261.8	36	**249.8**	-	Anderson et al. 1991
Topsmelt, *Atherinops affinis*	Larva, 8 d	S, M	C	212	192.7	37	**145.5**	-	Anderson et al. 1991
Topsmelt, *Atherinops affinis*	Larva, 8 d	S, M	C	235	213.6	38	**174.1**	185.0	Anderson et al. 1991
Inland silverside, *Menidia beryllina*	-	S, M	S	115.41	104.9	262	**55.31**	-	TOXSCAN, Inc. 1991a
Inland silverside, *Menidia beryllina*	-	S, M	S	63.05	57.31	263	**29.97**	-	TOXSCAN, Inc. 1991b
Inland silverside, *Menidia beryllina*	-	S, M	S	123	111.8	264	**58.77**	46.01	TOXSCAN, Inc. 1991c
Atlantic silverside, *Menidia menidia*	Larva, 3 wk	F, M	N	66.6	60.54	266	**42.95**	-	Cardin 1982; 1985
Atlantic silverside, *Menidia menidia*	Larva, 1 wk	F, M	N	216.5	196.8	267	**176.4**	-	Cardin 1982; 1985
Atlantic silverside, *Menidia menidia*	Larva, 3 d	F, M	N	97.6	88.72	268	**64.33**	-	Cardin 1982; 1985

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Atlantic silverside, *Menidia menidia*	Larva, 2 wk	F, M	N	155.9	141.7	269	**112.1**	85.97	Cardin 1982; 1985
Tidewater silverside, *Menidia peninsulae*	Larva, 19 d	S, U	N	140	117.3	271	**67.46**	-	Hansen 1983
Tidewater silverside, *Menidia peninsulae*	19 d	S, U	-	141	118.2	272	**68.00**	67.73	D'Asaro 1985
Striped mullet, *Mugil cephalus*	Fingerling, 1.5 cm, 0.13 g	R, M	C	-	2,740	744	**4,898**	4,898	Rajkumar 2012
Shiner perch, *Cymatogaster aggregata*	Adult, 97 mm	F, M	C	418	380.0	118	**611.0**	611.0	Dinnel et al. 1989
Mud-skipper, *Boleophthalmus sp.*	2.84 cm, 0.13 g	R, U	S	3,710	3,109	48	**3,690**	3,690	Kidwai and Ahmed 1999
Striped bass, *Morone saxatilis*	45.6-60.6 mm	F, M	C	8,400	7,636	280	74,083[g]	-	Hetrick et al. 1982
Striped bass, *Morone saxatilis*	70 d	S, U	S	69.4	58.16	281	**229.9**	-	Palawski et al. 1985
Striped bass, *Morone saxatilis*	Fingerling, 1-2 mo.	S, U	S	2,680	2,246	282	656.4[g]	-	Reardon and Harrell 1990
Striped bass, *Morone saxatilis*	Fingerling, 1-2 mo.	S, U	S	8,080	6,771	283	2,207[g]	-	Reardon and Harrell 1990
Striped bass, *Morone saxatilis*	Fingerling, 1-2 mo.	S, U	S	7,880	6,603	284	16,706[g]	229.9	Reardon and Harrell 1990
Spot, *Leiostomus xanthurus*	Adult, 0.5-0.6 g	S, U	N	280	234.6	236	**189.3**	-	Hansen 1983
Spot, *Leiostomus xanthurus*	0.5-0.6 g	S, U	-	282	236.3	237	**191.9**	190.6	D'Asaro 1985
Atlantic croaker, *Micropogonias undulatus*	16-19 cm	S, U	C	5,660	4,743	278	**8,863**	8,863	Steele 1983
Sheepshead, *Archosargus probatocephalus*	18-21 cm	S, U	C	1,140	955.3	30	**1,534**	1,534	Steele 1983

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Pinfish, *Lagodon rhomboides*	13-17 cm	S, U	C	2,750	2,305	234	**4,145**	4,145	Steele 1983
Thornfish, *Terapon jarbua*	Juvenile, 10 cm, 25 g	R, U	-	2,500	2,095	555	**2,512**	2,512	Vijayavel et al. 2006
Pompano, *Trachinotus carolinus*	Juvenile, 0.25 g, 25 mm	S, U	S	557.3	467.0	573	**920.9**	-	Birdsong and Avault 1971
Pompano, *Trachinotus carolinus*	Juvenile, 0.25 g, 25 mm	S, U	S	597.2	500.5	574	**770.0**	-	Birdsong and Avault 1971
Pompano, *Trachinotus carolinus*	Juvenile, 0.25 g, 25 mm	S, U	S	796.2	667.2	575	**947.0**	875.7	Birdsong and Avault 1971
Summer flounder, *Paralichthys dentatus*	Juvenile, 46 d, 18-22 mm	S, M	S	610	586.0	499	2,265[h]	-	CH2M Hill 1999a
Summer flounder, *Paralichthys dentatus*	Juvenile, 48 d, 20-24 mm	S, M	S	1,029	928.0	500	3,990[h]	-	CH2M Hill 1999a
Summer flounder, *Paralichthys dentatus*	Juvenile, 57 d, 24-28 mm	S, M	S	606	597.0	501	1,775[h]	-	CH2M Hill 1999a
Summer flounder, *Paralichthys dentatus*	Embryo - Early cleavage	F, M	C	16.3	14.82	496	**10.36**	-	Cardin 1982; 1985
Summer flounder, *Paralichthys dentatus*	Embryo - Early cleavage	F, M	C	11.9	10.82	497	**7.556**	-	Cardin 1982; 1985
Summer flounder, *Paralichthys dentatus*	Embryo - Blastula	F, M	C	111.8	-	498	75.97[g]	8.848	Cardin 1982; 1985
Winter flounder, *Pseudopleuronectes americanus*	Blastula	F, M	N	167.3	152.1	513	**129.8**	-	Cardin 1982; 1985
Winter flounder, *Pseudopleuronectes americanus*	Blastula	F, M	N	158	143.6	514	**121.0**	-	Cardin 1982; 1985
Winter flounder, *Pseudopleuronectes americanus*	Blastula - Embryo	F, M	C	173.7	157.9	515	**135.7**	-	Cardin 1982; 1985
Winter flounder, *Pseudopleuronectes americanus*	Fertilization/ Pre-cleavage	F, M	C	132.8	120.7	516	**94.46**	-	Cardin 1982; 1985
Winter flounder, *Pseudopleuronectes americanus*	Blastula - Embryo	F, M	N	148.2	134.7	517	**109.3**	-	Cardin 1982; 1985
Winter flounder, *Pseudopleuronectes americanus*	Early cleavage - Embryo	F, M	N	98.2	89.26	518	**65.94**	106.4	Cardin 1982; 1985

Species	**Organism Age, Size or Lifestage**	**Method[a]**	**Chemical[b]**	**Reported LC_{50}/EC_{50} (total µg/L)[c]**	**Reported LC_{50}/EC_{50} (dissolved µg/L)[d]**	**BLM Data Label**	**BLM Normalized LC_{50}/EC_{50} (µg/L)[e]**	**Species Mean Acute Value (µg/L)[f]**	**Reference**
Gulf toadfish, *Opsanus beta*	22-53 g	F, M	S	>21,607	>19,641	485	**>33,000**	>33,000	Grosell et al. 2004
Cabezon, *Scorpaenichthys marmoratus*	Post-hatch larva	S, M	C	95	86.36	532	**64.20**	64.20	Dinnel et al. 1989
Fat snook, *Centropomus parallelus*	Juvenile, 3.5 g, 6.8 cm	S, M	C	1,880	1,709	751	**4,428**	4,428	Oliveria et al. 2014

a S=static, R=renewal, F=flow-through, U=unmeasured, M=measured.

b S=copper sulfate, N=copper nitrate, C=copper chloride.

c Values in this column are total copper LC_{50} or EC_{50} values as reported by author.

d Values in this column are dissolved copper LC_{50} or EC_{50} values either reported by the author, or if the author did not report a dissolved value, then a conversion factor (CF) was applied to the total copper LC_{50} to estimate dissolved copper values (If copper was unmeasured, the total copper was multiplied by 0.838, if it was measured, it was multiplied by 0.909).

e Normalization Chemistry (only Temp, pH, DOC, and Salinity are needed for the model, but values for other ions are shown for reference).

Temperature (°C)	**pH**	**DOC (mg/L)**	**Salinity (ppt)**	**Ca (mg/L)**	**Mg (mg/L)**	**Na (mg/L)**	**K (mg/L)**	**SO_4 (mg/L)**	**Cl (mg/L)**	**Alkalinity (mg/L)**
22	**8**	**1.0**	**32**	367.2	1144.0	9607.5	355.7	2417.0	17244.3	89.8

f Bolded BLM Normalized values were used in the SMAV calculation.

g Value not used in the SMAV calculation, only the most sensitive life stage of the species.

h Value not used in the SMAV calculation because flow-through measured tests available.

Appendix B Acceptable Chronic Toxicity Data

Appendix Table B-1. Acceptable Estuarine/Marine Chronic Toxicity Data.

Species	Test[a]	Chemical[b]	Endpoint	Salinity (g/kg)	Chronic Limits (µg/L)	Chronic Value (total µg/L)	Chronic Value (dissolved µg/L)	BLM Data Label	BLM Normalized Chronic Value (Dissolved µg/L)[c]	Reference
Rotifer, *Brachionus plicatilis*	LC	N	Intrinsic rate of rotifer population	15	6.1-10.3	-	10.9 (EC$_{20}$)	C1	13.23	Arnold et al. 2010b
Sheepshead minnow, *Cyprinodon variegatus*	ELS	C	Growth	30	172-362	249.5	226.8	C2	204.1	Hughes et al. 1989

a LC=life-cycle; PLC=partial life-cycle; ELS=early life stage.

b S=copper sulfate, N=copper nitrate, C=copper chloride.

c Normalization Chemistry (only Temp, pH, DOC, and Salinity are needed for the model, but values for other ions are shown for reference).

Temperature (°C)	pH	DOC (mg/L)	Salinity (ppt)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)
22	**8**	**1.0**	**32**	367.2	1144.0	9607.5	355.7	2417.0	17244.3	89.8

Appendix Table B-2. Acute-Chronic Ratios.

Species	Hardness (mg/L as $CaCO_3$)	Acute Value (µg/L)	Chronic Value (µg/L)	Acute to Chronic Ratio	Reference	Species Mean ACR	Used in FACR calculation
FRESHWATER							
Snail, *Campeloma decisum*	35-55	1,673[a]	8.73	191.6	Arthur and Leonard 1970	171.2	
Snail, *Campeloma decisum*	35-55	1,673[a]	10.94	153.0	Arthur and Leonard 1970		
Pond snail, *Lymnaea stagnalis*	123	24.9	5.307	4.692	Ng et al. 2011	4.692	
Oyster mussel, *Epioblasma capsaeformis*	162	26	7.530	3.453	Wang et al. 2007b	3.453	
Fatmucket, *Lampsilis siliquoidea*	165	34	7.201	4.722	Wang et al. 2007b	4.722	

Species	Hardness (mg/L as $CaCO_3$)	Acute Value (µg/L)	Chronic Value (µg/L)	Acute to Chronic Ratio	Reference	Species Mean ACR	Used in FACR calculation
Rainbow mussel, *Villosa iris*	171	27	7.679	3.516	Wang et al. 2007b	2.733	
Rainbow mussel, *Villosa iris*	101 (DOC=0.5)	15	8.3	1.807	Wang et al. 2011a		
Rainbow mussel, *Villosa iris*	100 (DOC=10)	72	35	2.057	Wang et al. 2011a		
Rainbow mussel, *Villosa iris*	98 (DOC=2.5)	32	7.5	4.267	Wang et al. 2011a		
Cladoceran, *Ceriodaphnia dubia*	179	28.42[b]	7.9	3.597	Belanger et al. 1989	3.268	x
Cladoceran, *Ceriodaphnia dubia*	94.1	63.33[b]	19.36	3.271	Belanger et al. 1989		
Cladoceran, *Ceriodaphnia dubia*	57	13.4	24.5	0.5469[g]	Oris et al. 1991		
Cladoceran, *Ceriodaphnia dubia*	-	17.974[c]	9.17	1.960	Carlson et al. 1986		
Cladoceran, *Ceriodaphnia dubia*	54-72	4.16	29.34	0.1418[g]	Harmon et al. 2003		
Cladoceran, *Ceriodaphnia dubia*	82.4	18	3.641	4.944	Cooper et al. 2009		
Cladoceran, *Daphnia ambigua*	54-72	6.53	22.38	0.2918[g]	Harmon et al. 2003	-	
Cladoceran, *Daphnia magna*	51	26	12.58	2.067	Chapman et al. (Manuscript)	3.419	x
Cladoceran, *Daphnia magna*	104	33.76[d]	19.89	1.697	Chapman et al. (Manuscript)		
Cladoceran, *Daphnia magna*	211	69	6.06	11.39	Chapman et al. (Manuscript)		
Cladoceran, *Daphnia pulex*	57.5	25.737	2.83	9.094	Winner 1985	4.814	x
Cladoceran, *Daphnia pulex*	115	27.6	7.07	3.904	Winner 1985		
Cladoceran, *Daphnia pulex*	230	28.79	9.16	3.143	Winner 1985		
Rainbow trout, *Oncorhynchus mykiss*	120	80	27.77	2.881	Seim et al. 1984	2.357	x

Species	Hardness (mg/L as $CaCO_3$)	Acute Value (µg/L)	Chronic Value (µg/L)	Acute to Chronic Ratio	Reference	Species Mean ACR	Used in FACR calculation
Rainbow trout, *Oncorhynchus mykiss*	104	83	35.08	2.366	Besser et al. 2007		
Rainbow trout, *Oncorhynchus mykiss*	100	61.48[h]	32	1.921	Wang et al. 2014; Ingersoll and Mebane 2014		
Chinook salmon, *Oncorhynchus tshawytscha*	20-45	33.1	5.92	5.591	Chapman 1975, 1982	5.591	x
White sturgeon, *Acipenser transmontanus*	100	8.06	1.4	5.757	Wang et al. 2014; Ingersoll and Mebane 2014	5.757	x
Mottled sculpin, *Cottus bairdii*	102	45	28.47	1.581	Besser et al. 2007	2.075	x
Mottled sculpin, *Cottus bairdii*	104	12	4.408	2.722	Besser et al. 2007		
Bluntnose minnow, *Pimephales notalus*	172 - 230	231.9[e]	18	12.88	Horning and Neiheisel 1979	12.88	
Fathead minnow, *Pimephales promelas*	200	449.6[i]	12.86	34.96	Mount 1968	21.25	
Fathead minnow, *Pimephales promelas*	202	474.8[j]	19.72	24.08	Pickering et al. 1977		
Fathead minnow, *Pimephales promelas*	45	106.9[f]	9.38	11.40	Lind et al. 1978		
Fathead minnow, *Pimephales promelas*	-	250	<61	>4.098[k]	Scudder et al. 1988		
Bluegill, *Lepomis macrochirus*	21-40	1,100	27.15	40.52	Benoit 1975	40.52	

Species	Salinity (g/kg)	Acute Value (µg/L)	Chronic Value (µg/L)	Acute to Chronic Ratio	Reference	Species Mean ACR	Used in FACR calculation
ESTUARINE/MARINE WATER							
Rotifer, *Brachionus plicatilis*	15	13.4 (unfed)	10.9	1.229	Arnold et al. 2010b	1.229 (unfed)	x

Species	Salinity (g/kg)	Acute Value (µg/L)	Chronic Value (µg/L)	Acute to Chronic Ratio	Reference	Species Mean ACR	Used in FACR calculation
Rotifer, *Brachionus plicatilis*	15	20.8 (fed)	10.9	1.908	Arnold et al. 2010b	1.908 (fed)	
Sheepshead minnow, *Cyprinodon variegatus*	30	368	249.5	1.475	Hughes et al. 1989	1.475	x

a Geometric mean of two values from Arthur and Leonard (1970).
b Geometric mean of five values from Belanger et al. (1989). ACR is based on dissolved metal measurements.
c Geometric mean of two values from Carlson et al. (1986).
d Geometric mean of two values from Chapman et al. (Manuscript).
e Geometric mean of three values from Horning and Neiheisel (1979).
f Geometric mean of three values from Lind et al. (1978).
g ACR from Oris et al. (1991) and Harmon et al. (2003) not used in calculating overall ratio for species it is <1.
h Geometric mean of two values from Wang et al. 2014; Ingersoll and Mebane 2014.
i Geometric mean of two values from Mount 1968.
j Geometric mean of two values from Pickering et al. 1977.
k ACR from Scudder et al. (1988) not used in calculating overall ratio for species since it is non-definitive.

Freshwater FACR (from Copper Freshwater AWQC 2007 Document) = 3.22
Estuarine/Marine FACR (geometric mean of values with an x) = 3.022

Appendix C Estuarine/Marine Plant Toxicity Data

Appendix Table C-1. Estuarine/Marine Plant Toxicity Data.

Species	Method[a]	Chemical	Salinity (g/kg)	Duration (days)	Effect	Result (total µg/L)	Result (dissolved µg/L)	Reference
Dinoflagellate, *Amphidinium carteri*	S, U	Copper chloride	21	21	83% reduction in growth	<50		Erickson et al. 1970
Dinoflagellate, *Cochlodinium polykrikoides*	S, U	Copper sulfate	-	3	EC_{50}	12,740		Ebenezer and Ki 2012
Dinoflagellate, *Cochlodinium polykrikoides*	S, U	Copper sulfate	-	3	EC_{50}	5,030		Ebenezer and Ki 2012
Dinoflagellate, *Gymnodinium splendens*	S, U	Copper sulfate	31.6-33.3	5	LOEC (growth)	20	18.18	Saifullah 1978
Dinoflagellate, *Prorocentrum micans*	S, U	Copper sulfate	31.6-33.3	8	LOEC (growth)	5	4.545	Saifullah 1978
Dinoflagellate, *Prorocentrum minimum*	S, U	Copper sulfate	30-35	3	EC_{50} (biomass)	1,074		Guo and Ki 2012
Dinoflagellate, *Prorocentrum minimum*	S, U	Copper	-	3	EC_{50} (cell #)	1,070		Guo et al. 2012
Dinoflagellate, *Scrippsiella faeroense*	S, U	Copper sulfate	31.6-33.3	5	LOEC (growth)	5	4.545	Saifullah 1978
Dinoflagellate, *Simbiodinium microadriaticum*	S, M	Copper sulfate	Full strength seawater	23	46% reduction in growth (significant)	40		Goh and Chou 1997
Dinoflagellate, *Simbiodinium microadriaticum*	S, M	Copper sulfate	Full strength seawater	23	26% reduction in growth (not significant)	42		Goh and Chou 1997
Golden/brown flagellate, *Isochrysis sp.*	S, U	Copper sulfate	36	4	IC_{50} (growth)	2	1.8	Garr 2012
Brown alga, *Hizikia fusiformis*	S, U	Copper sulfate	-	7	NOEC-LOEC (relative growth rate)	25-50		Zhu et al. 2011
Cyanobacterium, *Cyanobium sp.*	S, M	Copper sulfate	33	3	EC_{50} (cell #)	500		Alquezar and Anastasi 2013
Alga, *Platymonas helgolandica var. tsingtaoensis*	S, U	Copper sulfate	-	1.5 hr	EC_{50} (% motile cells)	848.4		Zheng et al. 2012
Alga, *Platymonas subcordiformis*	S, U	Copper sulfate	-	1.5 hr	EC_{50} (% motile cells)	320.9		Zheng et al. 2012
Green alga, *Chlorella stigmatophora*	S, M	Copper chloride	35	21	EC_{50} (cell volume)	70		Christensen et al. 1979
Green alga (zoospores), *Enteromorpha intestinalis*	S, U	-	-	5	EC_{50} (development to 2+ cell stage)	10		Fletcher 1989
Green alga, *Olisthodiscus luteus*	S, U	Copper chloride	21	14	74% reduction in growth	<50		Erickson et al. 1970
Alga, *Ulva pertusa*	S, U	-	26-35	4	EC_{50} (chlorophyll fluorescence)	711		Kumar et al. 2009

Species	Method[a]	Chemical	Salinity (g/kg)	Duration (days)	Effect	Result (total µg/L)	Result (dissolved µg/L)	Reference
Alga, *Ulva lactuca*	R, M	Copper chloride	32	3	EC_{50} (growth)	127		Wendt et al. 2013
Diatom, *Odontella mobiliensis*	S, M	Copper chloride	30	3	EC_{50} (growth)	298.4		Manimaran et al. 2012
Diatom, *Nitzschia closterium*	-	-	-	4	EC_{50} (growth)	33		Rosko and Rachlin 1975
Diatom, *Nitzschia thermalis*	S, U	Copper sulfate	35.7	Several	No growth	38.1		Metaxas and Lewis 1991
Diatom, *Skeletonema costatum*	S, U	Copper chloride	21	14	58% reduction in growth	50		Erickson et al. 1970
Diatom, *Skeletonema costatum*	S, U	Copper sulfate	35.7	Several	LOEC (no growth)	31.8		Metaxas and Lewis 1991
Diatom, *Skeletonema costatum*	S, U	Copper chloride	-	4	EC_{50} (growth)	45		Nassiri et al. 1997
Diatom, *Thalassiosira aestevallis*	S, U	Copper chloride	-	3.0 - 4	Reduced growth	19		Hollibaugh et al. 1980
Red alga, *Ceramium tenuicorne*	S, U	Copper chloride	7	7	EC_{50} (growth)	6.4		Ytreberg et al. 2010
Red alga (tetrasporophyte), *Champia parvula*	R, M	Copper chloride	30	11	Reduced growth	4.6	4.181	Steele and Thursby 1983
Red alga (tetrasporophyte), *Champia parvula*	R, M	Copper chloride	30	11	Reduced production	13.3	12.09	Steele and Thursby 1983
Red alga (mature), *Champia parvula*	R, M	Copper chloride	30	14	Reduced female growth	4.7	4.272	Steele and Thursby 1983
Red alga (mature), *Champia parvula*	R, M	Copper chloride	30	14	Stopped sexual reproduction	7.3	6.636	Steele and Thursby 1983
Red seaweed, *Gracilaria lemaneiformis*	S, U	Copper sulfate	25	6	LOEC (growth rate)	50		Huang et al. 2013
Red seaweed, *Gracilariopsis longissima*	S, U	Copper sulfate	33	7	EC_{50} (growth) Plants collected from clean and polluted sites-April	31.1	28.27	Brown et al. 2012
Red seaweed, *Gracilariopsis longissima*	S, U	Copper sulfate	33	7	EC_{50} (growth) Plants collected from clean and polluted sites-Oct.	25.8	23.45	Brown et al. 2012
Red seaweed, *Gracilariopsis longissima*	S, U	Copper sulfate	33	7	EC_{20} (growth) Plants collected from clean and polluted sites-April	12.6	11.45	Brown et al. 2012

Species	Method[a]	Chemical	Salinity (g/kg)	Duration (days)	Effect	Result (total µg/L)	Result (dissolved µg/L)	Reference
Red seaweed, *Gracilariopsis longissima*	S, U	Copper sulfate	33	7	EC_{20} (growth) Plants collected from clean and polluted sites-Oct.	11.3	10.27	Brown et al. 2012
Kelp (meiospore), *Laminaria saccharina*	R, U	Copper sulfate	-	21	Reduced gametophyte development rate	5		Chung and Brinkhuis 1986
Kelp (1-3 cm sporophyte), *Laminaria saccharina*	S, U	Copper sulfate	-	9	LOEC (100% mortality)	100		Chung and Brinkhuis 1986
Kelp (8-10 cm sporophyte), *Laminaria saccharina*	S, U	Copper sulfate	-	-	23% decrease in blade growth	10		Chung and Brinkhuis 1986
Giant kelp, *Macrocystis pyrifera*	S, U	-	-	4	EC_{50} (photosynthesis)	60		Clendenning and North 1959
Giant kelp, *Macrocystis pyrifera*	R, M	Copper chloride	36	19-20	NOEC (sporophyte production)	<10.2	<9.2718	Anderson et al. 1990
Giant kelp, *Macrocystis pyrifera*	R, M	Copper chloride	36	19-20	LOEC (sporophyte production)	10.2	9.2718	Anderson et al. 1990

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured.

Appendix D Acceptable Estuarine/Marine Bioaccumulation Data

Appendix Table D-1. Acceptable Estuarine/Marine Bioaccumulation Data.

Species	Chemical	Concentration in water (µg/L)	Salinity (g/kg)	Duration (days)	Tissue	BCF or BAF	Reference
Polychaete, *Phyllodoce maculata*	Copper sulfate	40	Full strength seawater	35	Whole body	2,500	McLusky and Phillips 1975
Polychaete, *Neanthes arenaceodentata*	Copper nitrate	40	31	28	Whole body	2,950	Pesch and Morgan 1978
Polychaete, *Eudistylia vancouveri*	Copper chloride	6	30.4	29	Body (less radioles)	1,006	Young et al. 1979
Blue mussel (0.45 cm), *Mytilus edulis*	Copper chloride	3	25	550	Soft tissue	7,730	Calabrese et al. 1984
Blue mussel (0.45 cm), *Mytilus edulis*	Copper chloride	7.9	25	550	Soft tissue	4,420	Calabrese et al. 1984
Blue mussel (0.45 cm), *Mytilus edulis*	Copper chloride	12.7	25	550	Soft tissue	5,320	Calabrese et al. 1984
Mediterranean mussel (6.02-6.34 cm), *Mytilus galloprovincialis*	Field study	0.285	37-38	266	Soft tissue	3,263	Martincic et al. 1992
Mediterranean mussel (6.02-6.34 cm), *Mytilus galloprovincialis*	Field study	0.446	37-38	266	Soft tissue	2,491	Martincic et al. 1992
Mediterranean mussel (6.02-6.34 cm), *Mytilus galloprovincialis*	Field study	0.203	37-38	266	Soft tissue	4,384	Martincic et al. 1992
Mediterranean mussel (6.02-6.34 cm), *Mytilus galloprovincialis*	Field study	0.177	37-38	266	Soft tissue	4,915	Martincic et al. 1992
Bay scallop (5.12-6.26 cm), *Argopecten irradians*	Copper chloride	4.56	29-32	56	Muscle	185	Zaroogian and Johnson 1983
Bay scallop (5.12-6.26 cm), *Argopecten irradians*	Copper chloride	4.56	29-32	56	Viscera	3,816	Zaroogian and Johnson 1983
Pacific oyster, *Crassostrea gigas*	Field study	25.45	-	32	Soft tissue	34,600	Han and Hung 1990
Pacific oyster, *Crassostrea gigas*	Field study	9.66	-	32	Soft tissue	57,000	Han and Hung 1990
Pacific oyster, *Crassostrea gigas*	Field study	10.37	-	32	Soft tissue	33,400	Han and Hung 1990

Species	**Chemical**	**Concentration in water (µg/L)**	**Salinity (g/kg)**	**Duration (days)**	**Tissue**	**BCF or BAF**	**Reference**
Eastern oyster, *Crassostrea virginica*	Field study	25	31	140	Soft tissue	27,800	Shuster and Pringle 1968
Soft-shell clam, *Mya arenaria*	Field study	100	31	35	Soft tissue	790	Shuster and Pringle 1968

Appendix E Other Estuarine/Marine Toxicity Data

Appendix Table E-1. Other Estuarine/Marine Toxicity Data.

Species	Chemical	Duration (days)	Effect	Effect Concentration (total µg/L)	Effect Concentration (dissolved µg/L)	Reference
Ciliate, *Euplotes crassus*	-	8 hr	NOEC (survival)	31,775	-	Gomiero et al. 2012b
Bacterium, *Vibrio fischeri*	Copper sulfate	15 min	EC_{50} (luminescence)	397	-	Rosen et al. 2008
Bacterium, *Vibrio fischeri*	Copper chloride	15 min	EC_{50} (luminescence)	800	-	Ytreberg et al. 2010
Dinoflagellate, *Ceratocorys horrida*	Copper sulfate	1	EC_{50} (luminescence)	166	-	Rosen et al. 2008
Dinoflagellate, *Lingulodinium polyedrum*	Copper sulfate	1	EC_{50} (luminescence)	90	-	Rosen et al. 2008
Dinoflagellate, *Pyrocystis noctiluca*	Copper sulfate	1	EC_{50} (luminescence)	185	-	Rosen et al. 2008
Fungus, *Halophytophthora elongata*	Copper chloride	5	NOEC-LOEC (biomass)	10,000 - 100,000	-	Leano and Pang 2010
Fungus, *Halophytophthora spinosa*	Copper chloride	5	NOEC-LOEC (biomass)	1,000 - 10,000	-	Leano and Pang 2010
Fungus, *Halophytophthora vesicula*	Copper chloride	5	NOEC-LOEC (biomass)	1,000 - 10,000	-	Leano and Pang 2010
Green alga, *Chlorella autotrophyca*	Copper sulfate	3	EC_{50} (biomass) (initial cell density=10^3 cells/ml)	9.6	-	Moreno-Garrido et al. 2000
Green alga, *Chlorella autotrophyca*	Copper sulfate	3	EC_{50} (biomass) (initial cell density =$5x10^3$ cells/ml)	19.3	-	Moreno-Garrido et al. 2000
Green alga, *Chlorella autotrophyca*	Copper sulfate	3	EC_{50} (biomass) (initial cell density=10^4 cells/ml)	38.3	-	Moreno-Garrido et al. 2000
Green alga, *Isochrysis galbana*	Copper sulfate	3	EC_{50} (biomass) (initial cell density=10^3 cells/ml)	0.4	-	Moreno-Garrido et al. 2000
Green alga, *Isochrysis galbana*	Copper sulfate	3	EC_{50} (biomass) (initial cell density=$5x10^3$ cells/ml)	3.6	-	Moreno-Garrido et al. 2000
Green alga, *Isochrysis galbana*	Copper sulfate	3	EC_{50} (biomass) (initial cell density=10^4 cells/ml)	4.4	-	Moreno-Garrido et al. 2000
Green alga, *Nannochloris atomus*	Copper sulfate	3	EC_{50} (biomass) (initial cell density=10^3 cells/ml)	16.7	-	Moreno-Garrido et al. 2000

Species	**Chemical**	**Duration (days)**	**Effect**	**Effect Concentration (total µg/L)**	**Effect Concentration (dissolved µg/L)**	**Reference**
Green alga, *Nannochloris atomus*	Copper sulfate	3	EC_{50} (biomass) (initial cell density=5x10^3 cells/ml)	27.3	-	Moreno-Garrido et al. 2000
Green alga, *Nannochloris atomus*	Copper sulfate	3	EC_{50} (biomass) (initial cell density=10^4 cells/ml)	46.2	-	Moreno-Garrido et al. 2000
Diatom, *Ceratoneis closterium*	Copper sulfate	3	IC_{50} (growth rate)	7.1	-	Hook et al. 2014
Diatom, *Cylindrotheca closterium*	Copper sulfate	72 hr	EC_{50} (growth)	29	-	Araujo et al. 2008
Diatom, *Cylindrotheca closterium*	Copper sulfate	72 hr	EC_{50} (growth)	22	-	Araujo et al. 2008
Diatom, *Cylindrotheca closterium*	Copper sulfate	72 hr	EC_{50} (growth)	23	-	Araujo et al. 2008
Diatom, *Cylindrotheca closterium*	Copper sulfate	72 hr	EC_{50} (growth)	23	-	Araujo et al. 2008
Diatom, *Phaeodactylum tricornutum*	Copper sulfate	3	EC_{50} (biomass) (initial cell density=10^3 cells/ml)	9.8	-	Moreno-Garrido et al. 2000
Diatom, *Phaeodactylum tricornutum*	Copper sulfate	3	EC_{50} (biomass) (initial cell density=5x10^3 cells/ml)	34.4	-	Moreno-Garrido et al. 2000
Diatom, *Phaeodactylum tricornutum*	Copper sulfate	3	EC_{50} (biomass) (initial cell density=10^4 cells/ml)	35.0	-	Moreno-Garrido et al. 2000
Diatom, *Phaeodactylum tricornutum*	Copper sulfate	3	IC_{50} (growth)	8.5	-	Osborn and Hook 2013
Coral (explants), *Montastraea franksi*	Copper sulfate	8 hr	NOEC (paling/tissue loss)	100	-	Venn et al. 2009
Coral (explants), *Montastraea franksi*	Copper sulfate	8 hr	NOEC-LOEC (increase hsp70, hsp90 & P-gp expression)	10.0 - 30	-	Venn et al. 2009
Bryzoan, *Bugula neritina*	-	2	100% mortality	500	-	Piola and Johnston 2006
Bryzoan, *Watersipora subtorquata*	-	2	100% mortality	500	-	Piola and Johnston 2006
Bryzoan, *Schizoporella errata*	-	2	100% mortality	500	-	Piola and Johnston 2006
Bryzoan, *Tricellaria occidentalis*	-	2	100% mortality	500	-	Piola and Johnston 2006

Species	**Chemical**	**Duration (days)**	**Effect**	**Effect Concentration (total µg/L)**	**Effect Concentration (dissolved µg/L)**	**Reference**
Hydroid, *Campanularia flexuosa*	-	11	Growth rate inhibition	10.0 - 13	-	Stebbing 1976
Hydroid, *Campanularia flexuosa*	-	-	Enzyme inhibition	1.43	-	Moore and Stebbing 1976
Hydromedusa, *Phlalldium sp.*	-	1	LC_{50}	36	-	Reeve et al. 1976
Ctenophore, *Pleurobrachia pileus*	-	1	LC_{50}	33	-	Reeve et al. 1976
Ctenophore, *Mnemiopsis mccrdayi*	-	1	LC_{50}	17 - 29	-	Reeve et al. 1976
Rotifer, *Brachionus plicatillis*	-	1	LC_{50}	100	-	Reeve et al. 1976
Polychaete, *Phyllodoce maculata*	-	9	LC_{50}	80	-	McLusky and Phillips 1975
Polychaete (adult), *Neanthes arenaceodentata*	Copper nitrate	28	LC_{50}	44	40	Pesch and Morgan 1978
Polychaete, *Neanthes arenaceodentata*	Copper nitrate	7	LC_{50}	137	-	Pesch and Hoffman 1982
Polychaete, *Neanthes arenaceodentata*	Copper nitrate	10	LC_{50}	98	-	Pesch and Hoffman 1982
Polychaete, *Neanthes arenaceodentata*	Copper nitrate	28	LC_{50}	56	-	Pesch and Hoffman 1982
Polychaete (larva, 0.10 mg), *Neanthes arenaceodentata*	Copper chloride	4	LC_{50}	311	-	Pesch et al. 1986
Polychaete (larva, 0.10 mg), *Neanthes arenaceodentata*	Copper chloride	4	LC_{50}	252	-	Pesch et al. 1986
Polychaete (larva, 0.10 mg), *Neanthes arenaceodentata*	Copper chloride	4	LC_{50}	224	-	Pesch et al. 1986
Polychaete (larva, 0.10 mg), *Neanthes arenaceodentata*	Copper chloride	28	LC_{50}	83	-	Pesch et al. 1986
Polychaete (larva, 0.10 mg), *Neanthes arenaceodentata*	Copper chloride	28	LC_{50}	81	-	Pesch et al. 1986
Polychaete (larva, 0.10 mg), *Neanthes arenaceodentata*	Copper chloride	28	LC_{50}	86	-	Pesch et al. 1986
Polychaete, *Nereis virens*	Copper sulfate	8	LC_{50}	20.97	-	Caldwell et al. 2011
Polychaete, *Cirriformia spirabranchia*	Copper nitrate	26	LC_{50}	40	-	Milanovich et al. 1976
Polychaete (adult), *Hydroides elegans*	Copper sulfate	2	LC_{50}	715	649.9	Xie et al. 2005

Species	Chemical	Duration (days)	Effect	Effect Concentration (total µg/L)	Effect Concentration (dissolved µg/L)	Reference
Polychaete (larva), *Hydroides elegans*	Copper sulfate	2	LC_{50}	120	100.6	Bao et al. 2008
Flatworm, *Parorchis acanthus*	Copper sulfate	2	NOEC-LOEC (successful encystment)	10-100		Morley et al. 2003
Nematode (adult, 3-4 d), *Caenorhabditis elegans*	Copper chloride	4	LC_{50}	256	214.5	Williams and Dusenbery 1990
Annelids (mixed species, larva)	-	1	LC_{50}	89	-	Reeve et al. 1976
Black abalone, *Hailotis cracherodil*	-	4	Histopathological gill abnormalities	>32	-	Martin et al. 1977
Barnacle (nauplii), *Amphibalanus variegatus*	-	1	EC_{50} (swimming)	81.29	-	Gall et al. 2013
Red abalone, *Hailotis rufescens*	-	4	Histopathological gill abnormalities	>32	-	Martin et al. 1977
Channeled whelk, *Busycon canaliculatum*	-	77	LC_{50}	470	-	Betzer and Yevich 1975
Mud snail, *Nassarius obsoletus*	-	3	Decrease in oxygen consumption	100	-	MacInnes and Thurberg 1973
Blue mussel, *Mytilus edulis*	Copper chloride	7	LOEC (mortality)	200	167.6	Scott and Major 1972
Blue mussel (10-15 mm), *Mytilus edulis*	-	3	LOEC (growth)	10	8.38	Manley et al. 1984
Blue mussel (51-58 mm), *Mytilus edulis*	Copper sulfate	5	LOEC (mortality)	100	83.8	Al-Subiai et al. 2011
Mediterranean mussel (adult, 5 cm), *Mytilus galloprovincialis*	Copper chloride	5	LOEC (lysosomal membrane stability)	2.3	1.927	Bolognesi et al. 1999
Mediterranean mussel (50-80 mm), *Mytilus galloprovincialis*	-	28	LC_{50} (no sediment present)	100		Bat et al. 2013
Mediterranean mussel (50-80 mm), *Mytilus galloprovincialis*	-	28	LC_{50} (sediment present)	250		Bat et al. 2013
Mediterranean mussel (5-6 cm), *Mytilus galloprovincialis*	-	4 (16°C)	NOEC-LOEC (decrease lysosomal membrane stability in digestive gland)	20 - 40		Negri et al. 2013
Mediterranean mussel (5-6 cm), *Mytilus galloprovincialis*	-	4 (20°C)	NOEC-LOEC (decrease lysosomal membrane stability in digestive gland)	20 - 40		Negri et al. 2013
Pacific blue mussel (sperm), *Mytilus trossulus*	Copper chloride	100 min.	Reduced sperm swimming speed	100	90.9	Fitzpatrick et al. 2008
Pacific blue mussel (sperm), *Mytilus trossulus*	Copper chloride	100 min.	Reduced fertilization success	100	90.9	Fitzpatrick et al. 2008
Pacific blue mussel (embryo), *Mytilus trossulus*	Copper chloride	2	Increased abnormal larval development	10	9.09	Fitzpatrick et al. 2008

Species	**Chemical**	**Duration (days)**	**Effect**	**Effect Concentration (total µg/L)**	**Effect Concentration (dissolved µg/L)**	**Reference**
Bay scallop, *Argopecten irradians*	-	42	EC_{50} (growth)	5.8		Pesch et al. 1979
Bay scallop, *Argopecten irradians*	-	119	100% mortality	5		Zaroogian and Johnson 1983
Pacific oyster (embryo), *Crassostrea gigas*	Copper chloride	2	EC_{50} (development)	10	9.09	Harrison et al. 1981
Pacific oyster (embryo), *Crassostrea gigas*	Copper chloride	2	EC_{50} (development) (2 mg/L humic matter added)	28	25.45	Harrison et al. 1981
Pacific oyster (embryo), *Crassostrea gigas*	Copper chloride	2	NOEC (development)	2	1.676	Coglianese 1982
Pacific oyster (embryo, ≤4 hr), *Crassostrea gigas*	Copper sulfate	3	EC_{50} (arrested development)	4.46	3.737	Worboys et al. 2002
Pacific oyster (embryo), *Crassostrea gigas*	Copper chloride	1	EC_{50} (normal D-stage larval development)	20.77	18.88	Brooks et al. 2007
Pacific oyster (embryo), *Crassostrea gigas*	Copper chloride	1	EC_{50} (normal D-stage larval development)	24.33	22.12	Brooks et al. 2007
Pacific oyster (embryo), *Crassostrea gigas*	Copper chloride	1	EC_{50} (normal D-stage larval development)	41.09	37.35	Brooks et al. 2007
Pacific oyster (embryo), *Crassostrea gigas*	Copper chloride	1	EC_{50} (normal D-stage larval development)	37.87	34.42	Brooks et al. 2007
Pacific oyster (embryo), *Crassostrea gigas*	Copper chloride	1	EC_{50} (normal D-stage larval development)	38.17	34.70	Brooks et al. 2007
Pacific oyster (embryo), *Crassostrea gigas*	Copper chloride	1	EC_{50} (normal D-stage larval development)	40.52	36.83	Brooks et al. 2007
Eastern oyster (larva), *Crassostrea virginica*	-	12	LC_{50}	46	-	Calabrese et al. 1977
Common rangia, *Rangla cuneata*	-	4	LC_{50} (<1 g/kg salinity)	210	-	Olson and Harrel 1973
Quahog clam (larva), *Mercenaria mercenaria*	-	8.0 - 10	LC_{50}	30	-	Calabrese et al. 1977
Quahog clam (larva), *Mercenaria mercenaria*	-	77	LC_{50}	25	-	Shuster and Pringle 1968
Common Pacific littleneck, *Protothaca staminea*	-	17	LC_{50}	39	-	Roesijadi 1980
Soft-shell clam, *Mya arenaria*	-	7	LC_{50}	35	-	Eisler 1977
Copepod, *Undinula vulgaris*	-	1	LC_{50}	192	-	Reeve et al. 1976
Copepod, *Euchaeta marina*	-	1	LC_{50}	188	-	Reeve et al. 1976

Species	**Chemical**	**Duration (days)**	**Effect**	**Effect Concentration (total µg/L)**	**Effect Concentration (dissolved µg/L)**	**Reference**
Copepod, *Metridia pacifica*	-	1	LC_{50}	176	-	Reeve et al. 1976
Copepod, *Labidocera scotti*	-	1	LC_{50}	132	-	Reeve et al. 1976
Copepod, *Acartia clausi*	-	2	LC_{50}	34-82	-	Moraitou-Apostolopoulou 1978
Copepod, *Acartia tonsa*	-	6	LC_{50}	9.0 - 7.3	-	Sosnowski et al. 1979
Copepod, *Acartia tonsa*	-	1	LC_{50}	104 - 311	-	Reeve et al. 1976
Copepod (adult), *Acartia tonsa*	Copper chloride	2	LC_{50}	~40	36.36	Pinho and Bianchini 2010
Copepod (adult), *Acartia tonsa*	Copper chloride	2	LC_{50}	~90	81.81	Pinho and Bianchini 2010
Copepod (adult), *Acartia tonsa*	Copper chloride	2	LC_{50}	~110	99.99	Pinho and Bianchini 2010
Copepod (adult), *Nitokra spinipes*	Copper sulfate	3	LC_{50}	323	293.6	Ward et al. 2011
Copepod (nauplii, 24 hr), *Eurytemora affinis*	Copper chloride	2	LC_{50}	-	83.0	Hall et al. 1997
Copepod (nauplii, 24 hr), *Eurytemora affinis*	Copper chloride	8	LC_{50}	-	64.0	Hall et al. 1997
Copepod (nauplii, <24 hr), *Tisbe battagliai*	Copper sulfate	2	LC_{50}	83.1	-	Diz et al. 2009
Copepod (adult gravid female), *Tisbe battagliai*	Copper sulfate	3	LC_{50}	157	-	Diz et al. 2009
Copepod (adult gravid female), *Tisbe battagliai*	Copper sulfate	3	EC_{50} (fecundity)	30.8	-	Diz et al. 2009
Copepod, *Tisbe holothuriae*	-	2	LC_{50}	80	-	Moraitou-Apostolopoulou and Verriopoulos 1982
Copepod (mixed species, nauplii)	-	1	LC_{50}	90	-	Reeve et al. 1976
Amphipod, *Ampelisca abdita*	-	7	LC_{50}	90	-	Scott et al. (Manuscript)
Euphauslid, *Euphausia pacifica*	-	1	LC_{50}	14 - 30	-	Reeve et al. 1976
Grass shrimp, *Palaemonetes pacifica*	-	4	LC_{50}	12,600	-	Curtis et al. 1979; Curtis and Ward 1981
Coon stripe shrimp (larva/zoea, stage 1), *Pandalus danae*	Copper sulfate	46	Development	13.42	12.20	Young et al. 1979

Species	**Chemical**	**Duration (days)**	**Effect**	**Effect Concentration (total µg/L)**	**Effect Concentration (dissolved µg/L)**	**Reference**
Sand shrimp (adult, 61 mm), *Crangon sp.*	Copper chloride	4	LC_{50}	898	-	Dinnel et al. 1989
Shrimp (adult), *Crangon crangon*	Copper sulfate	2	LC_{50}	29,500	24,721	Connor 1972
Whiteleg shrimp (juvenile, 5-6.5 cm), *Litopenaeus vannamei*	Copper chloride	28	Gill alterations	186.5	156.3	Frias-Espericueta et al. 2008a
Whiteleg shrimp (juvenile, 1.5-2 g), *Litopenaeus vannamei*	Copper sulfate	4	LC_{50}	35,120	29,431	Frias-Espericueta et al. 2008b
Whiteleg shrimp (juvenile, 11.74 cm, 9.40 g), *Litopenaeus vannamei*	Copper chloride	4	NOEC-LOEC (increase hemolymph clotting time)	370-3,730	-	Bautista-Covarrubias et al. 2015
Pacific asteroid (sperm/egg), *Asterias amurensis*	Copper chloride	80 min.	EC_{50} (fertilization)	200	167.6	Lee et al. 2004
Sand dollar (gamete), *Dendraster excentricus*	Copper sulfate	40 min.	NOEC (fertilization)	10	8.380	Bailey et al. 1995
Sand dollar (gamete), *Dendraster excentricus*	Copper sulfate	40 min.	NOEC (fertilization)	13.1	10.98	Bailey et al. 1995
Sand dollar (sperm), *Dendraster excentricus*	Copper chloride	80 min.	EC_{50} (fertilization)	26	23.63	Dinnel et al. 1989
Blue crab (juvenile, 8.3 cm, 43.4 g), *Callinectes sapidus*	Copper chloride	4	LC_{50}	-	33.75	Martins et al. 2011b
Blue crab (juvenile, 8.3 cm, 43.4 g), *Callinectes sapidus*	Copper chloride	4	LC_{50}	-	3,367	Martins et al. 2011b
Shore crab (adult), *Carcinus maenas*	Copper sulfate	2	LC_{50}	109,000	91,342	Connor 1972
Long-spined sea urchin (embryo), *Diadema antillarum*	Copper sulfate	~ 40 hr	EC_{50} (abnormal development)	-	11	Bielmyer et al. 2005b
Sea urchin (sperm), *Arbacia punctulata*	-	-	58% decrease in sperm motility	300	-	Young and Nelson 1974
Sea urchin (sperm/egg), *Arbacia punctulata*	-	80 min.	IC_{50} (fertilization)	27.7	23.21	Neiheisel and Young 1992
Sea urchin (sperm/egg), *Arbacia punctulata*	-	80 min.	IC_{50} (fertilization)	34.6	28.99	Neiheisel and Young 1992
Sea urchin (sperm/egg), *Arbacia punctulata*	-	80 min.	IC_{50} (fertilization)	47.7	39.97	Neiheisel and Young 1992
Sea urchin (embryo, 1 hpf), *Arbacia punctulata*	Copper sulfate	2	IC_{50} (fertilization)	28.0	21.4	Science Applications International Corporation 1993
Green sea urchin (sperm), *Strongylocentrotus droebachiensis*	Copper chloride	80 min.	EC_{50} (fertilization)	59	53.63	Dinnel et al. 1989

Species	**Chemical**	**Duration (days)**	**Effect**	**Effect Concentration (total µg/L)**	**Effect Concentration (dissolved µg/L)**	**Reference**
Red sea urchin (sperm), *Strongylocentrotus franciscanus*	Copper chloride	80 min.	EC_{50} (fertilization)	1.9	1.727	Dinnel et al. 1989
Sea urchin (embryo), *Paracentrotus lividus*	-	2	LC_{50}	>500	>419.0	Radenac et al. 2001
Sea urchin (embryo), *Paracentrotus lividus*	-	2	LOEC (development)	50	41.9	Radenac et al. 2001
Purple sea urchin (sperm), *Strongylocentrotus purpuratus*	Copper chloride	80 min.	EC_{50} (fertilization)	25	22.73	Dinnel et al. 1989
Purple sea urchin (gamete), *Strongylocentrotus purpuratus*	Copper sulfate	40 min.	NOEC (fertilization)	20	16.76	Bailey et al. 1995
Purple sea urchin (gamete), *Strongylocentrotus purpuratus*	Copper sulfate	40 min.	NOEC (fertilization)	19.7	16.51	Bailey et al. 1995
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	180	150.8	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	90.9	76.17	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	277	232.1	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	120	100.6	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	122	102.2	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	152	127.4	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	135	113.1	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	249	208.7	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	33.4	27.99	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	51.8	43.41	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	243	203.6	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	20.8	17.43	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	20.9	17.51	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	55.7	46.68	Jonczyk et al. 2001

Species	**Chemical**	**Duration (days)**	**Effect**	**Effect Concentration (total µg/L)**	**Effect Concentration (dissolved µg/L)**	**Reference**
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	126	105.6	Jonczyk et al. 2001
White sea urchin (egg/sperm), *Lytechinus pictus*	Copper sulfate	20 min.	IC_{50} (fertilization)	>200	>167.6	Jonczyk et al. 2001
Arrow worm, *Sagitta hispida*	-	1	LC_{50}	43 - 460	-	Reeve et al. 1976
Cuttlefish (egg), *Sepia officinalis*	Copper chloride	50	NOEC-LOEC (hatchling weight)	2.3 - 23	-	Lacoue-Labarthe et al. 2010
Atlantic menhaden, *Brevoortia tyrannus*	-	14	LC_{50}	610	-	Engel et al. 1976
Topsmelt (larva, 9d), *Atherinops affinis*	Copper chloride	7	LC_{50} (test species fed)	162	147.3	Anderson et al. 1994
Topsmelt (larva, 9d), *Atherinops affinis*	Copper chloride	7	LC_{50} (test species fed)	55.7	50.63	Anderson et al. 1994
Topsmelt (larva), *Atherinops affinis*	Copper chloride	7	LC_{50}	365	331.8	McNulty et al. 1994
Topsmelt (larva, 9d), *Atherinops affinis*	Copper chloride	7	LC_{50}	134	121.8	McNulty et al. 1994
Pacific herring (embryo), *Clupea harengus pallasi*	-	6	Incipient LC_{50}	33	-	Rice and Harrison 1978
Pacific herring (larva), *Clupea harengus pallasi*	-	2	Incipient LC_{50}	900	-	Rice and Harrison 1978
Atlantic cod (embryo), *Gadus morhua*	-	14	LC_{50}	10	-	Swedmark and Granmo 1981
Mummichog, *Fundulus heteroclitus*	-	21	Histopathological lesions	<500	-	Gardner and La Roche 1973
Mummichog, *Fundulus heteroclitus*	-	4	Enzyme inhibition	600	-	Jackim 1973
Atlantic silverside, *Menidia menidia*	-	4	Histopathological lesions	<500	-	Gardner and La Roche 1973
Sheepshead minnow (larva, ≤24 hr), *Cyprinodon variegatus*	Copper nitrate	4	LC_{50} (test species fed)	>220	>200.0	Hutchinson et al. 1994
Sheepshead minnow (larva, ≤24 hr), *Cyprinodon variegatus*	Copper nitrate	7	Survival	160	145.4	Hutchinson et al. 1994
Northern anchovy (embryo), *Engraulis mordax*	Copper chloride	32 hr	LC_{50}	185	168.2	Rice et al. 1980
Northern anchovy (larva), *Engraulis mordax*	Copper chloride	46 hr	LC_{50}	372	338.1	Rice et al. 1980
Pinfish, *Lagodon rhomboides*	-	14	LC_{50}	150	-	Engel et al. 1976

Species	**Chemical**	**Duration (days)**	**Effect**	**Effect Concentration (total µg/L)**	**Effect Concentration (dissolved µg/L)**	**Reference**
Spot, *Leiostomus xanthurus*	-	14	LC_{50}	160	-	Engel et al. 1976
Atlantic croaker, *Micropogonias undulatus*	-	14	LC_{50}	210	-	Engel et al. 1976
Winter flounder, *Pseudopleuronectes americanus*	-	14	Histopathological lesions	180	-	Baker 1969
Cobia (egg), *Rachycentron canadum*	Copper sulfate	1	LC_{50}	91	76.26	Dung et al. 2005
Cobia (larva, 1 d), *Rachycentron canadum*	Copper sulfate	4	LC_{50}	60	50.28	Dung et al. 2005
Cobia (juvenile, 20 d), *Rachycentron canadum*	Copper sulfate	4	LC_{50}	87	72.91	Dung et al. 2005
Cobia (young, 40 d), *Rachycentron canadum*	Copper sulfate	4	LC_{50}	240	201.1	Dung et al. 2005
Mahi mahi (4 hpf, blastula stage), *Coryphaena hippurus*	Copper chloride	2	LC_{50}	15.5	14.09	Adema-Hannes and Shenker 2008
Mangrove killifish (adult, 2.5 cm, 0.5 g), *Kryptolebias marmoratus*	Copper chloride	2	LOEC (MT transcript induction)	10	8.380	Rhee et al. 2009

Appendix F Data Not Used in the Development of the Aquatic Life Ambient Estuarine/Marine Water Quality Criteria for Copper

Appendix Table F-1. Unused Studies Along with Reason.

Species	Reference	Reason Data Classified as Unused
Green mussel, *Perna viridis*	Aanand et al. 2010	Only one exposure concentration
Herring, *Clupea harengus*	Abbasi and Sheckley 1995	Only three exposure concentrations
Oyster, *Crassostrea virginica*	Abbe and Sanders 1986	Mixture
Oyster, *Crassostrea virginica*	Abbe and Sanders 2000	Mixture, Field exposure
Bivalve, *Malcoma balthica*	Absil et al. 1993	Steady state not reached for bioaccumulation study; Exposed in situ
Blue mussel, *Mytilus edulis*	Adema et al. 1972	Lack of detail (foreign language)
Sheepshead minnow, *Cyprinodon variegatus*	Adeyemi and Klerks 2012	Only one exposure concentration
Sheepshead minnow, *Cyprinodon variegatus*	Adeyemi et al. 2012	Only one exposure concentration
Mediterranean sponge, *Crambe crambe*	Agel et al. 2001	Pre-exposure to toxicant
European eel, *Anguilla anguilla*	Ahmad et al. 2005	Only two exposure concentrations
European eel, *Anguilla anguilla*	Ahmad et al. 2008	Only two exposure concentrations
Crab, *Scylla serrata*	Ahmed et al. 1997	Only one exposure concentration
Amphipod, *Allorchestes compressa*	Ahsanullah and Williams 1991	Low control survival (77.5%)
Teleost, *Trematomus bernacchii* Teleost, *Chionodraco hamatus*	Albergoni et al. 2000	Mixture; Survey, so prior exposure to many chemicals
Various species	Alekseev et al. 2010	Dilution water not characterized
Cyanobacteria, *Cyanobium sp.*	Alquezar and Anastasi 2013	Algal study
Turbot, *Scophthalmus maximus*	Alvarado et al. 2005	Only two exposure concentrations; No information on seawater
Turbot, *Scophthalmus maximus*	Alvarado et al. 2006	Only two exposure concentrations
Sea urchin, *Paracentrotus lividus*	Amaroli et al. 2013	Only one exposure concentration
Polychaete, *Nereis diversicolor* Peppery furrow shell, *Scrobicularia plana* Common shrimp, *Crangon crangon* European flounder, *Platichthys flesus*	Amiard et al. 1985	No control information; No information on dilution water
Blue mussel, *Mytilus edulis*	Amiard-Triquet et al. 1986	Bioaccumulation: steady state not documented (16 day exposure)
Potworm, *Enchytraeus albidus*	Amorim and Scott-Fordsmand 2012	Terrestrial exposure

Species	Reference	Reason Data Classified as Unused
Various species	Anderson and Norberg-King 1991	Lack of exposure details; dilution water not characterized
Diatom, *Phaeodactylum tricornutum*	Angel et al. 2015	Only one exposure; Pulsed exposure
Anemone, *Bunodosoma cangicum*	Anjos et al. 2014	Not North American species; Only two exposure concentrations
Mediterranean mussel, *Mytilus galloprovincialis*	Arnold et al. 2005	Modeling study (BLM)
Mussel, *Mytilus sp.*	Arnold and Cotsifas 2008	Review and analysis of previously reported data
Green Mussel, *Perna viridis*	Arockia Vasanthi et al. 2012	Field survey, exposure concentration not known
Flathead mullet, *Mugil cephalus*	Arockia Vasanthi et al. 2013	Field survey, exposure concentration not known
Mangrove crab, *Scylla serrata*	Arumugam and Ravindranath 1987	Not North American species; No LC_{50} data
Oyster, *Crassostrea virginica*	Ayling 1974	Mixture
Blue mussel, *Mytilus edulis*	Bakhmet et al. 2012	Only three exposure concentrations
Polychaete, *Hydroides elegans*	Bao et al. 2010	Effect of copper on biofilm development and larval settlement
Copepod, *Tigriopus japonicus*	Bao et al. 2013	Not North American species
Brown mussel, *Perna perna*	Baraj et al. 2011	Only one exposure concentration
Copepod, *Tigriopus brevicornis*	Barka 2007	Only three exposure concentrations
Copepod, *Tigriopus brevicornis*	Barka et al. 2010	Only three exposure concentrations
Blue shark, *Prionace glauca*	Barrera-Garcia et al. 2013	Field survey, exposure concentration not known
Isopod, *Idotea baltica*	Bat et al. 199b	LT50 is the endpoint
Sea urchin, *Strongylocentrotus purpuratus*	Bay et al. 1983	Only two exposure concentrations
Echinoid, *Phylum Echinodermata*	Bay et al. 1993	Review
Coral	Berry et al. 2013	Field survey, exposure concentration not known
Amphipod, *Parhalella natalensis*	Bhat and Vamsee 1993	Discrepancy in results; No control information
Hybrid striped bass, *Morone chrysops* x *Morone saxatilis*	Bielmyer et al. 2005a	Bioaccumulation: steady state not documented
Hybrid striped bass, *Morone chrysops* x *Morone saxatilis*	Bielmyer et al. 2006a	Only two fish per concentration
Copepod, *Acartia tonsa*	Bielmyer et al. 2006b	Dietary exposure

Species	**Reference**	**Reason Data Classified as Unused**
Coral, *Acropora cervicornis* Coral, *Pocillopora damicornis* Coral, *Montastrea faveolata* Dinoflagellate, *Symbiodinium sp.*	Bielmyer et al. 2010	Exposed coral and algal species at the same time
Sea urchin, *Strongylocentrotus droebachiensis*	Bielmyer et al. 2012	Dietary exposure
Sydney rock oyster, *Saccostrea commercialis*	Birch and Hogg 2011	Not North American species; Sediment exposure
Amphipod, *Gammarus annulatus*	Bisbal 1987	Only two exposure concentrations
Oyster, *Saccostrea cucullata*	Biswas et al. 2013	Field survey, exposure concentration not known
Killifish, *Fundulus heteroclitus*	Blanchard and Grosell 2005	Bioaccumulation: steady state not documented
Killifish, *Fundulus heteroclitus*	Blanchard and Grosell 2006	Only two exposure concentrations
Oyster, *Crassostrea virginica*	Blanchard et al. 2009	Bioaccumulation: steady state not documented
Plaice, *Pleuronectes platessa* Herring, *Clupea harengus*	Blaxter 1977	Only one exposure concentration
Striped bass, *Morone saxatilis*	Bodammer 1985	No control information; Culture water contained 57 ug/L copper
American sand lance, *Ammodytes americanus*	Bodammer 1987	Only two exposure concentrations
Atlantic horseshoe crab, *Limulus polyphemus*	Botton and Itow 2009	Review
Brown mussel, *Perna perna*	Boudjema et al. 2014	Only three exposure concentrations
Crab, *Neohelice granulata* Clam, *Mesodesma mactroides*	Boyle et al. 2013	Not North American species; Only one exposure concentration
Ostracod, *Diacypris compacta*	Brooks et al. 1995	Hypersaline conditions in exposure media
Three *Mytlius* species	Brooks et al. 2015	Bioaccumulation: unmeasured exposure
Red seaweed, *Gracilariopsis longissima*	Brown et al. 2012	Algal study
Gastropod, *Littorina littoralis* Brown seaweed, *Fucus vesiculosus*	Bryan 1983	Mixture
Peppery furrow shell, *Scrobicularia plana* Polychaete, *Hediste diversicolor*	Buffet et al. 2011	Only one exposure concentration
Polychaete, *Hediste diversicolor*	Burlinson and Lawrence 2007a	Mixture (field exposure)

Species	**Reference**	**Reason Data Classified as Unused**
Polychaete, *Hediste diversicolor*	Burlinson and Lawrence 2007b	Prior exposure (sequentially exposed to increasing copper)
Amphipod, *Melita plumulosa* Copepod, *Nitocra spinipes*	Campana et al. 2012	Sediment exposure
Sheepshead, *Archosargus probatocephalus*	Cardeilhac et al. 1979	Only one exposure concentration
Polychaete, *Arenicola marina*	Casado-Martinez et al. 2010	Sediment exposure
Mediterranean mussel, *Mytilus galloprovincialis*	Casas et al. 2008	Mixture
Starfish, *Asterias rubens* White sea urchin, *Echinus acutus*	Catarino et al. 2008	Mixture
Mediterranean sponge, *Chondrosia reniformis*	Cebrian et al. 2006	Mixture
Mediterranean sponge, *Crambe crambe* Mediterranean sponge, *Scopalina lophyropoda*	Cebrian and Uriz 2007a	Only one exposure concentration
Mediterranean sponge, *Scopalina lophyropoda*	Cebrian and Uriz 2007b	Only one exposure concentration
Sponge cell	Cebrian and Uriz 2007c	Only two exposure concentrations
Wedge sole, *Dicologlossa cuneata* Brill, *Scophthalmus rhombus* Senegalese sole, *Solea senegalensis*	Chairi et al. 2010	Injected toxicant; Not North American species
Oyster, *Saccostrea cucullata*	Chaharlang et al. 2012	Field survey, exposure concentration not known
Oyster, *Crassostrea virginica* Oyster, *Crassostrea gigas*	Chang 1995	Exposure via biofilm
Oyster, *Crassostrea virginica* Oyster, *Crassostrea gigas*	Chang et al. 1996	Exposure via biofilm
Mussel, *Mytilus trossulus*	Chelomin et al. 1998	Mixture
Goby, *Synechogobius hasta*	Chen et al. 2013	Not North American species; Only two exposure concentrations
Oyster, *Crassostrea gigas*	Cheng 1988a	Only one exposure concentration
Oyster, *Crassostrea gigas*	Cheng 1988b	Only one exposure concentration
Gastropod, *Babylonia lutosa*	Cheung and Wong 1998	Only three exposure concentrations
Hagfish	Chiu and Mok 2011	Field survey, exposure concentration not known

Species	Reference	Reason Data Classified as Unused
Rockbream, *Oplegnathus fasciatus*	Cho et al. 2006	Only three exposure concentrations
Red alga, *Porphya yezoensis*	Choi et al. 2005	Lack of exposure details; number of exposure concentrations not provided
Snail, *Bulinus rohlfsi*	Chu 1976	Formulation (50% copper sulfate)
Alga, *Colpomenia sinuosa*	Cirik et al. 2012	Adsorption study
Mussel, *Echyridella menziesii*	Clearwater et al. 2014	Not North American species
Bivalve, *Bathymodiolus azoricus*	Company et al. 2008	Only one exposure concentration
Brown seaweed, *Ascophyllum nodosum* Brown seaweed, *Fucus vesiculosus*	Connan and Stengel 2011	Only three exposure concentrations
Snail, *Ilyanassa obsoleta*	Conrad 1988	Mixture (copper and antibiotic)
Kelp, *Lessonia nigrescens*	Contreras et al. 2007	Not North American species
Amphipod, *Gammarus locusta*	Correia et al. 2002a	Only three exposure concentrations
Amphipod, *Gammarus locusta*	Correia et al. 2002b	Only three exposure concentrations
Sea bass, *Dicentrarchus labrax*	Cotou et al. 2009	Mixture (source of copper was antifouling painted nets); Not North American species
European sea bass, *Dicentrarchus labrax*	Cotou et al. 2012	Inappropriate form of toxicant (copper-treated nets)
Black-chinned tilapia, *Sarotherodon melanotheron*	Coulibaly et al. 2012	Field survey, exposure concentration not known
Epibionts	Crespo et al. 2014	Only one exposure concentration
Blue mussel, *Mytilus edulis*	Curtis et al. 2000	Only four organisms per concentration
Rough periwinkle, *Littorina saxatilis*	Daka and Hawkins 2004	Mixture
Pacific oyster, *Crassostrea gigas*	Damiens et al. 2006	Only three exposure concentrations
Black sea bream, *Acanthopagrus schlegeli*	Dang et al. 2009	Prior exposure
Blackhead seabream, *Acanthopagrus schlegelii schlegelii*	Dang et al. 2012	Not North American species
Scallop, *Pecten maximus* Pacific oyster, *Crassostrea gigas*	Davies and Paul 1986	Inappropriate form of toxicant (copper oxide-based anti-fouling paint)
Spiny dogfish, *Squalus acanthias*	De Boeck et al. 2007	Only three exposure concentrations
Spotted dogfish, *Scyliorhinus canicula*	De Boeck et al. 2010	Only one exposure concentration; Not North American species
Mediterranean mussel, *Mytilus galloprovincialis*	Deruytter et al. 2013	Test results not reported, only the model developed
Guppy, *Poecilia vivipara*	de Souza Machado et al. 2013	Not North American species

Species	Reference	Reason Data Classified as Unused
Snakehead catfish, Channa striata	Devi and Gopal 1986	Not North American species
Asian paddle crab, *Charybdis japonica*	Ding and Wang 2010	Not North American species; Text in foreign language
Mediterranean mussel, *Mytilus galloprovincialis*	Dragun et al. 2010	Mixture; Survey, so prior exposure to many chemicals
	Duran and Beiras 2013	Review of previously published studies
Sea urchin, *Strongylocentrotus intermedius* Sea urchin, *Strongylocentrotus nudus*	Durkina 1995	Only three exposure concentrations
Polychaete, *Nereis diversicolor*	Durou et al. 2005	LT50 is the endpoint
Dinoflagellate, *Cochlodinium polykrikoides*	Ebenezer and Ki 2012	Algal study
Sea urchin, *Tripneustes gratilla*	Edullantes and Galapate 2014	Not North American species
Mummichog, *Fundulus heteroclitus*	Eisler and Gardner 1973	Mixture
Clam, *Macoma balthica*	Eldon et al. 1980	Dilution water not characterized
Oyster, *Saccostrea cucullata* Oyster, *Crassostrea lugubris* Oyster, *Crassostrea belcheri*	Elfwing and Tedengren 2002	Only one exposure concentration
Barnacle, *Elminius modestus*	Elliott et al. 1985a	Bioaccumulation: static, unmeasured exposure
Mussel, *Mytilus edulis planulatus*	Elliott et al. 1985b	Bioaccumulation: steady state not achieved
Crab, *Carcinus maenas*	Elumalai et al. 2005	Only nine animals per concentration
Coral	El-Sorogy et al. 2012	Field survey, exposure concentration not known
Oyster	Engel and Fowler 1979	Only two exposure concentration
Mediterranean mussel, *Mytilus galloprovincialis*	Fabbri and Capuzzo 2006	Only one exposure concentration
Sea urchin, *Paracentrotus lividus*	Fabbrocini and D'Adamo 2011	Not North American species; Lack of details (no control information/procedures)
Benthic foraminiferal assemblages	Fabrizio and Rodolfo 2012	Sediment present in media
Mediterranean mussel, *Mytilus galloprovincialis*	Fafandel et al. 2008	Only three exposure concentrations
Fish, *Etroplus maculatus* Clam, *Villorita cyprinoides* var. *cochinensis* Prawn, *Macrobranchium idella idella* Crab, *Paratelphusa hydrodromus*	Fernandez et al. 1996	Dilution water not characterized

Species	Reference	Reason Data Classified as Unused
Polychaete, *Laeonereis acuta*	Ferreira-Cravo et al. 2009	Only one exposure concentration
Ascidian, *Ciona intestinalis*	Ferro et al. 2013	Only one exposure concentration
Rotifer, *Brachionus plicatilis*	Filenko and Samoylova 2008	Dilution water not characterized
Whiting, *Merlangius merlangus* Goatfish, *Mullus barbatus*	Findik and Cicek 2011	Field survey, exposure concentration not known
Blue mussel, *Mytilus edulis*	Fokina and Nemova 2012	Lack of detail (abstract only)
Blue mussel, *Mytilus edulis*	Fokina et al. 2013	Only three exposure concentrations
Sole, *Solea senegalensis*	Fonseca et al. 2009	Only three exposure concentrations
Copepod, *Tigriopus brevicornis*	Forget et al. 1999	Mixture
Ascidian, *Ciona intestinalis*	Franchi et al. 2012	Only one exposure concentration
Oyster, *Crassostrea gigas*	Frazier 1976	Mixture
Japanese flounder, *Paralichthys olivaceus* Red Sea bream, *Pagrus major*	Furuta et al. 2008	Not North American species
Seam bream, *Sparus aurata* Bivalve, *Scapharca inaequivalvis*	Gabbianelli et al. 2003	Only one exposure concentration
Sole, *Solea senegalensis*	Galindo et al. 2012	Field survey, exposure concentration not known
Barnacle, *Amphibalanus variegatus*	Gall et al. 2013	Not North American species
Sea squirt, *Styela plicata*	Galletly et al. 2007	Only three exposure concentrations
Rotifer, *Brachionus rotundiformis*	Gama-Flores et al. 2005	Not North American species
Isopod, *Idotea baltica*	Gambardella et al. 1998	Only acclimated one day
Brown flagellate, *Isochvysis sp.*	Garr 2012	Algal study
Asteroid, *Coscinasterias muricata*	Georgiades et al. 2006	Only three exposure concentrations
Polychaete, *Laeonereis acuta*	Geracitano et al. 2002	Only two exposure concentrations
Polychaete, *Laeonereis acuta*	Geracitano et al. 2004	Only two exposure concentrations
Oyster, *Crassostrea gigas* Mussel, *Mytilus edulis*	Geret et al. 2002a	Bioaccumulation: unmeasured exposure and steady state not achieved
Clam, *Ruditapes decussatus*	Geret et al. 2002b	Only three exposure concentrations

Species	**Reference**	**Reason Data Classified as Unused**
Isopod, *Exosphaeroma gigas*	Giarratano et al. 2007	Only 24 hour acclimation
Coon stripe shrimp, *Pandalus danae*	Gibson 1976	Acclimated to one temperature and tested at another
Clam, *Paphia malabarica*	Gireesh and Gopinathan 2009	Only one exposure concentration
Copepod, *Acartia sinjiensis*	Gissi et al. 2013	Not North American species
Alga, *Phaeocystis antarctica*	Gissi et al. 2015	Not North American species
Coho salmon, *Oncorhynchus kisutch* Masu salmon, *Oncorhynchus masou* Siberian sturgeon, *Acipenser baeri*	Glubokov 1990	No dose response
Doughboy scallop, *Mimachlamys asperrima*	Golding et al. 2006	No toxicity information; Not North American species
Mediterranean mussel, *Mytilus galloprovincialis*	Gomes et al. 2011	Only one exposure concentration
Mediterranean mussel, *Mytilus galloprovincialis*	Gomes et al. 2013	Only one exposure concentration
Protozoa, *Euplotes crassus*	Gomiero et al. 2012a	Protozoa; Lack of details (abstract only)
Protozoa, *Euplotes crassus*	Gomiero et al. 2014	Protozoa
Polychaete, *Hydroides elegans*	Gopalakrishnam et al. 2007	Prior exposure
Abalone, *Haliotis rubra*	Gorski and Nugegoda 2006b	Lack of detail (not sure what units the effect concentration is in)
Giant sea scallop, *Placopecten magellanicus*	Gould et al. 1985	Bioaccumulation: steady state not achieved
Giant sea scallop, *Placopecten magellanicus*	Gould et al. 1986	Lack of details (abstract only)
White prawn, *Penaeus indicus* Green mussel, *Perna viridis* Brine shrimp, *Artemia salina*	Govindarajan et al. 1993	Lack of details (procedure)
European eel, *Anguilla anguilla*	Gravato et al. 2006	Prior exposure
Skate, *Raja erinacea* Sculpin, *Myoxocephalus octodecemspinosus*	Grosell et al. 2003	Only two exposure concentrations
Brine shrimp, Artemia franciscana Cladoceran, *Daphnia magna* Alga, *Selenastrum capricornutum*	Guida et al. 2008	Mixed species exposure

Species	**Reference**	**Reason Data Classified as Unused**
Dinoflagellate, *Prorocentrum minimum*	Guo and Ki 2012	Algal study
Dinoflagellate, *Prorocentrum minimum*	Guo et al. 2012	Algal study
Abalone, *Haliotis discus*	Guo et al. 2013	Not North American species
Babylon snail, *Babylonia areolata*	Hajimad and Vedamanikam 2014	Not North American species
	Handy 2003	Review
Amphipod	Hanna et al. 2013	Inappropriate form of toxicant (nanoparticles)
Shore crab, *Carcinus maenas*	Hansen et al. 1992	Only one exposure concentration
Blue mussel, *Mytilus edulis*	Harrison et al. 1983	Only three exposure concentrations
Rats and Mice	Hasegawa et al. 1989	Non-aquatic organisms
Polychaete, *Nereis diversicolor*	Hateley et al. 1989	Mixture (field exposure)
Shore crab, *Carcinus maenas*	Hebel et al. 1999	Only five organisms per concentration
Coral, *Montipora capitata*	Hedouin and Gates 2013	Not North American species
Blue mussel, *Mytilus edulis*	Hellou et al. 2003	Mixture
Dinoflagellate, *Alexandrium catenella*	Herzi et al. 2013	Contaminated dilution water
Flower crab, *Portunus pelagicus*	Hilmy et al. 1985	Dilution water not characterized; Not North American species
Blue mussel, *Mytilus edulis*	Hines et al. 2010	Only two exposure concentrations
Brown mussel, *Perna perna*	Hodgson and Hoebeke 1984	Only five organisms per concentration
Blue mussel, *Mytilus edulis*	Hoher et al. 2013	Only three exposure concentrations
	Hori et al. 1996	Lack of details (foreign language)
Isopod, *Porcellio scaber*	Hornung et al. 1998	Sediment present in media
Alga	Horta-Puga et al. 2013	Field survey, exposure concentration not known
Sea anemone, *Aiptasia pulchella*	Howe et al. 2012	Not North American species
Sea anemone, *Aiptasia pulchella*	Howe et al. 2014	Not North American species
Nematode, *Enoplus brevis*	Howell 1984	LT50 is the endpoint
Various species	Hrovat et al. 2009	Review
Red alga, *Gracilaria lemaneiformis* Red alga, *Gracilaria lichenoides*	Huang et al. 2013	Algal study
Baltic clam, *Macoma balthica* Cockle, *Cerastoderma edule*	Hummel et al. 1998	Sediment present in media
Pacific kelps	Huovinen et al. 2010	Only one exposure concentration

Species	**Reference**	**Reason Data Classified as Unused**
Bivalve, *Austriella cf plicifera*	Hutchins et al. 2008	Sediment present in media
Bivalve, *Indoaustriella lamprelli*	Hutchins et al. 2009	Sediment present in media
Protozoa, *Alexandrium minutum*	Hwang and Lu 2000	Protozoa
Copepod, *Paracyclopina nana*	Hwang et al. 2010	Only one exposure concentration
Amphipod, *Corophium sp.*	Hyne and Everett 1998	No control survival information, and author suggests poor control survival if no sediment present
Seabream, *Sparus aurata*	Isani et al. 2012	Not North American species
Indian edible oyster, *Crassostrea madrasensis*	Ittoop et al. 2009	Not North American species; Only three exposure concentrations; Dilution water not characterized
Hard clam, *Mercenaria mercenaria*	Ivanina et al. 2013	Only two exposure concentrations
Filter feeders	Jara-Marini et al. 2013	Field survey, exposure concentration not known
Copepod, *Tigriopus japonicus*	Jeong et al. 2014	Not North American species
Pearl oyster, *Pinctada fucata*	Jing et al. 2006	Only two exposure concentrations
Butterfish, *Poronotus triacanthus*	Jiraungkoorskul et al. 2007	Only one exposure concentration
Pink shrimp, *Penaeus duorarum* Shrimp, *Penaeus stylirostris* Shrimp, *Penaeus setiferus*	Johnson 1974	Only two or three exposure concentrations; Purity of test material questionable
	Jones et al. 1968	Review
Isopods	Jones 1975	Only two exposure concentrations
Brine shrimp, *Artemia salina*	Jorgensen and Jensen 1977	Brine shrimp used
Mediterranean mussel, *Mytilus galloprovincialis*	Kanduc et al. 2011	Field survey, exposure concentration not known
Mangrove crab, *Macrophthalmus erato*	Kannupandi et al. 2001	Only three exposure concentrations
Sea bass, *Dicentrarchus labrax*	Kentouri et al. 1993	Only one exposure concentration
Killifish, *Aphanius dispar*	Khan and Khan 1999	Dilution water not characterized; Not North American species
Heliozoon, *Raphidiophrys contractilis*	Khan et al. 2006	Lack of exposure details; dilution water not characterized
Copepod, *Tigriopus japonicus*	Ki et al. 2009	Only one exposure concentration; Not North American species
Copepod, *Tigriopus japonicus*	Kim et al. 2012	Not North American species; Lack of exposure details
Various bivalves	Klumpp and Burdon-Jones 1982	Mixture (field exposure)

Species	Reference	Reason Data Classified as Unused
Sea urchin, *Hemicentrotus pulcherrimus* Sea urchin, *Anthocidaris crassispina*	Kobayashi and Okamura 2002	Inappropriate form of toxicant (copper pyrithione)
Black sea bivalve mollusks, *Anadara inaequivalvis & Chamelea gallina*	Kolyuchlina and Ismailov 2011	Not North American species
Mediterranean mussel, *Mytilus galloprovincialis*	Koukouzika and Dimitriadis 2008	Only one exposure concentration
Shore crab, *Carcinus maenas*	Krang and Ekerholm 2006	Only two exposure concentrations
Eastern oyster, *Crassostrea virginica*	Krishnamurthy 1994	Bioaccumulation: static exposure
Nile tilapia, *Oreochromis niloticus*	Kulac et al. 2013	Only one exposure concentration
Oyster, *Saccostrea cucullata* Snail, *Cerithium rubus*	Kumari and Nair 1992	Bioaccumulation: static, unmeasured exposure
Coral, *Platygyra acuta*	Kwok and Ang 2013	Not North American species
Copepod, *Tigriopus japonicus*	Kwok et al. 2009	Prior exposure; Not North American species
Cuttlefish, *Sepia officinalis*	Lacoue-Labarthe et al. 2009	Only one exposure concentration; Not North American species
Sea snail, *Hexaplex trunculus*	Lahbib et al. 2013	Field survey, exposure concentration not known
Green alga, *Ulva lactuca* *Seaweed,* *Codium fragile* Seaweed, *Jania rubens* Alga, *Dictyota dichotoma*	Laib and Leghouchi 2012	Field survey, exposure concentration not known
Red sea bream, *Chrysophrys major*	Lan and Chen 1991	Lack of detail (text in foreign language)
Copepod, *Acartia tonsa*	Lauer and Bianchini 2010	Intermittent exposure (12hr exposed and 12hr clean)
Estuarine crab, *Neohelice granulata*	Lauer et al. 2012	Not North American species; Only one exposure concentration
Crab, *Chasmagnathus granulatus*	Lavolpe et al. 2004	Only two exposure concentrations
Ammonia (foraminifera)	Le Cadre and Debenay 2006	Protozoa
Flatworm, *Stylochus pygmaeus*	Lee and Johnston 2007	Only two exposure concentrations
Blue crab, *Callinectes sapidus*	Lee and Oshima 1998	Lack of exposure details; dilution water not characterized
Blue crab, *Callinectes sapidus*	Lee et al. 1999	Dilution water not characterized
Copepod, *Tigriopus japonicus*	Lee et al. 2008a	Only two exposure concentrations; Not North American species

Species	Reference	Reason Data Classified as Unused
Hairy-handed crab, *Hemigrapsus crenulatus* Shield shell limpet, *Scutus breviculus*	Lee et al. 2010	Only two exposure concentrations; Not North American species
Blue mussel, *Mytilus edulis* Clam, *Macoma balthica*	Lehtonen and Leinio 2003	Only two exposure concentrations
Copepod, *Euchaeta japonica*	Lewis et al. 1972	Only three exposure concentrations
Polychaete, *Spirobranchus lamarckii*	Lewis et al. 2013	Not North American species
Gastropod, *Onchidium struma*	Li et al. 2009	Sediment present in media
Chinese oyster, *Ostrea plicatula*	Li et al. 2010	Not North American species
Mussel, *Mytilus coruscus*	Li et al. 2012a	Not North American species
Seagrass, *Thalassia hemprichii*	Li et al. 2012b	Not North American species; Only three exposure concentrations
Shrimp, *Penaeus japonicus*	Liao and Hsieh 1988	LT50 is the endpoint in the acute exposure; Chronic and bioaccumulation exposure was not measured
Shrimp, *Penaeus chinensis*	Liu 1995	Lack of detail (text in foreign language)
Fish, *Synechogobius hasta*	Liu et al. 2010	Not North American species; Only two exposure concentrations
Four marine bivalves	Liu et al. 2012	Mixture
Crescent-banded tigerfish, *Terapon jarbua*	Long and Wang 2005	Prior exposure
Crab, *Petrolisthes galathinus*	Lopez Greco et al. 2002	Only two exposure concentrations
Blue mussel, *Mytilus edulis*	Lorenzo et al. 2005	Bioaccumulation: steady state not achieved
Diatoms	Lozano et al. 2014	Only two exposure concentrations
Shore crab, *Carcinus maenas*	Lundebye and Depledge 1998a	Only six organisms per concentration
Shore crab, *Carcinus maenas*	Lundebye and Depledge 1998b	Only six organisms per concentration
Eastern oyster, *Crassostrea virginica*	Lunz 1972	River water used as dilution water; Bioaccumulation: steady state not achieved
Hermit crab, *Clibanarius longitarsus*	Lyla and Khan 2011	Not North American species
Eastern oyster, *Crassostrea virginica*	Macey et al. 2010	Only four organisms per concentration; Only three exposure concentrations
Guppy, *Poecilia vivipara*	Machado et al. 2013	Not North American species; Only three exposure concentrations
Eastern oyster, *Crassostrea virginica*	MacInnes 1981	Mixture
Mud snail, *Nassarius obsoletus*	MacInnes and Thurberg 1973	Too few organisms per exposure concentration (n=5)
Stone-loach, *Nemacheilus barbatulus*	Mackereth and Smyly 1951	Lack of details (abstract only)

Species	Reference	Reason Data Classified as Unused
Spiny lobster, *Panulirus homarus*	Maharajan et al. 2011	Not North American species; Only two exposure concentrations
Spiny lobster, *Panulirus homarus*	Maharajan et al. 2012a	Not North American species; Only two exposure concentrations
Spiny lobster, *Panulirus homarus*	Maharajan et al. 2012b	Not North American species
Sponge, *Hymeniacidon perlevis*	Mahaut et al. 2013	Field survey, exposure concentration not known
Pacific oyster, *Crassostrea gigas*	Mai et al. 2012	Only three exposure concentrations
Diatom, *Odontella mobiliensis*	Manimaran et al. 2012	Algal study
Various bivalves	Manley and Davenport 1979	Review
Grass shrimp, *Palaemonetes pugio*	Manyin 2008	Only acclimated for 24 hours; Only two exposure concentrations
Grass shrimp, *Palaemonetes pugio*	Manyin and Rowe 2009	Only three exposure concentrations
Grass shrimp, *Palaemonetes pugio*	Manyin and Rowe 2010	Only two exposure concentrations
Limpet, *Patella vulgata*	Marchan et al. 1999	Surgically altered test species
Blue mussel, *Mytilus edulis*	Martin et al. 1975	Chelating agent used in exposure media
Shore clam, *Ruditapes philippinarum*	Martin-Diaz et al. 2005	Only one exposure concentration
Blue crab, *Callinectes sapidus*	Martins et al. 2011a	Only one exposure concentration
Persian sturgeon, *Acipenser persicus*	Mashroofeh et al. 2012	Field survey, exposure concentration not known
Clam, *Sunetta scripta* Mussel, *Perna viridis*	Mathew and Damodaran 1997	Only one exposure concentration
Mussel, *Perna viridis* Clam, *Meretrix casta*	Mathew and Menon 1984	Insufficient acclimation time
European sea star, *Asterias rubens*	Matranga et al. 2012	Mixture; Not North American species
Amphipod, *Corophium volutator* Polychaete, *Hediste diversicolor*	Mayor et al. 2008	Sediment toxicity test
Amphipod, *Leptocheirus plumulosus*	McGee et al. 1999	Mixture and sediment exposure
Bryzoa, *Watersipora subtorquata*	McKenzie et al. 2011	Only two exposure concentrations
Lobster, *Homarus americanus*	McLeese 1974	LT50 is the endpoint; Only five organisms per concentration
	McLeese 1976	Species name not given

Species	**Reference**	**Reason Data Classified as Unused**
Clam, *Macoma balthica* Shrimp, *Crangon septemspinosa* Shrimp, *Pandalus montagui* Polychaete, *Nereis virens*	McLeese and Ray 1986	Only six organisms per concentration
Crab, *Chasmagnathus granulata*	Medesani et al. 2004a	Only one exposure concentration
Crab, *Chasmagnathus granulata*	Medesani et al. 2004b	Only one exposure concentration
Amphipod, *Corophium multisetosum*	Menchaca et al. 2010	Not North American species; Sediment exposure
Polychaete, *Capitella sp.*	Mendez and Green-Ruiz 2005	Only three exposure concentrations
Polychaete, *Capitella sp.*	Mendez and Green-Ruiz 2006	Only three exposure concentrations
Pacific oyster, *Crassostrea gigas*	Metzger et al. 2012	Only one exposure concentration
Turbot, *Psetta maxima*	Mhadhbi et al. 2010	Not North American species
Blue-green alga, *Synechococcus sp.* Diatom, *Thalassiosira weissflogii* Dinoflagellate, *Prorocentrum minimum*	Miao et al. 2005	Algal study; Excessive NTA in the media
Ribbed mussel, *Geukensia demissa*	Miller 1986	Lack of details (abstract only)
Ribbed mussel, *Geukensia demissa*	Miller 1988	Only two exposure concentrations
Meiofaunal community	Millward et al. 2001	Mixture
Sea bream, *Sparus aurata*	Minghetti et al. 2008	Prior exposure
Diatom, *Haslea ostrearia*	Minier et al. 1998	Algal study
Shrimp, *Penaeus monodon*	Misra et al. 2005	Not North American species; Dilution water not characterized
White mussel, *Donax trunculus*	Mizrahi and Achituv 1989	Not North Americans species; Only five organisms per concentration
White mussel, *Donax trunculus*	Mizrahi et al. 1993	Not North Americans species; Only three exposure concentrations
Mummichog, *Fundulus heteroclitus*	Mochida et al. 2008	Mixture
Fish	Mohan et al. 2012	Field survey, exposure concentration not known
Coral	Mokhtar et al. 2012	Field survey, exposure concentration not known
Pacific oyster, *Crassostrea gigas*	Money et al. 2011	Mixture

Species	**Reference**	**Reason Data Classified as Unused**
Mediterranean mussel, *Mytilus galloprovincialis* Blue mussel, *Mytilus edulis*	Moore et al. 2007	Only one exposure concentration
Oyster, *Crassostrea gigas*	Moraga et al. 2005	Only two exposure concentrations
Brown alga, *Ectocarpus siliculosus*	Morris and Russell 1973	Algal study; Prior exposure (tolerant strain)
Mozambique tilapia, *Oreochromis mossambica*	Mukhopadhyay 1983	Lack of details (abstract only)
Clam, *Tapes philippinarum*	Munari and Mistri 2007	Only one exposure concentration; Possible prior exposure
Shrimp, *Penaeus monodon*	Munshi et al. 1996a	Not North American species; Variable time for LC_{50} values
Shrimp, *Penaeus penicillatus*	Munshi et al. 1996b	Only acclimated for one hour
Blue crab, *Callinectes sapidus*	Mutlu et al. 2011	Field survey, exposure concentration not known
Pikeperch	Nabavi et al. 2012	Field survey, exposure concentration not known
Mussel, *Mytilus trossolus*	Nadella et al. 2009	Only acclimated for 24 hours
Mussel, *Mytilus viridis*	Nair et al. 1977	Only eight animals per concentration
Common cockle, *Cerastoderma edule*	Naylor 1987	Not North American species
Blue crab, *Callinectes similis*	Neff and Anderson 1977	Only three exposure concentrations
Polychaete, *Pectinaria koreni* Polychaete, *Nephthys ciliata* Mussel, *Mytilus calcarea* Mussel, *Mytilus baltica*	Neuhoff and Theede 1984	Lack of details (procedure)
Mussel, *Perna viridis*	Nicholson 1999	Only three exposure concentrations
Green mussel, *Perna viridis*	Ng and Wang 2007	Mixture
European eel, *Anguilla anguilla*	Nunes et al. 2014	Only three exposure concentrations
Polychaete, *Eurythoe complanata*	Nusetti et al. 1998	Only one exposure concentration
Senegal sole, *Solea senegalensis*	Oliva et al. 2009	Not North American species; Only acclimated for 24 hours
European eel, *Anguilla anguilla*	Oliveira et al. 2008	Only one exposure concentration
Fish and shellfish	Olmedo et al. 2013	Field survey, exposure concentration not known
Fish and crustaceans	Olsen 2011	Review of previously published studies

Species	Reference	Reason Data Classified as Unused
Flat oyster, *Ostrea edulis* Pacific oyster, *Crassostrea gigas*	Ong et al. 2013	Field survey, exposure concentration not known
Mummichog, *Fundulus heteroclitus*	Ortiz et al. 1999	Bioaccumulation: static, unmeasured exposure, steady state not achieved
Hermit crab, *Clibanarius africanus*	Otitoloju and Don-Pedro 2006	Sediment present in media
Alga, *Fucus vesiculosus*	Owen et al. 2012	Algal study; Only two exposure concentrations
Fish and mollusks	Oya et al. 1939	Text in foreign language
Mussel, *Lithophaga lithophaga*	Ozsuer and Sunlu 2013	Field survey, exposure concentration not known
Blue crab, *Callinectes sapidus*	Paganini and Bianchini 2009	Excised cells
Sea urchin, *Paracentrotus lividus* Sea urchin, *Echinus esculentus*	Pagano et al. 1986	Lack of details (procedures; dilution water not characterized)
Sea urchin	Pagano et al. 2002	Mixture
Crab, *Charybdis japonica*	Pan et al. 2011	Not North American species
Copepod, *Tigriopus japonicus*	Park et al. 2014	Not North American species
Scallop, *Pecten maximus* Oyster, *Crassostrea gigas*	Paul and Davies 1986	Formulation (Hard Racing Red)
Red drum, *Sciaenops ocellatus*	Peppard et al. 1991	Formulation (Copper Control®, 8.5% copper)
Mussel, *Perna perna*	Pereira et al. 2007	Mixture
Pistol prawn, *Alpheus malabaricus malabaricus*	Perumal and Subramanian 1985	Excessive control mortality (20%)
Polychaete, *Neanthes arenaceodentata*	Pesch 1979	Only one exposure concentration
Green mussel, *Perna viridis*	Pillai and Menon 1998	Excised tissue
Mangrove crab, *Ucides cordatus*	Pinheiro et al. 2012	Mixture
Copepod, *Acartia tonsa*	Pinho et al. 2007	Only one exposure concentration
Sea urchin, *Paracentrotus lividus*	Pinsino et al. 2011	Only one exposure concentration
Bryzoans	Piola and Johnston 2009	Surgically altered test species
Polychaete, *Nereis diversicolor*	Pook et al. 2009	Prior exposure
Amphipod, *Gammarus aequicauda*	Prato and Biandolino 2005	Sediment toxicity test
Copepod, *Tigriopus fulvus*	Prato et al. 2013a	Not North American species
Amphipod, *Gammarus aequicauda*	Prato et al. 2013b	Only two exposure concentrations
Oyster	Prytherch 1931	Mixture (field exposure)

Species	Reference	Reason Data Classified as Unused
Mediterranean mussel, *Mytilus galloprovincialis*	Pytharopoulou et al. 2011	Only three exposure concentrations
Mediterranean mussel, *Mytilus galloprovincialis*	Pytharopoulou et al. 2013	Only one exposure concentration
Decapod, *Palaemonetes varians*	Rainbow and Smith 2013	Not North American species
Mullet, *Mugil cephalus*	Rajkumar and Milton 2011a	Dilution water not characterized
Green mussel, *Perna viridis*	Rajkumar and Milton 2011b	Dilution water not characterized
Snail, *Cerithidae cingulata* Bivalve, *Modiolus philippinarum*	Ramakritinan et al. 2012	Not North American species
Polychaete, *Nereis sp.*	Raymont and Shields 1963	Inappropriate form of toxicant (copper sodium citrate)
Crab, *Scylla serrata*	Reddy 1997	Only one exposure concentration
Green alga, *Enteromorpha compressa*	Reed and Moffat 1983	Plant study
Antarctic scallop, *Adamussium colbecki*	Regoli et al. 1997	Only one exposure concentration
Antarctic scallop, *Adamussium colbecki*	Regoli et al. 1998	Only two exposure concentrations
Coral, *Goniastrea aspera*	Reichelt-Brushett and Harrison 1999	Only three exposure concentrations
Coral, *Lobophytum compactum*	Reichelt-Brushett and Michalek-Wagner 2005	Not North American species; Lack of details (exposure duration not given)
Polychaetes	Reish 1978	Lack of details (procedure)
Amphipod, *Corophium insidiosum* Amphipod, *Elasmopus bampo*	Reish 1993	No control survival information
Polychaete, *Ctenodrilus serratus* Polychaete, *Ophryotrocha diadema*	Reish and Carr 1978	Citrate added to dilution water
Polychaetes	Reish and LeMay 1991	Dilution water not characterized
Polychaete, *Neanthes arenaceodentata* Polychaete, *Capitella capitata*	Reish et al. 1976	Citrate added to dilution water
Copepod, *Tigriopus japonicus*	Rhee et al. 2009	Not North American species
Copepod, *Tigriopus japonicus*	Rhee et al. 2013	Not North American species; Only three exposure concentrations
Eastern oyster, *Crassostrea virginica*	Ringwood et al. 1998	Only two exposure concentrations
Copepod, *Tigriopus fulvus*	Rinna et al. 2011	Not North American species

Species	**Reference**	**Reason Data Classified as Unused**
Mediterranean mussel, *Mytilus galloprovincialis* Sand dollar, *Dendraster excentricus* Purple sea urchin, *Strongylocentrotus purpuratus*	Rivera-Duarte et al. 2005	Lack of exposure details; dilution water not characterized
Amphipod, *Peramphithoe parmerong*	Roberts et al. 2006	Not North American species
Red drum, *Sciaenops ocellatus*	Robinson et al. 2013	Prior exposure to pollutant
Clam, *Chamaelea gallina*	Rodriguez-Ortega et al. 2003	Only three exposure concentrations
Sea snail, *Hexaplex* (*Murex*) *trunculus*	Romeo et al. 2006	Only three exposure concentrations
Mediterranean mussel, *Mytilus galloprovincialis* Purple sea urchin, *Strongylocentrotus purpuratus* Sand dollar, *Dendraster excentricus*	Rosen et al. 2005	Mixture
Clam, *Venerupis decussata*	Ruiz-Azcona et al. 2013	Not North American species
Bivalves	Sakellari et al. 2013	Field survey, exposure concentration not known
Various organisms	Salazar and Salazar 1986	Only three exposure concentrations
Various organisms	Salazar and Salazar 1989	Not applicable, No copper toxicity information
Brine shrimp, *Artemia salina*	Saliba and Krzyz 1976	Brine shrimp used
Blue mussel, *Mytilus edulis*	Sanchez-Marin et al. 2012	Bioaccumulation study: steady state not achieved
Purple sea urchin, *Strongylocentrus purpuratus*	Sanders and Martin 1994	Inappropriate form of toxicant (Cu-NTA)
Crab, *Rhithropanopeus harrisii*	Sanders et al. 1984	Lack of details (procedure)
Mussel, *Brachiodontes exustus*	Sastre et al. 2005	Only three exposure concentrations
Clam, *Villorita cyprinoides* var. *cochinensis*	Sathyanathan et al. 1988	Only two exposure concentrations; Not North American species
Shark, *Scyliorhinus canicula*	Sayin et al. 2012	In vitro
Coral, *Montastraea franksi*	Schwarz et al. 2013	Only three exposure concentrations
Shore crab, *Carcinus maenas*	Scott-Fordsmand and Depledge 1997	Bioaccumulation: unmeasured exposure
Crab, *Neoepisesarma mederi*	Selvakumar et al. 1987	Lack of details (procedure)
Green mussel, *Perna viridis*	Sharma et al. 2006	Only one exposure concentration
Green mussel, *Perna viridis*	Sharma et al. 2007	Only one exposure concentration
Green mussel, *Perna viridis*	Shi and Wang 2004	Prior exposure

Species	Reference	Reason Data Classified as Unused
Sea anemone, *Exaiptasia pallida*	Siddiqui et al. 2015	Only two exposure concentrations
Abalone, *Haliotis rufescens*	Silva-Aciares et al. 2013	Only two exposure concentrations
Burrowing crab, *Neohelice granulata*	Simonetti et al. 2012	Field survey, exposure concentration not known
Bivalve, *Tellina deltoidalis*	Simpson et al. 2012	Not North American species; Sediment exposure
Prawn, *Metapenaeus dobsoni*	Sivadasan et al. 1986	Not North American species; Test species fed
Clam, *Ruditapes decussatus*	Sobral and Widdows 1997	Bioaccumulation: unmeasured exposure, steady state not achieved
White shrimp, *Litopenaeus vannamei*	Soegianto et al. 2013	Only three exposure concentrations
Javelin goby, *Synechogobius hasta*	Song et al. 2013	Not North American species; Only three exposure concentrations
Javelin goby, *Synechogobius hasta*	Song et al. 2014	Not North American species
Brown alga, *Dictyota kunthii*	Sordet et al. 2014	Only one exposure concentration
Winkle, *Littorina littorea*	Soto et al. 1999	Excised tissue
Snail, *Nassarius reticulatus*	Sousa et al. 2005	Not North American species
Hydroid, *Campanularia flexuosa*	Stebbing 1981	Colony exposure
Blue mussel, *Mytilus edulis*	Steinert and Pickwell 1985	Excised tissue
Abalone, *Haliotis midae*	Stofberg et al. 2011	Not North American species; Poor control survival (≤20%)
Amphipod, *Melita plumulosa* Bivalve, *Spisula trigonella* Bivalve, *Tellina deltoidalis*	Strom et al. 2011	Sediment exposure
Brown alga, *Ascophyllum nodosum*	Stromgren 1979	Algal study
Alga, *Synechococcus*	Stuart et al. 2009	Inappropriate form of toxicant (Cu-EDTA)
Blue mussel, *Mytilus edulis*	Sturesson 1984	Bioaccumulation: unmeasured exposure
Polychaete, *Perinereis aibuhitensis*	Sun et al. 2009	Not North American species
Copepod, *Acartia tonsa*	Sunda et al. 1990	Mixture
Blue mussel, *Mytilus edulis*	Sunila 1988	Only one exposure concentration
Blue mussel, *Mytilus edulis*	Sutherland and Major 1981	Only one exposure concentration
Sea urchin, *Strongylocentrotus intermedius* Sea urchin, *Strongylocentrotus nudus*	Syasina et al. 1992	Only two exposure concentrations

Species	**Reference**	**Reason Data Classified as Unused**
Green mussel, *Perna viridis* Mussel, *Septifer virgatus*	Sze and Lee 1995	Only one exposure concentration
Pacific oyster, *Crassostrea gigas*	Tanguy et al. 2002	Only one exposure concentration
Sydney rock oyster, *Saccostrea glomerata*	Taylor et al. 2013	Only one exposure concentration
European eel, *Anguilla anguilla*	Teles et al. 2005	Only two exposure concentrations
Green mussel, *Perna viridis*	Thiagarajan et al. 2006	Only one exposure concentration
Fish	Thiyagarajan et al. 2012	Field survey, exposure concentration not known
Mummichog, *Fundulus heteroclitus*	Thomas 1915	Only one exposure concentration
Green crab, *Carcinus maenas* Rock crab, *Cancer irroratus*	Thurberg et al. 1973	Copper level high in dilution water
Blue mussel, *Mytilus edulis*	Trevisan et al. 2011	Only one exposure concentration
Shore crab, *Carcinus maenas*	Truchot and Rtal 1998	Bioaccumulation: steady state not achieved
Mussel, *Mytilus californianus* Blue mussel, *Mytilus edulis*	Tullis 1980	Only four organisms per concentration
Brine shrimp, *Artemia salina*	Umarani et al. 2012	Brine shrimp used
Crab, *Sesarma quadratum*	Valarmathi and Azariah 2002	Only two exposure concentrations
Gilthead seabream, *Sparus aurata*	Varo et al. 2007	Only three exposure concentrations
Bivalve, *Glycymeris yessoensis*	Vasil'eva et al. 1979	Bioaccumulation: unmeasured exposure
Mysid, *Mysidopsis juniae*	Vaz et al. 2011a	Lack of details (procedure); Not North American species
Mysid, *Mysidopsis juniae*	Vaz et al. 2011b	Inappropriate form of toxicant (nanoparticles); Not North American species
Babylon snail, *Babylonia areolata*	Vedamanikam and Hayimad 2014	Not North American species
Abalone, *Haliotis rufescens*	Viant et al. 2002	Only two exposure concentrations
Protozoa, *Euplotes crassus*	Viarengo et al. 1996	Protozoa
Brown mussel, *Perna perna*	Vosloo et al. 2012	Bioaccumulation study: steady state not achieved
Nematode, *Monhystera disjuncta*	Vranken et al. 1991	Agar media used
Saltmarsh cordgrass, *Spartina alterniflora*	Waddell and Kraus 1990	Terrestrial exposure
Cladoceran, Moina monogolica	Wang et al. 2007a	Dietary exposure

Species	Reference	Reason Data Classified as Unused
Abalone, *Haliotis discus hannai*	Wang et al. 2009	Not North American species
Sea urchin, *Strongylocentrotus intermedius*	Wang et al. 2011a	Not North American species; Mixture
Bivalves	Wang et al. 2011b	Field survey, exposure concentration not known
Grouper, *Epinephelus coioides*	Wang et al. 2014	Only two exposure concentration
Alga, *Aureococcus anophagefferens*	Wange et al. 2012	Algal study; Excessive EDTA in the media
Rock sea urchin, *Paracentrotus lividus*	Warnau et al. 1996	Not North American species; Dilution water not characterized
Sea urchin, *Arbacia punctulata*	Waterman 1937	Lack of details (procedure)
Mollusks	Watling 1981	Lack of exposure details; dilution water not characterized
Brown alga, *Aureococcus anophagefferens*	Wei et al. 2013	Only three exposure concentrations
Macroalga, *Ulva lactuca*	Wendt et al. 2013	Algal study
Polychaete, *Perinereis nuntia*	Won et al. 2012	Only one exposure concentration; Not North American species
Shore crab, *Carcinus maenas*	Wong and Rainbow 1986	Method paper
Soft shell clam, *Mya arenaria* Eastern oyster, *Crassostrea virginica*	Wright and Zamuda 1987	Bioaccumualtion: steady state not achieved; Chelator (NTA) added to dilution water
Green mussel, *Perna viridis*	Wu and Wang 2010	Only one exposure concentration
Prawn, *Penaeus orientalis kishinouye* Clam, *Potamocorbula laevis*	Xu and Jing 1995	Dilution water not characterized
Sea urchin, *Glyptocidaris crenularis*	Xu et al. 2010	Not North American species; Lack of exposure details
Black abalone, *Haliotis cracherodii*	Yaffe 1979	Only one exposure concentration; No true control croup
Polychaeta, *Perinereis aibuhitensis*	Yang et al. 2012	Only three exposure concentrations
Sea urchin, *Arbacia punctulata*	Young and Nelson 1974	Only one exposure concentration
Chinese prawn, *Penaeus orientalis*	Zang et al. 1993	Dilution water not characterized; Not North American species
Oyster, *Crassostrea hongkongensis*	Zhang and Zhang 2012	Not North American species
Clam, *Venerupis* (*Ruditapes*) *philippinarum*	Zhang et al. 2012	Only two exposure concentrations
Guppy, *Poecilia vivipara*	Zimmer et al. 2012	Not North American species; Only one exposure concentrations
Ornate wrasse, *Thalassoma pavo*	Zizza et al. 2014	Not North American species

Appendix G Species Numbers Used in BLM Analysis

Appendix Table G-1. Species Numbers Used in BLM Analysis.

Organism	**Species**	**Species Number**
Blue mussel	*Mytilus edulis*	1
Mussel	*Mytilus galloprovincialis*	2
Copepod	*Tigriopus californicus*	3
Summer flounder	*Paralichthys dentatus*	4
Red abalone	*Haliotis rufescens*	5
Black abalone	*Haliotis cracherodii*	6
Mysid	*Holmesimysis costata*	7
Eastern oyster	*Crassostrea virginica*	8
Pacific oyster	*Crassostrea gigas*	9
Purple sea urchin	*Strongylocentrotus purpuratus*	10
Green sea urchin	*Strongylocentrotus droebachiensis*	11
Coot clam	*Mulinia lateralis*	12
Long-spined sea urchin	*Diadema antillarum*	13
Sea urchin	*Arbacia punctulata*	14
Bay scallop	*Argopecten irradians*	15
Copepod	*Acartia tonsa*	16
Copepod	*Acartia clausi*	17
Sand dollar	*Dendraster excentricus*	18
Copepod	*Eurytemora affinis*	19
Softshell clam	*Mya arenaria*	20
Rotifer	*Brachionus plicatilis*	21
Surf clam	*Spisula solidissima*	22
Lobster	*Homarus americanus*	23
Mysid	*Neomysis mercedis*	24
Dungeness crab	*Cancer magister*	25
Polychaete	*Anaitides maculata*	26
Cabezon	*Scorpaenichthys marmoratus*	27
Inland silverside	*Menidia beryllina*	28
Tidewater silverside	*Menidia peninsulae*	29
Atlantic silverside	*Menidia menidia*	30
Sea anemone	*Aiptasia pallida*	31
Amphipod	*Elasmopus rapax*	32
Mysid	*Americamysis bigelowi*	33
Mysid	*Americamysis bahia*	34
Amphipod	*Orchomenella pinguis*	35
Polychaete	*Hydroides elegans*	36
Copepod	*Tisbe furcata*	37
Copepod	*Pseudodiaptomus coronatus*	38
Winter flounder	*Pseudopleuronectes americanus*	39
Shrimp	*Metapenaeus sp.*	40
Polychaete	*Neanthes arenaceodentata*	41
Amphipod	*Echinogammarus olivii*	42
Topsmelt	*Atherinops affinis*	43
Spot	*Leiostomus xanthurus*	44
Squid	*Loligo opalescens*	45

Organism	**Species**	**Species Number**
Striped bass	*Morone saxatilis*	46
Shrimp	*Crangon crangon*	47
Pink shrimp	*Farfantepenaeus duorarum*	48
Barnacle	*Balanus amphitrite*	49
Barnacle	*Balanus eburneus*	50
Hard clam	*Mercenaria mercenaria*	51
Coho salmon	*Oncorhynchus kisutch*	52
Sheepshead minnow	*Cyprinodon variegatus*	53
Leon Springs pupfish	*Cyprinodon bovinus*	54
Amphipod	*Allorchestes compressa*	55
Mummichog	*Fundulus heteroclitus*	56
Bristle star	*Ophionereis dubia*	57
Shiner perch	*Cymatogaster aggregata*	58
Polychaete	*Hediste diversicolor*	59
Asian green mussel	*Perna viridis*	60
Shore crab	*Carcinus maenas*	61
Pompano	*Trachinotus carolinus*	62
Tiger shrimp	*Penaeus monodon*	63
Grooved snail	*Planaxis sulcatus*	64
Whelk	*Turbo coronatus*	65
Sheepshead	*Archosargus probatocephalus*	66
Gastropod	*Crepidula convexa*	67
Gastropod	*Crepidula fornicata*	68
Isopod	*Sphaeroma serratum*	69
Polychaete	*Eurythoe complanata*	70
Copepod	*Amphiascoides atopus*	71
Decapod	*Palaemon elegans*	72
Sand crab	*Emerita analoga*	73
Thornfish	*Terapon jarbua*	74
Grass shrimp	*Palaemonetes pugio*	75
Whiteleg shrimp	*Litopenaeus vannamei*	76
Mud-skipper	*Boleophthalmus sp.*	77
Copepod	*Nitokra spinipes*	78
Pinfish	*Lagodon rhomboides*	79
Fat snook	*Centropomus parallelus*	80
Striped mullet	*Mugil cephalus*	81
Mangrove killifish	*Rivulus marmoratus*	82
Atlantic croaker	*Micropogonias undulatus*	83
Blue crab	*Callinectes sapidus*	84
Amphipod	*Gammarus duebeni*	85
Horseshoe crab	*Limulus polyphemus*	86
Gulf toadfish	*Opsanus beta*	87
Clam	*Rangia cuneata*	88
Amphipod	*Corophium volutator*	89

Appendix H Water Chemistry Used in BLM Analysis

Normalizing the toxicity data with the marine BLM requires four water chemistry parameters in seawater: salinity, pH, DOC, and temperature. The marine BLM calculation uses all the same ions that are needed in the freshwater BLM (i.e., Ca, Mg, Na, K, SO_4, Cl, and alkalinity), but these ion concentrations are calculated from salinity with the assumption that ion composition of marine waters is constant. To normalize the toxicity data included in this document the complete BLM chemistry for each reported value is needed. If any of the four marine BLM parameters were missing from the data source, values for the missing parameters were estimated.

Several strategies were used to in the process for determining suitable estimates for missing parameters.

1. If the missing data were from a natural water body and other data were reported for the same or similar location, then an average value from the reported values was used as an estimate for missing values. Similarly, if the missing data were from a study in artificial seawater and other studies reported chemistry for the same type of artificial seawater, then an average value from the reported chemistry was used to estimate missing values.

2. For DOC in artificial seawaters, the reported DOC concentrations in Arnold et al. (2007) were used for any test conducted in either Instant Ocean or Tropic Marine salts.

3. If there were no other data for a location or artificial water, or the location was not given, then default values were used. These values were 30 ppt of salinity, pH of 7.8, 2.00 mg C/L of DOC, and a temperature of 20°C. These values were chosen based on the typical composition of seawater, and the average conditions reported in other toxicity tests.

Appendix Table H-1. Water Chemistry Used in BLM Analysis.

BLM Data Label	Genus	Reported chemistry					Reported plus assumed chemistry[a]			
		Source water type	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C
1	Acartia		30				30.00	7.80	2.00	20.00
2	Acartia	Artificial saltwater	30			10	30.00	7.80	2.00	10.00
4	Acartia	Natural saltwater (location not given)	10				10.00	7.80	2.00	20.00
5	Acartia	Natural saltwater (location not given)	10				10.00	7.80	2.00	20.00
6	Acartia	Natural saltwater (location not given)	30				30.00	7.80	2.00	20.00
7	Acartia	Natural saltwater (location not given)	30			20	30.00	7.80	2.00	20.00
12	Aiptasia	Natural seawater, filtered (SW; Whitney Laboratory)	35.00			23.00	35.00	7.80	2.00	23.00
14	Allorchestes	Natural saltwater (location not given)	34.1	7.8		20.3	34.10	7.80	2.00	20.30
16	Americamysis	Natural saltwater (location not given)	30			22.5	30.00	7.80	2.00	22.50
17	Americamysis	Natural saltwater (Narragansett Bay, Narragansett, RI)	31	7.755		20	31.00	7.76	1.45	20.00
18	Americamysis	Natural saltwater (Santa Rosa Sound, FL)	25	7.95		25	25.00	7.95	2.00	25.00
19	Americamysis	Natural saltwater (Narragansett Bay, RI)	30	7		20	30.00	7.00	1.45	20.00
20	Americamysis	Natural saltwater (Narragansett Bay, RI)	30	8		20	30.00	8.00	1.45	20.00
21	Americamysis	Natural saltwater (Narragansett Bay, RI)	30	9		20	30.00	9.00	1.45	20.00
23	Americamysis		30				30.00	7.80	2.00	20.00
30	Archosargus	Artificial saltwater (Sea Lakes Systems, Euclid, OH)	30			22	30.00	7.80	2.00	22.00
32	Argopecten	Natural saltwater (location not given)	25	7.2		20	25.00	7.20	2.00	20.00
36	Atherinops	Natural saltwater (Granite Canyon, Monterey County, CA)	35	7.8		21	35.00	7.80	1.74	21.00
37	Atherinops	Natural saltwater (Granite Canyon, Monterey County, CA)	35	7.8		21	35.00	7.80	1.74	21.00
38	Atherinops	Natural saltwater (Granite Canyon, Monterey County, CA)	35	7.8		21	35.00	7.80	1.74	21.00
44	Balanus	Artificial saltwater	34			24	34.00	7.80	2.00	24.00
45	Balanus	Artificial saltwater	34			24	34.00	7.80	2.00	24.00
46	Balanus	Artificial saltwater	34			24	34.00	7.80	2.00	24.00
48	Boleophthalmus	Natural saltwater (location not given)	37.54	7.92		20	37.54	7.92	2.00	20.00
50	Brachionus	Artificial saltwater (Instant Ocean®)	15	7.45	<1.0	25	15.00	7.45	1.00	25.00
51	Brachionus	Artificial saltwater (Instant Ocean®)	15	7.45	<1.0	25	15.00	7.45	1.00	25.00
53	Brachionus	Artificial saltwater (Instant Ocean®)	6	7.6	<0.5	25.05	6.00	7.60	0.50	25.05
54	Brachionus	Artificial saltwater (Instant Ocean®)	11	7.6	<0.5	25.05	11.00	7.60	0.50	25.05
55	Brachionus	Artificial saltwater (Instant Ocean®)	15	7.8	<0.5	25.05	15.00	7.80	0.50	25.05
56	Brachionus	Artificial saltwater (Instant Ocean®)	24	7.9	<0.5	25.05	24.00	7.90	0.50	25.05
57	Brachionus	Artificial saltwater (Instant Ocean®)	29	7.9	<0.5	25.05	29.00	7.90	0.50	25.05
58	Brachionus	Natural saltwater (Little Egg Harbor, NJ)	7	6.8	4.1	25.05	7.00	6.80	4.10	25.05
59	Brachionus	Natural saltwater (Little Egg Harbor, NJ)	7	8.3	4	25.05	7.00	8.30	4.00	25.05
60	Brachionus	Natural saltwater (Little Egg Harbor, NJ)	13	7.6	1.7	25.05	13.00	7.60	1.70	25.05
61	Brachionus	Natural saltwater (Little Egg Harbor, NJ)	13	8.6	1.7	25.05	13.00	8.60	1.70	25.05
65	Callinectes	Natural saltwater (Cassino Beach, Rio Grande, Brazil)	2.00	7.12	0.41	20.10	2.00	7.12	0.41	20.10
66	Callinectes	Natural saltwater (Cassino Beach, Rio Grande, Brazil)	30	7.28	5.20	20.30	30.00	7.28	5.20	20.30

BLM Data Label	Genus	Reported chemistry					Reported plus assumed chemistry[a]			
		Source water type	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C
68	Cancer	Natural saltwater (Big Sur, Monterey County, CA)	33.79	8.1		15	33.79	8.10	2.00	15.00
69	Cancer	Natural saltwater (Puget Sound at West Point, Seattle, WA)	30	8.1		8.5	30.00	8.10	1.46	8.50
71	Carcinus	Natural saltwater (location not given)				15	30.00	7.80	2.00	15.00
79	Corophium	Natural saltwater (Ythan estuary, Aberdeenshire, Scotland)	32	7.2		11	32.00	7.20	2.00	11.00
85	Crangon	Natural saltwater (location not given)				15	30.00	7.80	2.00	15.00
88	Crassostrea	Natural seawater, unfiltered	33	8		13	33.00	7.80	2.00	20.00
89	Crassostrea	Natural saltwater (Monterey, CA)	33	8.2		20	33.00	8.20	2.00	20.00
90	Crassostrea	Natural saltwater (Bodega Bay, CA)	30	7.6	1.68 (TOC)	20	30.00	7.60	1.68	20.00
93	Crassostrea	Natural saltwater (Bodega Bay, CA)	30	7.6		20	30.00	7.60	0.89	20.00
94	Crassostrea	Natural saltwater (Big Sur, Monterey County, CA)	33.79	8.1		20	33.79	8.10	2.00	20.00
96	Crassostrea	Natural saltwater (U.C. Marine Laboratory, Bodega Bay, CA)	30		<0.5	16	30.00	7.60	0.50	16.00
97	Crassostrea	Natural saltwater (U.C. Marine Laboratory, Bodega Bay, CA)	30		<0.5	16	30.00	7.60	0.50	16.00
106	Crassostrea	Natural saltwater (location not given)	26	7.7		20	26.00	7.70	2.00	20.00
107	Crassostrea	Natural saltwater (location not given)	26	7.7		25	26.00	7.70	2.00	25.00
108	Crassostrea	Natural saltwater (location not given)	26	7.7		30	26.00	7.70	2.00	30.00
109	Crassostrea	Natural and Artificial saltwater	29.8	7.75	0.8	25	29.80	7.75	0.80	25.00
110	Crassostrea	Natural and Artificial saltwater	29.6	7.82	2.6	25	29.60	7.82	2.60	25.00
111	Crassostrea	Natural and Artificial saltwater	29.7	7.92	3.9	25	29.70	7.92	3.90	25.00
112	Crassostrea	Natural and Artificial saltwater	29.6	7.97	5.7	25	29.60	7.97	5.70	25.00
114	Crepidula	Artificial saltwater (Instant Ocean)	30			20	30.00	7.43	0.20	20.00
116	Crepidula	Artificial saltwater (Instant Ocean)	30			20	30.00	7.43	0.20	20.00
118	Cymatogaster	Natural saltwater (Puget Sound at West Point, Seattle, WA)	29.5	7.8		13.2	29.50	7.80	1.46	13.20
120	Cyprinodon	Natural saltwater (ERLN, Narragansett, RI)	30			25	30.00	7.92	1.45	25.00
125	Dendraster	Natural saltwater (Puget Sound at West Point, Seattle, WA)	30	8.5		12.75	30.00	8.50	1.46	12.75
129	Dendraster	Natural and Artificial saltwater	32	7.85	1.2	15	32.00	7.85	1.20	15.00
130	Dendraster	Natural and Artificial saltwater	32	7.84	2.1	15	32.00	7.84	2.10	15.00
131	Dendraster	Natural and Artificial saltwater	32	7.88	3.5	15	32.00	7.88	3.50	15.00
132	Dendraster	Natural and Artificial saltwater	32	7.89	5	15	32.00	7.89	5.00	15.00
134	Diadema	Natural saltwater	33				33.00	7.80	2.00	20.00
137	Echinogammarus	Natural saltwater (location not given)	17	8.1		15	17.00	8.10	2.00	15.00
141	Elasmopus	Artificial saltwater (Tropic Marine)	33	8.25		25	33.00	8.25	0.60	25.00
142	Elasmopus	Artificial seawater (FAS; sea salt: Tropic Marine, Germany)	33.00	8.25		25.00	33.00	8.25	0.60	25.00
144	Emerita	Natural saltwater (Pingueral Beach, Concepcion, Chile)	30	7.9		15	30.00	7.90	2.00	15.00
151	Eurytemora		30				30.00	7.80	2.00	20.00
152	Eurytemora	Artificial saltwater	30			20	30.00	7.80	2.00	20.00
153	Eurytemora	Natural saltwater (location not given)					30.00	7.80	2.00	20.00
154	Eurytemora	Natural saltwater (location not given)					30.00	7.80	2.00	20.00
155	Eurytemora	Natural saltwater (location not given)					30.00	7.80	2.00	20.00

BLM Data Label	Genus	Reported chemistry					Reported plus assumed chemistry[a]			
		Source water type	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C
156	Eurytemora	Natural saltwater (location not given)					30.00	7.80	2.00	20.00
157	Eurytemora	Natural saltwater (location not given)					30.00	7.80	2.00	20.00
158	Eurytemora	Natural estuarine water (Choptank River, Cambridge, MA)	15.5	8.35		24.55	15.50	8.35	3.63	24.55
161	Eurytemora	Natural estuarine water (Choptank River, Cambridge, MA)	2.5	7.95	3.31	25	2.50	7.95	3.31	25.00
162	Eurytemora	Natural estuarine water (Choptank River, Cambridge, MA)	5	8.28	2.39	25	5.00	8.28	2.39	25.00
163	Eurytemora	Natural estuarine water (Choptank River, Cambridge, MA)	15	8.38	1.68	25	15.00	8.38	1.68	25.00
164	Eurytemora	Natural estuarine water (Choptank River, Cambridge, MA)	25	8.09	1.34	25	25.00	8.09	1.34	25.00
165	Eurytemora	Natural estuarine water (Choptank River, Cambridge, MA)	10	8.1	2.48	25	10.00	8.10	2.48	25.00
166	Eurytemora	Natural estuarine water (Choptank River, Cambridge, MA)	10	8.17	3.8	25	10.00	8.17	3.80	25.00
167	Eurytemora	Natural estuarine water (Choptank River, Cambridge, MA)	10	8.17	5.6	25	10.00	8.17	5.60	25.00
168	Eurytemora	Natural estuarine water (Choptank River, Cambridge, MA)	10	7.94	8.47	25	10.00	7.94	8.47	25.00
170	Eurythoe	Natural saltwater (location not given)	36	7.8			36.00	7.80	2.00	20.00
172	Fundulus	Natural saltwater (Horseshoe Cove or Asbury Park, NJ)	5.5			20	5.50	7.80	2.00	20.00
173	Fundulus	Natural saltwater (Horseshoe Cove or Asbury Park, NJ)	23.6			20	23.60	7.80	2.00	20.00
174	Fundulus	Natural saltwater (Horseshoe Cove or Asbury Park, NJ)	6.1			20	6.10	7.80	2.00	20.00
175	Fundulus	Natural saltwater (Horseshoe Cove or Asbury Park, NJ)	24			20	24.00	7.80	2.00	20.00
176	Fundulus	Artificial saltwater (Instant Ocean TM)	14			26.5	14.00	7.43	0.20	26.50
178	Fundulus	Natural saltwater (Bear Cut, FL)	2.5	7.67	2.497	25	2.50	7.67	2.50	25.00
179	Fundulus	Natural saltwater (Bear Cut, FL)	5	7.72	2.33	25	5.00	7.72	2.33	25.00
180	Fundulus	Natural saltwater (Bear Cut, FL)	10	7.74	2.395	25	10.00	7.74	2.40	25.00
181	Fundulus	Natural saltwater (Bear Cut, FL)	15	7.88	2.588	25	15.00	7.88	2.59	25.00
182	Fundulus	Natural saltwater (Bear Cut, FL)	22	7.96	2.438	25	22.00	7.96	2.44	25.00
183	Fundulus	Natural saltwater (Bear Cut, FL)	35	8.07	2.308	25	35.00	8.07	2.31	25.00
185	Gammarus	Natural saltwater (location not given)	33	7.5		15	33.00	7.50	2.00	15.00
187	Haliotis	Natural saltwater (location not given)	33			14	33.00	7.80	2.00	14.00
189	Haliotis	Natural saltwater (location not given)	33			14	33.00	7.80	2.00	14.00
190	Haliotis	Natural saltwater (location not given)	30.4	8		13	30.40	8.00	2.00	13.00
191	Haliotis	Natural saltwater (location not given)	34.5	7.875		14.75	34.50	7.88	2.00	14.75
193	Hediste	Natural saltwater (location not given)	5			7	5.00	7.80	2.00	7.00
194	Hediste	Natural saltwater (location not given)	10			7	10.00	7.80	2.00	7.00
195	Hediste	Natural saltwater (location not given)	17.5			7	17.50	7.80	2.00	7.00
196	Hediste	Natural saltwater (location not given)	34			7	34.00	7.80	2.00	7.00
197	Hediste	Natural saltwater (location not given)	7.3			12	7.30	7.80	2.00	12.00
198	Hediste	Natural saltwater (location not given)	7.3			17	7.30	7.80	2.00	17.00
199	Hediste	Natural saltwater (location not given)	7.3			22	7.30	7.80	2.00	22.00
200	Hediste	Natural saltwater (location not given)	14.6			12	14.60	7.80	2.00	12.00
201	Hediste	Natural saltwater (location not given)	14.6			17	14.60	7.80	2.00	17.00
202	Hediste	Natural saltwater (location not given)	14.6			22	14.60	7.80	2.00	22.00
203	Hediste	Natural saltwater (location not given)	21.9			12	21.90	7.80	2.00	12.00

BLM Data Label	Genus	Reported chemistry					Reported plus assumed chemistry[a]			
		Source water type	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C
204	Hediste	Natural saltwater (location not given)	21.9			17	21.90	7.80	2.00	17.00
205	Hediste	Natural saltwater (location not given)	21.9			22	21.90	7.80	2.00	22.00
206	Hediste	Natural saltwater (location not given)	29.2			12	29.20	7.80	2.00	12.00
207	Hediste	Natural saltwater (location not given)	29.2			17	29.20	7.80	2.00	17.00
208	Hediste	Natural saltwater (location not given)	29.2			22	29.20	7.80	2.00	22.00
209	Hediste	Natural saltwater (location not given)	7.6			12	7.60	7.80	2.00	12.00
210	Hediste	Natural saltwater (location not given)	7.6			17	7.60	7.80	2.00	17.00
211	Hediste	Natural saltwater (location not given)	7.6			22	7.60	7.80	2.00	22.00
212	Hediste	Natural saltwater (location not given)	15.25			12	15.25	7.80	2.00	12.00
213	Hediste	Natural saltwater (location not given)	15.25			17	15.25	7.80	2.00	17.00
214	Hediste	Natural saltwater (location not given)	15.25			22	15.25	7.80	2.00	22.00
215	Hediste	Natural saltwater (location not given)	22.8			12	22.80	7.80	2.00	12.00
216	Hediste	Natural saltwater (location not given)	22.8			17	22.80	7.80	2.00	17.00
217	Hediste	Natural saltwater (location not given)	22.8			22	22.80	7.80	2.00	22.00
218	Hediste	Natural saltwater (location not given)	30.5			12	30.50	7.80	2.00	12.00
219	Hediste	Natural saltwater (location not given)	30.5			17	30.50	7.80	2.00	17.00
220	Hediste	Natural saltwater (location not given)	30.5			22	30.50	7.80	2.00	22.00
221	Hediste	Artificial saltwater (Tropic Marin Neu)	16.3			10	16.30	8.25	0.60	10.00
223	Holmesimysis	Natural saltwater (location not given)	37	7.8		14	37.00	7.80	2.00	14.00
224	Holmesimysis	Natural saltwater (Big Sur, Monterey County, CA)	36.5	7.8		13	36.50	7.80	2.00	13.00
226	Homarus	Natural seawater (Narragansett Bay, RI)	30.5			20	30.50	7.92	1.45	20.00
230	Hydroides	Artificial seawater (FAS; sea salt: Tropic Marine, Germany)	33.00	8.25		25.00	33.00	8.25	0.60	25.00
234	Lagodon	Artificial saltwater (Sea Lakes Systems, Euclid, OH)	30			22	30.00	7.80	2.00	22.00
236	Leiostomus	Natural saltwater (location not given)	20			25	20.00	7.80	2.00	25.00
237	Leiostomus	Natural saltwater (location not given)	20			25.15	20.00	7.80	2.00	25.15
239	Litopenaeus	Natural saltwater (Mazatlan Bay, Mexico)	34	8.05		27.2	34.00	8.05	2.00	27.20
243	Loligo	Natural saltwater (Puget Sound at West Point, Seattle, WA)	30	8.1		8.6	30.00	8.10	1.46	8.60
262	Menidia	Artificial saltwater	27.5	8.05		24.9	27.50	8.05	2.00	24.90
263	Menidia	Artificial saltwater	28	8.125		24.45	28.00	8.13	2.00	24.45
264	Menidia	Artificial saltwater	29	8.03		24.4	29.00	8.03	2.00	24.40
266	Menidia	Natural saltwater (ERL, Narragansett, RI)	31			19	31.00	7.92	1.45	19.00
267	Menidia	Natural saltwater (ERL, Narragansett, RI)	30.4			18.5	30.40	7.92	1.45	18.50
268	Menidia	Natural saltwater (ERL, Narragansett, RI)	31			20	31.00	7.92	1.45	20.00
269	Menidia	Natural saltwater (ERL, Narragansett, RI)	30			20	30.00	7.92	1.45	20.00
271	Menidia	Natural saltwater (location not given)	20			25	20.00	7.80	2.00	25.00
272	Menidia	Natural saltwater (location not given)	20			25.25	20.00	7.80	2.00	25.25
274	Mercenaria	Natural saltwater (location not given)					30.00	7.80	2.00	20.00
276	Metapenaeus	Natural saltwater (location not given)	38	7.81		28	38.00	7.81	2.00	28.00
278	Micropogonias	Artificial saltwater (Sea Lakes Systems, Euclid, OH)	30			22	30.00	7.80	2.00	22.00

BLM Data Label	Genus	Reported chemistry					Reported plus assumed chemistry[a]			
		Source water type	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C
280	Morone	Natural saltwater (location not given)	10	7.1		22	10.00	7.10	2.00	22.00
281	Morone	Artificial saltwater (Instant Ocean)	5	7.9		20	5.00	7.90	0.20	20.00
282	Morone	Artificial saltwater (Rila® Marine mix)	5	8.5		26	5.00	8.50	2.00	26.00
283	Morone	Artificial saltwater (Rila® Marine mix)	10	8.4		26	10.00	8.40	2.00	26.00
284	Morone	Artificial saltwater (Rila® Marine mix)	15	7.8		26	15.00	7.80	2.00	26.00
286	Mulinia	Natural saltwater (Narragansett Bay, Narragansett, RI)	31	7.755		20	31.00	7.76	1.45	20.00
287	Mulinia	Natural saltwater (Narragansett Bay, Narragansett, RI)	29	8.03		20	29.00	8.03	1.45	20.00
288	Mulinia	Natural saltwater (Narragansett Bay, Narragansett, RI)	30	8.035		20	30.00	8.04	1.45	20.00
289	Mulinia	Natural saltwater (Narragansett Bay, Narragansett, RI)	32	8.035		20	32.00	8.04	1.45	20.00
290	Mulinia	Natural saltwater (Narragansett Bay, Narragansett, RI)	30.5	8.04		20	30.50	8.04	1.45	20.00
291	Mulinia	Natural saltwater (Narragansett Bay, Narragansett, RI)	31.5	8.045		20	31.50	8.05	1.45	20.00
293	Mya	Natural saltwater (Narragansett, RI)	30	7.95		22	30.00	7.95	1.45	22.00
295	Mytilus	Natural saltwater (Calleguas Creek 1, Ventura County, CA)	30		5.1		30.00	7.80	5.10	20.00
296	Mytilus	Natural saltwater (Calleguas Creek 1, Ventura County, CA)	30		8.6		30.00	7.80	8.60	20.00
297	Mytilus	Natural saltwater (Calleguas Creek 1, Ventura County, CA)	30		9.7		30.00	7.80	9.70	20.00
298	Mytilus	Natural saltwater (Calleguas Creek 2, Ventura County, CA)	30		4.8		30.00	7.80	4.80	20.00
299	Mytilus	Natural saltwater (Calleguas Creek 2, Ventura County, CA)	30		6.6		30.00	7.80	6.60	20.00
300	Mytilus	Natural saltwater (Calleguas Creek 2, Ventura County, CA)	30		10		30.00	7.80	10.00	20.00
301	Mytilus	Natural saltwater (Mugu Lagoon 3, Ventura County, CA)	30		1.5		30.00	7.80	1.50	20.00
302	Mytilus	Natural saltwater (Mugu Lagoon 3, Ventura County, CA)	30		7.3		30.00	7.80	7.30	20.00
303	Mytilus	Natural saltwater (Mugu Lagoon 3, Ventura County, CA)	30		11		30.00	7.80	11.00	20.00
304	Mytilus	Natural saltwater (Mugu Lagoon 4, Ventura County, CA)	30		1.4		30.00	7.80	1.40	20.00
305	Mytilus	Natural saltwater (Mugu Lagoon 4, Ventura County, CA)	30		6.2		30.00	7.80	6.20	20.00
306	Mytilus	Natural saltwater (Mugu Lagoon 5, Ventura County, CA)	30		2		30.00	7.80	2.00	20.00
307	Mytilus	Natural saltwater (Mugu Lagoon 5, Ventura County, CA)	30		4.7		30.00	7.80	4.70	20.00
308	Mytilus	Natural saltwater (Mugu Lagoon 5, Ventura County, CA)	30		12		30.00	7.80	12.00	20.00
309	Mytilus	Natural saltwater (Mugu Lagoon 6, Ventura County, CA)	30		1.7		30.00	7.80	1.70	20.00
310	Mytilus	Natural saltwater (Mugu Lagoon 6, Ventura County, CA)	30		3.4		30.00	7.80	3.40	20.00
311	Mytilus	Natural saltwater (Mugu Lagoon 6, Ventura County, CA)	30		9.9		30.00	7.80	9.90	20.00
312	Mytilus	Natural saltwater (Granite Canyon, Ventura County, CA)	30		1		30.00	7.99	1.00	15.70
313	Mytilus	Natural saltwater (Granite Canyon, Ventura County, CA)	30		1.2		30.00	7.99	1.20	15.70
314	Mytilus	Natural saltwater (Granite Canyon, Ventura County, CA)	30		2.9		30.00	7.99	2.90	15.70
315	Mytilus	Natural saltwater (Granite Canyon, Ventura County, CA)	30		3.2		30.00	7.99	3.20	15.70
316	Mytilus	Artificial saltwater (Crystal Sea Marinemix)	30		5.9		30.00	7.80	5.90	20.00
317	Mytilus	Artificial saltwater (HW Marinemix)	30		0.4		30.00	7.80	0.40	20.00
318	Mytilus	Artificial saltwater (General-Purpose salt)	30		0.1		30.00	7.80	0.10	20.00
319	Mytilus	Artificial saltwater (Kent Marine)	30.6	8.17	1.087	18	30.60	8.17	1.09	18.00
320	Mytilus	Natural saltwater (Chesapeake Bay)	29.9	8.1	3.606	18	29.90	8.10	3.61	18.00
321	Mytilus	Natural saltwater (San Diego Bay)	29.9	8.02	2.326	18	29.90	8.02	2.33	18.00

BLM Data Label	Genus	Reported chemistry					Reported plus assumed chemistry[a]			
		Source water type	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C
322	Mytilus	Natural saltwater (Tomales Bay)	30.2	7.8	3.374	18	30.20	7.80	3.37	18.00
323	Mytilus	Natural saltwater (Puget Sound)	29.5	7.52	1.88	18	29.50	7.52	1.88	18.00
324	Mytilus	Natural saltwater (Coal Harbour)	30.2	7.44	3.327	18	30.20	7.44	3.33	18.00
325	Mytilus	Natural saltwater (Arthur Kill)	29.9	7.78	6.936	18	29.90	7.78	6.94	18.00
326	Mytilus	Natural saltwater (Potomac River)	29.9	8.02	3.183	18	29.90	8.02	3.18	18.00
327	Mytilus	Natural saltwater (Halifax Harbour)	29.9	7.65	1.619	18	29.90	7.65	1.62	18.00
328	Mytilus	Natural saltwater (Albemarle Sound)	30.2	7.58	6.934	18	30.20	7.58	6.93	18.00
331	Mytilus	Natural saltwater (Big Sur, Monterey County, CA)	33.79	8.1		17	33.79	8.10	2.00	17.00
333	Mytilus	Natural saltwater (location not given)	25	6.9 - 7.5		20	25.00	7.20	2.00	20.00
334	Mytilus	Artificial saltwater	27.5	8.05		24.9	27.50	8.05	2.00	24.90
335	Mytilus	Artificial saltwater	28	8.125		24.45	28.00	8.13	2.00	24.45
336	Mytilus	Artificial saltwater	29	8.03		24.4	29.00	8.03	2.00	24.40
337	Mytilus	Natural saltwater (Narragansett Bay, Narragansett, RI)	30.5	8.025		20	30.50	8.03	1.45	20.00
338	Mytilus	Natural saltwater (Narragansett Bay, Narragansett, RI)	31.5	8.5		20	31.50	8.50	1.45	20.00
339	Mytilus	Natural saltwater (Narragansett Bay, Narragansett, RI)	31.5	8.075		20	31.50	8.08	1.45	20.00
340	Mytilus	Natural saltwater (Narragansett Bay, Narragansett, RI)	31.5	8.05		20	31.50	8.05	1.45	20.00
341	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8.1		15.25	28.00	8.10	1.74	15.25
342	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8.05		15.45	28.00	8.05	1.74	15.45
343	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8.2		15.05	28.00	8.20	1.74	15.05
344	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8.2		15	28.00	8.20	1.74	15.00
345	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8.05		15.15	28.00	8.05	1.74	15.15
346	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8.15		14.9	28.00	8.15	1.74	14.90
347	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8.15		15.4	28.00	8.15	1.74	15.40
348	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8		15.7	28.00	8.00	1.74	15.70
349	Mytilus	Natural saltwater (Granite Canyon, CA)	28	7.85		15.4	28.00	7.85	1.74	15.40
350	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8		15.45	28.00	8.00	1.74	15.45
351	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8.1		15.15	28.00	8.10	1.74	15.15
352	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8.2		15.05	28.00	8.20	1.74	15.05
353	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8.05		15	28.00	8.05	1.74	15.00
354	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8.05		15.2	28.00	8.05	1.74	15.20
355	Mytilus	Natural saltwater (Granite Canyon, CA)	27.9	8.05		14.85	27.90	8.05	1.74	14.85
356	Mytilus	Natural saltwater (Granite Canyon, CA)	27.5	7.85		15.6	27.50	7.85	1.74	15.60
357	Mytilus	Natural saltwater (Granite Canyon, CA)	27.5	7.85		15.45	27.50	7.85	1.74	15.45
358	Mytilus	Natural saltwater (Granite Canyon, CA)	28	7.85		14.95	28.00	7.85	1.74	14.95
359	Mytilus	Natural saltwater (Granite Canyon, CA)	28	7.95		15.1	28.00	7.95	1.74	15.10
360	Mytilus	Natural saltwater (Granite Canyon, CA)	28.75	7.9		14.85	28.75	7.90	1.74	14.85
361	Mytilus	Natural saltwater (Granite Canyon, CA)	28	7.75		15.35	28.00	7.75	1.74	15.35
362	Mytilus	Natural saltwater (Granite Canyon, CA)	28	7.95		15.3	28.00	7.95	1.74	15.30
363	Mytilus	Natural saltwater (Granite Canyon, CA)	28	8.15		14.8	28.00	8.15	1.74	14.80

BLM Data Label	Genus	Reported chemistry					Reported plus assumed chemistry[a]			
		Source water type	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C
364	Mytilus	Natural saltwater (Granite Canyon, CA)	34	8.2		14.55	34.00	8.20	1.74	14.55
365	Mytilus	Natural saltwater (Granite Canyon, CA)	34	8.25		14.55	34.00	8.25	1.74	14.55
366	Mytilus	Natural diluted saltwater (Narragansett, RI)	20	7.85		16	20.00	7.85	1.45	16.00
367	Mytilus	Natural diluted saltwater (Narragansett, RI)	20	7.85		16	20.00	7.85	1.45	16.00
368	Mytilus	Natural diluted saltwater (Narragansett, RI)	20	7.85		16	20.00	7.85	1.45	16.00
369	Mytilus	Natural saltwater (Granite Canyon Marine Lab., Carmel, CA)	30	7.82	0.5		30.00	7.82	0.50	15.70
370	Mytilus	Natural saltwater (Granite Canyon Marine Lab., Carmel, CA)	30	7.82	0.9		30.00	7.82	0.90	15.70
371	Mytilus	Natural saltwater (South San Francisco Bay, San Francisco, CA)	30	7.95	5.1		30.00	7.95	5.10	20.00
372	Mytilus	Natural saltwater (South San Francisco Bay, San Francisco, CA)	30	7.95	5.2		30.00	7.95	5.20	20.00
373	Mytilus	Natural saltwater (Granite Canyon and San Francisco Bay water)	30	7.91	2		30.00	7.91	2.00	15.70
374	Mytilus	Natural saltwater (Granite Canyon and San Francisco Bay water)	30	7.91	2.2		30.00	7.91	2.20	15.70
375	Mytilus	Natural saltwater (Granite Canyon and San Francisco Bay water)	30	7.98	3.5		30.00	7.98	3.50	15.70
376	Mytilus	Natural saltwater (Granite Canyon and San Francisco Bay water)	30	7.98	3.8		30.00	7.98	3.80	15.70
380	Mytilus	Natural saltwater (Granite Canyon, CA)	30		<1.5		30.00	7.99	1.50	15.70
381	Mytilus	Natural saltwater (Granite Canyon, CA)	30		<1.5		30.00	7.99	1.50	15.70
382	Mytilus	Natural saltwater (Granite Canyon, CA)	30		0.6		30.00	7.99	0.60	15.70
383	Mytilus	Natural saltwater (Granite Canyon, CA)	30		0.6		30.00	7.99	0.60	15.70
384	Mytilus	Natural saltwater (Granite Canyon, CA)	30		1		30.00	7.99	1.00	15.70
385	Mytilus	Natural saltwater (Granite Canyon, CA)	30		1.2		30.00	7.99	1.20	15.70
386	Mytilus	Natural saltwater (Granite Canyon, CA)	30		High		30.00	7.99	2.00	15.70
387	Mytilus	Natural saltwater (Granite Canyon, CA)	30		0.3		30.00	7.99	0.30	15.70
388	Mytilus	Natural saltwater (Granite Canyon, CA)	30		0.7		30.00	7.99	0.70	15.70
389	Mytilus	Natural saltwater (Redwood Creek, San Francisco, CA)	30		2.6		30.00	7.95	2.60	20.00
390	Mytilus	Natural saltwater (Redwood Creek, San Francisco, CA)	30		3.2		30.00	7.95	3.20	20.00
391	Mytilus	Natural saltwater (Redwood Creek, San Francisco, CA)	30		2.3		30.00	7.95	2.30	20.00
392	Mytilus	Natural saltwater (Redwood Creek, San Francisco, CA)	30		Low		30.00	7.95	1.00	20.00
393	Mytilus	Natural saltwater (San Bruno, San Francisco, CA)	30		<1.5		30.00	7.95	1.50	20.00
394	Mytilus	Natural saltwater (San Bruno, San Francisco, CA)	30		2.1		30.00	7.95	2.10	20.00
395	Mytilus	Natural saltwater (San Bruno, San Francisco, CA)	30		2.2		30.00	7.95	2.20	20.00
396	Mytilus	Natural saltwater (San Bruno, San Francisco, CA)	30		Low		30.00	7.95	1.00	20.00
397	Mytilus	Natural saltwater (Central Bay-midpoint, San Francisco, CA)	30		2		30.00	7.95	2.00	20.00
398	Mytilus	Natural saltwater (Central Bay-midpoint, San Francisco, CA)	30		3.2		30.00	7.95	3.20	20.00
399	Mytilus	Natural saltwater (Central Bay-midpoint, San Francisco, CA)	30		2.6		30.00	7.95	2.60	20.00
400	Mytilus	Natural saltwater (Central Bay-midpoint, San Francisco, CA)	30		3.5		30.00	7.95	3.50	20.00
401	Mytilus	Natural saltwater (Central Bay-nearshore, San Francisco, CA)	30		4.6		30.00	7.95	4.60	20.00
402	Mytilus	Natural saltwater (Central Bay-nearshore, San Francisco, CA)	30		3.3		30.00	7.95	3.30	20.00
403	Mytilus	Natural saltwater (Central Bay-nearshore, San Francisco, CA)	30		2.4		30.00	7.95	2.40	20.00
404	Mytilus	Natural saltwater (Central Bay-nearshore, San Francisco, CA)	30		Low		30.00	7.95	1.00	20.00
405	Mytilus	Natural saltwater (Oyster Point, San Francisco, CA)	30		<1.5		30.00	7.95	1.50	20.00

BLM Data Label	Genus	Reported chemistry					Reported plus assumed chemistry[a]			
		Source water type	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C
406	Mytilus	Natural saltwater (Oyster Point, San Francisco, CA)	30		2.2		30.00	7.95	2.20	20.00
407	Mytilus	Natural saltwater (Oyster Point, San Francisco, CA)	30		1.9		30.00	7.95	1.90	20.00
408	Mytilus	Natural saltwater (Oyster Point, San Francisco, CA)	30		Low		30.00	7.95	1.00	20.00
409	Mytilus	Natural saltwater (Yerba Beuna Island, San Francisco, CA)	30		<1.5		30.00	7.95	1.50	20.00
410	Mytilus	Natural saltwater (Yerba Beuna Island, San Francisco, CA)	30		1.7		30.00	7.95	1.70	20.00
411	Mytilus	Natural saltwater (Yerba Beuna Island, San Francisco, CA)	30		1.7		30.00	7.95	1.70	20.00
412	Mytilus	Natural saltwater (Yerba Beuna Island, San Francisco, CA)	30		Low		30.00	7.95	1.00	20.00
413	Mytilus	Natural saltwater (San Pablo Bay, San Francisco, CA)	30		2.1		30.00	7.95	2.10	20.00
414	Mytilus	Natural saltwater (San Pablo Bay, San Francisco, CA)	30		4.9		30.00	7.95	4.90	20.00
415	Mytilus	Natural saltwater (San Pablo Bay, San Francisco, CA)	30		2.1		30.00	7.95	2.10	20.00
416	Mytilus	Natural saltwater (San Pablo Bay, San Francisco, CA)	30		1.8		30.00	7.95	1.80	20.00
417	Mytilus	Natural saltwater (San Pablo Bay B15-B20, San Francisco, CA)	30		1.5		30.00	7.95	1.50	20.00
418	Mytilus	Natural saltwater (San Pablo Bay B15-B20, San Francisco, CA)	30		8.1		30.00	7.95	8.10	20.00
419	Mytilus	Natural saltwater (San Pablo Bay B15-B20, San Francisco, CA)	30		2.8		30.00	7.95	2.80	20.00
420	Mytilus	Natural saltwater (San Pablo Bay B15-B20, San Francisco, CA)	30		2		30.00	7.95	2.00	20.00
421	Mytilus	Natural saltwater (Petaluma River, San Francisco, CA)	30		3		30.00	7.95	3.00	20.00
422	Mytilus	Natural saltwater (Petaluma River, San Francisco, CA)	30		9		30.00	7.95	9.00	20.00
423	Mytilus	Natural saltwater (Petaluma River, San Francisco, CA)	30		4		30.00	7.95	4.00	20.00
424	Mytilus	Natural saltwater (Petaluma River, San Francisco, CA)	30		2.3		30.00	7.95	2.30	20.00
425	Mytilus	Natural saltwater (East San Pablo Bay-midpoint, San Francisco, CA)	30		1.7		30.00	7.95	1.70	20.00
426	Mytilus	Natural saltwater (East San Pablo Bay-midpoint, San Francisco, CA)	30		4.8		30.00	7.95	4.80	20.00
427	Mytilus	Natural saltwater (East San Pablo Bay-midpoint, San Francisco, CA)	30		2.2		30.00	7.95	2.20	20.00
428	Mytilus	Natural saltwater (East San Pablo Bay-midpoint, San Francisco, CA)	30		2.6		30.00	7.95	2.60	20.00
429	Mytilus	Natural saltwater (East San Pablo Bay-nearshore, San Francisco, CA)	30		2.3		30.00	7.95	2.30	20.00
430	Mytilus	Natural saltwater (East San Pablo Bay-nearshore, San Francisco, CA)	30		4.5		30.00	7.95	4.50	20.00
431	Mytilus	Natural saltwater (East San Pablo Bay-nearshore, San Francisco, CA)	30		2.5		30.00	7.95	2.50	20.00
432	Mytilus	Natural saltwater (East San Pablo Bay-nearshore, San Francisco, CA)	30		2.2		30.00	7.95	2.20	20.00
433	Mytilus	Natural saltwater (Pacheco Creek, San Francisco, CA)	30		1.7		30.00	7.95	1.70	20.00
434	Mytilus	Natural saltwater (Pacheco Creek, San Francisco, CA)	30		9.6		30.00	7.95	9.60	20.00
435	Mytilus	Natural saltwater (Pacheco Creek, San Francisco, CA)	30		2.9		30.00	7.95	2.90	20.00
436	Mytilus	Natural saltwater (Grizzly Bay, San Francisco, CA)	30		2		30.00	7.95	2.00	20.00

BLM Data Label	Genus	Reported chemistry					Reported plus assumed chemistry[a]			
		Source water type	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C
437	Mytilus	Natural saltwater (Grizzly Bay, San Francisco, CA)	30		10		30.00	7.95	10.00	20.00
438	Mytilus	Natural saltwater (Grizzly Bay, San Francisco, CA)	30		3.2		30.00	7.95	3.20	20.00
439	Mytilus	Natural saltwater (Puget Sound SUZ001, Bangor, WA)	30		1.4		30.00	7.99	1.40	11.00
440	Mytilus	Natural saltwater (Puget Sound HCB002, Bangor, WA)	30		1.1		30.00	7.99	1.10	11.00
441	Mytilus	Natural saltwater (Galveston Bay- Horsepen Bayou, Clear Lake, TX)	30		8.7		30.00	7.80	8.70	20.00
442	Mytilus	Natural saltwater (West Galveston Bay, Clear Lake, TX)	30		3.3		30.00	7.80	3.30	20.00
443	Mytilus	Natural saltwater (Narragansett Bay-USEPA Dock Low Tide, Narragansett, RI)	30		1.5		30.00	7.92	1.50	17.00
444	Mytilus	Natural saltwater (Narragansett Bay-USEPA Dock High Tide, Narragansett, RI)	30		1.4		30.00	7.92	1.40	17.00
446	Mytilus	Natural saltwater (Granite Canyon Marine Lab., Carmel, CA)	30	7.82	0.7		30.00	7.82	0.70	15.70
447	Mytilus	Natural saltwater (Granite Canyon Marine Lab., Carmel, CA)	30	7.82	1		30.00	7.82	1.00	15.70
448	Mytilus	Natural saltwater (South San Francisco Bay, San Francisco, CA)	30	7.95	4.9		30.00	7.95	4.90	20.00
449	Mytilus	Natural saltwater (South San Francisco Bay, San Francisco, CA)	30	7.95	5.7		30.00	7.95	5.70	20.00
450	Mytilus	Natural saltwater (Granite Canyon and San Francisco Bay water)	30	7.91	1.9		30.00	7.91	1.90	15.70
451	Mytilus	Natural saltwater (Granite Canyon and San Francisco Bay water)	30	7.91	2.2		30.00	7.91	2.20	15.70
452	Mytilus	Natural saltwater (Granite Canyon and San Francisco Bay water)	30	7.98	3.3		30.00	7.98	3.30	15.70
453	Mytilus	Natural saltwater (Granite Canyon and San Francisco Bay water)	30	7.98	3.8		30.00	7.98	3.80	15.70
454	Mytilus	Natural saltwater (San Diego Bay, CA)	34.3	7.89	1.3	15.5	34.30	7.89	1.30	15.50
455	Mytilus	Natural saltwater (San Diego Bay, CA)	34.1	7.85	1.7	15.3	34.10	7.85	1.70	15.30
456	Mytilus	Natural and Artificial saltwater	29.8	7.75	0.8	25	29.80	7.75	0.80	25.00
457	Mytilus	Natural and Artificial saltwater	29.6	7.82	2.6	25	29.60	7.82	2.60	25.00
458	Mytilus	Natural and Artificial saltwater	29.7	7.92	3.9	25	29.70	7.92	3.90	25.00
459	Mytilus	Natural and Artificial saltwater	29.6	7.97	5.7	25	29.60	7.97	5.70	25.00
460	Mytilus	Natural and Artificial saltwater	32	7.85	1.2	15	32.00	7.85	1.20	15.00
461	Mytilus	Natural and Artificial saltwater	32	7.84	2.1	15	32.00	7.84	2.10	15.00
462	Mytilus	Natural and Artificial saltwater	32	7.88	3.5	15	32.00	7.88	3.50	15.00
463	Mytilus	Natural and Artificial saltwater	32	7.89	5	15	32.00	7.89	5.00	15.00
469	Neanthes	Natural saltwater (Narragansett Bay, Narragansett, RI)	31			17	31.00	7.92	1.45	17.00
470	Neanthes	Natural saltwater (Narragansett Bay, Narragansett, RI)	31			17	31.00	7.92	1.45	17.00
472	Neanthes	Natural saltwater (Narragansett Bay, Narragansett, RI)	31			19	31.00	7.92	1.45	19.00
474	Neomysis	Artificial saltwater (Marine Environment®)	2			17	2.00	7.80	2.00	17.00
475	Neomysis	Artificial saltwater (Marine Environment®)	2			17	2.00	7.80	2.00	17.00
476	Neomysis	Artificial saltwater (Marine Environment®)	2			17	2.00	7.80	2.00	17.00
478	Nitokra	Natural brackish water (location not given)	7	8		20	7.00	8.00	2.00	20.00
481	Oncorhynchus	Natural saltwater (Puget Sound at West Point, Seattle, WA)	28.6	8.1		13	28.60	8.10	1.46	13.00
483	Ophionereis	Natural saltwater (location not given)	41.7	8.01		23	41.70	8.01	2.00	23.00
485	Opsanus	Natural saltwater (Bear Cut, FL)	30			23	30.00	7.84	2.43	23.00

BLM Data Label	Genus	Reported chemistry					Reported plus assumed chemistry[a]			
		Source water type	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C
487	Palaemon	Natural saltwater (location not given)	17	8.1		15	17.00	8.10	2.00	15.00
489	Palaemonetes	Natural saltwater (Santa Rosa Sound, Gulf Breeze, FL)	20	7.4		27	20.00	7.40	2.00	27.00
496	Paralichthys	Natural saltwater (ERL, Narragansett, RI)	30			14	30.00	7.92	1.45	14.00
497	Paralichthys	Natural saltwater (ERL, Narragansett, RI)	30			13	30.00	7.92	1.45	13.00
498	Paralichthys	Natural saltwater (ERL, Narragansett, RI)	30			12	30.00	7.92	1.45	12.00
499	Paralichthys	Natural diluted saltwater (Narragansett, RI)	22	7.4		20	22.00	7.40	1.45	20.00
500	Paralichthys	Natural diluted saltwater (Narragansett, RI)	22	7.4		20	22.00	7.40	1.45	20.00
501	Paralichthys	Natural diluted saltwater (Narragansett, RI)	22	7.6		20	22.00	7.60	1.45	20.00
503	Farfantepenaeus	Natural saltwater (Santa Rosa Sound, FL)	25	7.95		25	25.00	7.95	2.00	25.00
505	Anaitides	Natural saltwater (location not given)				10	30.00	7.80	2.00	10.00
507	Planaxis	Natural saltwater (location not given)	36.91	7.8		27	36.91	7.80	2.00	27.00
509	Pseudodiaptomus		30				30.00	7.80	2.00	20.00
510	Pseudodiaptomus	Artificial saltwater	30			20	30.00	7.80	2.00	20.00
511	Pseudodiaptomus	Artificial saltwater (Kester)	30			15	30.00	7.80	2.00	15.00
513	Pseudopleuronectes	Natural saltwater (ERL, Narragansett, RI)	30			5	30.00	7.92	1.45	5.00
514	Pseudopleuronectes	Natural saltwater (ERL, Narragansett, RI)	28			5	28.00	7.92	1.45	5.00
515	Pseudopleuronectes	Natural saltwater (ERL, Narragansett, RI)	30			8	30.00	7.92	1.45	8.00
516	Pseudopleuronectes	Natural saltwater (ERL, Narragansett, RI)	30			5	30.00	7.92	1.45	5.00
517	Pseudopleuronectes	Natural saltwater (ERL, Narragansett, RI)	30			4.5	30.00	7.92	1.45	4.50
518	Pseudopleuronectes	Natural saltwater (ERL, Narragansett, RI)	30			5	30.00	7.92	1.45	5.00
526	Rangia	Artificial saltwater (Instant Ocean)	5.5			24	5.50	7.43	0.20	24.00
527	Rangia	Artificial saltwater (Instant Ocean)	22			24	22.00	7.43	0.20	24.00
529	Rivulus	Artificial saltwater (Instant Ocean TM)	14			26.5	14.00	7.43	0.20	26.50
530	Rivulus	Artificial saltwater (Instant Ocean TM)	14			26.5	14.00	7.43	0.20	26.50
532	Scorpaenichthys	Natural saltwater (Puget Sound at West Point, Seattle, WA)	27	7.9		8.3	27.00	7.90	1.46	8.30
534	Sphaeroma	Natural saltwater (location not given)	17	8.1		15	17.00	8.10	2.00	15.00
536	Spisula	Natural saltwater (location not given)	25	7.2		20	25.00	7.20	2.00	20.00
538	Strongylocentrotus	Natural saltwater (Puget Sound at West Point, Seattle, WA)	30	7.95		8.3	30.00	7.95	1.46	8.30
543	Strongylocentrotus	Natural saltwater (Puget Sound at West Point, Seattle, WA)	30	7.95		8.3	30.00	7.95	1.46	8.30
547	Strongylocentrotus	Natural saltwater (Granite Canyon, CA)	33.5	8.3		14.85	33.50	8.30	1.74	14.85
548	Strongylocentrotus	Natural saltwater (Granite Canyon, CA)	33.5	8.3		14.95	33.50	8.30	1.74	14.95
549	Strongylocentrotus	Natural saltwater (San Diego Bay, CA)	34.2	8.09	2.47	15.8	34.20	8.09	2.47	15.80
550	Strongylocentrotus	Natural and Artificial saltwater	32	7.85	1.2	15	32.00	7.85	1.20	15.00
551	Strongylocentrotus	Natural and Artificial saltwater	32	7.84	2.1	15	32.00	7.84	2.10	15.00
552	Strongylocentrotus	Natural and Artificial saltwater	32	7.88	3.5	15	32.00	7.88	3.50	15.00
553	Strongylocentrotus	Natural and Artificial saltwater	32	7.89	5	15	32.00	7.89	5.00	15.00
555	Terapon	Natural saltwater (location not given)		7.9		28	30.00	7.90	2.00	28.00
557	Tigriopus	Artificial saltwater (AQUIL)	35	8		16	35.00	8.00	2.00	16.00
558	Tigriopus	Artificial saltwater (AQUIL)	35	8		16	35.00	8.00	2.00	16.00

BLM Data Label	Genus	Reported chemistry					Reported plus assumed chemistry[a]			
		Source water type	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C
559	Tigriopus	Artificial saltwater (AQUIL)	35	8		16	35.00	8.00	2.00	16.00
560	Tigriopus	Artificial saltwater (AQUIL)	35	8		16	35.00	8.00	2.00	16.00
561	Tigriopus	Artificial saltwater (AQUIL)	35	8		16	35.00	8.00	2.00	16.00
562	Tigriopus	Artificial saltwater (AQUIL)	35	8		16	35.00	8.00	2.00	16.00
563	Tigriopus	Artificial saltwater (AQUIL)	35	8		16	35.00	8.00	2.00	16.00
564	Tigriopus	Artificial saltwater (AQUIL)	35	8		16	35.00	8.00	2.00	16.00
565	Tigriopus	Artificial saltwater (AQUIL)	35	8		16	35.00	8.00	2.00	16.00
566	Tigriopus	Artificial saltwater (AQUIL)	35	8		16	35.00	8.00	2.00	16.00
567	Tigriopus	Artificial saltwater (AQUIL)	35	8		16	35.00	8.00	2.00	16.00
568	Tigriopus	Artificial saltwater (AQUIL)	35	8		16	35.00	8.00	2.00	16.00
569	Tigriopus	Artificial saltwater (AQUIL)	35	8		16	35.00	8.00	2.00	16.00
571	Tisbe	Natural saltwater (Drobak, Oslofjord, Norway)	34	8		13	34.00	8.00	2.00	13.00
573	Trachinotus	Natural saltwater (Grand Isle, LA)	10			22.5	10.00	7.81	2.00	22.50
574	Trachinotus	Natural saltwater (Grand Isle, LA)	20			22.5	20.00	7.81	2.00	22.50
575	Trachinotus	Natural saltwater (Grand Isle, LA)	30	7.81		22.5	30.00	7.81	2.00	22.50
577	Turbo	Natural saltwater (location not given)	37.43	8.17		27	37.43	8.17	2.00	27.00
730	Mytilus	Natural uncontaminated seawater (assumed collected from the Sinop Coast of the Black Sea, Turkey)	17.5	7.95	1.92% - TOC	15	17.50	7.95	2.00	15.00
731	Mytilus	Natural uncontaminated seawater (assumed collected from the Sinop Coast of the Black Sea, Turkey)	17.5	7.95	1.92% - TOC	15	17.50	7.95	2.00	15.00
732	Mytilus	Natural uncontaminated seawater (assumed collected from the Sinop Coast of the Black Sea, Turkey)	17.5	7.95	1.92% - TOC	15	17.50	7.95	2.00	15.00
733	Mytilus	Natural uncontaminated seawater (assumed collected from the Sinop Coast of the Black Sea, Turkey)	17.5	7.95		15	17.50	7.95	2.00	15.00
734	Acartia	Artificial salt water	5	6.88	<0.1	20	5.00	6.88	0.10	20.00
735	Acartia	Artificial salt water	15	7.21	<0.1	20	15.00	7.21	0.10	20.00
736	Acartia	Artificial salt water	30	7.49	<0.1	20	30.00	7.49	0.10	20.00
737	Amphiascoides	Artificial salt water, Instant Ocean Sea Salt, USA	30			23	30.00	7.43	0.20	23.00
738	Amphiascoides	Artificial salt water, Instant Ocean Sea Salt, USA	30			23	30.00	7.43	0.20	23.00
739	Amphiascoides	Artificial salt water, Instant Ocean Sea Salt, USA	30			23	30.00	7.43	0.20	23.00
740	Amphiascoides	Artificial salt water, Instant Ocean Sea Salt, USA	30			23	30.00	7.43	0.20	23.00
741	Balanus	Filtered natural sea water (assumed collected at Ionian Sea, southern Italy)	37			20	37.00	7.80	2.00	20.00
742	Balanus	Filtered natural sea water (assumed collected at Ionian Sea, southern Italy)	37			20	37.00	7.80	2.00	20.00
743	Penaeus	Filtered natural saltwater (collected from unpolluted site in Neelangarai, India)	28	7.78		28	28.00	7.78	2.00	28.00
744	Mugil	Natural filtered seawater (source)	28	7.78		28	28.00	7.78	2.00	28.00
745	Brachionus	Artificial salt water, Instant Ocean Sea Salt, USA	4	6.3	1.4	25	4.00	6.30	1.40	25.00

BLM Data Label	Genus	Reported chemistry					Reported plus assumed chemistry[a]			
		Source water type	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C
746	Brachionus	Artificial salt water, Instant Ocean Sea Salt, USA	14	6.9	1.4	25	14.00	6.90	1.40	25.00
747	Brachionus	Artificial salt water, Instant Ocean Sea Salt, USA	26	7.8	1.4	26	26.00	7.80	1.40	26.00
748	Brachionus	Artificial salt water, Instant Ocean Sea Salt, USA	14	6.6	1.4	25	14.00	6.60	1.40	25.00
749	Brachionus	Artificial salt water, Instant Ocean Sea Salt, USA	14	6.7	5	25	14.00	6.70	5.00	25.00
750	Brachionus	Artificial salt water, Instant Ocean Sea Salt, USA	14	6.9	10	25	14.00	6.90	10.00	25.00
751	Centropomus	Natural filtered estuarine water from the Piraqueacu River, Brazil	32.2	7.58		24.6	32.20	7.58	2.00	24.60
752	Mytilus	Natural estuarine water (Nieuwpoort, Belgium) + DI water + artificial sea water	22.9		3	16	22.90	7.80	3.00	16.00
753	Mytilus	Natural estuarine water (Nieuwpoort, Belgium) + DI water + artificial sea water	24.7		1.24	16	24.70	7.80	1.24	16.00
754	Mytilus	Natural estuarine water (Nieuwpoort, Belgium) + DI water + artificial sea water	25.1		3.92	16	25.10	7.80	3.92	16.00
755	Mytilus	Natural estuarine water (Nieuwpoort, Belgium) + DI water + artificial sea water	29.8		0.56	16	29.80	7.80	0.56	16.00
756	Mytilus	Natural estuarine water (Nieuwpoort, Belgium) + DI water + artificial sea water	29.8		4.66	16	29.80	7.80	4.66	16.00
757	Mytilus	Natural estuarine water (Nieuwpoort, Belgium) + DI water + artificial sea water	29.9		2.8	16	29.90	7.80	2.80	16.00
758	Mytilus	Natural estuarine water (Nieuwpoort, Belgium) + DI water + artificial sea water	30		2.8	16	30.00	7.80	2.80	16.00
759	Mytilus	Natural estuarine water (Nieuwpoort, Belgium) + DI water + artificial sea water	34.9		1.46	16	34.90	7.80	1.46	16.00
760	Brachionus	Recon saltwater + natural saltwater (Bouctouche)	30.1	8	4.83	25	30.1	8	4.83	25
761	Brachionus	Recon saltwater + natural saltwater (Petit Rocher)	30.2	8	2.1	25	30.2	8	2.1	25
762	Brachionus	Recon saltwater + natural saltwater (Major Kollock Creek)	29.9	8	7.57	25	29.9	8	7.57	25
763	Brachionus	Recon saltwater + natural saltwater (Naufrage Harbour)	29.9	8	5.2	25	29.9	8	5.2	25
764	Brachionus	Recon saltwater + natural saltwater (Rathtrevor Beach)	30.1	8	1.37	25	30.1	8	1.37	25
765	Brachionus	Recon saltwater + natural saltwater (Hawke's Bay)	30	8	1.28	25	30	8	1.28	25
766	Brachionus	Recon saltwater + natural saltwater (Blackberry Bay)	29.9	8	2.03	25	29.9	8	2.03	25
767	Brachionus	Recon saltwater + natural saltwater (Chesterman Beach)	30.1	8	0.55	25	30.1	8	0.55	25
768	Brachionus	Recon saltwater + natural saltwater (Jimbo)	30.1	8	1.13	25	30.1	8	1.13	25
769	Mytilus	Artificial seawater (ASTM 2004)	36	7.9-8.1		16	36	8	2	16
770	Mytilus	Artificial seawater (ASTM 2004)	36	7.9-8.1		16	36	8	2	16
771	Perna	Natural seawater (Neelangarai, India)	28	7.78		28	28	7.78	2	28
772	Nitokra	Natural seawater	7		4.7 (TOC)	22	7	7.8	4.7	22
773	Orchomenella	Natural seawater (source not defined)	33			10	33	7.8	2	10
774	Penaeus	Natural seawater (Neelangarai, India)	28	7.78		28	28	7.78	2	28
775	Limulus	Artificial seawater (Instant Ocean)	20	6.7-9.0		18-29	20	7.85	0.2	23.5

BLM Data Label	Genus	Reported chemistry					Reported plus assumed chemistry[a]			
		Source water type	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C	Salinity, g/kg	pH	DOC, mg C/L	Temp, °C
776	Limulus	Artificial seawater (Instant Ocean)	20	6.7-9.0		18-29	20	7.85	0.2	23.5
777	Limulus	Artificial seawater (Instant Ocean)	20	6.7-9.0		18-29	20	7.85	0.2	23.5
778	Arbacia	Natural seawater (source not provided)	30	8.01-8.06		20	30	8.035	2	20
779	Cyprinodon	Natural seawater (Gulf of Mexico) + DI water	2			20	2	7.8	2	20
780	Cyprinodon	Natural seawater (Gulf of Mexico) + DI water	15			20	15	7.8	2	20
781	Cyprinodon	Natural seawater (Gulf of Mexico) + DI water	2			20	2	7.8	2	20
782	Cyprinodon	Natural seawater (Gulf of Mexico) + DI water	15			20	15	7.8	2	20
C1	Brachionus	Artificial saltwater (Instant Ocean)	15	7.3-7.6	<1.0	23.9-26.1	15	7.45	1	25
C2	Cyprinodon	Natural saltwater (ERLN, Narragansett, RI)	28-32			23-27	30	7.92	1.45	25

a Given the relatively constant composition of marine waters, average values were reasonable estimates for missing parameters in a given toxicity test.

Appendix Table H-2. Summary Statistics of the Reported Water Chemistry for the Acceptable Toxicity Tests.

	Salinity (g/kg)	pH	DOC (mg C/L)	Temperature (°C)
Minimum	2.0	6.3	0.1	4.5
Maximum	41.7	9.0	12.0	30.0
Average	26.5	7.9	3.3	19.0

Appendix Table H-3. Average Chemistry

Location	Salinity (g/kg)	pH	DOC (mg C/L)	Temperature (°C)
Narragansett		7.92	1.45	17
Puget		7.99	1.46	11
Granite Canyon		7.99	1.74	15.7
Grand Isle		7.81		
Bodega		7.6	0.893	
San Francisco		7.95		
Black Sea			2	
Cambridge			3.63	
Bear Cut		7.84	2.43	
Instant Ocean[1]		7.43	0.2	
Tropic Marin[1]		8.25	0.6	
default	30	7.8	2	20

[1] Based on Arnold et al. 2007.

Appendix I Discussion of BLM Water Quality Parameters in the Estuarine/Marine Environment and Example Numeric Criteria Values

The pH of marine environments is relatively stable, where pH typically remains between 7.5 and 8.4 (Sverdrup et al. 1942). However, regional factors can temporarily affect pH in these systems. For example, the upwelling of deeper more acidic waters along the west coast of North America can temporarily lower the pH of surface waters (Feely et al. 2008). In comparison, pH is much more variable in estuaries, embayments, harbors, and other semi-enclosed coastal systems. The influx of freshwater from rivers, groundwater, and surficial runoff can lower the pH of these systems, based on the typically lower pH of freshwater (around 7) (Caldeira and Wickett 2003). Photosynthesis, meanwhile, can increase pH levels and algal blooms have been reported to increase pH levels above 9 in some estuaries, to the point where pH becomes lethal to aquatic species (Hansen 2002).

The salinity of marine systems is also relatively stable, with an average salinity of 35 ppt and range of 32 to 38 ppt across the world's oceans (Kalle 1971). Salinity within coastal waters can have greater variability, due primarily to the input of freshwater from rivers, surficial runoff, groundwater input, and tidal and coastal currents. Salinity can also vary as a result of diurnal, seasonal, and annual cycles and episodic occurrences (e.g, storm events). Salinity in semi-enclosed systems, including estuaries, embayments, and harbors can have extreme variability over space and time, and can have salinity ranging from saline to freshwater (<2 ppt). In the Cheseapeake Bay, for example, average salinity ranges from freshwater (<0.5 ppt) in the upper reaches of the Bay to full marine salinity adjacent to the Atlantic Ocean (VIMS 2016). Salinity typically decreases in the Chesapeake Bay during the spring, with increased freshwater inputs resulting from rain and snowmelt, and increases during the summer with increasing levels of evaporation (Levinton 2001). Inputs (e.g., municipal discharges) and changes in water flow patterns as a result of anthropogenic activity can also significantly affect the salinity of estuarine and marine systems.

DOC in estuarine and marine systems in most cases reflects a diversity of inputs from allochthonous and autochthonous sources that can originate from both terrestrial and aquatic autotrophs (inclusive of unicellular algae and vascular plants) and heterotrophs (inclusive of bacteria, fungi, and multicellular organisms) (Bauer and Bianchi 2011; Cloern 1996; Raymond and Bauer 2001; Cauwet 2002; Aitkenhead-Peterson et al. 2003; Bertilsson and Jones 2003). The highest DOC concentrations are generally found in estuarine and associated riverine systems, with DOC concentrations generally decreasing with movement from the estuarine to marine environment (Bauer and Bianchi 2011). DOC concentrations within estuarine and riverine systems can vary greatly, with some of the highest known DOC concentrations occurring in estuaries within the Gulf of Mexico, where DOC concentrations of greater than 1,000 µM (equivalent to approximately 12 mg/L) have been reported (Bauer and Bianchi 2011; Guo et al. 1999; Engelhaupt and Bianchi 2001). Although variable both spatially and temporally, representative DOC values reported for most other estuarine and riverine systems are lower, examples of which include Galveston Bay (145-469 µM, equivalent to approximately 1.7-5.6 mg/L), Chesapeake Bay (118-215 µM, equivalent to approximately 1.4-2.6 mg/L), and Potomac/Patuxent River (92-333 µM, equivalent to approximately 1.1-4.0 mgL) (Guo and Santschi 1997; Sigleo 1996).

Riverine systems and adjacent wetlands frequently represent important sources of DOC to estuarine and adjacent coastal ecosystems (Del Giorgio and Pace 2008). The magnitude of temporal variability in DOC loading within these systems has been shown to be related to the predominant source of DOC (Bianchi et al. 1998, Mantoura and Woodward 1983, Thurman 1985). For example, fringing wetlands have been demonstrated to provide a more consistent source of DOC than phytoplankton blooms (Bianchi et al. 1998; Mantoura and Woodward 1983; Thurman 1985). Anthropogenic inputs of DOC via municipal and industrial discharge can also alter the DOC present in estuarine and near coastal environments, either directly through the discharge of DOC or indirectly, such as via the discharge of nutrients which can then increase primary productivity.

Removal of DOC via flocculation typically occurs with the increasing ionic strength of higher salinity environments (Guo et al. 1999). In coastal and marine environments, DOC is mostly produced by biological processes (primary and secondary production) in the upper ocean, and is then mixed downward and diluted by physical processes (Hansell and Carlson 2001). Seasonal increases in DOC concentrations can occur as a result of phytoplankton blooms, particularly in areas with stratification that receive nutrient inputs during the winter (Hansell and Carlson 2001). Deep ocean waters generally have the lowest DOC concentrations, reaching levels of 2 µM (equivalent to approximately 0.02 mg/L) or less. DOC concentrations thus tend to be reduced in upwelling areas where deep waters dilute the surface water concentrations, even when primary production levels are relatively high (Hansell and Carlson 2001).

Marine water temperatures generally range from -2°C to 28°C, with some higher temperatures occurring seasonally in estuarine systems. Temperature is, in general, a function of solar input, with higher temperatures typically occurring at lower latitudes and during the summer. Water temperatures in near coastal environments and semi-enclosed systems such as estuaries, embayments, and harbors typically have some of the greatest variability. This variability is due primarily to the input of freshwater from rivers, surficial runoff, groundwater discharge, the shallower waters frequently present in these systems, and tidal and coastal currents. Temperatures in coastal and open water marine environments often vary with different, frequently stratified water layers that are characterized by differing temperature and salinity. Upwelling and current patterns in these stratified systems can lead to local and regional alteration in the temperature profile, such as observed with the California Current, where cooler deeper waters are brought to the surface and significantly reduce the surface water temperature profile.

The following tables provide representative example saltwater BLM CMC and CCC values determined with different temperature, pH, salinity, and DOC conditions.

Appendix Table I-1. Example BLM Numeric Criteria Values at 20°C and pH 7.8.

Salinity (ppt)	DOC (mg C/L)	FAV (µg/L)	CMC (µg/L)	CCC (µg/L)
5	1	3.294	**1.6**	**1.1**
	2	6.585	**3.3**	**2.2**
	4	13.16	**6.6**	**4.4**
	6	19.75	**9.9**	**6.5**
	8	26.33	**13**	**8.7**
	10	32.91	**16**	**11**
10	1	3.423	**1.7**	**1.1**
	2	6.847	**3.4**	**2.3**
	4	13.68	**6.8**	**4.5**
	6	20.52	**10**	**6.8**
	8	27.37	**14**	**9.1**
	10	34.21	**17**	**11**
15	1	3.545	**1.8**	**1.2**
	2	7.090	**3.5**	**2.3**
	4	14.17	**7.1**	**4.7**
	6	21.26	**11**	**7.0**
	8	28.35	**14**	**9.4**
	10	35.44	**18**	**12**
20	1	3.662	**1.8**	**1.2**
	2	7.318	**3.7**	**2.4**
	4	14.64	**7.3**	**4.8**
	6	21.96	**11**	**7.3**
	8	29.27	**15**	**9.7**
	10	36.59	**18**	**12**
25	1	3.776	**1.9**	**1.2**
	2	7.550	**3.8**	**2.5**
	4	15.09	**7.5**	**5.0**
	6	22.64	**11**	**7.5**
	8	30.17	**15**	**10**
	10	37.72	**19**	**12**
30	1	3.887	**1.9**	**1.3**
	2	7.771	**3.9**	**2.6**
	4	15.54	**7.8**	**5.1**
	6	23.29	**12**	**7.7**
	8	31.07	**16**	**10**
	10	38.84	**19**	**13**

Appendix Table I-2. Example BLM Numeric Criteria Values at 20°C and pH 8.0.

Salinity (ppt)	DOC (mg C/L)	FAV (µg/L)	CMC (µg/L)	CCC (µg/L)
5	1	3.324	**1.7**	**1.1**
	2	6.647	**3.3**	**2.2**
	4	13.29	**6.6**	**4.4**
	6	19.93	**10**	**6.6**
	8	26.58	**13**	**8.8**
	10	33.20	**17**	**11**
10	1	3.446	**1.7**	**1.1**
	2	6.886	**3.4**	**2.3**
	4	13.77	**6.9**	**4.6**
	6	20.66	**10**	**6.8**
	8	27.54	**14**	**9.1**
	10	34.41	**17**	**11**
15	1	3.563	**1.8**	**1.2**
	2	7.121	**3.6**	**2.4**
	4	14.24	**7.1**	**4.7**
	6	21.36	**11**	**7.1**
	8	28.48	**14**	**9.4**
	10	35.60	**18**	**12**
20	1	3.678	**1.8**	**1.2**
	2	7.352	**3.7**	**2.4**
	4	14.70	**7.3**	**4.9**
	6	22.04	**11**	**7.3**
	8	29.38	**15**	**9.7**
	10	36.73	**18**	**12**
25	1	3.790	**1.9**	**1.3**
	2	7.574	**3.8**	**2.5**
	4	15.14	**7.6**	**5.0**
	6	22.70	**11**	**7.5**
	8	30.26	**15**	**10**
	10	37.84	**19**	**13**
30	1	3.900	**1.9**	**1.3**
	2	7.794	**3.9**	**2.6**
	4	15.58	**7.8**	**5.2**
	6	23.36	**12**	**7.7**
	8	31.16	**16**	**10**
	10	38.95	**19**	**13**

Appendix Table I-3. Example BLM Numeric Criteria Values at 20°C and pH 8.2.

Salinity (ppt)	DOC (mg C/L)	FAV (µg/L)	CMC (µg/L)	CCC (µg/L)
5	1	3.279	**1.6**	**1.1**
	2	6.550	**3.3**	**2.2**
	4	13.10	**6.5**	**4.3**
	6	19.65	**9.8**	**6.5**
	8	26.20	**13**	**8.7**
	10	32.75	**16**	**11**
10	1	3.387	**1.7**	**1.1**
	2	6.769	**3.4**	**2.2**
	4	13.53	**6.8**	**4.5**
	6	20.28	**10**	**6.7**
	8	27.04	**14**	**8.9**
	10	33.78	**17**	**11**
15	1	3.494	**1.7**	**1.2**
	2	6.978	**3.5**	**2.3**
	4	13.94	**7.0**	**4.6**
	6	20.91	**10**	**6.9**
	8	27.87	**14**	**9.2**
	10	34.85	**17**	**12**
20	1	3.600	**1.8**	**1.2**
	2	7.187	**3.6**	**2.4**
	4	14.37	**7.2**	**4.8**
	6	21.55	**11**	**7.1**
	8	28.72	**14**	**9.5**
	10	35.90	**18**	**12**
25	1	3.705	**1.9**	**1.2**
	2	7.396	**3.7**	**2.4**
	4	14.78	**7.4**	**4.9**
	6	22.17	**11**	**7.3**
	8	29.55	**15**	**9.8**
	10	36.94	**18**	**12**
30	1	3.810	**1.9**	**1.3**
	2	7.606	**3.8**	**2.5**
	4	15.20	**7.6**	**5.0**
	6	22.79	**11**	**7.5**
	8	30.39	**15**	**10**
	10	37.95	**19**	**13**