Workshop on Causes of Sediment Toxicity in California Marine Waters

Sponsored by the San Francisco Estuary Institute
Conducted by the Southern California Coastal Water Research Project and UC Davis Department of Environmental Toxicology
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Summary

A one-day workshop (Workshop II) was held on November 16, 2012 in Long Beach to assist in the identification of the factors responsible for sediment toxicity in San Francisco Bay. This workshop provided a follow-up to an initial stressor identification workshop (Workshop I) held in April 2010 in Oakland. Twenty-two scientists (Table 1) with expertise in ecology, toxicology, chemistry, geology, and ecological risk assessment participated in the discussions. This document summarizes the key Workshop II activities, discussions, recommendations and post-workshop comments.

Background Presentations

Steve Bay gave an introduction to Workshop II and distributed handouts of the presentations. He described the genesis of the workshop and its primary goal: to understand what is causing the pervasive moderate toxicity in San Francisco Bay and improve stressor identification methods.

Monitoring programs have observed toxicity in California embayments. Southern California Coastal Water Research Project (SCCWRP) and the Regional Monitoring Program (RMP) have observed similar trends. Toxicity in the San Francisco Bay (Bay) is mostly moderate (i.e., less than 50% mortality to test organisms), and there are not many hotspots. Because the Bay is one of the largest on the west coast (80% of the embayment area in California), this waterbody is a priority for stressor identification studies.

The goal of Workshop II was to assess what is known about Bay sediment toxicity, develop research designs to improve our knowledge regarding stressors, and address priorities that are feasible for the Bay. The workshop participants were selected to provide a diverse set of perspectives and expertise. The focus of the workshop was on factors causing mortality to the amphipod *Eohaustorius estuarius*. The workshop was intended to provide an updated, improved, and refined list of potential stressors in the Bay. The workshop also provided a forum for discussion of additional data analyses or experimental data needed to help interpret the toxicity results.

A presentation by Tom Mumley provided the regulatory background. San Francisco Bay is a significant estuary, but highly urbanized with a significant amount of human stress. Water quality has greatly improved over the years, including remediation of several major sediment hotspots. Sediments in the Bay affect the health, diversity, and abundance of organisms, and can greatly affect how contaminants are transported. Many ecological resources depend upon a benthos-based food web, so protecting sediment quality is a high priority for environmental managers.

Tom Mumley provided an overview of sediment quality regulation. The California Water Code (Section 13390) identified sediment contamination hotspots with studies by the Bay Protection and Toxic Cleanup Program (BPTCP) and established standards for the protection of sediment quality through development of Sediment Quality Objectives (SQOs). The SQOs are narrative standards that protect benthic communities and human health from impacts related to sediment pollutants. Procedures to assess sediment quality include a multiple lines of evidence (MLOE) triad, which facilitates site categorization. The triad classifies sites from unimpacted to clearly impacted, with most sites in the Bay categorized as possibly impacted based on moderate toxicity and legacy chemicals. Existing methods can identify some contaminant and non-contaminant stressors and sources. Cleanup and abatement can be accomplished through permitting and regulation.

Monitoring and assessment of Bay sediment quality is accomplished through the RMP. The RMP budget is about $3 million per year, with about $1 million assigned to special studies, and about $300,000 designated for sediment-related questions. On-going questions regarding sediment quality include the causes of sediment toxicity, identification of contaminants that require remediation, and identification of the sources of contaminants that may require abatement. **Tom Mumley** also suggested the possibility that some forms of sediment contamination in the Bay may be something we are going to have to live with.

Tom Mumley issued a challenge to the workshop participants: "The cause of moderate sediment toxicity in The Bay cannot be identified - prove me wrong". If sediment toxicity stressor identification is not a solvable problem, should the RMP continue to provide resources for this issue? Additional questions and observations included: How specific do we need to be in terms of identifying the cause(s) of sediment toxicity (for example, identification of a specific metal vs. pyrethroids as a class of pesticides)? The sites in the Bay that have been identified as moderately impacted are largely driven by toxicity and not chemistry. How many causes of toxicity are we looking for?

Discussion:
David Moore did not think we should start with the presumption of guilt, and wanted to re-phrase the question as "what is the cause of amphipod mortality" and not "what is the cause of toxicity". This statement was intended to distinguish between contaminant and non-contaminant causes of mortality.

A presentation by **Brian Anderson** provided background on the sediment toxicity test protocol for *E. estuarius*, patterns of toxicity in the Bay, and previous stressor identification research.

Eohaustorius occurs in the sandy beach habitats as a free burrower. The amphipod is mesohaline and a detritivore. Sediment toxicity tests with this species use a well-vetted protocol based on DeWitt (1989) and formally adopted by the EPA in 1994. The organisms are collected intertidally at Beaver Creek, Oregon (more recently Yaquina Bay, Oregon) and shipped to testing labs. They are wild-caught and not cultured. **Brian Anderson** provided a short summary of non-contaminant factors that could influence test results (e.g., reference toxicant, acclimation, life cycle).

Selection of this species for toxicity testing was based on a rigorous comparison of methods by BPTCP. The amphipod tests had good controls and the organism was responsive to contaminants and gradients (particularly compared to *Ampelisca* and *Neanthes*, which were non-responsive). The State Water Board's SQO program performed a similar exercise and arrived at the same conclusion.

Toxicity in the Bay shows some seasonality in the magnitude of toxicity, and also demonstrates spatial patterns, with higher toxicity at sites in the margins of the Bay. The likely contaminants of concern are organic chemicals. Other stressors are unknown (such as algal toxins), and there are potentially non-contaminant factors (ammonia and sulfide are not a factor in The Bay, but grain size may be). Historically, about 30% of the samples in the Bay have been toxic. In 2001, the RMP included comparisons to *Ampelisca* (which did not show toxicity). Matching toxicity to benthos is difficult based on uncertainty regarding relative disturbance of mesohaline bethic community assemblages. There is some concordance between toxicity and benthos, but only about half of the sites have good benthic tools, and about half of those had favorable comparisons (e.g., if toxicity was present then the benthos was degraded).

Observed seasonal effects could be related to chemistry, but no obvious correlation is evident based on the current analyte list. Temporal responses of reference toxicants have been examined, but the data do not show a pattern suggesting seasonal variations in amphipod sensitivity. It could be assumed that the animals are more sensitive in the winter months, but **Ted DeWitt** was not sure, and recommended revisiting the original Bosworth thesis [1]. **Chris Ingersoll** suggested testing *Eohaustorius* from two populations to determine differences. **Bryan Brooks** and **Swee Teh** suggested that there may be interactive effects of physiochemical stressors (e.g., salinity and temperature) at the organism source site and that animal health might influence batch sensitivity.

Previous stressor identification studies have correlated toxicity with measured constituents. There are a lot of significant correlations, but no absolute causative factors have been identified.

DeWitt et al. (1989) evaluated grain size in 42 uncontaminated sites from Washington and Oregon and observed variable survival (60-100%) at sites with fines >70%. Environment

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[1] Bosworth, W.S., Jr. 1976. Biology of the genus *Eohaustorius (Amphipoda: Haustoriidae)* on the Oregon coast. Ph.D. thesis, Oregon State University, Corvallis, OR.

Canada does not recommend use of *Eohaustorius* at sites with >80% fines. The relationship between % clay in uncontaminated sediments and survival has also been examined by the UC Davis Marine Pollution Studies Laboratory (MPSL); the data show high variability at high clay content with a significant relationship. A recommendation was made to examine relationships with only high mortality samples (e.g., <70% survival) and look at what might be special about those sites. **Jim Shine** recommended transforming the data for statistical analysis, as untransformed data violated statistical assumptions.

Brian Anderson's presentation also included results from a single MPSL grain size test and a discussion about grain size vs. grain shape (**Ivano Aiello's** work). He also discussed the shell debris observed in a number of RMP samples and summarized the results of a preliminary experiment to investigate shell hash effects.

There was a suggestion to look at pathogens. There was also a suggestion to hold the sediment in refrigerated storage and see if the toxicity changes.

Variability: High variability is occasionally found in the sediment toxicity tests, but does not seem to be associated with routine laboratory procedures. **Meg Sedlak** commented that Bay sediments look well-homogenized as a result of wind, water currents, and shallow water. **David Moore** provided an example of 30 mercury cores in a single square meter that had huge variability. **Howard Bailey** suggested there might be a nugget effect due for example to the presence of hydrocarbon balls (e.g., at Mission Creek) or mortality due to the presence of a predator in particular replicates. **Ted DeWitt** suggested the presence of homogenized organisms (anemone) might contribute to variability because of the presence of active and toxic nematocysts. The workshop participants recommended trying to match up toxicity results with records of anemones, infaunal predators, or other sediment characteristics from field sampling or laboratory notes. It was also noted that routine screening of sediments to remove predators prior to testing could eliminate this problem.

Toxicity Identification Evaluation (TIE) Results: Brian Anderson presented the TIE flow chart developed during Workshop I. Evaluations conducted to date have narrowed the list of likely stressors, but have not shown a definitive cause. **David Moore** mentioned that rare-earth metals are non-reactive and could be substituting for minerals such as calcium (perhaps we can look at ion imbalance, but would not necessarily explain variability).

Hot Spot History: Historical Bay toxic hot spots have changed over time (e.g., Castro Cove and Paradise Cove). **Tom Mumley** added some perspective on these sites: there was a clean-up action at Castro, and there are no current inputs to this site. Islais Creek and Mission Creek have combined sewer overflows with current inputs.

Mission Creek TIE Summary: An exhaustive TIE was conducted; however, no primary toxicant was identified. Ammonia removal and carbon addition reduced toxicity, and the elution of extraction media returned toxicity, but the latter provided only a qualitative result. Contaminant concentrations of potential concern were found for chlordane (later determined through dose-response experiments to not be high enough to cause toxicity), chlorpyrifos, PAHs, and to a lesser extent copper, so mixtures were identified as the cause of toxicity at this site, along with ammonia.

Workshop I Summary: There was a consensus that TIE methods were sufficient, but required some improvements. Workshop I participants prioritized contaminants and concluded that the RMP effort was one of few formal programs in country addressing the development of sediment TIE methods. The primary recommendation of Workshop I was to define the influence of grain size and shape on *E. estuarius* mortality. In addition, workshop participants identified other likely contaminants of concern, and suggested conducting dose-response experiments with priority chemicals. Finally, a second workshop was recommended to develop a research strategy to address remaining issues.

Discussion

David Moore suggested comparing the response of amphipods observed in the Bay to other locations. Are we seeing more amphipod mortality in the Bay than in other places? **Steve Bay** indicated that previous analyses had shown much similarity between the Bay and the Southern California Bight (SCB) in terms of prevalence and magnitude of toxicity, but that Bay samples tended to show greater incidence of toxicity at similar levels of chemical contamination (e.g., using SQG index scores), relative to SCB samples.

Bryn Phillips recommended assembling the amphipod acclimation records from SCCWRP and MPSL and comparing the data to reference toxicant results, overall variability in test batches, and control performance. This was recommended to address the possibility that sensitivity of wild-caught test organisms could vary depending on seasonal factors affecting populations at Oregon collection sites. **Jay Field** suggested that a routine measure of amphipod lipid content would also allow a determination of the relative health of the test organisms. In addition, he suggested that because sensitivity of amphipods to organic chemicals is likely influenced by lipid content, this would allow a method to determine whether seasonal variability in lipids is correlated to sensitivity to contaminants.

Stressors of Concern:

Steve Bay led a discussion to review and update the list of stressors of concern developed at Workshop I. Workshop II participants discussed the previous list, provided suggestions regarding additional stressors of concern, and revised the priority ranking of some types of stressors (Table 2).

Discussion

Ted De Witt would like to see condition of animals, acclimation, etc. added to list of potential stressors.

Chris Ingersoll suggested using peepers in the exposure system to better measure interstitial concentrations of ammonia and sulfide (if this is high priority issue).

Several participants recommended that a high priority be assigned to investigating physical toxicity related grain size, clay content, and particle shape. The issue of shells and smothering by oils was also discussed. However, because of uncertainty regarding the magnitude of exposure to these factors, it is not clear what should be measured. **Bryn Phillips** and **Ted DeWitt** recommended that more detailed analyses of existing grain size data and toxicity be conducted, including an emphasis on the coarse end of the spectrum. Another suggestion was made to pre-sieve samples to remove shell debris and compare to un-sieved samples.

Grain size is a very complex issue, but the shell hash problem could be easily resolved. **Swee Teh** suggested that microplastics and microscrubbers could also be part of the grain size issue. These materials concentrate contaminants from ambient water and include chemical additives. Their size and shape can also cause effects. Amphipods are selective feeders and may be eating microplastics that have concentrated toxicants.

Sediment manipulation during laboratory testing was identified as another factor of potential importance. Pre-sieving sampling sites could help address impacts associated with shell hash or macrofauna, but these factors were not considered likely to account for the seasonal pattern seen in previous toxicity monitoring. .

David Moore suggested including a cost estimate in the ranking of new research or analyses.

Jay Field suggested that seasonal changes in toxicity might be due to differences in amphipod lipid content. It is likely that *Eohaustorius* has a seasonal lipid cycle, with highest lipid in the summer and lowest in the winter, as has been shown for other benthic amphipods.[2] Higher lipid content may reduce sensitivity to lipophilic contaminants (e.g., organochlorine pesticides) in

[2] Lehtonen, K. 1996. Ecophysiology of the benthic amhipiod *Monoporeia affinis* in a open-sea area of the northern Baltic Sea: seasonal variations in body composition, with bioenergetic considerations. Marine Ecology Progress Series 143: 87-98.

sediment toxicity tests. Meador (1993) observed an increased sensitivity to tributyltin in two amphipod species (*Eohaustorius* and *Rhepoxynius*) that was correlated with lower lipid concentrations.[3] Variation in contaminant sensitivity related to tissue lipid content is not likely to be detected with standard reference toxicants, which are typically trace metals.

Phytotoxins: Darrin Greenstein conducted at least one experiment with microcystin, but did not observe an effect. These toxins have been detected in sediments. Microcystin LR is available and could be tested to describe the dose response relationship. **Bryan Brooks** stated that biological, chemical, and physical factors influence the development of harmful algal blooms, but predictive models of how these factors control bloom formation are needed to understand site-specific bloom dynamics. **Swee Teh** has knowledge of bloom conditions and knows that the microcystin toxin can be present in the northern San Francisco Estuary water column. Some cyanobacteria actively release their toxins, but others do not. Cysts can also be a source of toxin exposure; they can be more toxic than the hatched organism. **Bryan Brooks** suggested examining the invertebrate literature (e.g., research on *Gammarus* or mayflies) to assess the potential for phytotoxin-related toxicity in the Bay. **Swee Teh** indicated that there is toxicity data for Bay area copepods. The 48-h LC-50 and LC-10 values for Microcystin-LR were 1.55 and 0.14 mg/L for *Eurytemora affinis*; and 0.52 and 0.21 mg/L for *Psuedodiaptomus forbesi*.[4] Dietary *Microcystis* has also been shown to cause copepod mortality and may be cause adverse impacts on Bay zooplankton. [5] The optimal conditions for bloom and toxin production are species and region specific, and there is a great amount of interaction among habitat parameters and species.

Rob Burgess suggested looking at TIE methods suitable for phytotoxins (e.g., identifying potentially useful existing methods based on chemical structures of selected toxins). **Sue Norton** suggested this is a high priority, at least for discussion purposes (try to mine the literature).

Howard Bailey suggested a higher priority be given to metals not traditionally considered to be important causes of toxicity (Mn, etc.). Examining minerals (Ca, Mg, etc.), and paying attention to ionic imbalance was also suggested. This could be accomplished by mining existing data.

Organics: Pesticides are still considered high priority. **David Moore** suggested looking at PBO (piperonyl butoxide) as an additional stressor compound. Emerging pesticides with high toxicity such as fipronil should be included in chemical monitoring, but these compounds did not account for the occurrence of toxicity in past data.

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[3] Meador, J.P. 1993. The effect of laboratory holding on the toxicity response of marine infaunal amphipods to cadmium and tributyltin. Journal of Experimental Marine Biology and Ecology 174:227-242.
[4] Ger, K.A., S.J. Teh, C.R. Goldman. 2009. Microcystin-LR toxicity on dominant copepods *Eurytemora affinis* and *Pseudodiaptomus forbesi* of the upper San Francisco Estuary. Science of the Total Environment 407:4852-4857.
[5] Ger, K.A., S.J. Teh, D.V. Baxa, S Lesmeister, C.R. Goldman. 2010. The effects of dietary *Microcystis aeruginosa* and microcystin on the copepods of the upper San Francisco Estuary. *Freshwater Biology* 55:1548-1559.

Tom Mumley stated that pyrethroids were low in the Bay, although much higher in the creeks, and that emerging chemicals would not explain past data; therefore, these should not be a high priority.

Polyaromatic hydrocarbons (PAHs) should still be listed as a high priority, although some of the data gaps have been filled. There was a suggestion to mine the chemistry data in order to try to predict toxicity using PAH toxicity models.

Polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) were considered to be of low priority because they are not expected to cause toxicity over the short term exposures used in the *Eohaustorius* sediment toxicity test. **Meg Sedlak** asked if any PCB-11 dose response studies are being performed on invertebrates. **Rob Burgess** replied that they are simply not very toxic, but **Chris Ingersoll** believed that they could cause sublethal toxicity in exposures greater than 10 days.

The influence of pharmaceuticals and personal care products (PPCPs) on sediment toxicity is very under-studied, but **Bryan Brooks** stated that some can act like pesticides in terms of cholinergic interactions. These include antihistamine pharmaceuticals. **Howard Bailey** thought this could be a possibility. **Bryan Brooks** noted that many PPCPs partition strongly to sediment and are persistent in the environment.

Other Factors: Variations in temperature and pH (e.g., ocean acidification) are not likely to be important, as they are controlled in laboratory tests; however, temperature could be a useful TIE treatment. Acclimation of test organisms and predators were identified as potentially important factors. Sediment organic enrichment of total organic carbon was considered not to be a likely cause of toxicity at the levels typically present in the Bay.

Chris Ingersoll suggested that non-optimal levels of grain size, temperature, or something else in the test system might make *Eohaustorius* temperamental. He suggested that the test temperature could be warmer and potentially more stable. **Ted DeWitt** mentioned that these critters are pretty tough considering the environment that they live in. **Brian Anderson** was concerned about temperature from the acclimation/health aspect.

David Moore asked what the dominant amphipod species in The Bay was. **Brian Anderson** responded that it was *Ampelisca* and maybe *Corophium*, but *Ampelisca* is introduced. If *Haustoriid* is used in evaluations, then *Eohaustorius* is a good choice ecologically because it is the most habitat-diverse.

Data Analysis and Research Designs:

Discussion in the afternoon focused on the development of plans to address the priority issues identified in the morning. Three types of activities were suggested by the workshop participants:

- **Analysis of existing data sets** to investigate the influence of factors related to animal condition, predation, sedimentology, and nontraditional contaminants. There is a wealth of high quality monitoring data with matched chemical, toxicity, and benthic community data that can be used to look for associations among some factors of interest. Such analyses represent "low hanging fruit" and can be accomplished rapidly and at modest cost. Multiple types of analyses were suggested, including:

  a) Compile collection/acclimation data on test animals and compare to toxicity patterns.

  b) Examine correlation of coarse grain size fraction or other sedimentological characteristics to toxicity (possibly multivariate or alternative statistical methods).

  c) Characterize presence of predators or other infauna likely to impact *Eohaustorius* survival and relate to toxicity results

  d) Examine association of other chemical analytes (e.g., Mn, Ca) with toxicity patterns. Might indicate whether ionic imbalance is a significant factor.

  e) Use various statistical methods to evaluate the association between various contaminant mixtures and toxicity. Pay particular emphasis to factors that correspond to seasonal variations in toxicity.

  f) Compare San Francisco Bay monitoring data to southern California data in order to identify similarities/differences in relationships between chemistry and toxicity.

  A work plan should be developed prior to conducting additional data analyses. The plan should identify the effects that are to be explained, as well as the seasonal and spatial scope of the analyses.

  Data sets from regions outside of the Bay (e.g., southern California, Yaquina Bay, Puget Sound) should be used to help validate cause-effect models developed from analyses of Bay monitoring data. The relationships between *Eohaustorius* survival and environmental/health factors should be broadly relevant to other regions if these factors constitute true constraints on the application of the test.

  While such analyses are likely to be productive and should help to confirm preliminary hypotheses, they may not yield definitive results due to lack of data on key parameters.

- **Sediment TIE studies**. Relatively few TIE studies have been conducted for San Francisco Bay sediments using the *Eohaustorius* test. While the low level of toxicity presents a challenge, application of modified/cost efficient TIE methods at multiple sites would help confirm existing conclusions/hypotheses regarding toxicants of concern. For example, it might be useful to focus on a limited number of TIE treatments (i.e., a targeted TIE design) that are most helpful for distinguishing between major contaminant classes and sediment characteristics.

- **Laboratory experiments and new analyses** to investigate influence of priority factors on *Eohaustorius*. Existing information is not sufficient to evaluate the role of several high priority potential stressors identified by the workshop, such as sedimentological characteristics, phytotoxins, and test animal condition. Several types of studies were suggested, but additional discussion among workshop participants is needed to develop specific research plans. Suggestions included:

    a) Conducting exposure to various fractions of natural sediments and looking for relationships between particle size/morphology and biological response (e.g., mortality, external abrasion, lacerations). Include a grain size control (or concentration series) with test batches containing sediments with high fines content.

    b) Analyses of gut contents to determine if phytotoxins or harmful algae are present

    c) Measurement of tissue lipids, stress biomarkers, or other condition measures (e.g., reburial ability to exhaustion) as an index of initial test animal condition and investigating correlation to toxicity results.

    d) Conduct interstitial water toxicity tests on a subsample of sediments that demonstrate marginal toxicity (i.e., 20-40% mortality) to assess the role of the presence of particles on toxicity

    e) Using representative commercially-available phytotoxins, conduct toxicity tests to evaluate the magnitude of toxicity to *Eohaustorius*

Next Steps

The workshop concluded with an agreement to continue discussion and development of research designs. The participants were encouraged to develop and circulate draft designs for studies/analyses among the group over the next two months. Two additional activities were planned:

- Early January: The workshop organizers will use input from the group to develop several draft study designs for discussion and refinement
- Late January: Hold a conference call among the participants to develop final recommendations.

Table 1. Participants in the November 16, 2012 workshop.

Name	Organization
Brian Anderson	UC Davis Marine Pollution Studies Laboratory
Howard Bailey	Nautilus Environmental
Steve Bay	Southern California Coastal Water Research Project
Chris Beegan	State Water Board
Bryan Brooks	Baylor University
Rob Burgess	USEPA Narragansett Laboratory
Don Cadien	LA County Sanitation Districts
Eric Chavez	NOAA National Marine Fisheries Service
Ted DeWitt	USEPA Hatfield Marine Science Center
Jay Field	NOAA Office of Response and Restoration
Darrin Greenstein	Southern California Coastal Water Research Project
Chris Ingersoll	US Geological Survey
David Moore	Weston Solutions
Tom Mumley	San Francisco Regional Water Quality Control Board
Ellen Willis-Norton	San Francisco Estuary Institute
Susan Norton	USEPA ORD National Center for Environmental Assessment
Bryn Phillips	UC Davis Marine Pollution Studies Laboratory
Meg Sedlack	San Francisco Estuary Institute
Jim Shine	Harvard School of Public Health
Karen Taberski	San Francisco Regional Water Quality Control Board
Swee Teh	UC Davis Aquatic Health Program
Josh Westfall	LA County Sanitation Districts

Table 2. Assessment of stressors of concern for San Francisco Bay sediment toxicity by workshop participants. Toxicity potential is a relative assessment of the sensitivity of response of the 10-day amphipod survival test to the stressor; magnitude of exposure is a relative assessment of the likelihood that toxic levels of the stressor are present in areas of San Francisco Bay distant from discharge sites; TIE method indicates whether currently available sediment TIE methods are likely to affect the stressor; Workshop I refers to the April 2010 TIE workshop in Oakland; Workshop II refers to the November 2012 TIE workshop in Long Beach. Bold type indicates a new or changed category. Shaded rows indicate high priority stressors.

Stressor	Toxicity Potential	Magnitude of Exposure	TIE Method	Workshop I Priority	Workshop II Priority
Biological Products					
NH3	High	Low	Yes	Low	Low
H2S	High	Low	Yes	Low	Low
Cyanototoxins	**Unknown**	**Unknown**	**No**	**Not Discussed**	**Moderate**
Anenome nematocysts	**Unknown**	**Unknown**	**No**	**Not Discussed**	**Low**
Sedimentological/Physical Characteristics					
Grain Size **Clay Size** **Shape**	**Uncertain**	**Uncertain**	**No**	**High**	**High**
Shells	**Uncertain**	**Variable**	**Yes**	**Not Discussed**	**High**
Smothering by oils	Uncertain	Unknown	No	Low	Low
Ecological Factors					
Animal Interactions	**Uncertain**	**Uncertain**	**No**	**Not Discussed**	**High**
Eohaustorius **Health & Acclimation**	**Uncertain**	**Uncertain**	**No**	**Not Discussed**	**High**
Metals					
Cations (Cu, Zn, Cd)	Low	Low	Yes	Low	Low
"Other" cations **(Mn, Mg, Fe, Ca)**	**Uncertain**	**Uncertain**	**Unknown**	**Not Discussed**	**High**

Anions (As, Cr)	Low	Low	Yes	Low	Low

Table 2. Continued.

Organic Compounds					
Organochlorine Pesticides	**High**	**Low**	**Yes**	**High**	**Low**
Organophosphate Pesticides	High	Moderate	Yes	Low	Low
Pyrethroid Pesticides	**High**	**Moderate**	**Yes**	**High**	**Low**
Other Pesticides	High	Uncertain	Yes	High	High
Fungicides & Herbicides	Unknown (low?)	Unknown	Yes	Moderate/Low	Low
PAHs	**High**	**Moderate**	**Yes**	**High**	**Low**
PCBs	Moderate	Low	Yes	Moderate/Low	Low
PBDEs	Unknown	Low	Yes	Low	Low
PPCPs	Unknown	Unknown	No	Low	Low
Other nonpolar organic compounds	Unknown	Unknown	Yes	Unknown	Not Discussed
Mixtures	**Unknown**	**Unknown**	**Some**	**Not Discussed**	**Moderate**