DRAFT

SECTION 21

Environmental Risk Assessment Guidance for Marine Coastal Environments in Hawaii

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Contents

Figures

Tables

Appendices

Acronyms and Abbreviations

µg/kg	Microgram per kilogram (ppb)
ANZECC/ARMCANZ	Australian/New Zealand Environment and Conservation Council / Agriculture and Resource Management Council of Australia and New Zealand
ASTM	American Society for Testing and Materials
AVS/SEM	Acid-volatile sulfide and Simultaneously Extracted Metals
BERA	Baseline Ecological Risk Assessment
BSAF	Biota-to-Sediment Accumulation Factor
CBR	Critical Body Residue
CCME	Canadian Council of Ministers of the Environment
COPEC	Contaminant of Potential Environmental Concern
CSM	Conceptual Site Model
DQO	Data Quality Objective
DU	Decision Unit
EAL	Environmental Action Level
ERA	Ecological Risk Assessment
ER-L	Effects Range-Low
ER-M	Effects Range-Median
ESA	Endangered Species Act
FWS	Fish and Wildlife Service
GIS	Geographic Information System
HDOH	(State of) Hawaii Department of Health
HEER Office	(HDOH) Hazard Evaluation & Emergency Response Office
HMW	High Molecular Weight
HQ	Hazard Quotient
ISQG	Interim Sediment Quality Guideline
LMW	Low Molecular Weight
LOAEL	Lowest Observed Adverse Effect Level
MC	Munitions Contaminants
mg/kg	Milligram per kilogram (ppm)
MHI	Main Hawaiian Islands
MIS	Multi Increment Sampling

NAVFAC	Naval Facilities Engineering Command
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No Observed Adverse Effect Level
NWHI	Northwest Hawaiian Islands
OC	Organic Carbon
PAH	Polynuclear aromatic hydrocarbon
PCB	Polychlorinated Biphenyl
PDBE	Polybrominated Diphenyl Ether
ppb	Part per billion
ppm	Part per million
SAP	Sampling and Analysis Plan
SQG	Sediment Quality Guideline
SLERA	Screening Level Ecological Risk Assessment
SUF	Site Use Factor
SVOC	Semi-Volatile Organic Compound
TBT	Tributyltin
TCDD	Tetrachlorodibenzo-p-dioxin
TEF	Toxic Equivalence Factor
TEQ	Toxic Equivalent
TGM	Technical Guidance Manual
TOC	Total Organic Carbon
TRV	Toxicity Reference Value
UCL_{95}	95 percent upper confidence limit on the mean concentration
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	Volatile Organic Compound

21.0 ECOLOGICAL RISK ASSESSMENT GUIDANCE FOR COASTAL MARINE ENVIRONMENTS IN HAWAII

An investigation of contaminants in coastal marine and estuarine sediments in Hawaii is necessarily influenced by the geophysical realities of the islands themselves and the dynamic Pacific Ocean. A brief introduction to the processes that create and redistribute sediments in Hawaii provides a context for the specific guidance on conducting ecological risk assessments (ERAs) in Hawaii.

The shield volcanoes that make up the main Hawaiian Islands are composed mainly of basaltic lavas. Erosion by wind and water break down these basaltic rocks into smaller particles that are transported into streams and ultimately deposited along the coast. At the same time, carbonate sediments derived from marine organisms in the surrounding waters are carried shoreward and deposited along the coast to form beaches (Fletcher et al. 2012). The processes of erosion and deposition of these two major sediment types creates a patchwork of unconsolidated substrates throughout coastal Hawaii. Physical characteristics of the sediment particles, such as grain size and associated organic carbon, play a substantial role in the fate and transport, bioavailability, and toxicity of contaminants in the marine environment. These topics are introduced briefly below.

Grain size is a primary characteristic of sediment that influences the fate and transport of chemicals within the marine or aquatic environment. Geologists identify sediments by size fractions (gravel, sand, silt, and clay) and classify sediments based on the ratio of size fractions using the Wentworth grade scale (USGS 2006):

gravel	2 mm
sand	<2 mm to >62.5 µm
silt	<62.5 µm to >4 µm
clay	< 4 µm

Geological reports typically define the top 2 cm below the sediment/water interface as surficial sediment (USGS 2006). However, standard practice in ERAs is to focus on the top 10 to 15 cm (about 4 to 6 inches), the biotic zone, where exposure of ecological receptors is greatest.

Many chemicals that cause ecological effects (such as metals, pesticides, PCBs) are known to be associated most strongly with finer-grained sediment, especially silts and clays (also called "muds") (Morrison et al. 2011). Fine-grained sediments generally accumulate in coastal bays and other sites where wave energy is low or absent. Contaminant concentrations are expected to be highest in such depositional areas where particles smaller than 62.5 µm accumulate (NRC 1989, Grabe and Barron 2003). In contrast, sites with predominantly sand or gravel are less likely to contain toxic levels of contaminants (Morrison et al. 2011).

One of the first studies to demonstrate the importance of grain size in sediment toxicity and bioavailability evaluations focused on PCBs in coastal marine sediments on the Mediterranean coast of France. The survey documented accumulation of low chlorinated PCB congeners with the sand-size fractions (> 63 µm) and of high chlorinated congeners with the silt-size fractions (< 63 µm). Greater bioavailability and toxicity were associated with the congeners in the fine-grained sediments (Pierard et al. 1996). Later studies in coastal marine harbors in the mainland United States corroborated these findings (Ghosh et al. 2003). Concentrations of dioxins and furans (PCDD/Fs) are also known to increase as grain size decreases in marine sediments (Lee et al. 2006). However, higher chemical

concentrations may not accurately represent bioavailable fractions when chemicals are bound to finer-grained sediment.

The association of PCBs with fine-grained sediments has been demonstrated in tropical habitats, as well. In a highly-contaminated marine bay in Puerto Rico, PCB concentrations were shown to be influenced not only by grain size, but also by organic content. Moreover, microbiological characteristics (biofilm, bacteria levels, and microbial community composition) acted on the PCBs to reduce chlorination levels both in deeper anoxic sediment and shallow well-oxygenated sediments (Klaus et al. 2016). Toxic levels of lead are reported to be associated with fine-grained particulates carried by certain urban streams on Oʻahu, Hawaiʻi (Hotton and Sutherland 2016).

Coastal habitats in Hawaii may contain a mixture of sediment grain sizes from various sources, creating complex sediment profiles and challenging risk assessment scenarios. For example, Hanalei Bay on the north side of Kauai receives fine-grained terrestrial basaltic sediment from taro fields delivered by the Hanalei River. Sand-sized sediment particles composed of calcium carbonate from nearshore coral reefs are transported into the bay by wave action. The Hanalei River carries so much suspended sediment that it often exceeds federal water quality standards for turbidity (Takesue et al. 2009). Despite the dominance of fine-grain sediments near the river mouth, organochlorine pesticides, PAHs, and metals were detected in sediment at very low levels. Concentrations of organic chemicals in Asian clam (*Corbicula fluminea*), giant mud crab (*Scylla serrata*), and Akupa sleeper fish (*Eleotris sandwicensis*) were also below ecological effect levels (Orazio et al. 2010). These findings suggest that measured concentrations of organic chemicals in sediments may not be 100 percent bioavailable. In contrast, sediment pore water was toxic to sea urchin fertilization (but not development) in clay and mud samples near the river mouth (Carr and Nipper 2007; Cochran et al. 2007). Further complicating the interpretation of ecological risk at this site is the seasonal influence of waves, which can flush out the finer-grained sediment from the bay during winter storms (Takesue et al. 2009).

The studies in Hanalei Bay illustrate the difficulty of drawing conclusions about ecological risk from a single line of evidence. Concentrations of chemicals in sediment of different grain sizes, surface water, pore water, and biota may all contribute to risk, but no single measure can adequately characterize the site. Actual exposure of ecological receptors to contaminant in sediment is influenced by both the presence and bioavailability of contaminated sediment and the absence of wave energy that removes sediment from the site. Although substantial deposition of fine-grained terrestrial sediment containing contaminants could indicate potential ecological risk, the regular winter flushing at this site reduced the risk to acceptable levels (Orazio et al. 2007, Takesue et al. 2009).

Beaches are eroding across Hawaiian Islands that have been evaluated (Kauaʻi, Oʻahu, Maui) more than accreting (Fletcher et al. 2012) and coastal erosion is expected to nearly double over the next few decades across areas studied, except Kailua Beach on Oʻahu (Anderson et al. 2015). Nevertheless, sediment dynamics are spatially variable, and areas of erosion and accretion may be separated by only a few hundred meters. Each small embayment created by rocky headlands is influenced by local wave energy and terrestrial processes, creating a patchwork of erosion and accretion along the shore. The most recent data on coastal erosion and accretion of shorelines on Kauai, Oahu, and Maui are available at http://pubs.usgs.gov/of/2011/1051/) (Fletcher et al. 2012). This USGS information should be consulted during the site characterization phase of the SLERA (See Section 21.3.3).

Data on grain sizes are site-specific; there is no comprehensive assessment for the state, as grain size on beaches changes seasonally due to wave energy. Most beaches are sand and thus less conducive to adsorbing contaminants compared with finer-grained silt and clay fractions (Storlazzi 2016, personal

communication). The risk assessor should review available data on grain size at the site. If grain size has not been adequately characterized at the site (considering season and specific location), data collection should be considered prior to initiating an ERA. If the site is predominantly sand, the need for conducting additional chemical characterization in the area should be evaluated. Based on the CSM, additional chemical characterization may or may not be necessary. If the site has a patchy distribution of grain sizes, chemical characterization should focus on areas where silts and clays are dominant.

The HEER Office ERA program for marine coastal environments provides guidance for conducting screening level ERAs (SLERAs) and Baseline ERAs (BERAs) in these coastal habitats. Alternative approaches or methods to the guidance provided in this section may be acceptable, but should be discussed with the HEER Office for approval. The ERA program is process-oriented in that a site progresses only as far as required by the site-specific characteristics. The level of effort devoted to preparing and submitting information to the HEER Office is determined by the level of risk posed by the site. A site may exit the process at any of several points marked by management decisions and supported by technical analysis.

An ERA at a marine sediment site typically begins as a SLERA, and then may proceed to a more site-specific and in-depth BERA, if necessary. In many cases, the ERA will be conducted as part of a larger site investigation, although some sites may be addressed as strictly ERA sites. In both instances, the overall approach to conducting an ecological site investigation should generally be consistent with guidance elsewhere in the TGM, particularly in the following sections:

- **TGM Section 3<link>:** ***Site Investigation Design and Implementation***
- **TGM Section 4<link>:*****Decision Unit Characterization***
- **TGM Section 5<link>:** ***Field Collection of Soil and Sediment Samples***

This ERA guidance is specific to the tropical marine environment of Hawai‘i, but draws on decades of technical development of ERA methods by federal agencies in the U.S. and their counterparts in Australia and New Zealand, individual state agencies, independent researchers, and universities. This guidance combines the widely-used U.S. EPA framework, which provides a logical step-wise approach to conducting ERAs, with a more regionally focused approach suitable for tropical marine ecosystems. The HEER Office has developed this regionally-focused guidance to efficiently evaluate exposure and effects using Hawai‘i-specific receptor and toxicity data wherever it is available. Readily available ecological exposure and effects data for 22 marine species in Hawai‘i are compiled in this guidance (see Appendix 21-A). As additional ERAs are prepared and more Hawai‘i-specific data become available, the on-line ERA TGM guidance will be updated to fill data gaps and refine exposure and effect default values and assumptions.

The HEER Office assumes that consultants and risk assessors using this guidance are familiar with the concepts and terminology of ERAs. Complete citations for references cited in this ERA guidance are provided in Section 21.7. Appendices to this guidance contain additional information, as follows:

APPENDIX 21-A SPECIES PROFILES AND EXPOSURE/EFFECTS DATA
APPENDIX 21-B ERA SCOPING CHECKLIST
APPENDIX 21-C DEFINING ECOLOGICALLY-BASED DECISION UNITS
APPENDIX 21-D HABITAT PROFILES
APPENDIX 21-E EVALUATING BIOACCUMULATING CHEMICALS
APPENDIX 21-F REFINING ASSUMPTIONS OF BIOAVAILABILITY

The risk assessor is responsible for providing technical justification for the methods and assumptions that underlie the ERA. All references cited in the ERA must be made available for review by the HEER Office upon request. The HEER Office maintains a large library of peer-reviewed literature and government reports that may be useful to the risk assessor. Close coordination with the HEER Office will provide opportunities to share references and ensure that the most current useful information is available throughout the ERA process.

21.1 Framework for Ecological Risk Assessments

An ERA is a qualitative and/or quantitative appraisal of the actual or potential effects of one or more chemicals on plants and animals in the wild. At its simplest, risk can be defined as a function of the overlap in space and time of a stressor (a chemical) and a living organism (a receptor) where the stressor causes some adverse effect on the receptor. The process of risk assessment is designed to (1) identify the distribution and magnitude of chemical stressors; (2) identify the locations of living organisms that are sensitive to the chemical stressor; and (3) quantify the probability that the receptor will be exposed to the stressor *and* experience adverse effects related to the exposure.

This simple model of spatial and temporal overlap of a chemical and an organism is rarely encountered in the field, however. Instead, ERAs must often address sites where multiple chemicals have been released into several media (soil, groundwater, sediment, surface water) and numerous receptors are potentially exposed during all or part of their complex life cycles. Chemicals may be present but physically bound to media so that they do not exert a toxic effect on organisms. Concentrations of chemicals in background/ambient/reference samples may confound the interpretation of risk at the site. Information on the sensitivity of local organisms to the chemicals at the site may be unavailable. These and other difficult issues make the ERA process complex and add to the uncertainty of decisions based on ERA results.

In an effort to strengthen and streamline the ERA process, USEPA published an 8-step framework for ERAs that has been widely adopted, with modification, by national and state programs around the world (USEPA 1992). Steps 1 and 2 of the USEPA framework, generally referred to as the SLERA, are primarily based on limited site-specific sediment data and default assumptions about exposure and effects. Oftentimes, the SLERA incorporates the initial part of Step 3 (commonly referred to as Step 3a) in which the conservative default assumptions of Steps 1 and 2 are refined to focus the ERA process on the chemicals and receptors of greatest concern at the site. This HEER Office guidance includes Step 3a in the SLERA.

In addition to the USEPA framework, information and technical advances from the Australian/New Zealand Environment and Conservation Council / Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ) Guidance on ERAs will continue to be evaluated as they pertain to tropical marine sediments. Tables and data in the HEER Office TGM will be updated periodically as new information becomes available from sources relevant to tropical marine environments.

The risk assessor should realize that preparing an ERA is seldom a simple or linear process. More often, the risk assessor will work with data from many disciplines, including geologists, hydrologists, toxicologist, ecologists, and chemists to develop an understanding of the unique situation at the site. Some of the required elements may be available to the risk assessor from the start, while others may

prove to be unobtainable within the time frame of the investigation. The steps and tasks can be approached in a different order; some processes may run concurrently and some may be repeated as the need for additional information becomes apparent. The risk assessor should maintain communication with the HEER Office and seek confirmation and clarification on the chosen approach whenever necessary.

21.2 Determine the Need for a SLERA

An ERA is not required at every site where a release of chemicals has occurred. Sites where no ecological habitat exists or exposure pathways are incomplete are not required to be evaluated for ecological risk. Areas of coarse-grained sediment and high wave energy may require little or no investigation (see *ERA Scoping Checklist* in Appendix 21-B). To determine the need for an ERA, a person familiar with the site should complete the *ERA Scoping Checklist* (Appendix 21-B). The checklist is designed to help the risk assessor characterize the ecological setting of the target site and to identify complete and potentially important ecological exposure pathways. The checklist guides the risk assessor through the process of identifying relevant documents and organizing available information on the need for an ERA, referring to sections of this HEER Office ERA Guidance when necessary. The *ERA Scoping Checklist* should be completed early in the investigation process to support a determination on the need for a SLERA at the site.

The preparer submits the *ERA Scoping Checklist* to the HEER Office for review. The HEER Office confirms that the checklist is complete and recommends future action, if warranted. If the *ERA Scoping Checklist* indicates that the site is excluded from ERA requirements, no other action is necessary. If the *ERA Scoping Checklist* indicates that exposure pathways are potentially complete and ecological habitat may be affected, then the risk assessor should initiate a SLERA in accordance with this guidance.

Sites where a potential ecological risk occurs may be evaluated using a SLERA, a BERA, or both. Most sites begin with the SLERA, although this is not strictly required. If the risk assessor believes that site conditions are relatively certain to warrant a BERA, then it is not necessary to conduct a separate SLERA. The conceptual elements of a SLERA will ultimately be incorporated into the BERA, but skipping the SLERA steps can save the risk assessor time and effort that can be better dedicated to the BERA. The risk assessor should consult with the HEER Office to obtain agreement on such an approach before initiating a BERA.

21.3 Screening Level Ecological Risk Assessment

Unlike the *ERA Scoping Checklist*, which can be completed by anyone familiar with the site, the SLERA should be prepared by a person or a team with knowledge of the chemicals, receptors, exposure pathways, and other ERA elements necessary to the investigation.

The purpose of the SLERA is to focus investigation and remediation on sites and chemicals that may pose an unacceptable risk to ecological receptors. The SLERA provides an opportunity for a site to exit the ERA Program with a minimum of effort if the site truly poses very little or no risk to ecological receptors. In cases where the entire site cannot be shown to pose a level of risk below applicable screening levels or alternate (approved) decision level based on a more a detailed evaluation, selected chemicals or receptors may still be identified for possible elimination from further investigation in later steps of the ERA.

21.3.1 Preparing for a SLERA

If the ERA is being conducted as part of a larger site investigation, data collected for other purposes may be available to initiate the SLERA, as shown in Step 1b (Table 21-1). For example, sites where a chemical release happened some time ago may have been investigated for risk to human health. Sites where a discrete release of chemicals occurred may have been subjected to emergency removal actions and/or an investigation of residual risk. In such cases, the risk assessor should gather all available data from the site in preparation for the SLERA. Note that the existence of data from an umbrella investigation does not necessarily mean that no additional samples will be required. Available site-specific data are reviewed for usability during Step 1b and the need for additional data to adequately characterize current site conditions is determined. The risk assessor is encouraged to consult with the HEER Office if unsure about the need for additional data collection. Of special concern is the potential need for additional data collection in cases where existing data were based on a small number of discrete samples, which are not likely to be representative of the decision unit (see Section 4<link>). On the other hand, the risk assessor may have access to additional site-specific data not typically required for a SLERA (such as field-collected tissue samples). In such cases, the additional data can certainly be used in the SLERA to support a decision on the need for further investigation (see Step 2).

If the SLERA is being conducted outside the context of a larger investigation, then some additional steps will be necessary to initiate development of data collection suitable to support a SLERA. (Step 1a, Table 21-1). Guidance on conducting a general site investigation is provided in Sections 3.0<link>, 4.0<link>, and 5.0<link> of the TGM. Specifically, any field sampling and analysis plan (SAP) should be prepared in accordance with the decision unit (DU) and Multi Increment sampling (MIS) approach described in the TGM. Additional guidance on defining DUs for ERAs is in Appendix 21-C.

The risk assessor should review the pertinent sections of the TGM, then consult with the HEER Office for assistance in developing a SAP that satisfies the requirements of a SLERA.

Table 21-1. SLERA Framework

Only as Needed:	**Step 1A: Develop and Implement Screening Level Sampling and Analysis Plan (if available data are not adequate to support a SLERA)**	
	Activities: If site-specific data are not available, prepare a sampling and analysis plan (SAP) in accordance with site investigation guidance in Section 3<link>, 4<link>, and 5<link> of the TGM, including clear data quality objectives (DQO). Once data are available, complete the outputs in Step 1B and then proceed to Step 2 below.	**Outputs:** • DQOs • SAP • Maps or figures of site, including habitats and proposed sample locations • Data tables (if analytical data are available) • Preliminary Conceptual Site Model (CSM)

Step 1b: Screening Level Site Characterization Data and Ecological Effects Evaluation	
Activities: Task 1-1: Describe environmental setting (location, habitats, expected species, sources of chemicals, previous investigations) Task 1-2: Compile available site-specific and background, ambient, and reference analytical data (from *ERA Scoping Checklist* or other sources); include a description of ecotoxicity and bioaccumulative potential of target chemicals Task 1-3: Select assessment and measurement endpoints (see USEPA 1996; 2005a) Task 1-4: Identify exposure pathways and ecological receptors Task 1-5: Develop preliminary CSM	**Outputs:** • Maps or figures of site • Data tables • Assessment and Measurement Endpoints identified • Preliminary CSM
Step 2: Estimate Preliminary Exposure Concentrations and Calculate Hazard Quotients	
Activities: Task 2-1: Compile screening levels for all media in your dataset. Sediment quality guidelines (SQG) are in Table 217<link>. Surface water, groundwater, and sediment pore water should be screened against HEER Office Environmental Action Levels (EALs) for aquatic toxicity (aquatic habitat goals), surface water, and/or groundwater, as applicable and if included in this guidance (see HEER Office EAL Surfer tool<link>). USEPA National Water Quality Criteria (U.S. EPA 2016, or current reference) can be referenced for chemicals not included in HEER Office EALs (if available).Tissue concentrations may be compared with critical body residues (CBR) reported in the literature). Toxicity reference values (TRV) for receptors evaluated through food chain modeling (e.g. mammals and birds) may be derived from published studies and reports. Task 2-2: Estimate average exposure concentrations that are representative for sediment and/or water decision units at the site (see Sections 3<link>,4<link>, and 5<link>.	**Outputs:** • List of applicable screening levels (and source) for selected media and receptors • Estimated contaminant levels in site decision units/media compared with screening levels • Summary of HQs • Identification of COPECs • Decision Statements

Task 2-3: Calculate daily dose for higher trophic level receptors (birds and mammals). Task 2-4: Calculate hazard quotients (HQ) using *representative DU-MIS concentrations for sediments/no effect screening levels, representative pore water or surface water concentrations/no effect screening levels,* or *maximum tissue concentrations* to calculate daily doses for comparison with low TRVs. Task 2-5: Summarize HQs, identify chemicals of potential ecological concern [COPEC], and make a decision about the site. If risk is potentially unacceptable, continue to Step 3A), otherwise the ERA process can stop.	
Step 3a: Refine Screening Level Default Assumptions	
Activities: Task 3-1: Compile available data representing background, ambient, or reference concentrations and submit to the HEER Office for concurrence. Compare the site sediment and/or water concentrations with background, ambient, and reference concentrations, as available. Task 3-2: Evaluate the magnitude of exceedance, frequency of detection, and distribution of exceedances in sediment (and water, if appropriate) at the site to determine whether any chemicals should be eliminated as COPECs. Task 3-3: Confirm that the data used are reasonably representative for decision units at the site. Evaluate the reasonableness of default conservative exposure assumptions (100 percent bioavailability of chemicals, 100 percent site use by receptors, maximum chemical concentrations, etc.) and adjust assumptions (if appropriate). Consider the influence of geophysical and geochemical parameters such as grain size, total organic carbon, pH, and other factors on bioavailability of chemicals. If the area is known to be erosional, consider the short-term and long-term fate of contaminated sediments.	**Outputs:** • Data tables of background or reference concentrations • Technical justification for adjusting exposure assumptions and concentrations • Table of adjusted HQs • Technical justification for elimination of COPECs, if applicable • Decision Statements

Task 3-4: Confirm with HEER Office that the Step 3a refinements are technically defensible based on site conditions. Task 3-5: Recalculate HQs using more realistic representative exposure concentrations. Task 3-6: Summarize HQs, evaluate uncertainty, and develop risk characterization to support a decision about the site. If risk is potentially unacceptable, continue to the baseline ERA (BERA); if not, the ERA process can stop.	

21.3.2 Components of a Marine Sediment SLERA

In the interest of streamlining the SLERA process and promoting consistency among SLERAs, the HEER Office provides examples or templates for many of the common components of a SLERA. Additional examples/templates will be added to this TGM as they are developed.

Table 21-2. Components of a Marine Sediment SLERA

Required Information	Source of Information
Representative concentrations of chemicals in sediment from the site	Risk assessor (representing site owner/regulated community) compiles available site-specific data.
Sediment Quality Guidelines (SQG), HEER Office EALs and background/ambient/reference concentrations	HEER Office provides SQGs for most target chemicals (See Table 21-7<link>); HEER Office provides EALs for aquatic toxicity, surface water, and groundwater (see EAL surfer<link>; risk assessor supplements as needed.
Potential receptors (identified by habitat or exposure guild)	HEER Office provides species profiles and exposure/effects data (Appendix 21-A<link>, habitat profiles (Appendix 21-D); risk assessor selects and augments as necessary.
Conceptual Site Model (CSM) (identifying pathways and representative receptors)	HEER Office provides examples for several habitats (Figures 21-2 through 21-7); risk assessor customizes to site and supplements when necessary.
Sediment dynamics (erosional or depositional)	Risk Assessor provides, based on US Geological Survey reports (http://pubs.usgs.gov/of/2011/1051/) or site-specific data
Toxicological profiles for COPECs	Risk Assessor provides; HEER Office may assist with reference materials.
Exposure factors for assessment endpoint receptors	HEER Office provides examples for some common receptors; risk assessor supplements as necessary (Appendix 21-A).

21.3.3 Step 1B: Screening Level Site Characterization Data

The screening-level site characterization, known as preliminary problem formulation, serves as an organizing foundation for the SLERA. It incorporates physical, chemical, and biological elements and features of the site that will guide the ERA process. Although each site is different, Step 1B usually includes five tasks, which are introduced below and discussed in more detail in the sections below:

- Describe environmental setting (location, habitats, expected species, sources of chemicals, previous investigations) and summarize results of previous investigations [Step 1B, Task 1]
- Compile available site-specific, background, ambient, and reference analytical data (from *ERA Scoping Checklist* or other sources); include a description of ecotoxicity and bioaccumulative potential of target chemicals [Step 1B, Task 2]
- Select assessment and measurement endpoints [Step 1B, Task 3].
- Identify exposure pathways and receptors [Step 1B, Task 4]
- Develop preliminary CSM, [Step 1B, Task 5]

21.3.3.1 Step 1B, Task 1. Describe Environmental Setting

The environmental site setting includes a description of the location, habitats, expected species, sources of chemicals, and other site-specific information pertinent to the SLERA. The site setting should be based on information gathered during a site visit and/or readily available information.

The HEER Office has compiled a list of habitat types (see Table 21-3<link>) and more detailed information on several key habitat types in Hawai‘i (see Appendix 21-D<link>) to aid in developing the environmental setting and help foster consistency in ERAs across the state. Additional habitat profiles will be provided under subsequent phases of guidance development.

Habitat information in Appendix 21-D<link> should be augmented by the following site-specific information whenever possible:

- Physical description of the site including:
    - Size (acres)
    - Potentially affected habitats (mudflats, coral reefs, seagrass beds, etc.) [Include map or figure of location and habitat types.]
    - Sediment type or grain size distribution (coral rubble, coarse sand, silt, etc.)
    - Wave environment (high energy, low energy, protected harbor, etc.)
    - Salinity, tidal range (intertidal, subtidal), bathymetry, etc.
    - Erosional/Depositional area (see Fletcher et al. 2012)
- Current and historical uses of the site (known or suspected)
- Potential ecological receptors present at the site (per habitat within site)
- Surrounding land use
- Any potential sources of contaminants not related to the site activities (storm water outfalls, stream discharge, nearby industries, recreational vessel traffic, etc.)
- Known or suspected threatened and/or endangered species or other protected species/habitats within or adjacent to the site
- Maps, photographs, and figures of the site (current and historical)
- Any site-specific studies conducted at the site or in adjacent habitats

A habitat is considered important if it comprises a substantial portion of the site or provides high-value areas for target receptors. Provide as much detail as is available about the relative distribution of habitats within the site. For example, at a site that is 90 percent soft-bottom and 10 percent coral rubble covered with algae, both soft-bottom and algae-covered rubble would be included as important habitat types. The soft-bottom is spatially dominant and the algae-covered rubble provides sheltering and foraging habitat likely to be used disproportionately by some receptors.

Table 21-3. Unique or Distinct Aquatic Habitat Types and Locations in Hawai‘i

Habitat Type	Description/ Example Locations
Mudflats/Coastal Wetlands/Lagoon (Appendix 21-D)	Significant mudflats occur in Mamala Bay, Pearl Harbor, and Kāne‘ohe Bay
Rocky Intertidal and Tidepools (Appendix 21-D)	Rocky intertidal habitat dominates most shorelines of all islands where constant wave action, currents, steep submarine slopes, and a lack of offshore sand reservoirs limit the accumulation of sand. Ilio Point on Hawai‘i is a typical high-energy tidepool habitat.
Coastal Fishponds (Appendix 21-D)	Mamala Bay, Pearl Harbor, several around Kāne‘ohe Bay, and three on the southwestern coast of Kaua‘i; conversion to invasive mangrove habitat
Seagrass Beds (Appendix 21-D)	Significant seagrass beds are known from the inner reef flats of south Moloka‘i; ‘Anini (Kaua‘i); near Mamala Bay and Kāne‘ohe Bay; others exist but are not mapped
Mixed Sediment Bays and Harbors (Appendix 21-D)	Pearl Harbor; soft sediment overlaid on limestone platform of fossil reef origin; soft sediments often composed of carbonate grains derived from coralline algae, coral, mollusk fragments, foraminiferans, and tests of bryozoans and echinoderms
Young Volcanic Substrate; Little Sediment (profile not yet complete)	Big Island
Deep Channels (profile not yet complete)	‘Alenuihāhā Channel, between Hawai‘i and Maui
Soft Sediment Bays (profile not yet complete)	Hanale‘i Bay, Kaua‘i; no coral rubble
Sandy Beach (profile not yet complete)	Along the lagoon reaches of atoll islets and especially along the west and south sides of Kaua‘i, O‘ahu, Moloka‘i, Maui, Lāna‘i, and Hawai‘i; also along bays and coves on mature islands
Anchialine Pools (profile not yet complete)	Rocky shorelines on most islands, up to several hundred meters inland; The Kaloko-Honokohau Park on the western coast of Hawai‘i contains about 10% of Hawaii’s anchialine ponds.
Stream-fed Estuarine Wetlands (profile not yet complete)	Mamala Bay and Kāne‘ohe Bay, O‘ahu
Mangroves (Introduced) (profile not yet complete)	In addition to invading coastal fishponds (see above), mangroves have spread to mud flats and estuarine waters

Habitat Type	Description/ Example Locations
	around most of the Islands and to some rocky coastal areas around Hawaiʻi Island.
Subtidal Hardbottom (profile not yet complete)	Hardbottom occurs on every island; shallow benthic communities occur in depths of up to 50 meters or more, on basalts, and on consolidated limestone (reef carbonates, beach rock). The distribution of benthic communities is determined by light penetration, temperature, wave action, availability of substrate, and movement and accumulation of sediments.
Coral Reef (profile not yet complete)	About 80% of coral reef habitat in Hawaiʻi is in the Northwest Hawaiian Islands (NWHI), including atolls, islands, and banks. The high volcanic islands of the Main Hawaiian Islands (MHI) typically include non-structural reef communities, fringing reefs, and two barrier reefs (Kāneʻohe Bay and Moanalua Bay, Oʻahu).

Species at the Site

Species at the site should be grouped into two categories: (1) typical or common species and (2) threatened, endangered, or specially protected species. A list of typical or common species can be generated using Hawaii-specific publications and websites cited throughout this guidance. Profiles of select species are in

Information on threatened, endangered and otherwise protected species and habitats is widely available on websites published by state and federal resource agencies. The status of species and habitats may change over time. The risk assessor should check the websites below, and other websites, as necessary, to make sure the most current information is used in the ERA:

- The Hawai'i Department of Land and Natural Resources 700-page review, *Hawaii's Comprehensive Wildlife Conservation Strategy*, describes habitats, species, and threats across the MHI and NWHI (Mitchell et al. 2005; http://www.teaming.com/sites/default/files/Hawaii%20Wildlife%20Action%20Plan.pdf). This document lists and describes the distribution and abundance of species of "greatest conservation need," and provides locations and relative condition of key habitats; threats to species; conservation actions proposed; and plans for monitoring species and their habitats. Fact sheets address larger taxa or groups relevant to the marine ERA program, including waterbirds, seabirds, migratory shorebirds and waterfowl, anchialine pond fauna, marine mammals, marine reptiles, marine fishes, and marine invertebrates.

- Species *Recovery Plans*, critical habitat designations, and *5-Year Status Reviews* provide extensive information on life history and habitat requirements, as well as current threats to the species protected under the Endangered Species Act (ESA). Recovery plans for species under the jurisdiction of U.S. Fish and Wildlife Service (FWS), such as coastal birds, are available at http://www.fws.gov/endangered/species/recovery-plans.html. See http://www.fws.gov/endangered/what-we-do/critical-habitats.html for links to documents proposing and designating critical habitat for FWS species. Links to *5-Year Status Reviews* are on the species profile page for each species.

- The National Oceanic and Atmospheric Administration (NOAA), Pacific Islands Regional Office of the National Marine Fisheries Service (NMFS) provides information on ecological resources including protected species and unique habitats (http://www.fpir.noaa.gov/).

- The U.S. Navy has compiled data on Hawaiian species in the following documents:
  - U.S. Navy's most recent marine resource assessment for Hawai'i (Navy 2011). http://www.navfac.navy.mil/content/dam/navfac/Environmental/PDFs/MRA/HAWAII%20FINAL%20MRA%20-%20DECEMBER%202005.pdf
  - Hawai'i-Southern California Training and Testing Environmental Impact Statement (EIS) and Overseas EIS (Navy 2013) http://hstteis.com/DocumentsandReferences/HSTTDocuments/FinalEISOEIS.aspx
  - Hawai'i Range Complex EIS (Navy 2009) http://www.govsupport.us/navynepahawaii/FEIS.aspx

Identify Potential Sources of Contamination

The site-specific data compilation activities of the SLERA should identify contaminants potentially present at the site and the sources of those contaminants based on the types of activities known or suspected to have taken place at the site. Typical point sources and COPECs are compiled in Table 21-4. While the information in Table 21-4 can be used as a starting point, it should not be assumed that these are the only chemicals associated with site activities. Activities specific to a particular facility may have resulted in different and/or additional chemicals being released into the environment. Also, because operations often change at a site over time, a thorough search of the site history is needed to determine which chemicals may be present at the site.

Table 21-4. Point Sources of Target COPECs in Hawai‘i

Type of Point Source	Chemicals	Example Locations	Documents
Harbors and marinas	Antifouling compounds (Irgarol and other copper-based compounds); polycyclic aromatic hydrocarbons (PAHs)	Ala Wai Marina, Kāne‘ohe Bay Yacht Club , Kāne‘ohe Bay Makani Kai Marina, Sand Island Keehei Marina, Waikiki Yacht Club	Knutson et al. (2012)
Former military installations or disposal sites	Metals, polychlorinated biphenyls(PCBs), munitions (energetics), pesticides	Wai‘anae, O‘ahu; Mākua Military Reservation, O`ahu; Midway Atoll, Sand Island	Garcia et al. (2009); ACOE (2012); Tetra Tech (2009); Taylor et al. (2009)
Long Range Navigation (LORAN) stations	PCBs, lead	Kure Atoll, Cocos Island, Guam; Ilio Point, Moloka‘i; Tern Island, French Frigate Shoals	Element Environmental (2009); Element Environmental (2010); ESI (2012); USCG (2000); Woodward-Clyde Consultants (1994)
Shipyards	Tributyltin (TBT), antifouling paints, copper, zinc	Pearl Harbor, O‘ahu	Grovhoug (1992) NAVFAC (2007)
Former shooting ranges on coast	Lead shot		
Estuaries	Metals, PAHs, pesticides, pharmaceuticals, polybrominated		Grovhoug (1992) NAVFAC (2007)

Type of Point Source	Chemicals	Example Locations	Documents
	diphenyl ethers (PDBE), pathogens, PCBs		
Sugar mill or canec manufacture dumping areas	arsenic, herbicides	Waiākea Mill Pond, Wailoa River	Hallacher et al. (1985) HDOH (2005)
Urban/ storm drains	PAHs	Various streams, Oʻahu	Zheng et al. (2011)
Urban/ storm drains	Metals	Nuuanu watershed, Oʻahu	Andrews and Sutherland (2004)
Urban Run-off	Microbial and nutrients	Hanaleʻi Bay, Kaua'i	Boehm et al (2011)
Urban Run-off	Pesticides and metals	Various locations in Oʻahu and Kauaʻi	Brasher and Wolf (2007)
Agricultural Run-off	Pesticides	Pineapple fields; Honolua Stream entering Honolua Bay, Maui	
Agricultural Run-off	Arsenic, herbicides, pesticides	Island of Hawaiʻi sugar cane plantation	Cutler et al. (2013)
Agricultural Run-off	Pesticides	Taro ponds; run-off to Hanaleʻi River, Kauaʻ	Hawaiʻi Division of Aquatic Resources (2012)
Golf courses	Herbicides; pesticides		
Sewage outfalls	Metals, PAHs, pharmaceuticals, pathogens		
Sediment disturbance			
Coastal marine construction sites	All chemicals associated with sediment in given location		
Dredging	All chemicals associated with sediment	Kuhio and Hilo Bays, Hilo Commercial Harbor, Hawaiʻi Island	ACOE (2008)
Shoreline erosion (landfill)	All chemicals associated with sediment; solid waste in landfills exposed to water and air		

21.3.3.2 Step 1b, Task 2. Compile Available Site-Specific and Reference Data on Chemicals and Endpoints

Step 1b, Task 2 requires the risk assessor to compile available site-specific and reference analytical data (from *ERA Scoping Checklist* or other sources), evaluate ecotoxicity screening levels, and identify bioaccumulative chemicals.

All analytical data collected at the site during current or previous investigations should be compiled and evaluated for use in the SLERA. Analytical data more than five years old may no longer be representative of site conditions and should be discussed with the HEER Office.

A list of site-related chemicals compiled during the scoping phase (see Section 21.2 and Appendix 21-B, Table B-1) will be evaluated in the SLERA. Chemicals that act primarily through direct toxicity are evaluated using a hazard quotient (HQ) approach in Step 2. Chemicals that are known or expected to bioaccumulate in living organisms are also evaluated separately because sediment and water screening levels do not typically incorporate risk due to bioaccumulation in tissues (see Appendix 21-E).

Site-specific and reference data compilations for the SLERA should describe the direct toxicity and bioaccumulation potential of COPECs at the site. Direct ecotoxicity of COPECs in sediment is evaluated by comparison of sediment concentrations with SQG designed to be protective of benthic invertebrates in direct contact with sediment (see Section 21.3.4 and Table 21-7<link>). In the SLERA, the ecotoxicity evaluation may focus on groups of chemicals such as organochlorine pesticides, as opposed to specific pesticides. The risk assessor may augment the HEER Office SQG in Table 21-7with data from the published literature to develop ecotoxicity profiles for COPECs whose primary mode of action is direct toxicity. HEER Office EALs (screening levels) for aquatic habitat goals, surface water, and groundwater can be referenced and used for data evaluation, as applicable. See the detailed table links in the EAL surfer tool<link> for breakdown of the aquatic habitat goals and surface water EALs by marine, estuarine, or freshwater categories.

Separate from direct toxicity, some chemicals bioaccumulate in living organisms, meaning that they contain higher concentrations of a chemical in their tissues than in surrounding sediment or water. When bioaccumulated chemicals are transferred from one organism to another through the food web, the concentration may increase even more, in a process called biomagnification. Bioaccumulation of chemicals in tissues provides a pathway for chemicals to transfer to on-site and off-site receptors. The concentration of a bioaccumulating chemical in sediment may be considered safe for receptors in direct contact with sediment but not for receptors higher on the food web. Therefore, bioaccumulative chemicals require additional evaluation in the SLERA to determine whether they pose adverse risks to higher trophic levels that are not addressed by the SQGs.

21.3.3.3 Table 21-Step 1b, Task 3. Select Assessment and Measurement Endpoints

A key task of the SLERA site characterization process is to identify the ecological resources to be protected at the site (known as **assessment endpoints**) and the measures used to evaluate risks to

those resources (known as **measurement endpoints** or **measures of effect**). Assessment endpoints are explicit expressions of the environmental value that is to be protected. The selection of these endpoints is based on the habitats present, migration pathways of probable contaminants, and relevant exposure routes for the receptors. Suitable assessment endpoints species are characterized as follows:

- ecological relevance;
- susceptibility to known or potential stressors; and
- relevance to management goals (EPA 1998).

For additional discussion of the selection of proper assessment endpoints, see the following:

- *Generic Ecological Assessment Endpoints (GEAEs) for Ecological Risk Assessment* (USEPA 2005a) http://www.epa.gov/raf/publications/pdfs/GENERIC_ENDPOINTS_2004.PDF

- *Guidelines for Ecological Risk Assessment* (USEPA 1998) http://www.epa.gov/raf/publications/pdfs/ECOTXTBX.PDF

- *ECO Update: Identify Candidate Assessment Endpoints Ecological Significance and Selection of Candidate Assessment Endpoints* (USEPA 1996) http://www.epa.gov/swerrims/riskassessment/ecoup/pdf/v3n01.pdf

Measurement endpoints are estimates of quantifiable biological features or processes (such as mortality, growth, and reproduction) that are believed to be linked to meaningful effects on the assessment endpoints selected at the site.

Assessment endpoints selected for the SLERA are typically carried through to the BERA, unless it is discovered during the SLERA that the species does not fit the requirements of an assessment endpoint (it is not present, not exposed to contaminated media, not valued by the community, or eliminated during earlier steps in the SLERA). Measurement endpoints selected for the SLERA are often augmented in the BERA by endpoints more focused on particular chemicals or pathways of interest at the site.

Example preliminary assessment and measurement endpoints for a coastal marine sediment site in Hawai‘i are in Table 21-5. Measurement endpoints for the SLERA and the BERA are shown to illustrate the differences between the two phases of an ERA.

Table 21-5. Assessment and Measurement Endpoints: Coastal Marine Sediments

Ecological Guild	Assessment Endpoint	Typical Species	Measurement Endpoint
Seaweed (Limu)	Organism Level: Survival, growth, and reproduction Population/Community Level: Distribution and abundance within DU	• Sea lettuce (*Ulva fasciata*) • Limu kohu (*Asparagopsis taxiformis*)	**SLERA:** • Concentrations of chemicals in site MIS sediment samples compared with SQG protective of marine algae. • Estimates of tissue concentrations using biota-to-sediment-accumulation-factors (BSAFs) compared with tissue effect levels for marine algae (Tissue effect levels identified through literature review).
			BERA: • Concentrations of chemicals in composite samples of tissues collected from the DU or estimates of tissue concentrations from sediment using BSAFs compared with tissue effect levels for marine algae (Tissue effect levels identified through literature review). • Comparison of tissue concentrations in site samples to tissue concentrations in reference areas • Laboratory toxicity test measuring survival and growth; laboratory bioaccumulation test to provide tissue concentrations (in place of field-collected organisms: see above) • Comparison of population metrics in DU (distribution and abundance) with reference area

Ecological Guild	Assessment Endpoint	Typical Species	Measurement Endpoint
Soft-bodied benthic invertebrates (macroinfauna)	Organism Level: Survival, growth, and reproduction Population Level/Community Level: Distribution and abundance within DU	• Polychaete (*Neanthes arenaceodentata*)	**SLERA:** Concentrations of chemicals in site MIS sediment samples compared with SQG protective of polychaetes. **BERA:** • Concentrations of chemicals in composite samples of whole body tissues collected from the DU or estimates of whole body tissue concentrations from sediment using BSAFs compared with CBR levels (effect levels) for polychaetes (CBRs identified through literature review). • Laboratory toxicity test measuring survival and growth; laboratory bioaccumulation test to provide tissue concentrations (in place of field-collected organisms: see above) • Comparison of population/community metrics in DU (distribution and abundance) with metrics at a reference area
Stony Corals	Organism Level: Survival, growth, and reproduction (of colony) Population/Community Level: Distribution and abundance within DU	• Lobe coral (*Porites lobata*)	**SLERA:** Concentrations of chemicals in site MIS sediment samples compared with SQG protective of corals. **BERA:** • Concentrations of chemicals in composite samples of coral tissues from the DU compared with CBR for corals and with reference areas

Ecological Guild	Assessment Endpoint	Typical Species	Measurement Endpoint
			• Comparison of tissue concentrations in site samples to tissue concentrations in reference areas • Direct toxicity test using coral test organisms • Comparison of relative percent cover, growth rates, external signs of health with corals in reference area
Epibenthic Invertebrate (macrofauna)	Organism Level: Survival, growth, and reproduction Population/Community Level: Distribution and abundance within DU	• Samoan crab (*Scylla serrata*) • Kona crab (*Ranina ranina*) • White crab (*Portunus sanguinolentus*) • Helmet urchin (*Colobocentrotus atratus*) • Hawaiian limpet (*Cellana exarata*) • Black sea cucumber (*Holothuria atra*) • Day octopus (*Octopus cyanea*)	**SLERA:** • Concentrations of chemicals in site MIS sediment samples compared with SQG protective of epibenthic macrofauna • Estimates of whole body tissue concentrations from sediment using BSAFs compared with CBR levels (effect levels) for surrogate benthic invertebrates. **BERA (Echinoderm only):** Laboratory toxicity test of effect of exposure to sediments and/or sediment pore water on sea urchin survival and development. **BERA (Other macrofauna):** • Concentrations of chemicals in composite samples of whole body tissues representing the DU or estimates of whole body tissue from sediment using BSAFs compared with critical body residues levels (effect levels) for surrogate epibenthic invertebrates. • Comparison of population metrics (distribution and abundance) with metrics at a reference area

Ecological Guild	Assessment Endpoint	Typical Species	Measurement Endpoint
Benthic Fish (herbivores, corallivores, carnivores)	Organism Level: Survival, growth, and reproduction Population Level: Distribution and abundance within DU	• Goatfish (*Mulloides vanicolensis*) • Hawaiian flagtail (*Kuhlia sandvicensis*) • Pacific sergeant (*Abudefduf abdominalis*) • Mozambique tilapia (*Oreochromis mossambicus*) • Spectacled parrotfish (*Chlorurus perspicillatus*) • Yellowbar parrotfish (*Calotomus zonarchus*) • Moray Eel (Muraenidae)	**SLERA:** • Concentrations of chemicals in MIS sediment samples compared with SQG protective of fish. • Estimates of tissue concentrations from sediment using BSAFs) derived from field studies on similar fishes compared with CBR (effect levels) for tropical fishes. **BERA:** • Concentrations of chemicals in composite samples representing the DU (whole body or organ tissues) or estimates of tissue concentrations from sediment using BSAFs derived from field studies on similar fishes compared with critical body residues levels (effect levels) for tropical fishes. • Comparison of population metrics (distribution and abundance) with metrics at a reference area
Pelagic Fish (piscivores)	Organism Level: Survival, growth, and reproduction Population Level: Distribution and abundance within DU	• Giant trevally (*Caranx ignobilis*) • Mahi mahi (*Coryphaena hippurus*)	**SLERA:** No direct link to sediment. Assume food web link to lower trophic levels in the DU. **BERA:** • Concentrations of chemicals in composite samples of tissues from decision unit compared with CBR levels (effect levels) for tropical fishes. • Concentrations of chemicals in composite samples of

Ecological Guild	Assessment Endpoint	Typical Species	Measurement Endpoint
			tissues from DU compared with reference area
Sea turtles	Organism Level: Survival, growth, and reproduction Population Level: Distribution and abundance within DU	• Green sea turtle (*Chelonia mydas*)	**SLERA:** Conservative estimate of daily ingested dose of contaminant within DU compared with no observed adverse effect level (NOAEL) TRVs for sea turtles (or surrogate reptiles). (TRVs identified through literature review).
			BERA: Realistic estimate of daily ingested dose of contaminant within DU compared with lowest observed adverse effect level (LOAEL) TRV for sea turtles (or surrogate reptiles). TRVs identified through literature review.
Piscivorous birds	Organism Level: Survival, growth, and reproduction Population Level: Distribution and abundance within DU	• Wedge-tailed shearwater (*Puffinus pacificus*) • Black-crowned night heron (*Nycticorax nycticorax hoactli*) • Hawaiian coot (*Fulica alai*)	**SLERA:** Conservative estimate of daily ingested dose of contaminant within DU compared with NOAEL TRV for piscivorous seabirds (or surrogate birds). (TRVs identified through literature review).
			BERA: Realistic estimate of daily ingested dose of contaminant within DU compared with LOAEL TRV for piscivorous seabirds (or surrogate birds). TRVs identified through literature review.
Marine mammals	Organism Level: Survival, growth, and reproduction Population Level:	• Spinner dolphin (*Stenella longirostris*) • Hawaiian monk seal (*Monachus*	**SLERA:** Conservative estimate of daily ingested dose of contaminant within DU compared with NOAEL TRV for marine mammals (or surrogate carnivorous mammal). TRVs

Ecological Guild	Assessment Endpoint	Typical Species	Measurement Endpoint
	Distribution and abundance within DU	*schauinslandi*) [endangered species: assess at the level of individual]	identified through literature review.
			BERA: Realistic estimate of daily ingested dose of contaminant within DU compared with LOAEL TRV for marine mammals (or surrogate carnivorous mammal).

21.3.3.4 Step 1b, Task 4. Identify Complete Exposure Pathways and Potential Routes of Exposure

Complete exposure pathways consist of contaminants, receptors, and routes (such as direct contact, sediment ingestion, and food chain transfer).

- ***Receptors:*** Living organisms present or potentially present at the site are the focus of the SLERA
- ***Exposure Medium:*** This part of the TGM addresses sediment as the primary exposure medium. Organisms in direct contact with the sediment may take up chemicals in their tissues and become sources of contaminants to animals that consume them. Exposure to contaminated food items (and ingested sediment) is evaluated using food chain models (see Section 21.3.4: Step 2, Task 3 below).
- ***Depth of Sediment Exposure:*** Benthic invertebrates typically live either on the surface of the sediment or within the top layer where water and oxygen exchange occur (the biotic zone). The default assumption of exposure depth for a SLERA is that benthic and epibenthic receptors are exposed to the top 10 cm of sediment. However, if receptors are known to burrow deeper in the sediment at a particular site, the exposure pathway to deeper sediment layers should be evaluated in the SLERA.
- ***Routes of Exposure:*** The SLERA should focus on routes of exposure most likely to be significant. Receptors living on or in the sediment are exposed primarily through direct contact; they may also be exposed to ingested sediment. Other receptors are indirectly exposed to sediment by consuming organisms that were in direct contact with the sediment.

The preliminary CSM for a SLERA relies on the published literature to predict occurrence of receptors and the trophic relationships among receptors at the site. Reports and publications written for purposes other than contaminant studies can be good sources of information on ecological processes and relationships in a given habitat type or location. For example, NOAA prepared a diagram of trophic linkages on the kaloko reef system for a report on energy flow on the Kona coastline (http://www.pifsc.noaa.gov/kona_iea/projects/ecological_modeling.php) (Figure 21-1). Although the NOAA project was not focused on contaminants, it provides valuable information on species occurrence and trophic relationships that could be incorporated into a SLERA in that location.

21.3.3.5 Step 1b, Task 5. Develop the Screening Level Preliminary Conceptual Site Model

The CSM presents a description of predicted relationships between receptors and chemicals. It is an integrated model of contaminant sources, transport pathways, and receptors that represents potential contaminant dynamics at the site. CSMs range from simple diagrams to detailed illustrations of habitat emphasizing trophic transfer. To the extent possible, include expected effects of climate change, such as sea level rise, in the CSM.

Elements of a CSM

Regardless of the style, the CSM should depict how contaminants are believed to move across the site (fate and transport) and how receptors might be exposed to contaminants in various media (exposure pathways). The CSM should also identify assessment endpoints, which are the particular functional features of the ecological community to be protected, or representative surrogate species. Table 21-6 presents a list of required elements of the CSM.

Table 21-6. Elements of a Marine Sediment Ecological CSM

Sources of Chemical in Marine Sediments
• Terrestrial soils (via erosion, stream discharge) • Spills into water body • Surface water runoff • Ground water infiltration • Sediment "hot spots" (of unknown origin) • Outfalls (combined sewer, storm water, industrial) • Atmospheric deposition (including volcanic activity)
Contaminant Transport Pathways
• Sediment resuspension (natural or by human activity) • Surface water transport • Soil erosion • Ground water advection • Bioturbation • Food chain transfer
Exposure Pathways to Ecological Receptors*
• Direct contact with sediment (algae and invertebrates only) • Intentional or incidental ingestion of sediment • Direct contact with sediment interstitial water (pore water) (algae and invertebrates only) • Direct contact with overlying surface water (primarily algae, invertebrates, bottom-dwelling fish, and pelagic fish) • Ingestion of other organisms
Ecological Receptors
• Algae, seagrasses • Benthic/epibenthic invertebrates • Bottom-dwelling fish • Pelagic fish • Seabirds and shorebirds • Marine mammals

Modified from USEPA (2005c): *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites*

The preliminary CSM developed during the SLERA may include multiple chemicals and receptors to ensure that all potentially complete exposure pathways are included. The CSM is typically updated as more information is learned about the site. For example, if the risk assessor learns that a predicted pathway is incomplete because an expected receptor does not occur at the site, then the CSM is revised to eliminate that pathway and receptor.

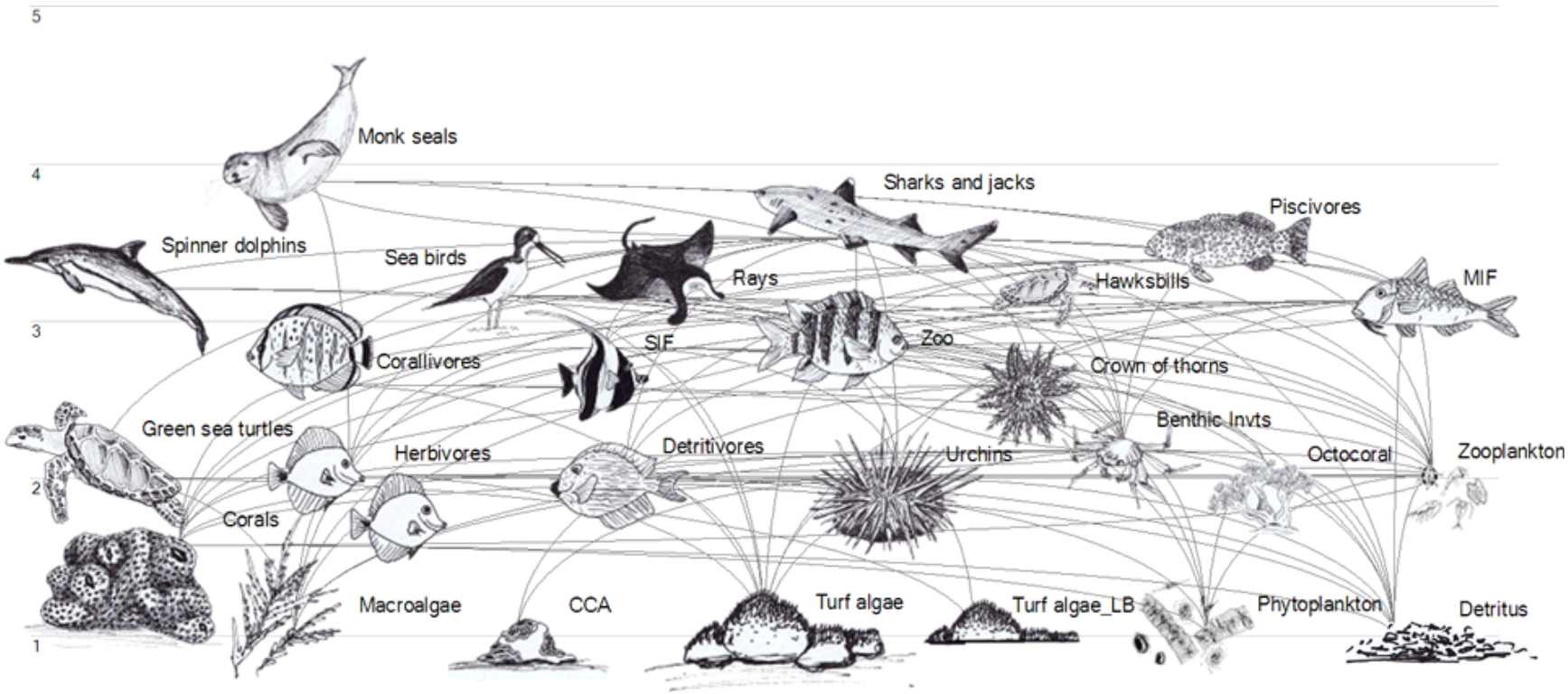


Figure 21-1. Food Chain Models Can Support Development of Conceptual Site Model

Graphical representation of the trophic linkages (i.e., who-eats-whom) within the Kaloko reef ecosystem. Each animal group within the system is identified here by an illustration (© M. Bailey); where relevant, an image of a species representative of its group is depicted. Images are not drawn to scale or proportional to the group's biomass. The light grey horizontal lines and associated numbers represent trophic levels (position in the food web); lines connecting individual groups represent trophic links. (http://www.pifsc.noaa.gov/kona_iea/projects/ecological_modeling.php)

Example CSMs

The HEER Office has prepared several examples to illustrate acceptable preliminary CSMs for a marine sediment SLERA. The risk assessor may adapt one of these CSMs or develop a new CSM incorporating the required elements from Table 21-6.

- Figures 21-2 and 21-3 present two types of CSM for the same site, a rocky intertidal site such as Ilio Point on Molokaʻi. Figure 21-2 is a simple diagram and Figure 21-3 is a pictorial representation.
- Figure 21-4 is a CSM for a soft-bottom bay/harbor habitat (such as Hanaleʻi Bay, Kauaʻi or Pearl Harbor) that illustrates both direct exposure to sediment and secondary exposure to contaminated prey. This CSM would be suitable to represent bioaccumulating COPECs (such as PCBs or organochlorine pesticides) that were originally released to soil, then washed into the marine habitat. In this scenario, ingestion of COPECs associated with sediment particles is considered the principal exposure pathway.
- Figure 21-5 is a CSM prepared for a BERA at Pearl Harbor. Note the multiple sources of COPECs that contribute to the existing load in the sediment.
- Figure 21-6 presents a focused CSM that illustrates the exposure of a single receptor group (water birds) to a single COPEC (arsenic) in sediments and surface water in Waiākea Pond on Hawaiʻi Island.
- Figure 21-7 is a CSM focused on a particular class of COPECs (energetic compounds associated with discarded munitions).

Other Features to Consider in CSMs

The following considerations should be taken into account when developing CSMs for marine sediment sites in Hawaiʻi:

- At intertidal sites, the CSM must capture both high tide and low tide exposure pathways. The intertidal habitat depicted in Figure 21-3 shows the inundated state, during which large pelagic fishes and sea turtles are present. At low tide, the large organisms move offshore and seabirds become the dominant predators. The CSM must account for exposure pathways under the full tidal cycle. See Harborne (2013) for a discussion of foraging shifts between low and high tides on reef flats.

- At sites with stream discharge or other terrestrial inputs, the CSM must reflect the seasonal flux of contaminants entering the site. For example, in Hilo Bay, Hawaiʻi, the dominant exposure pathway to marine receptors varied throughout the year. Streams discharged heavy loads of soil/sediment as suspended particulate matter during the rainy season. Contaminants associated with terrestrial sources were transported to the bay along with the fresh water. Exposure of organisms in the bay to terrestrially-derived contaminants fluctuated from station to station, influenced by proximity to stream discharge and the time interval since the last major storm (Atwood et al. 2012). The CSM at a site with substantial terrestrial input must reflect this type of variability.

- At an anchialine pond site, the CSM must be developed specifically to reflect the relatively simple but unusual food web typical of this habitat. Apart from, or in addition to, effects mediated by contamination, any physical or biological perturbation of the food web can upset

the balance of species in the pond, many of which are rare, endemic, or endangered. For background on anchialine ponds (see Dalton et al. 2013).

- The wave energy at a site must be considered in the CSM because waves are influential in sediment transport, deposition, and particle sorting processes that affect exposure of organisms to contaminants. Also, some receptors thrive in high energy environments while others prefer calmer environments. Many COPECs become bound to fine-grained sediment in the field, which tend to accumulate in areas where wave energy is dissipated by vegetation, such as seagrasses and mangroves, or around coastal protrusions such as jetties and piers. When fine-grained sediments are disturbed, either naturally by storms and erosion or purposefully by dredging or construction, metals can become remobilized from the sediments into the water column (Batley et al. 2013). Organic COPECs can become more bioavailable as fine sediment particles are suspended and ingested by receptors. The U.S. Geological Survey (USGS) has conducted numerous studies of natural processes that affect erosion and deposition in Hawai‘i. Geophysical processes affect not only where sediments accumulate, but also how receptors are exposed to contaminated sediments. To assist risk assessors in describing the wave environment at a contaminated sediment site, the HEER Office has compiled a database of geophysical information provided in USGS reports, as well as in the primary literature, including descriptions and locations of high and low energy aquatic environments; erosional and depositional areas; and other features. The risk assessor should ensure that the influence of wave action is accurately represented in the CSM.

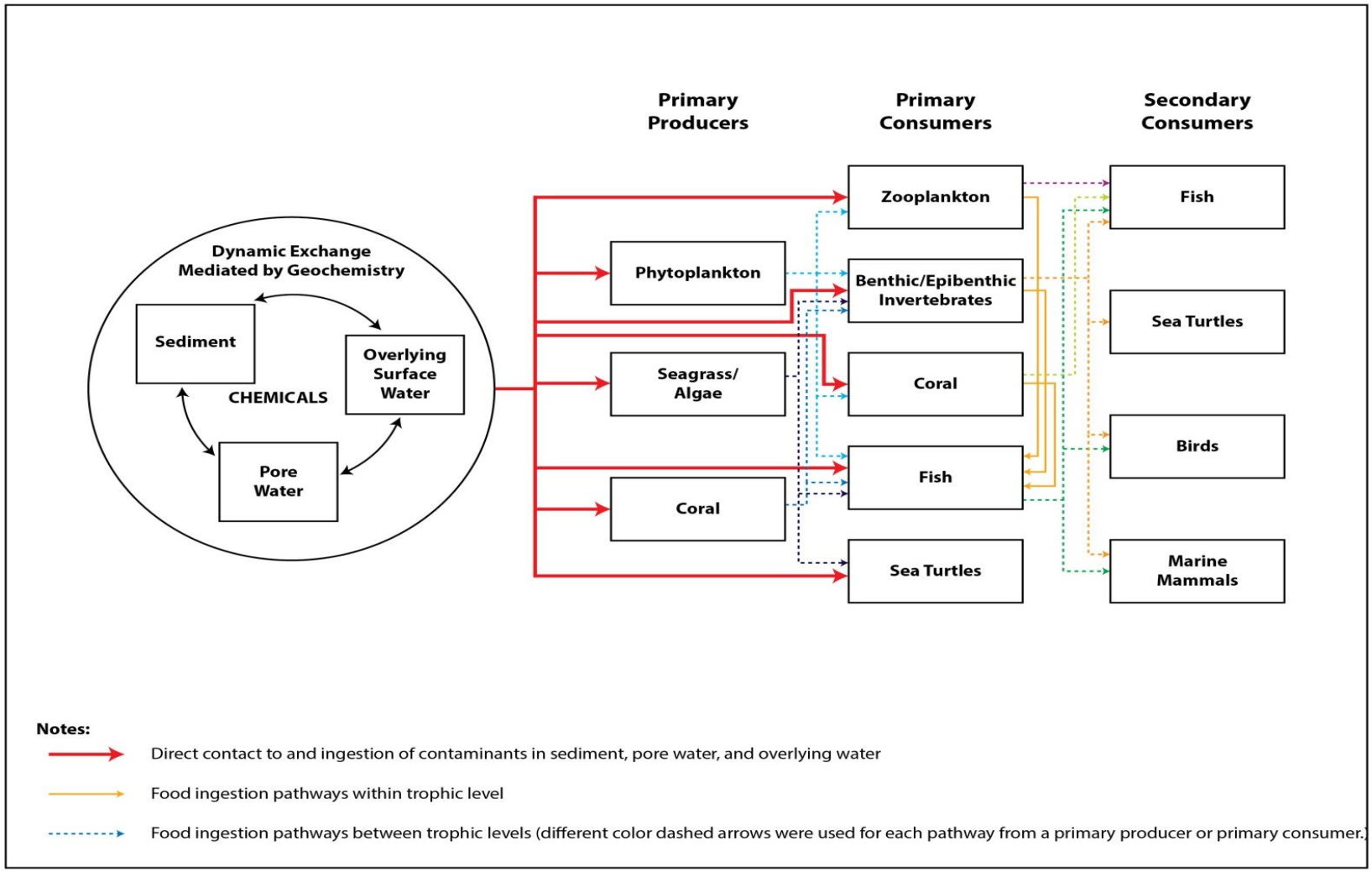
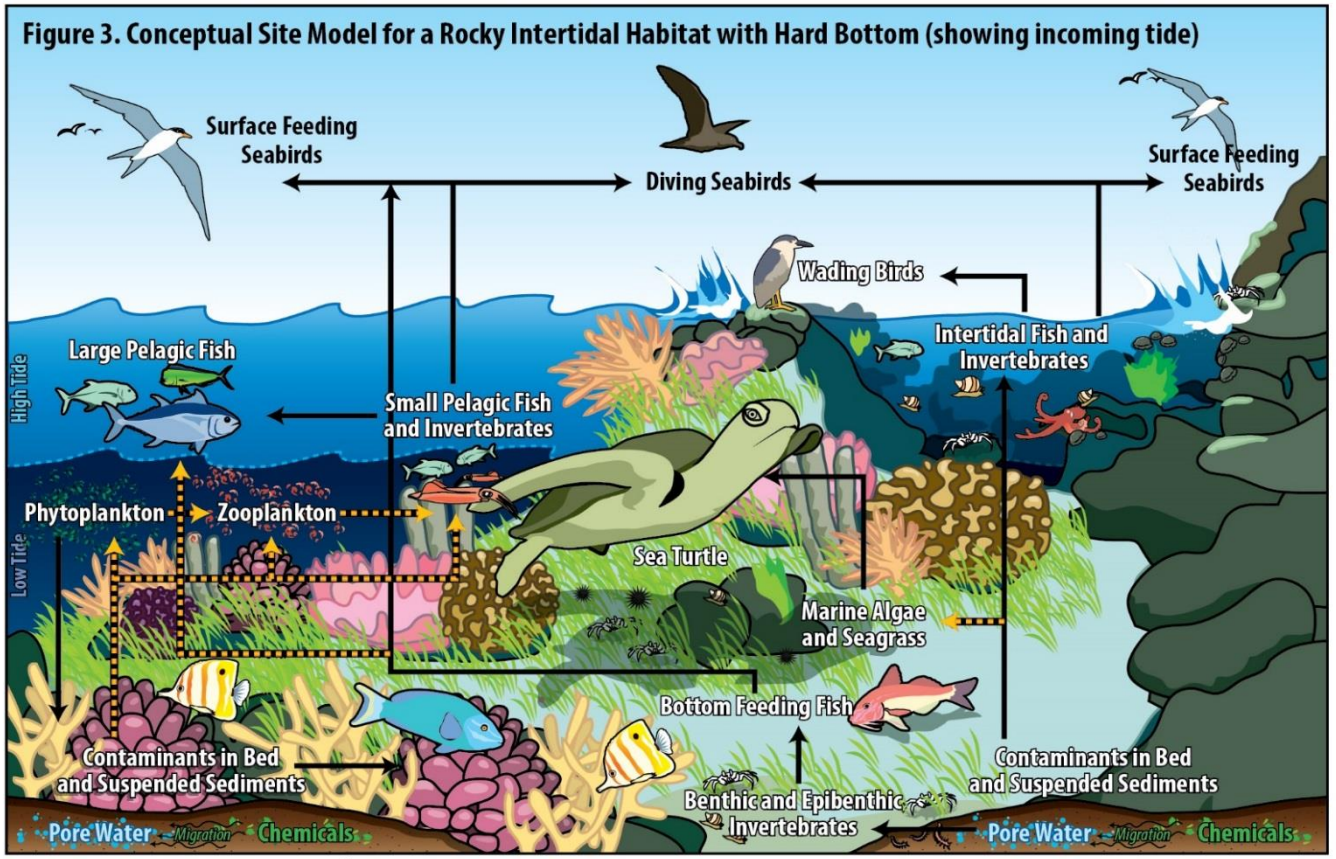


Figure 21-2. A Simple Diagrammatic Conceptual Site Model for a Rocky Intertidal Habitat with Hardbottom (such as Ilio Point, Moloka‘i)



Legend

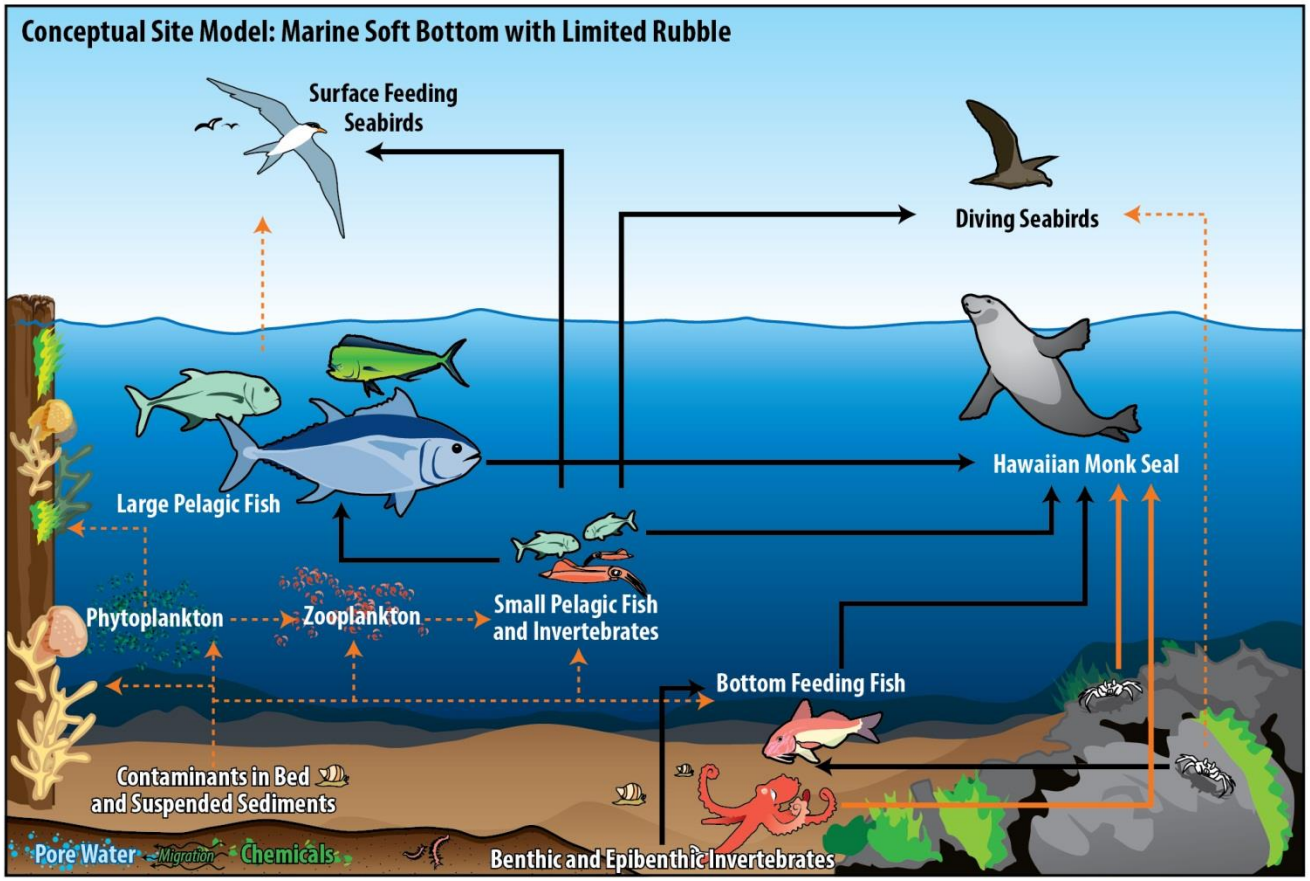
→ Primary exposure

⇢ Potential limited exposure

Notes:

- Contaminant bioavailability is expected to be relatively high in calcareous sediment with low organic carbon.
- Bioturbation and movement from high wave energycan redistribute contaminants throughout the sediment column.
- Contaminants in sediment (and water) may bioaccumulate in plants, invertebrates, and fish and be transferred to upper trophic level receptors through the food chain.
- Figure portrays species that may be present at high tide; at low tide, large fish and sea turtles will be absent in the shallow areas, and seabirds/wading birds will feed on small fish and/or invertebrates in the intertidal area.

Figure 21-3. Conceptual Site Model for a Rocky Intertidal Habitat with Hardbottom



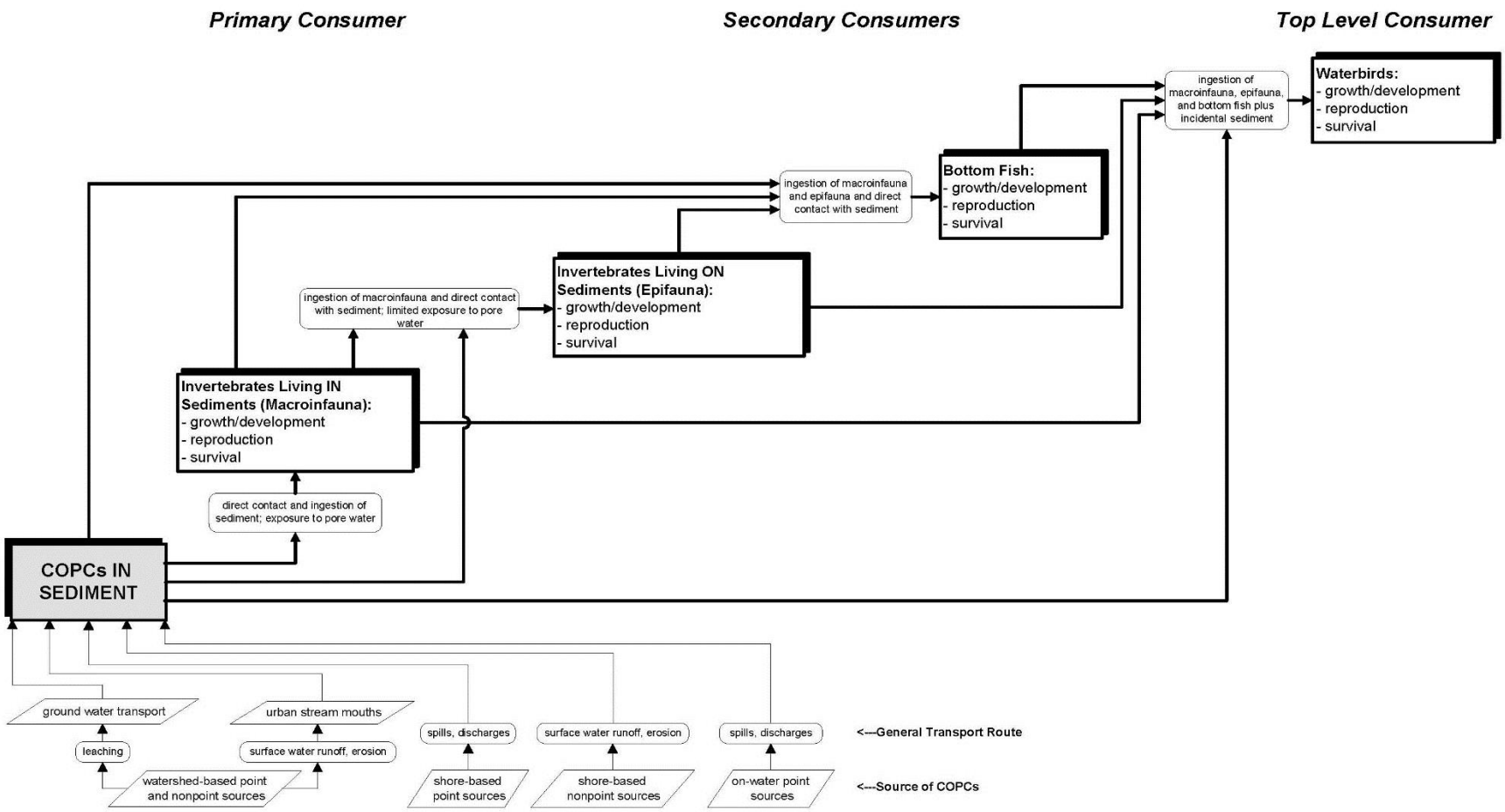
Legend

- Primary exposure
- Likely occasional exposure
- Potential limited exposure

Notes:

- Contaminant bioavailability is expected to be relatively low in soft-bottom, high organic carbon sediment.
- Bioturbation can redistribute contaminants throughout the sediment column.
- Contaminants may bioaccumulate in plants, invertebrates, and fish and be transferred to upper trophic level receptors through the food chain.

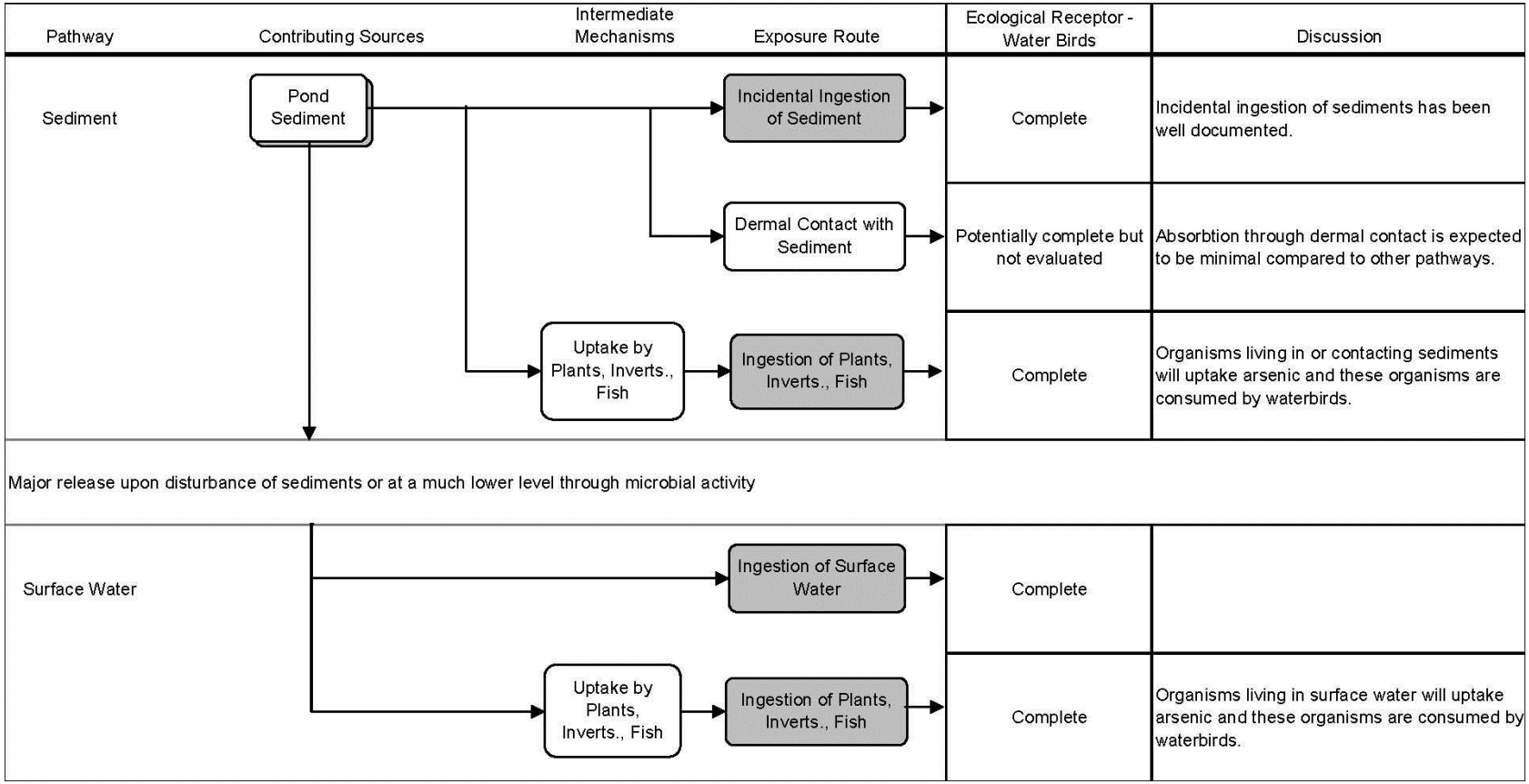
Figure 21-4. Conceptual Site Model for a Soft-Bottom Bay/Harbor Habitat (such as Hanale‘i Bay, Kaua‘i, or Pearl Harbor, O‘ahu)



Source: NAVFAC (2007), Figure 2-7

Figure 21-5. Conceptual Site Model Prepared for a BERA at Pearl Harbor

(Note the multiple sources of COPECs that contribute to the existing load in the sediment.)



Source: HDOH (2005), Figure 2-1

Figure 21-6. Conceptual Site Model Focused on Exposure of a Single Receptor Group (Water Birds) to a Single COPEC (Arsenic) in Sediments and Surface Water at Waiākea Pond on Hawai'i Island

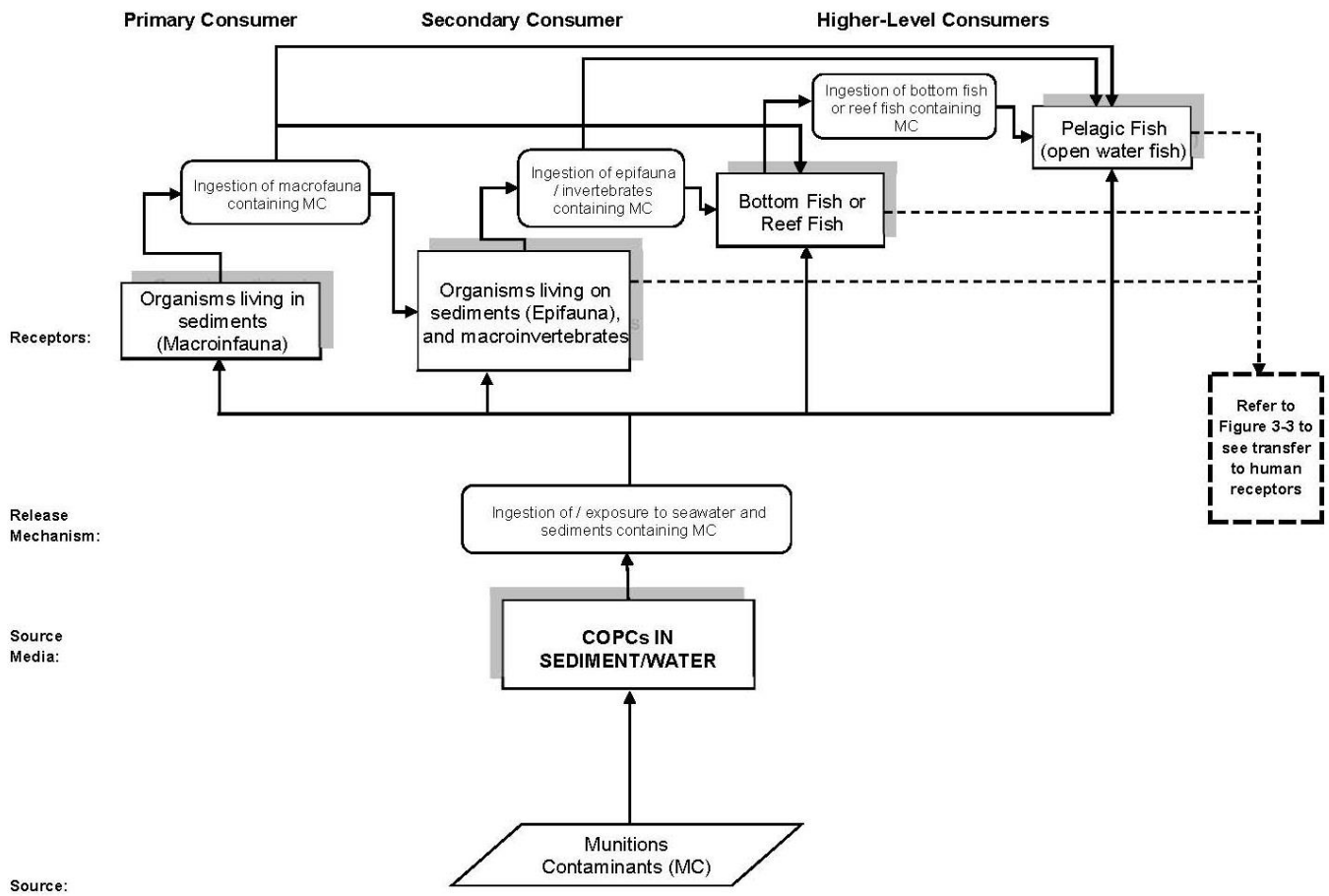


Figure 21-7. Conceptual Site Model Focused on a Single Class of COPECs (Energetic Compounds Associated with Discarded Munitions)

Source: ACOE (2012) Figure 3-2

21.3.4 Step 2: Estimating Exposure and Effects

In Step 2, available site-specific data are used to estimate conservative contaminant concentrations, which are then compared with screening levels to identify (1) chemicals that may pose potential risk and (2) chemicals that may be eliminated from further investigation.

21.3.4.1 Step 2, Task 1. Compile Screening levels

SQGs and other screening levels are compiled as part of the *ERA Scoping Checklist* following the examples in Tables 21B-1 through 21B-4. If additional analytical data or screening levels have become available, update the table. The HEER Office has developed screening levels for common COPECs at sediment sites in Hawai'i. Each of the screening levels is used to evaluate a different aspect of potential risk to receptors, as described below.

(1) **Sediment quality guidelines (SQG)** are used to evaluate risks to receptors in direct contact with the sediment, especially benthic invertebrates. The SQGs were derived from large datasets on toxicity to benthic invertebrates under a variety of field conditions. Although the SQGs are not necessarily protective of seagrasses, marine algae, fish, or receptors that are not intimately exposed to sediment, they serve as surrogates during the SLERA. The HEER Office will add SQGs to this guidance as they become available. See Table 21-7.

(2) **HEER Office Environmental Action Levels (EALs)** used to evaluate aquatic toxicity (aquatic habitat goals), surface water, and groundwater are available for screening of chemicals in water (see EAL Surfer<link>). See detailed Tables in the EAL Surfer tool for listings of aquatic toxicity and surface water EALs for marine, estuarine, or freshwater environments, as applicable.

(3) **Toxicity reference values (TRV) are daily doses of ingested chemicals used to evaluat**e risk to birds and mammals that are exposed to contaminants primarily through ingestion of contaminated food items (as well as sediment and water).

(4) **Critical body residues (CBR)** are used to evaluate risk to receptors from chemicals accumulated by all routes into their tissues. CBRs are available for only a few receptors at this time.

HEER Office Interim Sediment Quality Guidelines

HEER Office SQGs are used to evaluate the potential for sediments to pose a risk to benthic invertebrates through direct exposure. The concentration below which sediments are considered safe for benthic marine organisms is called the interim "No Effect SQG." The concentration above which adverse effects are indicated on benthic marine organisms may occur is called the interim "Potential Effect SQG." Chemicals known or expected to bioaccumulate are indicated on Table 21-7 and may require additional evaluation, as described in appendix 21-E.

The SQGs are considered interim because they are subject to revision as new data become available. The HEER Office anticipates that the HDOH interim SQGs will be revised as warranted by a review of new toxicity data reported from other tropical marine ecosystems, including the ANZEC/ARMCANZ

ecotoxicology group. In the future, a range of revised SQGs will represent sediments that vary in percent organic carbon and grain size.

The HEER Office interim SQGs incorporate the Effects-Range Low (ER-L) and Effects-Range Median (ER-M) sediment levels published by Long and Morgan (1990) and modified by Long et al. (1995), as well as the ANZECC/ARMCANZ interim SQGs derived from other sources. Interim SQGs for 2,3,7,8-TCDD, which were not available from ANZECC/ARMCANZ or NOAA, were adopted from Canadian Council of Ministers of the Environment (CCME) (2001).

HDOH HEER considers the chemicals listed in Table 21-7 the most likely to be potential risk drivers at marine sediment sites in Hawai'i. Chemicals detected in sediment for which no HEER Office interim SQG is available should be screened using the most recent publically available literature available. Suggested sources are listed below:

- Interim SQGs from Simpson et al. (2005) and related documents
- Marine sediment screening levels from sources presented in the U.S. Department of Energy, Risk Assessment Information System - Ecological Benchmark Tool http://rais.ornl.gov/tools/eco_search.php
- Marine sediment screening levels from sources presented in the NOAA Screening Quick Reference Tables (Buchman 2008) http://response.restoration.noaa.gov/sites/default/files/SQuiRTs.pdf

Table 21-7. HDOH HEER Office Interim Sediment Quality Guidelines for Selected Chemicals

Analyte	Recommended Interim Sediment Quality Guidelines for Direct Exposure	
	No Effect SQG	Potential Effect SQG
Inorganic Chemicals (mg/kg dry weight)		
Arsenic	20	70
Copper	34[a]	270
Lead	50	220
Mercury	0.15	1
Tributyltin (**µg/kg** Sn/kg dry weight)	5	70
Zinc	200	410
Organic Compounds		
***Pesticides/PCBs/Dioxins* (µg/kg dry weight)**		
4,4'-DDD	2	20
4,4'-DDE	2.2	27
Total DDTs	1.6	46
Total Chlordane	0.5	6
Dieldrin	0.02	8
Endrin	0.02	8
Total PCBs	23	180
TEQ Dioxins and Furans	0.00085	0.0215
***Semivolatile Organic Compounds* (µg/kg dry weight)**		
Acenaphthene	16	500
Acenaphthylene	44	640
Anthracene	85	1100
Benzo(a)anthracene	261	1600
Benzo(a)pyrene	430	1600
Chrysene	384	2800
Dibenzo(a,h)anthracene	63	260
Fluoranthene	600	5100
Fluorene	19	540
Naphthalene	160	2100
Phenanthrene	240	1500
Pyrene	665	2600
Sum HMW PAHs	***1700***	***9600***
Sum LMW PAHs	***552***	***3160***
Total PAHs	***4000***	***45000***

HMW	High molecular weight
LMW	Low molecular weight
µg/kg	Microgram per kilogram
mg/kg	Milligram per kilogram
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl

SQG	Sediment quality guideline
TEQ	Toxic equivalent

Notes:
The chemicals in Table 21-7 are also considered bioaccumulative and must undergo further evaluation for this hazard (see Appendix 21-E).

Some local background/ambient/reference concentrations may exceed No Effect SQG.

All organic SQGs are normalized to 1% organic carbon

[a] If data are available for both total organic carbon and grain size fraction, the No Effect SQG for copper is organic carbon (OC)-normalized copper concentration of 3.5 mg Cu/g OC in the <63 µm sediment fraction. The **copper** SQG is under review by both ANZECC/ARMCANZ and researchers in Hong Kong (Kwok et al. 2008) and is expected to be revised.

The following individual PAHs are typically reported by laboratories using standard EPA analytical methods. This list may change, depending on which specific parameters are requested:

- ***LMW PAH*** = acenaphthene, acenaphthylene, anthracene fluorene, naphthalene, phenanthrene, 1-methylnaphthalene, 2-methylnaphthalene.
- ***HMW PAH*** = benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene.

The chemicals on the HEER Office SQG table (Table 21-7) are also known as common bioaccumulating chemicals, based on a review of technical manuals prepared by USEPA, other states, and international organizations. Therefore, these chemicals should also be considered potential bioaccumulators, and evaluated accordingly using food chain models (see Step 1b, Task 3). The risk assessor should also consider other technical sources of information when determining whether chemicals detected in sediment at a site may be bioaccumulators. The *Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment, Status, and Needs* (*http://water.epa.gov/polwaste/sediments/cs/biotesting_index.cfm*) USEPA (2000) provides technical direction on identifying bioaccumulators. More detailed guidance on evaluating risk of bioaccumulating chemicals is in Appendix 21-E<link>.

Toxicity Reference Values

A TRV is an ingested daily dose of a chemical associated with a designated effect level. A low TRV is a conservative value consistent with a chronic no observable adverse effect level (NOAEL). A high TRV is consistent with a lowest observable adverse effect level (LOAEL). When compared to site-specific doses ingested by receptors, the high TRV should be used to identify sites posing potential risk to birds or mammals. Conversely, the low TRV is a dose level below which no adverse effects are expected.

The HEER Office has not compiled a comprehensive list of TRVs for all receptors. The risk assessor may select TRVs based on site-specific receptors and exposure conditions, and provide technical rationale for the TRVs selected. TRVs are available from several sources in the literature, including, but not limited, to the following:

- TRVs developed by the U.S. Navy for 20 chemicals common at San Francisco Bay area naval installations, including 12 metals and metalloids (arsenic, butyltins, cadmium, cobalt, copper, mercury, lead, manganese, nickel, selenium, thallium, and zinc), five pesticides (aldrin, DDT, heptachlor, lindane, and methoxychlor) and three other organic compounds (benzo(a)pyrene, naphthalene, and total polychlorinated biphenyls) (Navy 1998). Several of the Navy TRVs have been updated using more recent toxicological studies (California Department of Toxic Substances Control 2009)
- Toxicological Benchmarks for Wildlife (Sample et al. 1996)
- Standard Practice for Wildlife Toxicity Reference Values. U.S. Army (2000) (and chemical-specific documents) (HTTP://USAPHCAPPS.AMEDD.ARMY.MIL/ERAWG/TOX/)
- FCSAP Supplemental Guidance for Ecological Risk Assessment Selection or Development of Site-specific Toxicity Reference Values (Azimuth 2010). This document does not present specific TRVs but list several sources of TRVs.
- Recommendations for the Development and Application of Wildlife Toxicity Reference Values (Allard et al. 2010). This document does not present specific TRVs but presents recommendations on the derivation and application of wildlife TRVs.
- EPA Ecological Soil Screening Level Documents (EPA 2005a (http://www.epa.gov/ecotox/ecossl/) and supporting documents). Although these documents pertain to soil, some of the toxicological literature cited within them is relevant to birds and mammals exposed to chemicals in surface water and sediment.
- Los Alamos National Laboratory, ECORISK Database (Release 3.1) (LANL, 2013). This database presents TRVs for several chemicals and receptors (http://www.lanl.gov/community-environment/environmental-stewardship/protection/eco-risk-assessment.php).

Note that TRVs used in ERAs in Hawai‘i are provided in the species profiles, where available. The HEER Office does not necessarily endorse the use of the particular TRVs presented in earlier ERAs, but does recommend that the risk assessor make use of existing literature to select and provide rationale for TRVs suitable to the site.

Critical Body Residues

The CBR can be used to evaluate risk to a receptor based on a chemical concentration in its tissue. However, CBR data are available for only a few chemicals and selected species from a limited number of locations. Few, if any, of the published CBRs cited are for native Hawaiian species. No standard CBR values have been developed by EPA or other national agencies. Limited CBR data are available from the following sources:

- *Linkage of Effects to Tissue Residues: Development of a Comprehensive Database for Aquatic Organisms Exposed to Inorganic and Organic Chemicals* (Jarvinen and Ankley 1999). Most of the available data are for freshwater species, although some marine and estuarine species are included.
- *Guidance for Assessing Bioaccumulative Chemicals of Concern in Sediment* provides freshwater and marine CBRs for metals, pesticides, PCBs, and 2,3,7,8-TCDD TEQs (ODEQ, 2007).
- *Environmental Residue Effects Database* (*ERED*) is a searchable compendium of CBRs derived by USEAP and the ACOE from literature published in the 1960s to 1990s. Available at http://el.erdc.usace.army.mil/ered/index.cfm.
- *Environmental Contaminants in Biota: Interpreting Tissue Concentrations*, Second Edition (Beyer and Meador 2011) summarizes data on CBR for numerous species and contaminants.

21.3.4.2 Step 2, Task 2. Calculating Contaminant Concentration(s) in Sediment and Water

At a minimum, the SLERA requires site-specific sediment concentrations. The preferred approach to estimating exposure concentrations at a sediment site is to use MIS sampling to represent the typical exposure of receptors within a DU. The general guidance in the TGM on developing a sampling plan for a sediment investigation is applicable to an ERA (see Sections 3<link>,4<link>, and 5<link>). However, the designation of DUs is more complex for an ERA because no single DU is appropriate for all ecological receptors at a site (See Appendix 21-C).

Stationary and relatively immobile species such as algae, benthic infauna, and coral are primarily exposed to chemicals in sediment through direct contact. The MIS concentration detected in a DU is used as the representative contaminant concentration in the SLERA. Assuming laboratory detection limits are lower than the SQGs, non-detects are treated as zero values. If the laboratory detection limit exceeds the SQG, the detection limit is used as the reported value for all nondetects. (In this case, the data should be scrutinized and laboratory methods reviewed so that detection limits appropriate for a SLERA can be achieved.)

If site-specific concentrations are available for surface water, sediment pore water, or groundwater discharging to the site, the MIS detected concentration is used as the contaminant concentration for the SLERA (given the protocol for estimating nondetects in the previous paragraph). Samples should be analyzed for dissolved concentrations for constituents that have WQC based on dissolved concentrations (see Hawai'i Water Quality Standards Title 11, Chapter 54).

The SLERA is purposefully designed to be conservative, evaluating the worst-case exposure scenario and often overestimating contaminant concentrations in early steps. Subsequent steps allow refinement of conservative assumptions to reflect site-specific conditions that may reduce estimated contaminant levels or risk.

21.3.4.3 Step 2, Task 3. Estimating Daily Ingested Dose to Birds and Mammals

The SQG are considered protective of algae, benthic invertebrates, and fish exposed directly to sediment but cannot be used to evaluate risk to birds or mammals feeding on prey at a contaminated sediment site. Risk to birds and mammals ingesting sediment, water, and prey at a site is evaluated using food chain modeling to estimate the dose of a chemical ingested by these animals.

Tissue concentrations are a key component of dose estimates to birds and mammals, but are not always available during a SLERA. If tissue concentrations from organisms collected at the site or from organisms exposed to site-sediment in the laboratory are available, site-specific doses to birds and mammals can be estimated. Site-specific tissue concentrations (also known as CBRs) can also be used to estimate direct effects to the organisms from contaminant body burdens. If no tissue data are available, chemical concentrations in tissue may be estimated using concentrations in sediment, literature BSAFs, and parameter assumptions (see Appendix 21-F).

Ingested doses of bioaccumulative chemicals are estimated using food chain models. The dose estimate represents the mass of chemical ingested per day, indexed to the receptor's body weight (mg/kg-body weight/day). Daily ingested doses are estimated for higher trophic level receptors (birds and mammals) that are exposed to contaminants primarily through their diet rather than through direct contact with sediment. Where appropriate, the dose estimate should include incidental sediment ingestion. For example, the Hawaiian monk seal is reported to consume substantial amount of sediment when it hauls out on beaches. The risk assessor should review the relevant literature on key receptors at the site to determine the need to include sediment ingestion in the dose for a given receptor.

The ingested dose should be estimated using the following generic exposure equation. The equation can be modified, as necessary, based on the specific exposure pathways evaluated in the SLERA:

$$ED = \frac{\left[\left(C_f * I_f\right) + \left(C_s * I_s\right)\right] * SUF}{BW}$$

Where:

ED	=	exposure dose (mg/kg-day)
C_f	=	chemical concentration in food (mg/kg)
C_s	=	chemical concentration in sediment (mg/kg)
I_f	=	food ingestion rate (kg/day)
I_s	=	incidental sediment ingestion rate (kg/day)
SUF	=	site use factor (site/species home range – cannot exceed 1.0) (unitless)
BW	=	body weight (kg)

Chemical concentrations and ingestion rates (for sediment and food) should be reported in dry weight. If tissue concentrations are reported by the analytical laboratory in wet weight, dry weight concentrations can be estimated using either laboratory measures or standard default values for percent moisture.

For the SLERA, the estimated daily dose is intentionally biased high so that any error will be toward indicating greater risk than is present. In later phases of the ERA, biases are relaxed in favor of more realistic assumptions. For example, the estimated dose in the SLERA should be based on the

- Maximum chemical concentration in sediment and food;
- Maximum ingestion rates for sediment and food;
- Lowest body weight;
- Highest site use factor; and
- Most sensitive life stage present at the site.

The HEER Office provides species profiles for selected receptors at coastal marine sediment sites (Table 21-8). Species profiles are in Appendix 21-A. Values for exposure parameters required in the food chain model, such as body weight and home range, are included in the species profiles when available. The risk assessor should review the current published literature to obtain additional information where data are not provided.

Table 21-8. Selected Species Profiles

Receptor Group	Selected Species*
Marine Algae	Sea lettuce (*Ulva fasciata*) <link> each species to its profile in Appendix 21-A
Invertebrates	Samoan crab (*Scylla serrata*)
	Kona crab (*Ranina ranina*)
	White crab (*Portunus sanguinolentus*)
	Helmet urchin (*Colobocentrotus atratus*)
	Hawaiian limpet (*Cellana exarata*)
	Day octopus (*Octopus cyanea*)
	Polychaete (*Neanthes arenaceodentata*)
	Lobe coral (*Porites lobata*)
	Black sea cucumber (*Holothuria atra*)
Fish	Goatfish (*Mulloides vanicolensis*)
	Hawaiian flagtail (*Kuhlia sandvicensis*)
	Convict tang (*Acanthurus triostegus*)
	Pacific sergeant (*Abudefduf abdominalis*)
	Mozambique tilapia (*Oreochromis mossambicus*)
	Spectacled parrotfish (*Chlorurus perspicillatus*)
	Yellowbar parrotfish (*Calotomus zonarchus*)
	Moray eel (*Muraenidae*)
Birds	Wedge-tailed shearwater (*Puffinus pacificus*)
	Black-crowned night heron (*Nycticorax nycticorax hoactli*)
	Hawaiian coot (*Fulica alai*)
Sea Turtles	Green sea turtle (*Chelonia mydas*)
Marine Mammals	Monk seal (*Monachus schauinslandi*)

***** See Appendix 21-A for profiles of these species.

Calculate Critical Body Residues

The HEER Office does not require that tissue concentrations be obtained during the SLERA. However, tissue samples collected to support a human consumption study or other phase of investigation at the site may be available for inclusion in the SLERA. The risk assessor should present the available tissue data in tabular form with details on the sample date, location, species, size of specimen, body part, analytical methods, and results (with data qualifiers). If the tissue samples are composites of more than one individual organism, the details above should be provided for all individuals in the composite. (When possible, tissue concentrations should be measured in single individuals rather than composites for comparison to CBRs.) The maximum detected tissue concentration is used as the exposure concentration in the SLERA. Non-detects are treated as zero values when detection limits are acceptable (see Step 2, Task 2).

21.3.4.4 Step 2, Task 4. Calculate Site-Specific Hazard Quotients

Risk calculations in the SLERA are simple and straightforward for chemicals that are not considered bioaccumulators. The maximum exposure concentration is divided by the no-effect screening level to calculate a hazard quotient (HQ). If the resulting HQ is greater than 1.0, that chemical is designated a chemical of potential ecological concern (COPEC) and should be evaluated further. If the HQ is less than 1.0 for that chemical, it is eliminated as a COPC and dropped from further consideration. Chemicals without screening levels are retained as COPECs at this point in the process. To compensate for the uncertainty inherent in single chemical SQGs, the initial step of the SLERA is purposefully biased toward including chemicals that may not pose a risk rather than eliminating COPECs that may pose a risk, by use of conservative exposure assumptions. This bias toward including COPECs is corrected during later phases of the ERA (i.e., Step 3a or the BERA) in which the COPEC list is refined using more realistic assumptions and site-specific exposure data. The HQs for receptors directly exposed to sediment should be calculated as follows:

$$HQ_{sediment} = \text{maximum sediment concentration/no effect SQG}$$

Risks from chemicals that bioaccumulate can be evaluated using the equation above to assess direct toxicity to organisms. If the resulting HQ is less than 1.0, no direct toxicity is indicated. However, a bioaccumulating chemical cannot be eliminated as a COPEC based on a simple sediment screen because it may be bioaccumulated even when its concentration in sediment is less than the SQG. Risk posed by food chain transfer of contaminants is evaluated using TRVs derived for higher trophic level receptors. The estimated daily dose of a chemical in a given receptor is compared with the no-effect TRV to calculate an HQ:

$$HQ\text{-}TRV_{low} = \text{estimated daily dose/no-effect TRV}$$

Bioaccumulating chemicals can also pose a direct risk to the receptor in the form of causing neurological, developmental, or other impairment. The concentration of a bioaccumulating chemical in the whole body (or specific tissue type) of a receptor can be compared to the concentration demonstrated to cause an adverse effect on that receptor (or a surrogate species). When tissue effect levels for comparable species and tissue types are available in the literature, risk is estimated by comparing site specific tissue concentrations to CBRs from the literature:

$$HQ_{tissue} = \text{site-specific tissue concentration/CBR}$$

21.3.4.5 Step 2, Task 5. Decision Checkpoint

By this stage of the process, all available sediment, water, and tissue data have been screened against no-effect screening levels and HQs have been calculated. Chemicals for which all HQs are less than 1.0 can be eliminated from further evaluation. Chemicals for which at least one HQ is greater than 1.0 are retained as COPECs. The HEER Office recommends the SLERA include a summary table supporting the decision to eliminate or retain each chemical.

21.3.5 Step 3A: Refine Screening Level Default Assumptions

The COPECs retained at the end of Step 2 were shown to pose *potential* risk to receptors when conservative assumptions were used. Step 3A is focused on refining the list of COPECs to represent more realistic site-specific conditions. The objective of the COPEC refinement is to identify chemicals that significantly contribute to potentially unacceptable levels of ecological risk, and eliminate from further consideration those chemicals that are not likely causing a significant risk. This step consists of refining the conservative exposure assumptions/concentrations used to evaluate potential risks to ecological receptors and re-evaluating the analytical data using screening levels that are more appropriate for the assessment endpoints.

This refinement may result in eliminating chemicals as COPECs for some receptors, but retaining them as COPECs for other receptors. For example, a chemical might be retained as a COPEC for benthic invertebrates but eliminated as a COPEC for shorebirds. This is important because if the site proceeds to a BERA, the studies in the BERA should focus only on the chemicals-receptor pairs for which risk is predicted. The following tasks will support a decision regarding the need for further evaluation.

21.3.5.1 Step 3A, Task 1. Conduct Background Screening

The risk assessor should compare site-specific concentrations of COPECs with regionally-appropriate background, ambient, or reference concentrations to ensure that only site-related chemicals are carried through to the BERA. Inorganic chemicals pose unique difficulties for ERAs because of the role of site-specific geology in influencing exposure and effect concentrations. Background evaluations for sediment in Hawai‘i are complicated by spatial heterogeneity of volcanic and coralline sediment types.

In the absence of CBRs for selected receptors, the risk assessor may compare site-specific tissue concentrations with results from similar habitats or regions considered to be “unimpacted” by chemicals or to represent “background” tissue concentrations. The HEER Office is compiling tissue concentrations reported as “background” or “reference” in various published literature and reports. The values are not considered to represent “no effect” concentrations because the samples were not associated with toxicity testing. At best, the “reference” or “background” tissue concentrations indicate the range of concentrations existing in the area outside of known contaminated sediment sites. The risk assessor may compare site-specific tissue concentrations with the “reference tissue” results for the same species and habitat. Such comparisons are necessarily limited by uncertainty, yet they can provide a useful context for interpreting site-specific data. The relative magnitude of site-specific tissue concentrations compared with reference concentrations may indicate the need for further tissue sampling during the BERA or may strongly suggest that chemicals are not accumulating in tissues at the site to any measurable degree. The identification and interpretation of background, ambient, or reference concentrations should be discussed with the HEER Office before proceeding with the next task.

21.3.5.2 Step 3a, Task 2. Evaluate Magnitude of Screening Level Exceedance and Frequency of Detection

Although the magnitude of risks may not relate directly to the magnitude of a criterion exceedance, the magnitude of the criterion exceedance may be used in a weight-of-evidence approach to determine the need for further site evaluation. The greater the criterion exceedance, the greater the probability and concern that an unacceptable risk exists.

Likewise, the frequency of chemical detection and spatial distribution of concentrations greater than the screening levels may indicate the need for additional investigation. A chemical detected at a low frequency typically is of less concern than a chemical detected at higher frequency if toxicity and concentrations and spatial areas represented by the data are similar. All else being equal, chemicals detected frequently are given greater consideration than those detected relatively infrequently. In addition, the spatial distribution of a chemical may be evaluated to determine the area that a sample represents. The risk assessor should discuss magnitude and frequency distributions with the HEER Office to resolve any issues before continuing with the SLERA.

21.3.5.3 Step 3a, Task 3. Refine Conservative Exposure Assumptions

Initial steps in the SLERA use assumptions of 100 percent bioavailability, high site use by sensitive receptors, representative contamination concentrations, and other factors to ensure that a chemical is not excluded from the SLERA if it poses an unacceptable risk. In Step 3a, more realistic site-specific exposure values replace the default values.

- Bioavailability: When selecting chemicals as COPECs in the SLERA, it is typically assumed that the chemicals are 100 percent bioavailable. However, in the COPEC refinement, the potential bioavailability of the chemicals can be evaluated by considering total organic carbon (TOC) and grain size data. Typically, this evaluation is more qualitative than quantitative in the SLERA. However, in a BERA, bioavailability can be measured directly through uptake in living organisms. Guidance on adjusting the assumption of 100 percent bioavailability is in Appendix 21-F.

- Site Use: The conservative default value of 100 percent site use assumes that an organism spends all of its time in contact with contaminants at the site. For some mobile species, this assumption is clearly unrealistic, and a more representative site use factor may be used.

- Contaminant Concentrations: The most conservative and reasonably representative contaminant concentration for a specific target chemical is used for initial comparison to applicable screening levels, and some potential COPECs may be eliminated from the SLERA using this approach. However, smaller or additional DUs and/or more representative sampling techniques may be used during Step 3a to support further evaluation of the site.

21.3.5.4 Step 3a, Task 4. Obtain HEER Office Concurrence on Refinements

Provide the HEER Office with tables, text, figures, or other defensible rationale for refining the exposure assumptions. After reviewing the submitted materials, the HEER Office may accept the refinements or request a meeting to discuss the rationale and assumptions so that consensus can be reached.

21.3.5.5 Step 3a, Task 5. Recalculate HQs using Refined Exposure Assumptions

Recalculate HQs using more realistic estimate of contaminant concentration and screen against background concentrations. Prepare a summary table of COPECs eliminated and retained and provide rationale for the decisions. If risk is below applicable screening levels (or approved alternative screening level) for all chemicals, the SLERA is complete and the site can move to closure. If COPECs are retained and risk is potentially unacceptable, the site will continue to the BERA (Step 3).

21.3.5.6 Step 3a, Task 6. Develop SLERA Risk Characterization and Decision

Risk characterization in the SLERA focuses on the summary of HQs prepared in Step 3a, Task 5 and a discussion of uncertainty and data gaps to be addressed in the BERA.

21.3.6 Uncertainty

During the risk characterization phase, the exposure and effects data are interpreted within the context of other site-specific information. Specifically, various sources of uncertainty are evaluated so that the risk assessor can provide a realistic description of risks posed by contaminants at the site. Uncertainty stems from many sources, including the extrapolation of exposure and effects data form one species to another. Efforts to customize the ERA to tropical marine conditions and native Hawaiian species will greatly reduce this source of uncertainty and strengthen the risk characterization. Conversely, modifying existing toxicity tests and adapting protocols to accommodate the environmental conditions that prevail in Hawai‘i may introduce additional uncertainty in the short term. Such trade-offs are explicitly recognized and addressed in the *Sediment Quality Assessment Handbook* (Simpson et al. 2005). The following paragraphs present some of the key uncertainties in SLERAs, and where applicable, how the uncertainties relate to sites in Hawai‘i.

Uncertainty in Ecotoxicity

The HEER Office recommended interim SQGs specifically acknowledge that uncertainty stems from gaps in the science of toxicology, particularly in tropical marine ecosystems. One fundamental source of uncertainty stems from the derivation of single-chemical trigger values from toxicity tests using field-collected sediments containing multiple contaminants. Attributing toxic effects to any one of the many chemicals in such sediments leads to uncertainty that must be addressed in controlled laboratory investigations using single contaminants (Batley and Simpson 2008). The ANZECC/ARMCANZ is actively working to develop bioassays using native Australian or New Zealand species that will better reflect the genetic and ambient environmental conditions in sediments there. Some opportunity exists to adapt the Australian bioassays by substituting native Hawaiian species of similar taxonomic and functional characteristics. Therefore, although toxicity testing is typically not conducted until the BERA, the use of native Hawaiian species as test organisms for toxicity tests is encouraged, when applicable, to reduce uncertainty.

Some ecological risk investigations have been conducted in tropical marine regions, but Australia has developed an organized national program to tailor EPA and ASTM International (ASTM) protocols to tropical marine ecosystems. Although the Australian program is still in a fledgling state, many of the foundational principles are congruent with Hawai'i's goal to develop a state-specific ERA program. The Australian program recognizes the EPA framework and the large body of subsequent work on refining questions of metals bioavailability in whole sediments (Batley and Simpson 2008). The Australian group has focused on developing bioassays that reflect reasonable exposure and effects conditions for local habitats (see below). Finally, that group has implemented a regionalized program that incorporates land use, climate, and contaminant source data specific to a watershed so that background conditions can be properly evaluated (Australian Government 2006).

Uncertainty in Exposure

As indicated above, tissue samples can provide a direct measure of the bioavailability of chemicals. However, there is uncertainty in where and how they accumulated the chemicals (i.e., sediment, surface water, food, or a combination). Also, the choice of organisms, portion analyzed (whole body, fillet, liver, etc.), environmental parameters (i.e., pH, TOC, grain size), along with other factors influence bioaccumulation.

Particulate metal concentrations are nearly always higher in fine-grained sediments (<63 µm) because smaller sediment particles have a higher surface area and more binding sites available for metals (Angel et al. 2012). Although, HDOH does not recommend biasing sediment collection methods to only collect fine-grained sediments, sampling techniques must be appropriate to ensure that the finer-grained fractions are not lost during sample collection. For example, ponar samplers often allow silts to escape as the sampler is being lifted. A coring device may be more appropriate for ensuring that fine-grained sediments are represented in the sample to the extent they are present at the site (see Section 5<link>.

21.4 Anticipating and Addressing Data Gaps

The risk assessor should characterize and address data gaps during the scoping phase of the ERA, as part of the DQO process (see Section 3<link>). A data gap can be generally categorized as resulting from one of two sources: natural variability or incomplete knowledge. A direct evaluation of these types of data gaps can strengthen the DQO process and guide the risk assessor toward a more robust sampling design and a more defensible risk assessment.

The risk assessor should first distinguish between data gaps that result from incomplete knowledge and data gaps that result from inherent variability in the ecosystem. This categorization is based on general knowledge of environmental processes at the site, the CSM, the COPECs, and available data (Table 21-9).

Table 21-9. Data Gap Analysis

For data gaps that result from *natural variability* in the ecosystem, answer the questions below:

- Could this data gap be filled by additional study? (If you answer yes, make sure you have correctly identified the data gap as resulting from natural variability rather than lack of information).
- What is the source of variability for the parameter in question? Daily or seasonal fluctuations, genetic variations (including gender), age, size, and other features may introduce variability. Note that natural variability encompasses differences within the same individual over time (lifetime, seasonal, or daily); among individuals within a population (based on gender, size, or other factors); and among populations.
- Are existing data adequate to describe the variability statistically using probabilistic models and other quantitative techniques?
  - If yes, describe the methods used to develop probabilistic values and clearly explain any residual uncertainty associated with the values used in the ERA.
  - If no, choose one of the following:
    - Use the most conservative (i.e. most protective) value from the available range and provide rationale for why that value is or is not representative of conditions at the site.
    - Conduct additional study (sampling) to provide the necessary data covering the range of variability.

For data gaps that result from *incomplete knowledge* about a particular site, chemical, or receptor, answer the questions below:

- Could this data gap be filled by additional study?
- What is the range of possible values for the parameter in question?
  Work through two hypothetical scenarios using the maximum value and the mean value for this parameter, respectively.
- Consider the two results: Are the results of the two hypothetical scenarios different enough to substantially change remedial decisions at the site?
  - If no, then don't waste time or money refining this value. *(Use the maximum as a default value.)*
  - If yes, estimate the value (or order-of-magnitude) at which a different decision would be triggered and design a study to develop a realistic value. *The study could be desk-based, in which you search the existing literature and develop a rationale for extrapolating from another study, or for amassing a large set of relevant data to provide a reasonable context for your site. If the value is critical to a decision that will lead to a very expensive or controversial remediation, then you may find it is justifiable to conduct a site-specific study.*

21.5 Summary of Decision Logic for ERAs

The HEER Office applies the decision logic indicated in Tables 21-10 and 21-11, and Figures 21-8 for sediment investigations (see below). It is important to note that the linear flow of the decision tree shown in Figure 21-8 should just be used as a starting point as it is not the only way to approach an ERA. The specific approach should be based on the process outlined in the DQOs and an iterative assessment of meaningful effects, dependent on the particular chemicals and receptors of concern at a site. Many of the items in Table 21-10 and Figure 21-8 are conducted as part of the BERA, such as toxicity testing and tissue sampling. Required, preferred, and optional data for sediment ERAs are summarized in Table 21-11.

Table 21-10. Questions Guiding Decision Logic for Contaminated Sediment Investigation

	Question	Method	Step
1	Do any chemicals in sediment in the DU exceed HDOH interim No Effect SQGs?	Compare with HEER Interim No Effect SQGs	SLERA Step 2
2	Could chemicals in prey organisms at the site adversely affect other organisms that consume them?	Evaluate using food chain modeling	SLERA Step 2
3	Are the chemicals present at concentrations greater than what occur naturally in these sediments or typically in the local environment?	Compare with background/ambient/reference locations	SLERA Step 3A
4	Are the chemicals in a bioavailable form representing exposure to organisms?	Evaluate factors affecting bioavailability	SLERA Step 3A
5	Are organisms at the site directly affected by exposure to chemicals in sediment?	Conduct direct toxicity test or model using representative data	BERA
6	Are organisms at the site bioaccumulating chemicals from the sediment?	Measure field collected organisms or model bioaccumulation using representative data	BERA
7	If yes, could organisms at the site be adversely affected by the chemicals in their tissues?	Evaluate using appropriate tissue effect levels	BERA

Figure 21-8. Interim Decision Logic for Sediment Investigations in Hawai'i

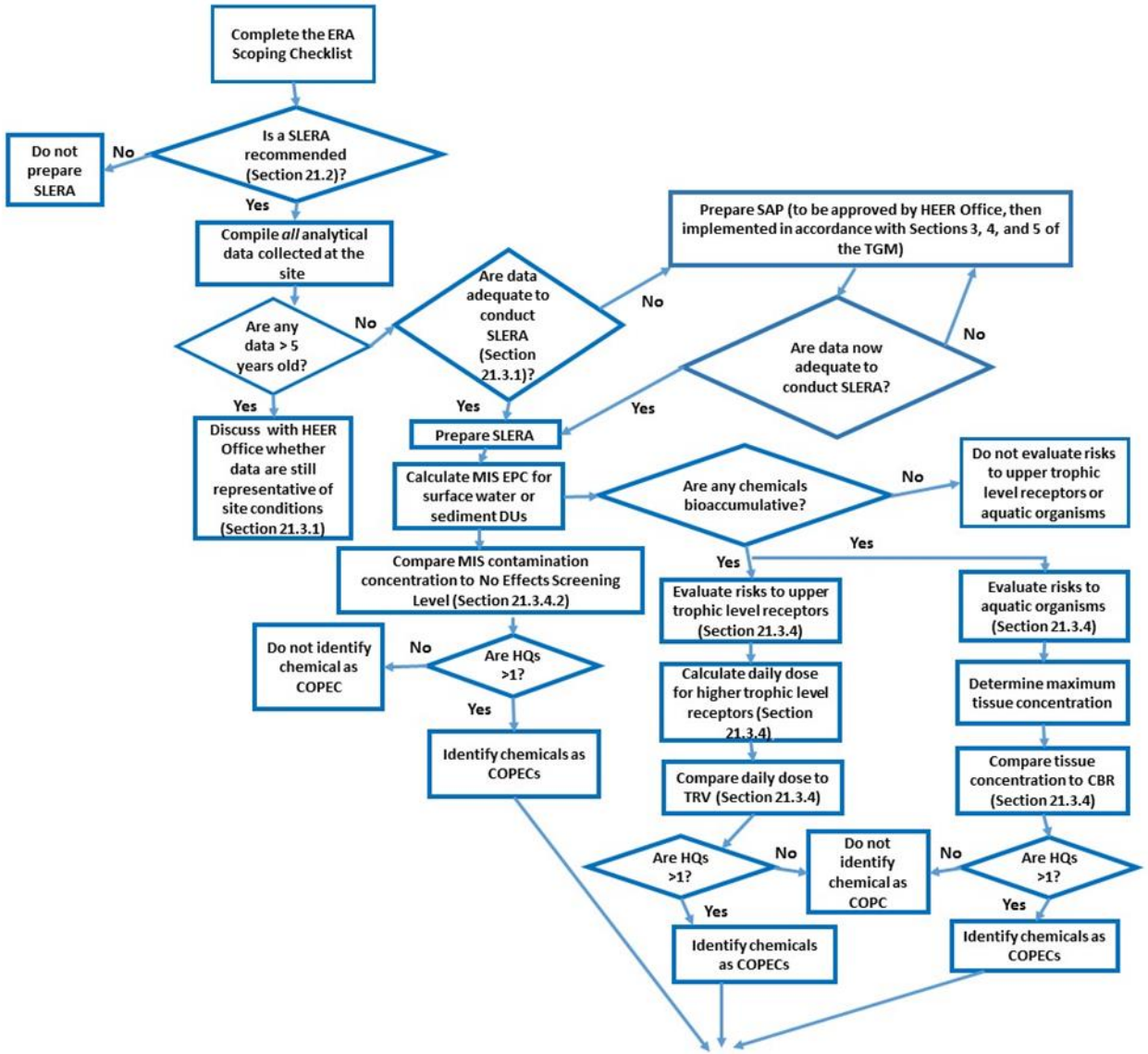


Figure 21-8 (continued). Interim Decision Logic for Sediment Investigations in Hawai'i

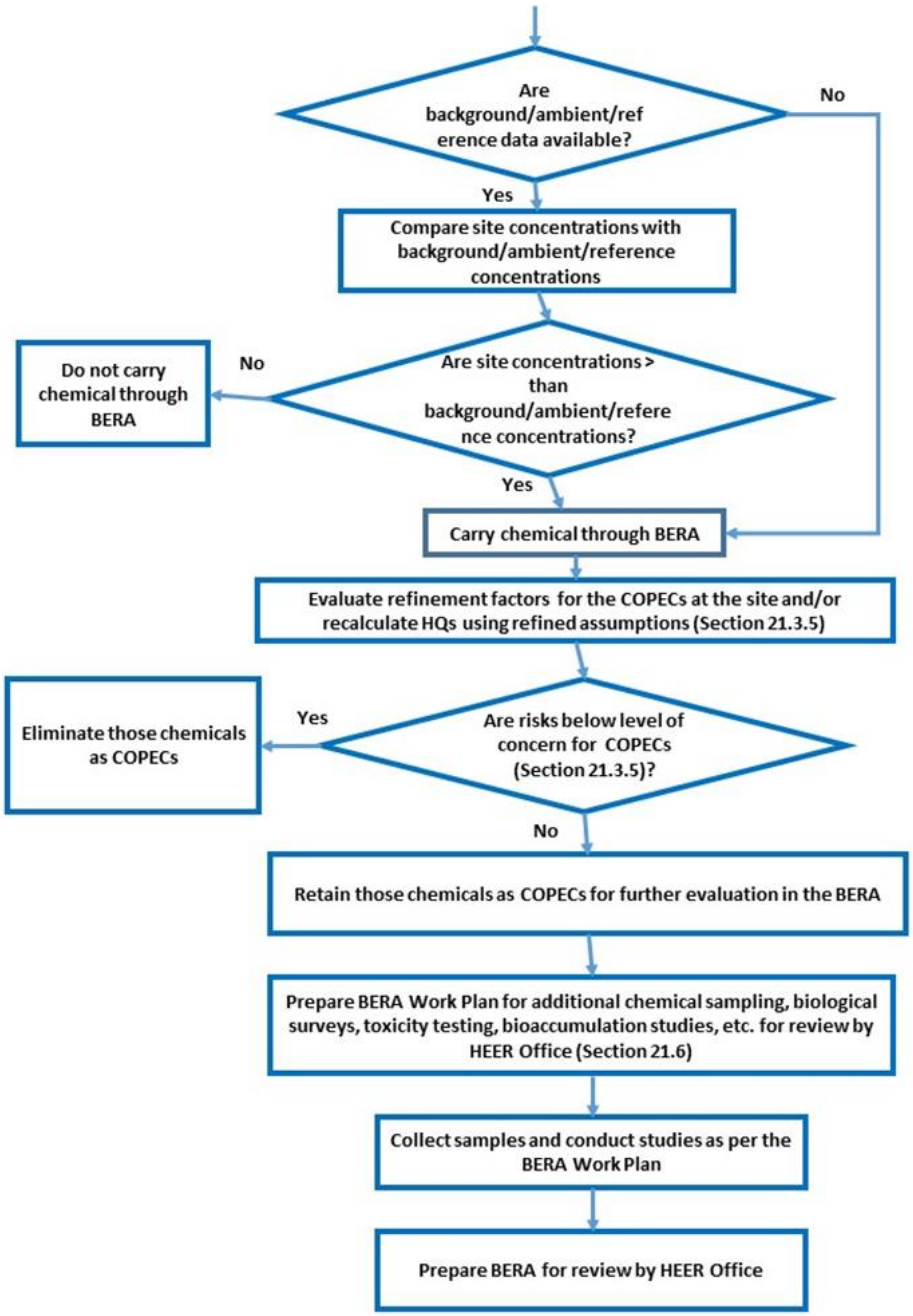


Table 21-11. Required, Preferred, and Optional Data for Sediment ERAs

Data Type	Required	Preferred	Optional
Sediment (for SLERA or BERA)			
Multi Increment Sediment (MIS) Samples in appropriate decision units (DU)	●		
Pre-approved Reference Location – all sample types	●		
Background metals analysis (literature)	●		
Total organic carbon	●		
Grain size distribution	●		
Acid-volatile sulfide and simultaneously extracted metals (AVS/SEM)			●
Pore water		●	
Surface water		●	
Site-specific tissue (for bioaccumulating chemicals)		●	
Laboratory Tests (typically just for the BERA)			
Bioaccumulation Test (using native Hawaiian species[1])	(if known bioaccumulator is present or suspected)		
Lethal and sublethal toxicity tests using native Hawaiian species	(if one or more chemicals is greater than the Probable Effect SQG)	(if one or more chemicals is between the No Effect SQG and the Probable Effect SQG)	
Field-Collected Tissue *(typically just for the BERA)*			
Field-Collected Tissue (Benthic/epibenthic invertebrate such as crab or octopus; fish species with direct or indirect exposure to sediment)	(if known bioaccumulator is present or suspected)	(in general)	
Passive sampling device (for PCBs)			if PCBs exceed No Effect SQG

[1] If no standard test using a native species is available, provide rationale for a carefully-selected surrogate species

21.6 Baseline Ecological Risk Assessment

After completing the SLERA, including the Step 3a refinement, the risk assessor is ready to begin Step 4: the BERA. The first task of Step 4 is to prepare a BERA work plan (WP). If additional field data collection is required, the WP may include a field sampling and analysis plan (SAP). Typically, a combined WP/SAP is prepared to streamline the planning and approval process before BERA data collection begins.

The purpose of preparing a BERA WP is two-fold: (1) it compels the risk assessor to thoroughly evaluate existing data, describe site conditions, formulate DQOs, identify data gaps, and anticipate issues that may arise during later risk characterization and data interpretation phases; and (2) it provides a site-specific framework for discussions with the HEER Office during which information can be shared and common goals can be established. This section guides the risk assessor through the tasks typically included in the BERA, describes best practices, and reviews technical references to support the process. This section assumes that a combined WP/SAP is being prepared. The process of developing the BERA WP/SAP is described below.

1. Review the SLERA and ensure that you have access to all available data that contributed to the conclusions of the SLERA.
2. Compile any pertinent information collected since the SLERA was prepared. If any new information leads you to question the need for a BERA, present the information and your rationale to the HEER Office for discussion.
3. Once you are sure that a BERA is appropriate, prepare a BERA WP/SAP using the outline in Appendix 21-G. The rest of this section will provide templates and examples to help you develop the BERA WP.
4. Notify the HEER Office that you are preparing a BERA WP/SAP and request additional guidance as needed.
5. Submit the draft BERA WP/SAP to the HEER Office well before you expect to begin field work.

As described in previous sections, the SLERA usually relies on literature-based toxicity and bioaccumulation factors and conservative default assumptions about exposure because site-specific data are not available. The purpose of the BERA is to replace literature or default values with site-specific data so that risk can be more accurately characterized. Site-specific data collection may include toxicity and bioaccumulation tests, collection of organisms, passive sampling of water or sediment, analysis of TOC and grain size, and other types of information. In addition to collection of new data, a more detailed analysis of data available during the SLERA may be warranted.

The components of the BERA mirror those of the SLERA. First, the problem formulation is refined to better describe the environmental setting, ecological receptors, and complete exposure pathways, resulting in a revised CSM (Section 2 of the BERA WP/SAP). Then, exposure and effects estimates are updated using site-specific information. The study design for collecting and analyzing new data is in Section 3 of the BERA WP/SAP (Study Design and DQOs). Elements of the BERA are presented in Section 21.6.1 through 21.6.4 below.

Although each BERA WP/SAP will represent site-specific conditions and address unique considerations, most or all can be prepared using the template in Appendix 21-G. The template provides general direction on which elements should be included in a site-specific BERA WP/SAP and includes useful tips. The HEER Office does not require that the risk assessor follow the template

exactly, but it is important that all the necessary components of the BERA be included in the WP/SAP. The full set of topics to be included in the BERA will be determined by the location and geophysical features of the site, the site-specific COPECs, the selected assessment and measurement endpoints, and complete exposure pathways.

21.6.1 BERA Refined Problem Formulation

The problem formulation section serves as the "backbone" of the ERA. The SLERA problem formulation (described in Section 21.3.3) included a description of the environmental setting, including ecological receptors, potential sources of contamination, and potential exposure pathways, which were used to develop the preliminary CSM. At the start of the BERA, the problem formulation is refined to reflect the conclusions from the SLERA.

The result of Step 3a is a list of COPECs that require further evaluation in the BERA and a list of chemicals eliminated from further evaluation because they were found not likely to cause significant risk. Ideally, the BERA will focus only on chemical-receptor pairs posing potential risk. Careful completion of this step will prevent the risk assessor from wasting time and effort evaluating chemicals in the BERA that should have been screened out during Step 3A.

The refined problem formulation should also identify any data gaps necessary to characterize site-specific risk at the end of the BERA. In some case, information obtained since the SLERA was written may warrant inclusion of chemicals, receptors, or exposure pathways that were not evaluated in the SLERA. For example, the risk assessor may have learned of a historical spill at the site, or a unique habitat with receptors not considered during the SLERA may have been identified. Data gaps identified during review of the SLERA may also require additional lines of investigation. In general, the refined problem formulation should include the environmental setting, COPECs, and assessment and measurement endpoints. Each of these is discussed below.

This section of the BERA should describe the environmental setting, COPECs, and sources identified in Step 3a, and ecological receptors. Although much of the site characterization will remain as described in the SLERA, it should be updated with any new information, especially on habitats that will be the focus of the BERA.

21.6.1.1 Sediment Dynamics

The SLERA may have relied on assumptions about sediment grain size based on regional geology, as described in the introduction to Section 21. For example, the area may have been described as depositional based on regional data, habitat, or conservative assumptions. For the BERA, it may be necessary to confirm substrate type and grain size at the site to determine whether the area is depositional to better predict chemical behavior and presence of receptors when refining the CSM. Grain size and wave energy must also be considered when selecting an appropriate reference location for the BERA.

Beaches are eroding more than accreting across Hawaii (Fletcher et al. 2012) and coastal erosion is expected to nearly double over the next few decades across the state (except Kailua Beach on Oʻahu) (Anderson et al. 2015). Nevertheless, sediment dynamics are spatially variable, and areas of erosion and accretion may be separated by only a few hundred meters. Each small embayment created by

rocky headlands is influenced by local wave energy and terrestrial processes, creating a patchwork of erosion and accretion along the shore. The most recent data on coastal erosion and accretion of shorelines on Kauai, Oahu, and Maui are available at http://pubs.usgs.gov/of/2011/1051/) (Fletcher et al. 2012). This USGS information should be consulted during the site characterization phase of the BERA.

21.6.1.2 Chemicals of Potential Ecological Concern

The list of COPECs developed at the end of Step 3A should include only those chemicals that exceed background or reference concentrations and ecotoxicological effect levels for receptors at the site. If new information suggests the presence of additional chemicals that were not analyzed during the SLERA, then new chemicals should be added to the BERA WP/SAP.

21.6.1.3 Ecological Receptors (Assessment and Measurement Endpoints)

Based on the results of Step 3a, some receptors considered in the SLERA may be eliminated from further evaluation, and others may be added. The refined problem formulation should include only receptors that will be evaluated in the BERA, based on their known or expected presence at the site or their selection as surrogates for species of interest. The HEER Office has prepared species profiles for selected marine species in Hawai'i (Appendix 21-A). The appropriate receptors from this list should be considered for evaluation in the BERA, noting that additional exposure information may be needed to quantify risks to some receptors. Note that the list of species in Appendix 21-A is not comprehensive; other species may be evaluated in the BERA if approved in advance by the HEER Office. In the BERA WP/SAP, explain any changes to the list of receptors in the SLERA.

Assessment and measurement endpoints that are commonly evaluated in marine sediment ERAs are summarized in Table 21-5 (see Section 21.3.3). This section of the BERA should provide rationale for the selected assessment endpoints and describe how each assessment endpoint will be evaluated using the selected measurement endpoints. A table similar to Table 21-5, including the following elements, should be developed for the BERA:

- ***Ecological Guild***: The functional niche of the receptor (such as benthic invertebrate)
- ***Assessment Endpoint***: The specific attributes of value for the ecological guild at the organism or population level.
- ***Species Evaluated***: Table 21-8 lists typical species included in each ecological guild. In the BERA, identify the species that were used to represent the ecological guild, along with the rationale for selecting the species. In some cases, species other than those listed in Table 21-8 may be used based on available data. Use of other species should be presented in the BERA WP/SAP and approved in advance by the HEER Office.
- ***Measurement Endpoint***: Table 21-5 lists common measurement endpoints for each of the assessment endpoints. In the BERA, present the specific measurement endpoints that were used to evaluate the assessment endpoints, along with the rationale for selecting those endpoints. The measurement endpoints may include some or all the endpoints listed in Table 21-5, and endpoints not listed in the table that are deemed appropriate for the site.

21.6.1.4 Refined Conceptual Site Model

The screening level CSM was developed as part of the SLERA based on what was known about the site at that time, without regard to potential ecological risks. As described in Step 1b, Task 5 (Section

21.3.3), the elements of the CSM include (1) ecological receptors present at the site; (2) sources of chemicals in the environment; (3) contaminant transport pathways; and, (4) exposure pathways to the ecological receptors. The same elements are included in the refined CSM, which represent the chemicals, receptors, and exposure pathways evaluated in the BERA.

Appendix 21-C describes the approach for defining the ecological DU. DUs set the boundaries for where the BERA investigations will be conducted. The refined conceptual site model should describe the DUs that were selected for each assessment endpoint evaluated in the BERA and the rationale for selecting them. Refer to the discussion of sediment types at the beginning of Section 21 before identifying DUs. Note also that the size of the DUs is determined in part by the receptors, as home range is an important variable in the evaluation of exposure and effects. The site may contain several DUs designated by sediment type, wave energy, preliminary contaminant concentrations, receptor distribution, and other factors.

21.6.2 BERA Study Design and Data Quality Objectives

The BERA should describe the investigations conducted to evaluate each assessment endpoint, such as chemical analysis, toxicity testing, bioaccumulation studies, biological surveys, and tissue analyses. The DQO process that was followed during the SLERA (see TGM Sections 3, 4, and 5) should be revisited when preparing the BERA WP/SAP. The study design and DQOs should be presented in the BERA WP/SAP and cited in the BERA. Because the BERA WP/SAP will be included as an appendix to the BERA, it is not necessary to repeat the DQO section. A Quality Assurance Project Plan (QAPP) should also be prepared as part of the BERA planning effort (see Section 10<link>)

21.6.2.1 Laboratory Analyses

Additional data collected for the BERA are likely to include field samples of sediment, sediment pore water, surface water, groundwater, or even soil (in case where terrestrial erosion is suspected as a transport pathway to the marine site). The BERA WP/SAP should identify analytical methods and detection limits to ensure that detection limits lower than selected screening levels can be achieved.

The HEER Office recommends evaluating chemicals with similar modes of toxicity as "total" concentrations, but analysis of individual constituents may also be necessary. Total concentrations are commonly calculated for HMW PAHs, LMW PAHs, total PAHs, total PCBs, DDT and its breakdown products (total DDTx), and dioxin toxic equivalency quotients (TEQs). Methods for calculating total PCBs and dioxin TEQs are discussed later in this section, but the risk assessor is encouraged to review the current literature and determine the most appropriate method for the site. No specific list of constituents or summation method is prescribed because methods are rapidly changing as new technical literature is published, methods are vetted, and best practices are disseminated within the risk assessment community. The BERA WP/SAP should describe the proposed methods of summing constituents and clearly identify the individual constituents to be included in the sum. Relevant literature should be cited to support the proposed methods.

In general, DOH requires the following when calculating total values:

- Non-detected values should be assigned a value of zero provided the detection limits were acceptable, as described above.
- The mean of duplicate pairs should be used for the calculation.
- The list of individual constituents included in the total calculations must be given (see notes at the bottom of Table 21-7 for a list of HMW and LWM PAH totals).

Risks from dioxins/furans should be evaluated by using Toxicity Equivalence Factors (TEFs) to calculate toxicity equivalence concentration (TEQ) as described in the *Framework for Application of the Toxicity Equivalence Methodology for Polychlorinated Dioxins, Furans, and Biphenyls in Ecological Risk Assessment* (USEPA 2008). The detected concentration of each dioxin (or furan) in a sample is multiplied by its TEF. The resulting values for each sample are summed to calculate the TEQ Dioxins/Furans for each sample. TEQs should be calculated for birds, mammals, and fish using chemical-specific TEFs for each group; no dioxin TEFs are available for plants and invertebrates.

PCBs results historically have been reported as Aroclors (i.e., Aroclor-1254, Aroclor-1260) in BERAs because the early ecotoxicological studies were based on total PCBs expressed as the sum of Aroclors. Although some current studies continue to report effects of total PCBs, newer literature is increasingly focused on one or a small set of the 209 PCB congeners. Each Aroclor originally contained a specific combination of PCB congeners and could be identified by its distinctive chromatographic pattern when is analyzed by gas chromatography. However, as Aroclors age and weather, the chromatographic patterns may change and not be recognizable as standard patterns. Such degradation of Aroclors may cause the laboratory to underestimate the concentration of total PCBs in a sample. (See *Issue Paper for Polychlorinated Biphenyl Characterization at Region 4 Superfund and RCRA Sites* 2013 for more detail on this issue).

Analysis of PCB congeners is considerably more expensive than Aroclors, so the decision of analytical method must be made with care. The HEER Office recommends that PCBs be analyzed as Aroclors during the SLERA. However, if total PCBs are detected at concentrations exceeding the screening level in the SLERA samples, a subset of samples (no less than 10 percent) should be analyzed for all 209 congeners. Note that twelve of the PCB congeners have been designated by the World Health Organization (WHO) as having "dioxin-like" toxicity (Van den Berg et al. 1998). The same process described above to calculate the TEQs for dioxins (USEPA 2008) can be used to sum the dioxin-like PCBs when site conditions warrant. The BERA WP/SAP should describe the rationale for the selected analytical methods for PCBs (Aroclors, congeners, or a combination of the two) and discuss how the dioxin-like PCBs will be summed if samples are analyzed for PCB congeners.

21.6.2.2 Sediment Sampling

The objectives of the study and availability of existing data play an important role in dictating the sampling design, methods, and equipment. For example, MI sampling should be conducted to determine representative average contaminant concentrations in sediment across a designated DU (see Sections 3<link>, 4<link>, and 5<link>. Section 5.7 of the TGM (Sediment Sampling) discusses issues affecting sediment sampling in more detail.

A wide variety of sampling equipment is available for collecting sediment, but not all equipment is suitable for all sites. For example, grab samplers such as a ponar dredge or Van Veen grabs are capable of sampling only the top several inches of sediment, while sediment corers and vibracores can be used

to collect deeper samples if historical chemical concentrations are needed. Other considerations include whether the sediment sample must be undisturbed (as it should be for analyzing volatile organic compounds). Water depth, currents, sediment volume, bottom firmness, and other parameters also influence the likelihood of success of each collection method. When acid volatile sulfides [AVS] are to be analyzed, exposure of the sample to oxygen must be limited. A thorough discussion of the various sediment sampling devices, including advantages and disadvantages of each and the best samplers to use for different types of sediment is presented in Chapter 3 in *Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual* (USEPA 2001). The BERA WP/SAP should include a complete description of equipment, techniques, and standard operating procedures (SOPs) for all sediment collection methods, and cite references as needed to support the proposed methods.

The BERA WP/SAP should describe the procedures for any representative sub-sampling of sediment samples in the field. This is a critical component of sample processing and should be based on the objective of the investigation, the COPECs, and the sediment matrix. Typically, processing and representative sub-sampling of MI samples are conducted in the laboratory following an established SOP (see Section 4<link>).

Sediment samples must be collected from the appropriate depth to address the goals of the BERA (as identified in the DQO analysis). General guidance on selecting the appropriate depth for collecting sediment samples in the biologically active zone is in *Determination of the Biologically Relevant Sampling Depth for Terrestrial and Aquatic Ecological Risk Assessments* (USEPA 2015). Table 21-12 summarizes the depths of the biotic zone associated with different sediment substrates and lists habitats in Hawai‘i that may contain that substrate.

Table 21-12. Typical Depths of Biotic Zone1

Depth	Sediment Substrate	Example Habitat Type[2]
5 cm	oligohaline/polyhaline mud	Mudflats
5 cm	oligohaline sand and marine coastal sand	Sandy Beach
10 cm	marine coastal mixed and marine offshore sand	Seagrass beds
10 to 15 cm	estuarine and tidal freshwater environments	Stream-fed Estuarine Wetlands

The HEER Office recommends taking the above-referenced guidance into consideration when determining appropriate sampling depths to capture the biotic zone. However, depending on the objective of the investigation, deeper samples (below the biotic zone) may also be needed to characterize vertical extent of contamination.

Special sediment sampling consideration may be warranted for target receptors that ingest sediment directly, as sediment effect levels may not account for the ingestion pathway. Ingestion is the basis for the food chain modeling used to evaluate risk to birds and mammals, but many benthic invertebrates and fish also consume sediment as part of a typical diet. Tissue concentrations of benthic invertebrates may reflect chemicals adsorbed to ingested sediment particles as well as chemicals absorbed directly from sediment and water (Lee et al. 2006; Belzunce-Segarra et al. 2015). To evaluate the sediment ingestion pathway, sample collection methods must ensure that the top layer of fine particles is retained for analysis.

When developing the BERA WP/SAP, sediment sample collection log sheets from the SLERA should be reviewed to determine whether they contain useful information to guide the BERA. For example, if sulfide odors were detected during sediment sampling, than AVS may be present in the sediment. Methods for evaluating bioavailability of metal mixtures in sediment containing AVS are discussed in *Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Metal Mixtures (Cadmium, Copper, Lead, Nickel, Silver, and Zinc)* (USEPA 2005b).

At some sites, it may be appropriate to use a Dynamic Sampling Approach, in which field analytical methods such as x-ray fluorescence (XRF), immunoassays, or other mobile screening approaches help make quick decisions regarding the need to collect samples in a location. This approach is discussed briefly in Sections 3.10 and 5.5.8 of the TGM. Basically, this approach allows samples to be collected and sites to be characterized more efficiently and quickly than traditional sampling. The costs and benefits of a dynamic sampling approach should be discussed in the BERA WP/SAP. See *A Guideline for Dynamic Workplans and Field Analytics: The Keys to Cost-Effective Site Characterization and Cleanup* (Robbatt and USEPA 1997) for more information on field assessment techniques.

21.6.2.3 Pore Water Sampling

In sediments where sediment pore water is relatively static, contaminants in the pore water are expected to be at thermodynamic equilibrium with the sediment (solid phase), making pore water useful for assessing contaminant levels and associated toxicity (USEPA 2001). The utility of collecting sediment pore water at a site is influenced by a variety of factors, including the solubility of the chemicals, ongoing sources of chemicals in groundwater, grain size and organic content of sediment, and other factors. Sites where pore water analysis may be appropriate include fine-grained sediments in low energy depositional areas (such as bays and harbors) and nearshore sites where contaminated groundwater is known or suspected to discharge to sediment. The suitability of sediment pore water as an exposure pathway to ecological receptors should be evaluated as part of the DQO process and documented in the BERA WP/SAP.

Several *in situ* an *ex situ* methods are available to collect sediment pore water. No single method is clearly superior in all cases. For example, peepers are suitable for collecting small volumes of pore water for one or two analyses, but are not practical for collecting large volumes required to analyze for numerous chemicals. Fine-grained sediments may be collected in buckets and taken to the laboratory for extraction of pore water by centrifugation. Coarser-grained sediments do not retain water when collected, which greatly increases the volume of sediment that has to be collected to yield adequate pore water for analysis. Pore water in coarse-grained sediments may be more efficiently sampled using in situ passive samplers. Technical reviews of passive sampling are provided in Ghosh et al. (2014), Greenberg et al. (2014), Lydy et al. (2014), Mayer et al. (2014), and Peijnenburg et al. (2014).

The BERA WP/SAP should specify which method of collecting and analyzing sediment pore water will be used and provide rationale for selecting the method. It is essential that the same collection procedures be used and the pore water be collected at the same depth across the site so that appropriate comparisons can be made (USEPA 2001). Likewise, the same methods must be used at the reference location. Methods are discussed in several comprehensive technical references:

- USEPA (2001): *Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual* (Chapter 6).

- Carr et al. 2001: *SETAC Technical Workshop on Porewater Toxicity Testing: Biological, Chemical, and Ecological Considerations with a Review of Methods and Applications, and Recommendations for Future Areas of Research*
- Various authors 2014: *"Passive Sampling Methods for Contaminated Sediments,"* in the SETAC Technical Workshop *"Guidance on Passive Sampling Methods to Improve Management of Contaminated Sediments"* in *Integrated Environmental Assessment and Management* (Volume 10) reviews the use of passive samplers to quantify concentrations of chemicals in sediment pore water.

21.6.2.4 Surface Water Sampling

The surface water pathway is evaluated by comparing chemical concentrations in surface water with water quality standards based on ecotoxicity. However, surface water should be evaluated only in places where the water has a relatively long residence time so that the exposure duration is meaningful. For example, surface water is not considered a measureable pathway at sites where high energy wave action mixes the water constantly. The HEER Office generally does not recommend collecting surface water samples from high energy environments or areas where considerable flushing occurs. In contrast, surface water could be an important pathway in a protected bay contaminated by a surface release, stream input, or groundwater flow. Surface water samples should be collected if chemicals in groundwater are known or suspected to discharge through sediment into protected surface water areas.

Surface water samples may be analyzed for total or dissolved chemicals, depending on the proposed use of the results. Samples that will be compared with the Hawai'i Water Quality Standards (Title 11, Chapter 54) for metals should be analyzed for dissolved fractions, represented by samples passed through a 0.45 micrometer (µm) filter. The filtering step typically takes place in the lab, although field-filtering is an option under special circumstances. The USGS provides comprehensive guidance on proper methods for collecting water samples in the *National Field Manual for the Collection of Water-Quality Data: U.S. Geological Survey Techniques of Water-Resources Investigations,* Book 9, Chapters A1-A10 (http://pubs.water.usgs.gov/twri9A).

Both freshwater and saltwater (marine) standards are available. Freshwater and saltwater standards apply to waters with a dissolved inorganic ion concentration less than and greater than 0.5 parts per thousand (ppt), respectively. Saltwater samples can be analyzed for dissolved constituents only. In freshwater habitats, however, total concentrations from unfiltered samples are better indicators of the concentrations ingested by animals as drinking water and are preferred as inputs to the food chain model (see Step 2, Task 3). Freshwater samples may be split and analyzed as both total and dissolved concentrations. The BERA WP/SAP should clearly indicate and provide rationale for which water quality standards will be applied and which water samples will be filtered.

Sample numbers and locations, sampling equipment, and proposed analyses should be presented in the BERA WP/SAP. Equipment should be selected based on the depth of water to be sampled, volume of water needed, strength of currents, and other logistical factors. For example, if the objective is to collect surface water samples at the surface water-sediment interface to determine whether groundwater discharge is transporting chemicals to surface water, a horizontal water bottle sampler may be appropriate. Alternatively, passive sampling devices can be deployed at the sediment-water interface to measure concentrations over time in a specific area. Passive sampling devices are newer

and less standardized, but may be acceptable for use at some sites. Regardless of the methods and equipment selected, it is important that site samples and reference area samples be collected in the same way.

The BERA WP/SAP should present a rationale for the selection of devices, equipment, and methods. The procedure should be designed so as to minimize incidental collection of suspended solids with the water sample, as solids can artificially inflate measured chemical concentrations. Such interference can be especially important when relatively hydrophobic chemicals such as PCBs and pesticides are being analyzed. In such cases, side-by-side analyses of filtered and unfiltered samples may be warranted.

21.6.2.5 Biological Surveys

Biological surveys may be conducted as part of a BERA for many reasons:

1. To document the presence and abundance of ecological receptors at the site, including protected or rare species;
2. To compare the distribution or abundance of species with reference areas or historical records;
3. To evaluate the health or integrity of the ecological community; and
4. To collect tissue samples for chemical analysis (described below) for use in food chain models or critical body residue analyses.

Field surveys may be designed for the reasons listed above, as well as simply to ground-truth the CSM. Unlike sediment and water sampling, which may be conducted by general field teams, biological surveys should be conducted by experienced biologists or ecologists who are prepared to document and interpret what they see in the field. Although a single species or type of organism may be targeted for collection, the presence and condition of other species may inform the BERA. Well-designed biological surveys focus on structured data collection, but a competent field biologist will also make opportunistic findings, such as the presence of unanticipated species; the relative scarcity of individuals where abundance was expected; evidence of degraded habitat such as algal overgrowth, stressed vegetation, or chemical sheens and odors; and other features that are not the direct target of the survey.

The BERA WP/SAP should describe the proposed survey as thoroughly as possible, including but not limited to the elements below:

- Objectives of the survey
- Qualifications of the field team
- Locations to be surveyed (with rationale), and process for adjusting the location when field conditions warrant
- Relation of survey locations to established DUs
- Intended dimensions of each survey location (length and width)
- Survey methods (areal grid, transect, etc.)
- Sample field forms
- Protocol for avoiding habitat degradation during survey
- Protocol for unintended encounters with protected species
- Temporal requirements of the survey: time of day, season, restrictions based on weather

- Health and safety issues (to be documented in a separate health and safety plan)
- Use of survey data (species richness, taxonomic diversity, percent dominant taxa, frequency and dominance of stressor tolerant taxa, etc.)

Surveys at the site should be repeated to the extent feasible at reference locations. The reference locations should be similar in size, substrate (grain size distribution), wave energy, surrounding habitat/land use (i.e. urban, rural, forested, etc.).

21.6.2.6 Field-Collected Tissue Sampling

Organisms may be collected from the site (and reference location) during a biological survey or as a separate activity. Field-collected organisms may contribute in several ways to the BERA:

1. Whole organisms or body parts may be analyzed for selected chemicals. When appropriate, chemical concentrations in the organisms can be compared with concentrations in sediment to evaluate bioavailability and uptake by the organism. Note that this approach requires that both the organisms and the sediment be relatively immobile.
2. Organisms may be collected as part of a biological inventory focused on characterizing the health of the community in a given area. Species distribution and abundance, species diversity, age or size class distribution, reproductive condition, and other parameters may be measured.
3. Organisms may be collected for evidence of disease, which may then be linked to chemical contaminants in the sediment or water. External tumors or lesions may indicate exposure to PAHs, for example. Internal examination may reveal parasites, liver damage, or other evidence of degraded health.

Note that a Special Activity Permit may be required for collecting marine organisms for the BERA, even if the organisms are returned to the water unharmed. The Hawai'i Division of Aquatic Resources should be contacted during the BERA planning stages to identify necessary permits http://dlnr.hawaii.gov/dar/licenses-permits/. Other permits may be required for collecting protected species or certain native species, or for collecting in parks or other specified areas. The risk assessor should coordinate with the Hawaii Division of Forestry and Wildlife (http://dlnr.hawaii.gov/dofaw/permits/) to obtain the required permits.

In addition to the elements listed above for biological surveys of any kind, the BERA WP/SAP should fully describe the proposed rationale and methods for collecting and analyzing organisms, including at a minimum the following details:

- Objective of the collection effort
- Target species to be collected and alternate species in the event that the target species cannot be collected
- Locations, relative to DU, and protocol for field adjustment of locations
- Number of individuals of each species to be collected (by sex and size, if relevant), per location, including reference location
- Number of organisms to be composited in each sample (single species only)
- Body part(s) to be tested (whole body, liver, eggs, blood, etc.)
- Other parameters to be measured (lesions, parasites, fin rot, etc.)

Selection of Appropriate Species for Field Collection

Selecting the appropriate species for field collection is critical to the defensibility of the BERA. Not all species are suitable for answering all questions. The three principal reasons for collecting organisms from the site are (1) chemical analysis; (2) community metrics; and (3) evidence of disease.

All three of these lines of evidence require species with the following characteristics:

- ***Exposure:*** The species is exposed to the site (and the reference area) for a substantial period of time relative to its lifespan, so that observed effects can be linked to the site. Year-round residency is desired but not required.

- ***Ecological Relevance***: Organisms should be ecologically relevant to the evaluation. For example, if risk to the wedge-tailed shearwater from fish consumption is being evaluated, individual fish of the appropriate species and size should be collected. Seasonality should also be considered (see below).

- ***Abundance*:** Field-collected species should be abundant enough at the site and reference area to support collection of specimens for the intended use. See Table 21-13 for tissue volumes generally required for chemical analyses.

Table 21-13. Typical Tissue Volumes Required for Selected Chemical Analysis

Chemical Group	Tissue Volume Required (grams wet weight)	
	Low Level Detection	Standard Level Detection
Metals	2	2
Pesticides	15	1.5
PCBs	15	1.5
Dioxins/Furans	10	10
SVOCs	30	2
Percent Lipids and Moisture	10	3

Species collected specifically for chemical analysis must meet the following additional criteria:

- **Ability to accumulate the chemical:** Many metals are accumulated by both plants and animals, but most organic chemicals are not likely to be accumulated in plants. Metals that are essential nutrients may be actively regulated by the organism and thus not suitable for use as indicators of bioavailability. Verify that the COPECs being evaluated are known or expected to accumulate in the organism targeted for collection.

- **Limited ability to metabolize the chemical:** Some organisms metabolize certain organic chemicals, which makes the compounds less likely to accumulate in tissues. For example, PAHs induce mixed function oxidase enzymes (and thus their own biotransformation) in fish and other vertebrates, but not in mollusks or crustaceans (USEPA 2000). Although

fish may show signs of PAH exposure, such as lesions or tumors, tissues may not contain elevated concentrations of PAHs relative to sediments.

- **Sex and Seasonal Variability:** Chemical concentrations in a species may vary by sex, often influenced by reproductive processes. For example, a female fish or invertebrate may transfer some organic chemicals to her eggs, thus reducing her body burden. Chemical analysis of composite samples made up of several individuals may vary from one another simply because the sex ratios in the samples differed. This situation would confound the analysis of site-related bioavailability and compromise the findings of the BERA. Whenever possible, the sex and reproductive condition (pre- or post-spawning) of individuals in a composite (and across the site and reference area) should be matched. Likewise, chemical concentrations in organisms may vary by season. A study of tissue concentrations at Ordnance Reef reported that metals were higher in goatfish samples in the fall, but higher in octopus samples in the spring. The BERA WP/SAP should include a review of published findings on factors affecting seasonal variability to support the proposed sampling approach.

Collection and analysis of organisms can be time consuming and costly, as well as potentially affecting the habitats and communities at the site and reference area. The rationale for tissue collection should be clearly explained in the BERA WP/SAP so that the most appropriate organisms are collected to address the study objectives. Appendix 21-A presents profiles of 22 common Hawaiian species, including information on previous tissue analysis. The HEER Office recommends that these 22 species be used whenever possible so that a more robust statewide dataset can be developed.

Tissue Sample Handling and Processing

The BERA WP/SAP should describe methods for handling and processing field-collected organisms, including preservation (freezing or refrigerating), dissection (body parts to be analyzed), homogenization techniques, and other procedures. No single approach is appropriate for all tissue samples. If the tissue concentrations will be used in a food chain model, then the whole body should generally be analyzed. If a COPEC is known to differentially accumulate in a single organ, such as the liver, then an organ-specific analysis may be more appropriate. In some cases, only a part of an organism (blood, eggs, feathers) is collected.

The approach to preparing laboratory duplicate of tissue samples should be described in the QAPP. In most cases, duplicate samples for tissue will be prepared by the laboratory after the sample is homogenized. Separate samples collected in the field, even from a single location, are considered replicates, not duplicates.

In most cases, the HEER Office recommends that the laboratory report the results in dry weight and also measure and report percent moisture. Various uses of the results may require wet weight or dry weight concentrations. For example, if the results will be used as inputs into a food chain model, and the predator's ingestion rate is on a dry-weight basis, then the results should be in dry-weight. However, if the tissue results will be compared to critical body residues that are presented in wet-weight, then the results should be presented in wet-weight. In either case, if percent moisture in the tissue samples is reported, concentrations can be converted between wet-weight and dry-weight by the risk assessor as needed. Percent lipids should also be measured in any tissue analyzed for organic chemicals.

Spatial Correlation with Sediment Samples

As mentioned above, tissue concentrations can provide a strong line of evidence for bioavailability and potential toxicity of chemicals in sediment. However, the strength of this line of evidence is dependent on the degree to which the organisms are linked to the area of known sediment concentrations. It is essential that tissue samples be co-located in space and time with sediment samples, and that both are relevant to the DUs previously established.

Collection of Reference Samples

Because most sites are affected by general human activity apart from any site-related chemical release, the use of reference locations is essential to a strong ERA. Reference samples are used as a basis of comparison so that site-related chemical concentrations can be interpreted in the context of ambient or background chemical concentrations. The designation of reference areas was discussed previously (Step 3a, Task 1 in Section 21.3.4 and Appendix 21-E, Step 3). The HEER Office is compiling a database of tissue concentrations collected across the state for numerous purposes. During the BERA WP/SAP review process, the HEER Office may make these data available to the risk assessor to support a more robust analysis of ambient tissue concentrations.

The HEER Office must approve the reference area prior to sample collection. A minimum of three tissue samples should be collected at the reference site, using the following guidelines:

- Reference samples should be of the same species, size (± 20%), and sex as the site samples.
- Site samples should be collected first, followed immediately by reference samples. This ensures that the reference species can be matched to the site samples.
- Reference areas should reflect general regional conditions (air deposition, general land use) but not be affected by site contaminants or other known sources of contamination. Physical habitat must be comparable to the site (wave energy, grain size, salinity, etc.)

21.6.2.7 Toxicity Testing

Chemicals detected in sediment, surface water, or pore water are not necessarily in a form that can cause adverse effects on receptors. To directly measure of the bioavailability and potential toxicity of a sample, a test organism is exposed to the sample under controlled conditions. Laboratory bioassays are used to test the reactions of living organisms to water or sediment collected from a potentially contaminated site. Because interpretation of *in situ* field bioassays using native organisms can be confounded by multiple factors, standardized laboratory bioassay tests with a small number of well-studied species are typically used instead. Whether the suite of bioassay organisms and the particular test protocols that have become the norm in the mainland U.S. are reasonable tools for tropical marine assessments has been the topic of discussion during the past 20 years (Peters et al. 1997; Batley and Simpson 2008; Simpson et al. 2007).

Need for specific protocols to address ecological risk in tropical marine ecosystems was identified during the early stages of the USEPA ERA framework process because differences in the geochemistry and physical nature of sediment, climatic conditions, and other features of tropical ecosystems suggest that the exposure pathways may not be adequately represented by protocols developed for temperate ecosystems. Tropical marine ecosystems are not well represented by standard USEPA bioassays or exposure models.

Since that initial review paper (Peters, Gassman et al. 1997), which thoroughly described the steps necessary to develop a tropical marine program, progress has been slow. Despite substantial advances in assessing ecological risk in general, the focus is still on temperate ecosystems (Batley and Simpson 2008).

Tropical marine species can be substituted for temperate species in some cases. Examples of new bioassay protocols developed to address tropical regions of Australia include the following (based on Adams and Stauber 2008):

- Tests using native benthic unicellular microalgae measure enzyme activity rather than growth; the test can be used in a wide range of grain sizes.
- A native polychaete (*Scoloplos* sp.) was substituted in an ASTM method; the native polychaete is an infaunal tunneler that lives in sediment of a wide range of grain sizes.
- No tropical amphipod test has been developed, but these authors suggest that amphipods exposed to typical coarse-grained sediments of coralline habitats may have to be fed during the test. (Tests with the freshwater Australian amphipod *Melita plumulosa* were not compromised by feeding.)
- The tropical hermit crab (*Diogenes* sp.) can be used for whole sediment bioassays. (Although this genus may not occur in Hawaii, other members of the Family Diogenidae may be equally useful as test organisms.)
- A standard bivalve bioassay can be modified to use the widespread tropical *Donax cuneata.*

The HEER Office continues to work with researchers to identify appropriate test organisms for contaminated marine sediment sites in Hawaii. The BERA WP/SAP should provide rationale for the proposed toxicity tests, including and modifications to standard protocols that would make the tests more representative of site conditions (water temperature, day length, etc.). The HEER Office will discuss other options with the risk assessor as needed.

In addition to the test species, the BERA WP/SAP Work Plan should describe the overall approach to the toxicity tests, including the duration of exposure; feeding regime; endpoints evaluated (growth, survival, reproduction, other); number of replicates; parameters measured during the test and frequency of measurements (pH, ammonia, other); and other specific test procedures. The criteria for sample selection should also be described. Issues that must be considered in the design of toxicity test samples include, but are not limited to, those below:

- What is the purpose of the toxicity test? What is the null hypothesis?
- Will toxicity testing run concurrent with or after chemical analysis?
- If chemical results are known, will samples for toxicity tests be selected randomly or purposefully to represent a range of concentrations?
- If purposefully selected, how will concentration bins be determined? What if more than one chemical is detected at the site (the most typical situation)?
- What types of correlation or regression analyses are planned? How many samples are required for robust analysis?
- How will variability among endpoints be interpreted? (For example, the test may show no effect on growth but a significant decrease in reproductive output, or vice versa.)
- How will samples form the reference area be selected?
- How will toxicity in site samples be evaluated with respect to the reference area?

The questions above, and any other relevant issues, should be thoroughly discussed in the BERA WP/SAP. Well-designed toxicity tests can provide a strong line of evidence to the BERA, but poorly designed tests waste time and money while only adding to the uncertainty in the BERA.

21.6.2.8 Laboratory Bioaccumulation Testing

Several limitations with field collected organisms can be addressed by conducting laboratory bioaccumulation tests. For example, while field collected organisms can answer questions about exposure to chemicals in the wild, it is never possible to identify with certainty when or how the chemicals were taken into the organism's tissues. In other cases, organisms may be too scarce or difficult to collect from the site. Laboratory bioaccumulation tests also have disadvantages, such as using test organisms that are not native to the site, misrepresenting conditions in overlying water at the site, and interrupting normal feeding habits of the test organisms. Even when the same species is tested in the field and in the laboratory, results may vary. For example, tests comparing bioaccumulation in an estuarine bivalve (*Tellina deltoidalis*) under lab and field conditions reported that important parameters differed between lab and field over the 31-day exposure period. Percent fines at the surface of the test sediment increased in the field but not in the lab. AVS increased in lab but not in the field (Belzunce-Segarra et al. 2015). This and other studies serve as a caution against extrapolating or over-interpreting both lab and field results. Despite these caveats, laboratory bioaccumulation tests can provide an independent line of evidence to the ERA.

The proposed laboratory bioaccumulation test should be thoroughly described in the BERA WP/SAP, referencing protocols when available. Include information on the exposure duration, test organisms, depuration, parameters measured during the test, frequency of measurements, endpoints, replacement of overlying water, feeding, and any other variable that could affect the usefulness of the test. The BERA WP/SAP should describe how samples will be selected for bioaccumulation testing, in keeping with the discussion above for toxicity tests.

Prior to initiating the test, at least one representative tissue sample of test organisms must be collected and either immediately analyzed or frozen for analysis with the test samples after the test is completed. This sample will serve as the baseline concentration for comparison of test samples.

Depending on the study objective, organisms may or may not be depurated to eliminate sediment from the gut prior to chemical analysis. When the goal of the test is to derive a BSAF, or to compare bioaccumulation among several samples, then the organisms are typically depurated. If the goal of the bioaccumulation test is to provide concentrations in prey organisms for use in the food chain model, then the test organisms should not be depurated. The rationale for depurating (or not) should be given in the BERA WP/SAP.

After the exposure period, test organisms are processed and analyzed for chemical constituents. The BERA WP/SAP should provide details on which samples (if not all) will be analyzed, how they will be homogenized, whether they will be frozen or otherwise preserved, and which analyses will be performed.

As mentioned above, tissue analytical results should be reported as dry weights. Percent moisture and percent lipids should be measured whenever organic compounds are analyzed. The BERA WP/SAP

should specify how tissue results will be interpreted with respect to laboratory controls and reference area samples. For example, what does it mean when tissue concentrations at the site are 10 times concentrations at the reference area?

21.6.3 Data Analysis and Interpretation

The results of the chemical sampling, biological surveys, toxicity testing, bioaccumulation studies, and any other data collected are evaluated in the data analysis section of the BERA. The HEER Office expects that the risk assessor will follow current practice and adhere to professional standards in analyzing and interpreting the data. If the risk assessor is not familiar with the general process of preparing an ERA or would like a review, numerous publications available to the public offer guidance and assistance on specific topics. Current USEPA ERA guidance can be accessed online at https://www.epa.gov/risk/guidelines-ecological-risk-assessment. Older ERA guidance documents have been made easily accessible by Oak Ridge National Laboratory https://rais.ornl.gov/guidance/epa_eco.html).

In general, all field-generated data and records (such as the field data sheets) should be reviewed for completeness and accuracy by risk assessment technical lead. All field-generated data, including photographs and videos, should be maintained in the project file and included (as appropriate) in the final BERA. Notes on selected topics important to the HEER Office are presented below. The risk assessor should contact the HEER Office to request additional support if needed.

21.6.3.1 Field Notes

Descriptions of the sediment, surface water, and habitat such as odors, colors, sheens, debris, presence of organisms, sediment substrate (i.e., sand, silt, gravel), signs of scouring, water depth, outfalls, and other features can be helpful when interpreting results of site-specific studies. Therefore, all observations should be documented in a field log book and photographs should be taken of the sediment and sample locations. Any field variances of the SAP should be clearly documented in the field log book. These observations should be presented in a summary table to aid the reviewer of the BERA (Table 21-14).

Table 21-14. Example of Qualitative Field Notes

Station	Redox Discontinuity (cm)	Sediment Description	Biota Present	Other Comments/Notes	Photos
SD01	<1	black color, silt/clay with some sand	worm burrows, iron secretions	Collected samples in the mudflat located on the peninsula on the side facing the bridge.	2
SD02	no redox	red-brownish color sand with some silt	none observed		1
SD03	3	medium brown sand with medium grey silt below	worm burrows	Moved 14 feet toward water because riprap was present at proposed sample location.	1
SD04	<1	black silt	one mussel shell (open)	Collected sample 30 feet south of 2nd wooden pier.	1
SD05	1 to 4	brown sand at surface, brown/dark grey to black silt below	limu, eelgrass, some live gastropods		3

Redox Discontinuity - Depth at which the color changes from brown to gray/black

21.6.3.2 Analytical Results

Data that will be used in a risk assessment should undergo a Stage 4 data validation in accordance with the USEPA National Functional Guidelines to ensure that the data are of good quality and are legally defensible. Methods for validating the data should be given briefly in the BERA WP/SAP and explained fully in the QAPP, along with the criteria for determining the acceptability of the data. Guidance on data validation is available from USEPA through the Contract Laboratory Program National Functional Guidelines for Data Review (https://www.epa.gov/clp/contract-laboratory-program-national-functional-guidelines-data-review).

Data packages should also be reviewed to determine whether any data should be rejected and whether any data qualifiers assigned during the validation process affect the usability of the data as defined in the QAPP. The validated analytical data packages should contain a summary of all data qualifier flags and their explanations.

Analytical results for all media should be presented in summary statistics tables including the following information: chemical name and CAS number, number of samples analyzed, maximum and minimum detected concentrations, data qualifiers, range of detection limits, and frequency of detection. When samples sizes are large enough (n>10), estimates of the mean such as the 95 percent upper confidence limit on the mean concentration (UCL_{95}) may be used to represent the exposure point concentration in the DU. See TGM Section 4 for more information on calculating UCL_{95}. When appropriate, separate tables that show results only for chemicals detected in at least one sample may be presented to focus the BERA. However, whenever a result is listed as "not detected," the sample-specific detection limit must be given in the table.

The sample-specific detection limits reported by the laboratory should be reviewed prior to using the data in the BERA. If the laboratory was not able to meet the detection limits presented in the WP/SAP, the data may not be useable for the BERA. Regardless of the format of tables chosen by the risk

assessor, all data for all analyzed parameters, including parameters not detected in any sample, must be included as appendices to the BERA.

Pay close attention to concentration units (e.g., µg/kg, mg/kg) in all tables and throughout the text. Laboratory results, regulatory criteria, and published literature may use different units. It is the risk assessor's responsibility to convert all units to a uniform standard so that meaningful comparisons can be made. Many components of the BERA incorporate ratios (such as hazard quotients and bioaccumulation factors) that are rendered meaningless when units are not consistent. Likewise, double-check that the dry-weight or wet-weight concentrations are properly represented. In peer-reviewed publications, this detail may appear only in a table or figure legend rather than stated explicitly in the text. When in doubt, contact the HEER Office for assistance.

21.6.3.3 Toxicity and Bioaccumulation Tests

The BERA should refer to the description of toxicity and bioaccumulation tests proposed in the WP/SAP and explain any variances to the proposed procedures. When results of the laboratory toxicity tests are presented, the reasons for variances and potential effects of results should be explained. For example, the laboratory technician may have decided to aerate the samples because the dissolved oxygen level decreased below a certain threshold.

The full laboratory toxicity test report should be included as an appendix to the BERA and the results summarized in the BERA. The format of results may vary with the type of test; Table 21-15 is provided as an example only. Any potentially confounding factors, such as high ammonia or low dissolved oxygen, should be discussed in the text. The laboratory control sample results should be evaluated to determine whether the test met acceptability criteria.

Table 21-15. Summary of *Leptocheirus plumulosus* Toxicity Test Results

Sample Number	Mean Survival (%)	Mean Dry Weight (mg/organism)	Mean Overall Juvenile Production (juveniles/ amphipod)	Mean Juvenile Production per Surviving Female (juveniles/female amphipod)
Lab Control Sample	85	1.47	6	13
Reference Samples				
RF-SD01	83	1.40	7	13
RF-SD02	84	1.48	6	14
RF-SD03	80	1.52	6	12
Site Samples				
SD101	63	0.99	6	12
SD102	77	1.57	5	17
SD103	81	1.27	5	9
SD104	53	1.30	7	13
SD105	71	1.55	9	17

Several methods can be used to evaluate toxicity test results. The three most common endpoints for sediment toxicity testing include (1) mortality as measured by survival of the amphipods; (2) growth as measured by weight and biomass; and (3) reproduction as measured by overall juvenile production and juvenile production per surviving female. The BERA WP/SAP should provide details on how results

will be interpreted for any endpoints other than these.

Site samples are identified as toxic relative to the reference samples using a statistical test. The laboratory control samples are included simply to determine whether the test organisms were healthy; laboratory controls are not used to evaluate site-specific toxicity. Methods to interpret toxicity test results should have been specified in the BERA WP/SAP and discussed with the HEER Office. (Guidance on statistical tests appropriate for analyzing toxicity test results is under development and will be added to this TGM when available.)

Laboratory bioaccumulation studies should be treated in the same way as toxicity studies, with the added component of final tissue concentrations. As discussed previously, tissue concentrations should be provided in dry weight, along with percent moisture and percent lipid results. Tissue results from laboratory bioaccumulation tests should be presented in the same way as field-collected tissues, with the additional component of calculated BSAFs, if warranted.

Risks to Receptors from Food Chain Exposure

Tissue concentrations are used in food chain models to estimate daily doses to consumers, as described in Section 21.3.3. While the SLERA intentionally biased the estimated daily dose high using conservative exposure parameters, the average dose is used in the BERA to represent a more realistic exposure scenario. The focus of the BERA is risk to populations of receptors, not to individual organisms. Therefore, average exposure assumptions are used. For example, the estimated daily dose in the BERA should incorporate the components below:

- Mean chemical concentrations in sediment and food;
- Mean ingestion rates for sediment and food;
- Mean body weight;
- Appropriate site use factor; and
- Most sensitive life stage present at the site.

In the SLERA, concentrations in food are estimated from concentrations in sediment using BSAFs as described in Appendix 21-E. However, if site-specific tissue samples were analyzed in the BERA, those concentrations should be substituted in the dose equation. Alternatively, if site-specific BSAFs are determined in the BERA, they should be used instead of BSAFs from the literature to estimate tissue concentrations at the site.

21.6.4 Risk Characterization

The risk characterization section of the BERA is where all available data are evaluated holistically to determine whether the site poses unacceptable risk to any of the assessment endpoints. The risk characterization should present both quantitative and qualitative characterizations of risk, to the extent supported by available data. As described in Step 3a (Task 6), the risk characterization focused on interpreting exposure and effects data within the context of other site-specific information. Risk characterization in the BERA is similar, in that it synthesizes all available data and various sources of uncertainty, while acknowledging data gaps that may limit conclusions.

When multiple measures of effect are available for a single assessment endpoint, then a weight-of-

evidence approach should be used to interpret the implications of different datasets. For example, as discussed in Section 21.6.2.5, biological surveys are often collected as part of a sediment triad approach where three lines of evidence (sediment chemistry, sediment toxicity test data, and benthic community data) are evaluated to as part of an overall investigation of the benthic community. This can be done by assigning each line of evidence a score and associated weighting factors.

The risk assessment results can be presented graphically to highlight locations where chemical concentrations exceed toxicity screening levels that were identified in the BERA WP/SAP. Maps and graphs may be used to illustrate spatial distribution of risk using various measures. The HEER Office can offer examples of effective data presentation methods, as needed.

21.7 References

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APPENDIX 21-A
SPECIES PROFILES AND EXPOSURE/EFFECTS SUMMARY

TABLE OF CONTENTS

SEA LETTUCE (*ULVA FASCIATA*)

Limu palahalaha (Sea lettuce) (*Ulva fasciata*)	Limu kohu (*Asparagopsis taxiformis*)

Native Hawaiian Species: Numerous native species of seaweed, or limu, occur around the main Hawaiian Islands and the Northwest Hawaiian Islands.

Habitat: Sea lettuce and other limu generally occur in the intertidal zone on rock or coral; a few species grow in sandy locations (Waikiki Aquarium 2014). Heavy growth may indicate high nutrients and freshwater input from storm water runoff or mouths of streams. Limu is most abundant where wave action is low (University of Hawaii 2001).

Locations: Limu occurs throughout the Hawaiian Islands.

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): Various species of limu are added to stews and salads; prepared as flavorful condiments; and eaten as a source of vitamins (A, C, B12, and riboflavin) (Preskitt 2002). Some species were used to make traditional hula attire (Waikiki Aquarium 2014).

Recreational Harvest: Yes, popular for consumption (University of Hawaii 2014, Preskitt 2002).

Commercial Harvest: Yes.

Home Range: Not applicable.

Size/Body Weight: Some species, such as Limu palahalaha, may grow up to 1 meter in length (University of Hawaii 2001). Tissues of limu may contain up to 86 percent water (McDermid et al. 2007).

Diet/Ingestion Rates: Photosynthetic organisms.

Predators: Consumed by humans, the green sea turtle (McDermid et al. 2007), herbivorous fishes, and sea urchins. Some Hawaiian herbivores appear to prefer to feed on invasive algal species rather than native limu (Vermeij et al. 2009).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation factors:

- Sea lettuce is high in energy, soluble carbohydrate, protein, vitamin A content, and some minerals (McDermid, et al. 2007). In a study of several species of seaweed evaluating their use as bioindicators, sea lettuce had the lowest concentration of metals (El-Din et al. 2014). This study also determined bioconcentration factors for metals in several algal species.

- A total of 19 seaweed samples (species not given) were collected in 2009 from locations on the Waiʻanae Coast of Oʻahu (fall and spring samples), including five samples from a reference location. Samples were analyzed for energetic compounds, metals, phthalate esters, and pyrene (U.S. Army Corps of Engineers [ACOE] 2012). Detected constituents at the reference location (Table 9 in ACOE 2012) included the following:
    - *Inorganic Constituents:* Arsenic, Barium, Chromium, Cobalt, Copper, Lead, Nickel, Strontium, Vanadium, and Zinc
    - *Organic Constituents:* None

- Four seaweed composites samples were collected from the nearshore waters at Mākua (See Figure 2-1 in Tetra Tech 2009). The samples were composites of *Acanthophora spicifera, Sargassum muticum*, and *Sargassum polyphyllum*. Samples were analyzed for dioxins/furans, VOCs SVOCs, organochlorine pesticides, explosives, and metals (See Tables 2-2 and 3-1 in Tetra Tech 2009). The sample had 75.4 to 88.4 percent moisture. Detected constituents included the following:
    - *Inorganic Constituents:* Aluminum, Antimony, Arsenic, Barium, Beryllium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Mercury, Selenium, Silver, Thallium, Vanadium, and Zinc
    - *Organic Constituents:* Dioxins/Furans, m+p-Xylenes, Bis(2-ethylhexyl)phthalate, di-n-Butylphthalate, Aldrin, beta-BHC, Heptachlor, Heptachlor epoxide, Perchlorate, and RDX

Conservation Status: Not threatened.

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Photo Credit: Preskitt, L. 2002. Edible Limu: Gifts from the Sea. Poster. http://www.hawaii.edu/reefalgae/publications/ediblelimu/index.htm

SAMOAN CRAB (*SCYLLA SERRATA*)

Native Hawaiian Species: No. Crabs from Samoa were released on Oahu, Molokai, and Hawaii to establish a commercial crab fishery (Eldredge and Smith 2001).

Habitat: This crab inhabits muddy bottoms in brackish water along the shoreline, mangrove areas, and river mouths (Eldredge and Smith 2001). During the day, it may live intertidally in burrows but mostly buries in the mud at subtidal levels (Rowling and Ives 2010).

Locations: All main islands (Eldredge and Smith 2001).

Cultural Use (historical and current): None found.

Recreational Harvest: Yes, but no harvest numbers available.

Commercial Harvest: Prized, sought-after commercial species (Eldredge and Smith 2001).

Home Range: In Australia, apart from spawning migrations, the mud crab appears to move little within its habitat; most individuals remain on site in distinct populations (Shelley and Lovatelli 2011). However, longer-term tagging has shown that individuals can move several kilometers from their home range over time; nightly movements of *S. serrata* fitted with transmitters averaged 461 meters (Shelley and Lovatelli 2011).

Size/Body Weight: It is the largest portunid in Hawaii, exceeding 18 cm in width of carapace (Eldredge and Smith 2001). It can reach 28 cm in carapace width and 3 kg in weight, but is more commonly 15 to 20 cm in width and 0.5 to 1.0 kg (Rowling and Ives 2010).

Diet/Ingestion Rates: It is primarily a carnivore, eating mollusks, crustaceans, and polychaetes, as well as small amounts of plants and debris (Eldredge and Smith 2001). Feeding rates are linked to body weight. On a wet weight basis, feeding rates were reported as 5 to 10 percent of body weight (Baliao, De Los Santos & Franco 1999; Quinitio 2004 [as cited in Rowling and Ives 2010]). No food or sediment ingestion rates were found.

Predators: No predators other than humans were reported.

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors: One sample of Samoan crab from the Mākua north muliwai was analyzed for dioxins/furans, VOCs SVOCs, organochlorine pesticides, explosives, and metals (See Figure 2-1 and Tables 2-2 and 3-1 in Tetra Tech 2009). The sample had 0.7 percent lipids and 71.3 percent moisture. Detected constituents included the following:

- Inorganic Constituents: Aluminum, Arsenic, Barium, Chromium, Cobalt, Copper, Iron, Manganese, Mercury, Selenium, Vanadium, and Zinc
- Organic Constituents: Dioxins/furans

Conservation Status: No special status, but taking females is prohibited (Hawaii DLNR Fishing Regulations).

Other Notes:
The Samoan crab was first introduced into Kaneohe Bay to start a fishery in 1926 (Eldredge and Smith 2001). Between 1926 and 1935, 98 crabs were released on Oahu, Hawaii, and Molokai, all from Samoa (Brock 1960, as cited in Eldredge and Smith 2001). By 1940 it had "already become thoroughly established about the shores, entering estuaries of streams and ascending far up some of the larger rivers" (Edmondson and Wilson 1940, as cited in Eldredge and Smith 2001).

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Photo Credit: Eldredge and Smith. 2001

KONA CRAB (*RANINA RANINA*)

Native Hawaiian Species: Yes

Habitat: The Kona crab is found in offshore coastal environmental at depths between 6 and 200 meters. It prefers sandy ocean bottoms where it burrows in the sand (Fielding and Haley 1976). It spends 95% of its time buried in sand and emerges from the sand less than two hours a day, on average (Skinner and Hill 1986).

Locations: Found throughout the Indo-Pacific region and in the Hawaiian Islands (Fielding and Haley 1976).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): None identified.

Recreational Harvest: Yes. Spearing these crabs is not permitted (Hawaii Administrative Rules, 1989).

Commercial Harvest: Yes, this species is harvested commercially in Hawaii (Fielding and Haley 1976). Per Hawaiian fishing regulations, the minimum size to harvest is 4 inches (carapace length) (Hawaii Administrative Rules, 1989). Females cannot be collected, per a 2006 ruling.

Home Range: Not reported.

Size/Body Weight: Mature female Kona crabs have a minimum carapace length of 86 ± 8 mm (Fielding and Haley 1976). The estimated time for a Kona crab to reach 100 mm in length ranged from approximately 6 years for females to 4 years for males (Kirkwood et al. 2005). The estimated mean maximum lengths of the Kona crab is 122 mm for females and 156 mm for males, based on commercial catch data (Kirkwood et al. 2005).

Diet/Ingestion Rates: This crab is likely a scavenger, given the composition of items found in its gut (Baylon and Tito 2012, Skinner and Hill 1986). Kona crabs in the Philippines feed on fish (*Sardinella*), other crabs, shrimp, bivalves, rays, hydroids, copepods, and squid (Baylon and Tito 2012). Silt and sand accounted for 12 to 20 percent of gut contents (Baylon and Tito 2012). In Australia, echinoderms were the most common item in the gut of Kona crabs, followed by polychaetes and fish (Skinner and Hill 1986).

Predators: Humans, sharks, rays, jacks, turtles, and marine mammals (Thomas, undated).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- 28 crabs (species inferred to be Kona crab) collected in 2009 from three locations on the Waiʻanae Coast of Oʻahu (fall and spring samples) were analyzed for energetic compounds, metals, phthalate esters, and pyrene (U.S. Army Corps of Engineers [ACOE] 2012). Detected constituents (as shown in Table 8 in ACOE 2012) included the following:
    - *Inorganic Constituents:* Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Selenium, Strontium, and Zinc
    - *Organic Constituents:* 1,3,5-Trinitrobenzene.

- One Kona crab sample was collected from nearshore waters at Mākua and analyzed for dioxins/furans, VOCs, SVOCs, organochlorine pesticides, explosives, and metals (See Figure 2-1 and Tables 2-2 and 3-1 in Tetra Tech 2009). The sample had 21 percent lipids and 61.5 percent moisture. Detected constituents included the following:
    - *Inorganic Constituents:* Aluminum, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Selenium, Vanadium, and Zinc
    - *Organic Constituents:* None

Conservation Status: Not threatened.

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WHITE CRAB (*PORTUNUS SANGUINOLENTUS*)

Native Hawaiian Species: Yes. The white crab is also known as the three spot swimming crab (Atlas of Living Australia 2014).

Habitat: The white crab is found on sandy ocean floors at depths around 30 meters (Sumpton et al. 1989, Carpenter et al. 1997 [as cited in Rasheed and Mustaquim 2010]). It is also reported to inhabit sandy and muddy substrates in shallow coastal waters from 10-30 meters, but can occur at depths outside coastal waters reaching 80 m (Atlas of Living Australia 2014).

Locations: This crab is found throughout the Indo-Pacific region and in the Hawaiian Islands (Apel and Spiridonov 1998 [as cited in Rasheed and Mustaquim 2010]).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): None identified.

Recreational Harvest: Yes

Commercial Harvest: Yes

Home Range: A related species of crab (*Portunus pelagicus*) in the coastal water of the South China Sea was reported to travel mean distances of 7.36 km ± 1.78 (males) and 9.15 km ± 1.87 (females) (Ikhwanuddin et al. 2012). The movement of the crabs was attributed to migration associated with reproduction as the male crabs moved to deeper off-shore areas and the female crabs moved both to deeper off-shore and shallow near-shore areas. Generally, crabs were recaptured within a 2-km radius of the sampling site (Ikhwanuddin et al. 2012). A study of *Portunus pelagicus* in Australia reported similar movements, with 79% caught within 2 km of the release point and 4% caught more than 10 km from the release point (Potter et al. 1991 [as cited in Ikhwanuddin et al. 2012]).

Size/Body Weight: The maximum sizes of white crabs captured in one study were 125 mm short carapace width (SCW) for males (n = 233) and 130 mm SCW for females (n = 224) (Rasheed and Mustaquim 2010). Juvenile and adult crabs were captured. The study determined that the crabs were mature at 64–69 mm SCW or 83–89mm long carapace width (LCW) for males and 63–71mm SCW or 81–93 mm LCW for females (Rasheed and Mustaquim 2010). An investigation of the white crab in

Australia determined mature males were 83 mm long carapace width (LCW) and mature females were 74 mm LCW (Sumpton et al. 1989 [as cited in Rasheed and Mustaquim 2010]).

Diet/Ingestion Rates: The white crab eats mostly crustaceans (47%) followed by fish (29%) and mollusks (6%); sand; it also consumes sand/mud/debris (5%) (Sukumaran and Neelakantan 1997). It is reported to scavenge dead fish discarded by fishing vessels (Paul 1981, and Wasseflberg and Hill 1982 [as cited in Sukumaran and Neelakantan 1997]). It also feeds on detritus (Atlas of Living Australia 2014).

Predators: Predators include turtles, sharks, rays and large fish.

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

Conservation Status: Not threatened.

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HELMET URCHIN (*COLOBOCENTROTUS ATRATUS*)

Native Hawaiian Species: Yes. Also known as the shingle urchin or haukeuke kaupali (Parrish et al. 1990).

Habitat: The helmet urchin is abundant in the intertidal zone, often on vertical substrates and in shallow basalt pavement habitats (Parrish, et al., 1990). The helmet urchin inhabits areas of high wave energy (*Waikiki Aquarium 2014*).

Locations: Indo-Pacific region and throughout the Hawaiian Islands (*Waikiki Aquarium 2014*).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): Historically, other sea urchins (*Echinothrix calamaris* and *Echinothrix diadema*) were preferred for food over the helmet urchin (Parrish et al. 1990).

Recreational Harvest: The helmet urchin is harvested for food, particularly the eggs (Parrish et al. 1990).

Commercial Harvest: Yes.

Home Range: Not identified.

Size/Body Weight: The helmet urchin may reach 3 inches in diameter (*Waikiki Aquarium 2014*).

Diet/Ingestion Rates: Feeds on algae (Parrish et al. 1990). The helmet urchin grazes predominately on red coralline algae (*Waikiki Aquarium 2014*).

Predators: Predators of sea urchins in general include humans and large fish (such as Balistidae, Labridae, Lethrinidae, Gaterinidae and Lutjanidae (McClanahan 1998).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- The helmet urchin (*Colobocentrotus atratus*) was collected from tidal pools at Ilio Point, Molokai in 2010 from locations near a debris pile site and a reference location 150 meters northeast of the debris pile site (See Figure 9 in ESI 2012). Individuals weighed 41 to 87 grams and were 3.8 to 7.5 cm in length (See Table 2-12 in ESI 2012). Tissue samples were analyzed for

metals and PCBs (See Tables 2-18 and 2-19 in ESI 2012). No significant difference was noted between site and reference samples.

- Two composite samples were collected from nearshore waters at Mākua and three composite samples from a background location at Sandy Beach (See Figure 2-1 and Section 5.4.1 in Tetra Tech 2009). A single sample required collecting more than 100 sea urchins (See Section 3.1 in Tetra Tech 2009). Samples were analyzed for dioxins/furans, VOCs, SVOCs, organochlorine pesticides, explosives, and metals (See Tables 2-2 and 3-1 in Tetra Tech 2009). Samples ranged from 0.77 to 2.7 percent lipids and 37.7 to 48.1 percent moisture. Detected constituents included the following:
    - *Inorganic Constituents:* Aluminum, Arsenic, Barium, Beryllium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Selenium, Vanadium, and Zinc
    - *Organic Constituents:* Dioxins/Furans, Toluene, Aldrin, and Perchlorate

- Sediment pore water from Hanalei Bay on the north coast of Kauai and a reference location at Ke'e Beach, Kauai were tested for effects on fertilization and embryonic development of the purple-spined sea urchin (*Arbacia punctulata*), which is generally used as a surrogate echinoderm for toxicity testing of sediment pore water (Carr et al. 2006). Toxicity was reported at two stations; however, no synoptic chemical analyses were conducted to identify the cause of the toxicity.
- Sea urchin fertilization tests and larval development tests were used to evaluate toxicity of sediment pore water in Australia (McCready et al. 2006).

Conservation Status: Not threatened.

Other Notes: Sea urchins may have a beneficial effect on coastal ecosystems through foraging on invasive seaweeds. Native Hawaiian collector urchins (*Tripneustes gratilla*) were released in Kaneohe Bay to control fast growing seaweed on coral reefs (Department of Land and Natural Resources 2014).

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Photo Credit: "Colobocentrotus atratus. ha'uke'uke kaupali. helmet urchin" Photo taken by Bryan Harry, National Park Service.
http://www.botany.hawaii.edu/basch/uhnpscesu/htms/kahoinvr/fish_pops/echinomet/wana05.htm

HAWAIIAN LIMPET (*CELLANA EXARATA*)

opihi

Native Hawaiian Species: Yes. Known locally as opihi. Three species are endemic to the Hawaiian Islands: blackfoot (*Cellana exarata*), yellowfoot (*Cellana sandwicensis*), and giant opihi (*Cellana talcosa*) (Bird et al. 2007).

Habitat: The three endemic Hawaiian limpets inhabit different positions on wave-exposed rocky shores. *C. exarata* inhabits the high intertidal zone, followed by *C. sandwicensis* at the low intertidal zone, and *C. talcosa* in the shallow subtidal zone (Kay and Magruder 1977, C.E.B. unpublished data [as cited in Bird et al. 2007]). *C. talcosa* is submerged at high tide but occurs no deeper than 3 to 4 meters (Bird 2011).

Locations: Throughout the MHI and NWHI (Bird et al. 2007).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): Hawaiian limpets are a component of culinary culture (Bird et al. 2007).

Recreational Harvest: Yes. All species of *Cellana* must be 31.8 mm shell length to harvest (Hawaii Administrative Rules 1981).

Commercial Harvest: Yes.

Home Range: Not identified; but assumed small.

Size/Body Weight: Mature *C. sandwicensis* have a shell length of 20 mm and mature *C. talcosa* have a shell length of 35 to 40 mm (Kay et al. 2006).

Diet/Ingestion Rates: Algae.

Predators: Humans, intertidal thaid gastropods, and crabs. *C. talcosa* is also exposed to predatory fish (Bird 2011).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors: The Hawaiian limpet (*Cellana exarata*) was collected from tide pools at Ilio Point, Molokai in 2010 from locations near a debris pile site and a reference location 150 meters northeast of the debris pile site (See Figure 9 in ESI 2012). Individuals weighed 10 to 40 grams and were 3.1 to 5.5 cm in length (See Table 2-12 in ESI 2012). Samples were analyzed for metals and PCBs (See Tables 2-18 and 2-19 in ESI 2012). No significant difference was noted between results for site and reference samples.

Conservation Status: Not threatened.

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Photo Credit: "Cellana sandwicensis. 'opihi 'alinalina. yellow-foot opihi" Photo taken by Larry Basch, National Park Service.
http://www.botany.hawaii.edu/basch/uhnpscesu/htms/kahoinvr/fish_pops/patell/shell02.htm

DAY OCTOPUS (*OCTOPUS CYANEA*) AND NIGHT OCTOPUS (*O. ORNATUS*)

he‘e; he‘e-mākoko

Native Hawaiian Species: Yes. The day octopus (*Octopus cyanea) and the night octopus (Octopus ornatus*) are common in Hawaii *(Waikiki Aquarium 2014).*

Habitat: The day octopus is a common Pacific coral reef resident. It may excavate holes or occupy existing crevices in rocky areas from the intertidal zone to depths of about 45 meters on reef flats and reef slopes (Van Heukelem 1976; Sims 1998). The day octopus in Kaneohe Bay most often dens in areas of loose rocks and broken coral on a sandy bottom (Sims 1998). An octopus den is not permanent, but may be occupied for several days (Forsythe and Halon 1997). Once inside the den, the octopus may pull loose rocks or rubble over the opening, camouflaging the den and its entrance (Forsythe and Halon 1997).

Locations: Throughout the Hawaiian Islands (*Waikiki Aquarium 2014)*

Seasonality (year-round resident or migrant): Year-round resident

Cultural Use (historical and current): None identified

Recreational Harvest: Yes. The day octopus is often collected with a three-pronged spear in shallow depths or by handline (Monterey Bay Aquarium Seafood Watch 2014).

Commercial Harvest: Yes.
In terms of biomass caught, he'e ranked 28th of the 87 species/categories commercially fished in Hawaii in 2011 at 35,347 pounds, and had the highest catch of any invertebrate fishery. Combined with catch from the recreational fishery, the overall he'e catch is likely to be at least twice as large. *O. cyanea* comprised approximately 45% and 26,000 pounds of the estimated total annual harvest (1991) of fishes and invertebrate species in Kaneohe Bay (Everson 1994 [as cited in Sims, 1998]).

Home Range: Distances traveled during hunting trips for prey ranged from 3 to 91 meters in six individual octopus studied within constructed ponds. The maximum distances ranged from 21 to 91 meters (Yarnall 1969). The estimated total forage distance observed in two octopuses on a coral atoll in French Polynesia was 15 to 120 meters with average distances for each octopus of 52 ± 9.3 meters

and 65 ± 12.7 meters (Forsythe and Hanlon 1997). The octopus foraged both morning and afternoon, travelling more than 100 meters a day for food (Forsythe and Hanlon 1997).

Size/Body Weight: The day octopus has been reported to reach 6 kilograms (Van Heukelem 1983; Roper and Hochberg 1988 [as cited in Forsythe and Hanlon 1997]), although typical specimens of both species do not exceed 4.5 kilograms (Waikiki Aquarium 2014).

Diet/Ingestion Rates: The diet of the day octopus in Kaneohe Bay, Oahu, is dominated by five genera of crabs, including *Thalamita* and *Leptodius* (Mather et al. 2012). Bivalve and gastropod mollusks are also eaten (Forsythe and Hanlon 1997).

Predators: Humans, Hawaiian monk seal, eels, large fish

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- Pearl Harbor Ecological Risk Assessment: Octopus tissues were analyzed for 16 metals and 19 energetic compounds at four marine areas in spring and fall: (1) discarded military munitions (ordnance) locations; (2) the Wai‘anae wastewater treatment plant outfall area; (3) the coastal non-point source discharge area; and (4) a control area with habitat similar to the ordnance area but assumed not to contain discarded munitions. Metals concentrations in octopus tissue were generally higher in samples collected in spring than in fall (Navy 2007).

- A total of 36 whole-body samples of octopus were collected in 2009 from locations on the Wai‘anae Coast of O‘ahu (fall and spring samples) including eight samples from a reference location. Samples were analyzed for energetic compounds, metals, phthalate esters, and pyrene (U.S. Army Corps of Engineers [ACOE] 2012). Metals concentrations in octopus tissue were higher in the spring than the fall (this is opposite of the pattern observed in goatfish also sampled in this investigation). Detected constituents at the reference location as shown in Table 7 (ACOE 2012) included the following:
    - *Inorganic Constituents:* Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Selenium, Strontium, and Zinc
    - *Organic Constituents:* None

Conservation Status: Not threatened.

Other Notes:

The day octopus lives about 12 to 15 months (Van Heukelem 1976 [as cited in Sims 1998). It mates once, then dies soon after (Sims 1998). Upon reaching sexual maturity, an unmated female lays a clutch of unfertilized eggs, then dies (Sims 1998).

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Photo Credit: "*Octopus ornatus*" Dr. Dwayne Meadows, NOAA/NMFS/OPR (http://www.photolib.noaa.gov/index.html)

POLYCHAETE (*NEANTHES ARENACEODENTATA*)

Native Hawaiian Species: not determined.

Habitat: This polychaete occurs in sandy sediments near ocean outfalls (Bailey-Brock et al. 2002). *Neanthes arenaceodentata* co-occurs with *Neanthes succinea* in a variety of marine and estuarine intertidal to subtidal habitats, including sand and mud bottoms, seagrass meadows, rocky benthic areas, mussel and oyster beds, and dock pilings (Orth 1973, Craig et al. 2003 [as cited in Masterson 2008]). This worm generally occurs from 10 to 15 cm beneath the sediment surface (Hines and Comtois 1985 [as cited in Masterson 2008]).

Locations: Throughout the Hawaiian Islands.

Seasonality (year-round resident or migrant): Year-round.

Cultural Use (historical and current): None identified.

Recreational Harvest: None.

Commercial Harvest: None.

Home Range: Not reported, but assumed small based on observed behavior.

Size/Body Weight: Approximately 5 to 12 mm in length (Bailey-Brock et al. 2002).

Diet/Ingestion Rates: Omnivorous, feeding on particles and debris of various sizes (Bailey-Brock et al. 2002).

Predators: Numerous birds and fish feed extensively on benthic invertebrates, including polychaetes.

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors: *Neanthes arenaceodentata* is commonly used in laboratory tests. Standardized laboratory toxicity tests have focused predominantly on bioaccumulation in *N. arenaceodentata*, which is known to for its high sediment ingestion rates and rapid bioaccumulation of organic compounds such as PCBs (Janssen et al. 2011). A new 96-hour feeding test using *N. arenaceodentata* is being developed to evaluate sublethal effects following exposure to toxic water or sediment (Burton et al. 2011).

Conservation Status: Not threatened.

Other notes: *Neanthes arenaceodentata* is recognized internationally as a bioindicator for contaminated sediments.

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LOBE CORAL (*PORITES LOBATA*)

Native Hawaiian Species: This is one of several species of stony coral native to Hawaii.

Habitat: This reef building coral is dominant all habitats, including forereef, backreef, and lagoons (Kenyon et al. 2006). *Porites* occurs at depths up to 30 meters (Sheppard et al. 2014).

Locations: *Porites lobata* is the most abundant coral species throughout the Hawaiian Islands.

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): Historically, coral reef ecosystems have provided food and medicine (Hawaii Coral Reef Initiative 2002).

Recreational Harvest: None.

Commercial Harvest: None. Commercial harvesting of live coral is illegal within Hawaiian waters (Friedlander et al. 2005).

Home Range: Not applicable.

Size: This species of coral develops massive and encrusting growth forms. In forereef locations, high-energy sea conditions limit its size to generally less than 20 cm in diameter (Grigg 1983, Kenyon et al. 2006).

Diet/Ingestion Rates: Corals feed on small plankton and the sugars produced by symbiotic algae.

Predators: Several species of reef fish specialize on coral, including *Porites lobata* (Cole et al. 2008). Typical corallivorous fishes in Hawaii include the spotted puffer (*Arothron meleagris*) and the barred filefish (*Cantherhines dumerilii*) (Jayewardene et al. 2009).

Tissue Data/Bioaccumulation Factors/Toxicity Data:

- Irgarol 1051®, a marine herbicide (anti-fouling compound) was shown to be toxic to coral larvae at concentrations measured in small boat marinas in Oahu. Laboratory exposures of

100 ng/L Irgarol caused a reduction in settlement of larvae of *Porites hawaiiensis,* a Hawaiian coral typical of shady marinas (Knutson et al. 2012).

- Bioaccumulation of trace metals from sediment and seawater were reported in *Porites lobata* in Malaysia (Mokhtar et al. 2012).

- Coral (*Porites astreoides*) collected in Puerto Rico were analyzed for PAHs, PCBs, organochlorine pesticides, and metals (Pait et al. 2009). Coral tissues accumulated PAHs, PCBs and trace elements, such as copper and zinc. Generally, corals contained higher levels of alkylated PAHs than the sediments.

- PCBs and metals (arsenic, cadmium, lead, and selenium) were analyzed in coral (*Porites lobata*) collected from Tern Island in the NWHI (Miao et al. 2000a). Results indicated that coral preferentially accumulated less chlorinated PCBs. Metal concentrations in coral were generally equal to or less than those in sediment. Another coral species (*Porites evermanni*) collected from Tern Island and Disappearing Island in the French Frigate Shoals was analyzed for PCBs (Miao et al. 2000b).

- Metals (arsenic, cadmium, chromium, copper, lead, and selenium) were analyzed in coral (*Porites evermanni*) collected from Oahu and French Frigate Shoals (Miao et al. 2001). Lead concentrations were greater in samples from French Frigate Shoals than from Oahu. Lead may be from activities associated with Navy and USCG occupation of the atoll.

- Scleractinian coral (*Stylophora pistillata*) obtained from culture tanks in Taiwan were exposed to Aroclor-1254 (Chen et al. 2012) to evaluate short and long term toxicity. No mortality or bleaching was observed during the 96-hour exposure period and delayed effects were not observed in the 50-day recovery period.

- Three species of scleractinian corals were exposed to copper (Bielmyer et al. 2010). Sensitivity to copper varied among the three species.

Conservation Status: Not threatened.

Other notes: Many stony corals are threatened by overgrowth of introduced marine algae (Hawaii Coral Reef Initiative 2002). Other threats include disease, fishing pressures, and nutrient and sediment runoff (Hawaii Coral Reef Initiative 2002). *Porites lobata* has demonstrated low susceptibility to bleaching (Kenyon et al. 2006).

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Photo Credit: Dr. James P. McVey, NOAA Sea Grant Program and National Oceanic and Atmospheric Administration/Department of Commerce (http://www.photolib.noaa.gov/index.html)

BLACK SEA CUCUMBER (*HOLOTHURIA ATRA*)

loli okuhi kuhi

Native Hawaiian Species: Yes

Habitat: Fourteen species of sea cucumbers are known to occur in Hawaii. They are found in tide pools, on reefs, in bays and lagoons, and in deeper waters (Waikiki Aquarium 2014a). The black sea cucumber is a common species of tide pools (Waikiki Aquarium 2014a). The black sea cucumber occurs in sandy habitats in Indonesia and Guam and among coral rubble in Western Australia (Roberts and Bryce 1982).

Locations: The black sea cucumber is the most common holothurian on Hawaiian coral reefs and is found throughout the Indo-Pacific region (Skillings et al. 2014).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): None known

Recreational Harvest: Yes, certain species are consumed (Waikiki Aquarium 2014a).

Commercial Harvest: In the Pacific, *H. atra* is harvested, although it is a low value species (Skillings et al. 2014). Other species of sea cucumbers such as *H. whitmaei* are preferred as a food source. There is no regulated sea cucumber fishery in Hawaii (Skillings et al. 2014).

Home Range: The movement of another species of sea cucumber, *H. sanctori*, found that they traveled between 1.86 and 21.47 meters each day with a mean distance of 11.12 ± 4.24 meters (Navarro, et al., 2013). These distances are greater than those observed in other sea cucumber species, such as *A. mauritiana* (3.02 meters, Graham and Battaglene 2004 [as cited in Navarro et al. 2013]) and *P. californicus* (3.93 meters, Da Silva et al. 1986 [as cited in Navarro et al. 2013]). In areas with numerous potential refuges, the sea cucumbers do not return to the same shelters (Navarro et al. 2013). Sea cucumbers may also move accidents as they can become dislodged from the ocean floor by waves (Roberts and Bryce 1982).

Size/Body Weight: The black sea cucumber may reach up to 12 inches in length (Waikiki Aquarium 2014b).

Diet/Ingestion Rates: Sea cucumbers feed on organic matter in water and sediment (Waikiki Aquarium 2014b).

Predators: Humans and marine invertebrates such as crabs and gastropods (Kropp 1982). The black sea cucumber releases a red substance to defense itself against predators (Waikiki Aquarium 2014b); the substance is toxic to marine fish but is not effective against crustaceans (Yamanouchi 1955, Bakus 1968 [as cited in Kropp 1982]).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors: None identified.

Conservation Status: Not threatened.

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Photo Credit: "*Holothura atra*. loli okuhi kuhi. black sea cucumber" Photo taken by Scott Godwin, National Park Service.
http://www.botany.hawaii.edu/basch/uhnpscesu/htms/kahoinvr/fish_pops/holothur/wana02.htm

GOATFISH (*MULLOIDES*)

Yellowfin Goatfish (*Mulloides vanicolensis*) Weleʻula

Native Hawaiian Species: Yes
Other commonly observed native goatfishes include the kūmū [white-saddle goatfish (*Parupeneus porphyreus*)], the moano [banded or manybar goatfish (*Parupeneus multifasciatus*), and the wekeʻā [yellowstripe goatfish (*Mulloides flavolineatus*)] (Schumacher and Parrish 2004).

Taxonomy: Family Mullidae

Habitat: Goatfish comprise a major component of Hawaiian reefs. They are named for the chemosensory barbels on their chins that they use to detect benthic invertebrate prey (Szabó et al. 2014). All goatfish are expected to be exposed to sediment. The yellowtail goatfish is most abundant near primary reefs. This species tends to remain low in the water column; most individuals observed off O'ahu were less than 2 meters above the substrate. Other species of goatfish occur is slightly different habitats: the manybar goatfish ventures farther from the primary reef, but also stays low in the water column. The white goatfish lives in large schools higher in the water column (Schumacher and Parrish, 2004). The white-saddle goatfish and white goatfish forage at night on sandflats (Meyer et al. 2000, Holland et al. 1993).

Locations: Goatfish occur throughout the Hawaiian Islands and Indo-Pacific region.

Seasonality: Year-round resident.

Cultural Use (historical and current): Some species of goatfish, such as the kūmū, were historically used in religious ceremonies as offerings (Titcomb 1972 [as cited in Meyer et al. 2000], Waikiki Aquarium 2014).

Recreational Harvest: Yes. Goatfishes may be harvested by spear fishing (Meyer 2010). They are a popular food in Hawaii (Waikiki Aquarium 2014). Recreational catch of weke'ā (yellowstripe goatfish) constitutes the second largest landings within the state, with over 1.0 million kg in reported landings between 2005 and 2009, and 1.2 million kg reported for all species of Mullidae during that period (WPRFMC 2011). The arrival of large numbers of juvenile goatfish, o'ama, is a popular event for recreational fishermen, who can be seen all around the islands in late summer standing in the shallow waters, catching the small fish for live bait or to eat.

Commercial Harvest: The mean archipelago-wide commercial catch of goatfish between 2005 and 2009 was 5,395 kg, which is down 80 percent from the long-term (1966-2009) average (WPRFMC 2011). Hawaii DLNR (2011) reported on commercial landings of almost 50,000 pounds of goatfishes (all species combined), including 9400 pounds of kumu and 5400 pounds of moano.

Home Range: Movement patterns indicate that goatfishes are mobile and have a less well-defined home range compared to surgeonfish and parrotfish (Meyer et al. 2010). In an investigation of several reef fishes (parrotfishes, surgeonfishes, and goatfishes) most fish ranged along 0.2 to 1.6 km of coastline (Meyer et al. 2010). The white-saddle goatfish range across 9,070 to 35,163 square meters in 3 to 14 days (Meyer et al. 2000). The white goatfish ranged across 8,267 square meters at night and 2,533 square meters during the day (Holland et al. 1993).

Size/Body Weight: Adult goatfishes range from 23 to 40 cm in length (Waikiki Aquarium, 2014).

Diet/Ingestion Rates: Goatfishes feed on benthic organisms in sand and mud around reefs. Their diet includes bottom-dwelling invertebrates such as worms, crustaceans, small mollusks, brittle stars and heart urchins (Waikiki Aquarium, 2014). Some goatfish species will also feed on small fishes (Waikiki Aquarium, 2014).

Predators: Humans, marine mammals, other goatfishes, and the greater amberjack (*Seriola dumerili*) (Schumacher and Parrish 2004).

Available Tissue Data/Bioaccumulation Factors:

- Constituents in 21 samples of goatfish fillets from reference locations on the Wai'anae Coast of O'ahu (fall and spring samples) (U.S. Army Corps of Engineers [ACOE] 2012):
    - *Inorganic Constituents:* Antimony, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Nickel, Selenium, Strontium, Thallium, Uranium, Vanadium, and Zinc
    - *Organic Constituents:* PCBs, several energetic compounds.

- Composite samples of manybar goatfish (*Parupeneus multifasciatus*) were collected from nearshore waters at Makua (2 samples) and the background location Sandy beach (1 sample) (See Figure 2-1 and Table 2-2 in Tetra Tech 2009). Samples were analyzed for dioxins/furans, VOCs SVOCs, organochlorine pesticides, explosives, and metals (Table 3-1 in Tetra Tech 2009). The samples had 3.9 to 9.6 mg/kg total lipids and 65.8 to 70 percent moisture. Detected constituents included the following:
    - *Inorganic Constituents:* Aluminum, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Mercury, Methyl Mercury, Selenium, Silver, Vanadium, and Zinc

- *Organic Constituents:* Dioxins/furans, Acetone, m+p-Xylenes, bis(2-ethylhexyl)phthalate, di-n-Butylphthalate, Aldrin, alpha-BHC, 4,4'-DDT, Heptachlor, Heptachlor epoxide, Nitroglycerin, Perchlorate, and RDX

- 7 whole-body samples of the bandtail goatfish (*Upeneus taeniopterus*) were collected from Pearl Harbor and analyzed in 1996 for metals, butyltins, polycyclic aromatic hydrocarbons, semi-volatile organic compounds, organochlorine pesticides, PCBs, dioxins/furans, herbicides, triazine pesticides, 2,4,6-trinitrotoluene , and other ordnance chemicals (See Section 4.3 and Table 4-3 in Navy 2007.) These data along with data from tilapia were used to estimate bioaccumulation in bottom fish (See Section 6.1.3 in Navy 2007).

- 60 whole fish samples (composites or single specimens) of the bandtail goatfish (*Upeneus taeniopterus*) were collected from Pearl Harbor in 2009 and analyzed for metals, PCBs, pesticides, and dioxins/furans. Fish were 6.5 to 12.5 inches total length. Concentrations of these constituents in goatfish were reported to have decreased since previous sampling in 1996 (See Section 3.2.3 in Navy 2010).

- Whole body samples and whole body composite samples were collected from the Kure Lagoon (length 7 to 12 inches and weight 5.75 to 14.5 grams) in 2008 and analyzed for PCBs, metals (arsenic, cadmium, chromium, lead, and mercury), and percent lipids (See Figure 3-3 and Tables 3-5 and B-10 to B-12 in Element Environmental 2009). Lead and PCBs analyzed for in whole body goatfish samples from Tern Island and Midway Atoll, which were used as reference locations (Element Environmental 2009).

- Metal concentrations in goatfish from Honolua Bay compared to other geographical areas (See Table 2 and 4 in Hedouin et al. 2011).

- Yellowfin goatfish (*Mulloidichthys vanicolensis)* collected from Disappearing Island in French Frigate Shoals were analyzed for PCBs and metals (arsenic, cadmium, chromium, copper, lead, selenium, and zinc) (Miao et al. 2000; Miao et al. 2001).

Conservation Status: Not threatened.

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Names of fishes in this species profile are taken from *Fishes of Kaloko-Honokohau National Historical Park* (http://www.botany.hawaii.edu/basch/uhnpscesu/htms/kahofish/NSAlista_g.htm), which cites *Reef and Shore Fishes of the Hawaiian Islands* (Randall 2007).

Photo Credit: Bryan Harry (yellowfin and manybar goatfishes); Peg Bethany (yellowstripe goatfish) http://www.botany.hawaii.edu/basch/uhnpscesu/htms/kahofish/plates/pictz05.htm

HAWAIIAN FLAGTAIL (*KUHLIA SANDVICENSIS*)

aholehole

Native Hawaiian Species: yes (McRae et al. 2011)

Habitat: Marine and freshwater habitats (Benson and Fitzsimons 2002). Two recognized forms of *Kuhlia* occur in Hawaii (*K. sandvicensis and K. xenura);* both live in schools on or near coral reefs as adults, and spawn in marine or estuarine waters (see other notes below). *K. sandvicensis* occurs predominately in marine habitats, but juvenile *K. xenura* are known from freshwater streams, estuaries, on reef flats, along rocky shorelines, and in tide-pool habitats. Along rocky shorelines and in tidepools, *K. sandvicensis* uses microhabitats characteristic of high-energy surge zones-deep areas close to the open ocean that have high salinities. *K. xenura* occurs along shallower rocky shorelines, typically in lower salinities; it may range farther inland, including protected tide pools with low salinities (McRae et al. 2011).

Locations: All islands (Hawaii DLNR 2005)

Cultural Use (historical and current): These species were culturally important to the ancient Hawaiian people and were often used in religious ceremonies (Titcomb 1972 [as cited in McRae 2011]).

Recreational Harvest: Important food fish in the Hawaiian Islands (Gosline and Brock 1965).

Commercial Harvest: Commercial landings for both *Kuhlia* species in the Main Hawaiian Islands averaged about 1,350 kilograms (3,000 pounds) a year in recent years; landings dropped to 900 kilograms (2,000 pounds) in 2003, the most recent year for which data are available (Hawaii DLNR 2005).

Home Range: No data found.

Size/Body Weight: The aholehole can grow to about 30 cm total length (Gosline and Brock 1965, as cited in McRae, 2011). No body weight data were found.

Diet/Ingestion Rates: The aholehole consumes a variety of small items, consisting of algae, invertebrates, and, insects (Tester and Trefz 1954). No food or sediment ingestion rates were found.

Predators: Humans. No other specific predators were reported.

Tissue Data: One composite sample of Hawaiian flagtail (*Kuhlia sandvicensis*) collected from the Mākua north muliwai was analyzed for dioxins/furans, VOCs, SVOCs, organochlorine pesticides, explosives, and metals (See Figure 2-1 and Tables 2-2 and 3-1 in Tetra Tech 2009). The sample had 6.4 percent total lipids and 72.3 percent moisture. Detected constituents included the following:

- *Inorganic Constituents:* Aluminum, Antimony, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Mercury, Methyl Mercury, Selenium, Silver, Vanadium, and Zinc
- *Organic Constituents:* Dioxins/furans, di-n-Butylphthalate, Aldrin, 4,4'-DDT, Heptachlor epoxide

Conservation Status: None, but regulations set minimum catch size at five inches (Hawaii DLNR 2005).

Other Notes:

Two morphotypes (based primarily on eye size) had long been noted by local fishermen and biologists, before 2001, but only one species, *K. sandvicensis* (Steindachner 1876) was recognized in the scientific literature until recently (McRae, 2011). Randall and Randall (2001 [as cited in McRae 2011]) published a revision of the genus that, effectively "split" *K. sandvicensis* into two species. The "big-eyed" (colloquial) morphotype was assigned the name *K. xenura* (Jordan & Gilbert 1882); this species is believed to be endemic to the Hawaiian Islands. Meanwhile, the "small-eyed" morphotype, even though less frequently observed in what were formerly known as the Sandwich Islands, retained the name *K. sandvicensis*.

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CONVICT TANG (*ACANTHURUS TRIOSTEGUS*)

manini

Native Hawaiian Species: Yes

Habitat: The convict tang is common on coral reefs, but also occurs in tide pools and other nearshore habitats. This species occurs across the Indo-Pacific in temperatures from 24 to 26 °C and depths of 0 to 45 m (Waikiki Aquarium 2014; Gamoke 2012 and references within).

Locations: The convict tang occurs on all Hawaiian islands. It was reported among the top 10 most common species within most of the Marine Life Conservation Districts (MLCD) in the state (Friedlander et al. 2006).

Cultural Use (historical and current): Used as food by early Hawaiians; various life stages of this fish are known by separate Hawaiian names (Waikiki Aquarium 2014).

Recreational Harvest: Convict tangs are popular recreational fish in Hawaii (McIlwain 2012, Longenecker et al. 2008). An average of 84,000 pounds were harvested annually between 2004 and 2011 throughout the state; in some years, the recreational catch occasionally exceeds 100,000 pounds (Williams and Ma 2013).

Commercial Harvest: Hawaii LDNR reported that about 18,000 pounds of manini were landed by commercial fisheries in 2011, the last year for which records are available (LDNR 2011).

Home Range: No published information on the home range or territory size of the convict tang is available (Gamoke, 2012). An early tagging study indicated that juveniles remain in the same tidepool to which they originally recruit, then move onto a nearby reef to live out their adult lives. Migration was not observed, although some logistical problems with the tagging study limited the interpretation of the data (Randall 1961). However, data for other surgeonfish with similar life histories indicate that individuals generally move between foraging locations and spawning locations every two or three days. Some convict tangs were reported to migrate up to 2 km to reach spawning sites on the seaward side of reefs in Hawaii (Domeier and Colin, 1997, as cited in Gamoke, 2012)

Size/Body Weight: The convict tang averages about 17 cm total length; a typical adult has a total length of 20 cm and weighs 200 grams (Longenecker et al. 2008). Life expectancy is estimated to be at least 4 years (Longenecker et al. 2008).

Diet/Ingestion Rates: The adult convict tang is herbivorous, grazing on fine, filamentous algae growing on rocks and corals. It will not take animal food even when deprived of other food under laboratory conditions (Randall 1961). It is often observed feeding on algae-covered rocks where freshwater enters nearshore waters (McIlwain 2012). Sediment ingestion by the manini is virtually zero. Unlike other surgeonfishes that ingest coarse sediment to aid digestion in their thick-walled stomachs, the thin-walled stomachs of manini were completely devoid of sediment (Randall 1961).

Predators: Juvenile manini are consumed by many larger fishes, but adults are thought to be relatively free from predation except by humans (Randall 1961). Eagle rays are also known to feed on manini gametes, which are released unguarded into the water column (Gamoke 2012 and references within).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation factors:

- Whole body samples were collected at Kure Atoll at the site of a former Coast Guard LORAN Station (Length 5 to 8 inches and Weight 3.25 to 7 grams) in 2008 and were analyzed for PCBs, metals (arsenic, cadmium, chromium, lead, and mercury), and percent lipids (See Figure 3-3 and Tables 3-5 and B-10 to B-12 in Element Environmental 2009). Reference tissue concentrations in manini were reported from other NWHI locations.

- Whole body samples were collected from locations within Cocos Lagoon, Guam (sample coordinates provided in Table 3-4 in Element Environmental 2010). This fish is typically eaten whole. Samples (45 to 96 grams) were analyzed for PCBs with a mean concentration of 13.74 µg/kg (See Table 6-1 in Element Environmental 2010).

- Convict tang (*Acanthurus triostegus*) were collected from the near shore area at Ilio Point, Molokai in 2010 from locations near a debris pile site (See Figure 9 in ESI 2012). Species weighted 25 to 173 grams and were 10.4 to 19.2 cm in length (See Table 2-12 in ESI 2012). Samples were analyzed for metals and PCBs (See Tables 2-18 and 2-19 in ESI 2012).

- Convict tang (*Acanthurus triostegus*) collected from Disappearing Island in French Frigate Shoals were analyzed for PCBs and metals (arsenic, cadmium, chromium, copper, lead, selenium, and zinc) (Miao et al. 2000; Miao et al. 2001).

Conservation Status: No special status (Gamoke 2012; McIlwain 2012).

Other Notes: The convict tang is considered by some to be a subspecies endemic to Hawaii, *Acanthurus triostegus sandvicensis* (Longenecker et al. 2008; Randall 1961).

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PACIFIC SERGEANT (*ABUDEFDUF ABDOMINALIS*)

mamo

Native Hawaiian Species: Yes, endemic to Hawaii (Waikiki Aquarium 2014).

Habitat: Common marine reef fish; non-migratory; depth range 1 to 50 m (Lieske and Myers 1994 [as cited in Froese and Pauly 2011]). Large aggregations occur in quiet waters over rocky bottoms on inshore and offshore reefs; juveniles frequent surge and tide pools (Waikiki Aquarium 2014, Breder and Rosen 1966). Aggregations of Hawaiian sergeants swarm high off the bottom during the day to feed on plankton, then settle to the bottom during the night. Spawning occurs almost year round, but is most common from January to June (Hoover 2003).

Locations: Endemic to Hawaii; widespread within MHI and NWHI (Waikiki Aquarium 2014).

Cultural Use (historical and current): None known.

Recreational Harvest: Taken as food by Hawaiians (Titcomb 1972 [as cited in Froese and Pauly 2011]).

Commercial Harvest: None

Home Range: Aggregations of adults generally feed in water column above spawning substrate. Males are territorial around nest sites. Juveniles occur in tide pools prior to joining adult population (Hoover 2003, Waikiki Aquarium 2014.

Size/Body Weight: 30.0 cm total length (Lieske and Myers 1994 [as cited in Froese and Pauly 2011]). Up to 25 cm, but usually smaller (Hoover 2003, Waikiki Aquarium 2014).

Diet/Ingestion Rates: Feed in the water column on a variety of algae and zooplankton (Froese and Pauly 2011, Hoover 2003). No food or sediment ingestion rates were found.

Predators: Hawaiian sergeant eggs provide a significant food source for other fish (including milletseed butterflyfish, raccoon butterflyfish, and black triggerfish) (Hoover 2003).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation factors:

- Composite samples of blackspot sergeant *(Abudefduf sordidus)* were collected from the nearshore waters at Makua (1 sample) and the background location at Sandy Beach (1 sample)

(See Figure 2-1 and Table 2-2 in Tetra Tech 2009). Samples were analyzed for dioxins/furans, VOCs, SVOCs, organochlorine pesticides, explosives, and metals (See Table 3-1 in Tetra Tech 2009). The samples had 2.6 to 9.09 percent lipids and 69.3 to 71.2 percent moisture. Detected constituents included the following:

- *Inorganic Constituents:* Aluminum, Antimony, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Mercury, Methyl Mercury, Selenium, Silver, Thallium, Vanadium, and Zinc
- *Organic Constituents:* Acetone, m+p-Xylenes, di-n-Butylphthalate, delta-BHC, 4,4'-DDT, Heptachlor epoxide, and Perchlorate

- Whole body samples of sergeant major (*Abudufduf abdominalis*) were collected from locations within Cocos Lagoon, Guam (sample coordinates provided in Table 3-4 in Element Environmental 2010). This fish is typically eaten whole. Samples (60 to 120 grams) were analyzed for PCBs with a mean concentration of 123.76 µg/kg (See Table 6-1 in Element Environmental 2010).

Conservation Status: No special status

Other Notes: *Abudefduf vaigiensis*, the Indo-Pacific damselfish, has appeared in Hawaiian waters in the past two decades, and has been shown to hybridize with the Hawaiian sergeant (Maruka and Peyton 2007, Maruka et al. 2007). Based on life history characteristics and field observations, hybridization is expected to continue and to possibly lead to replacement of the endemic Hawaiian sergeant over time (Maruka and Peyton 2007, Maruka et al. 2007).

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Waikiki Aquarium 2014. Hawaiian sergeant. http://www.waikikiaquarium.org/experience/animal-guide/fishes/damselfishes/hawaiian-sergeant/

Photo Credit: National Park Service, Brian Harry
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MOZAMBIQUE TILAPIA (*OREOCHROMIS MOSSAMBICUS*)

Native Hawaiian Species: No. *Oreochromis mossambicus* was introduced in 1951 around Oahu (Coles et al. 1999, Randall 1987). The blackchin tilapia (*Sarotherodon melanotheron*) has also become established in Hawaiian waters (Randall 1987).

Habitat: These tilapia occur in diverse habitats throughout Hawaii including harbors, streams, estuaries, low wetlands, and reservoirs or ponds of Hawaii (Coles 1999, USGS 2013). Tilapia can tolerate a range of salinities, temperatures, and dissolved oxygen levels (MacKenzie and Bruland 2012). *O. mossambicus* occurs in high salinities of atoll lagoons, where it nests in the calm sandy areas (Jubb 1967 [as cited in Russell et al. 2012], Lobel 1980 [as cited in ISSG 2014]).

Locations: Established throughout the Hawaiian Islands (Randall 1987).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): None identified.

Recreational Harvest: Limited.

Commercial Harvest: Yes. Tilapia were introduced as potential aquaculture species (Yamamoto and Tagawa 2000 [as cited in MacKenzie and Bruland 2012]). About 3,000 pounds of tilapia (undefined species) were landed by commercial fisheries in 2011 (Hawaii DLNR 2011).

Home Range: Not identified.

Size/Body Weight: Approximately 40 cm total length (Skelton 1993 [as cited in USGS 2013]). Adult tilapia collected from a stream and canal in O'ahu weighed approximately 200 grams (Yang et al. 2008).

Diet/Ingestion Rates: Tilapia are opportunistic omnivores, consuming vegetation, algae, plankton, invertebrates, and fish (Arthington and Bluhdorn 1994, Bruton and Boltt 1975, De Moor et al. 1986, De Silva et al. 1984, Fuselier 2001, Jameson 1991, Komarkova and Tavera 2003, Mathavan et al. 1976, Wager and Rowe-Rowe 1972 [as cited in Russell et al. 2012]). A laboratory investigation estimated a maximum ingestion rate of 3.89×10^9 μm^3 g^{-1} h^{-1} for another tilapia species consuming blue-green algae (Northcott et al. 1991).

Predators: Humans and predatory fishes such as barracuda (Randall 1987).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- PCBs in tilapia in streams on O'ahu were in the middle range of levels found worldwide in freshwater and marine waters (Yang 2008).

- 8 whole-body samples of *Oreochromis mossambicus* were collected from Pearl Harbor and analyzed in 1996 for metals, butyltins, polycyclic aromatic hydrocarbons, semi-volatile organic compounds, organochlorine pesticides, PCBs, dioxins/furans, herbicides, triazine pesticides, 2,4,6-trinitrotoluene , and other ordnance chemicals (See Section 4.3 and Table 4-3 in Navy 2007). These data along with data from goatfish were used to estimate bioaccumulation of by bottom fish (See Section 6.1.3 in Navy 2007).

- Composite samples of tilapia (*Talapia zillii*, *T. rendalii*, *Oreochromis macrochir*, *O. mossambicus*, *Sarotherdon melanotheron, Melanotheron)* were collected from Makua North Muliwai (3 samples), Makua South Muliwai (3 samples) and the background location Nanakuli Muliwai (3 samples) (See Figure 2-1 and Table 2-2 in Tetra Tech 2009). Samples were analyzed for dioxins/furans, VOCs, SVOCs, organochlorine pesticides, explosives, and metals (See Table 3-1 in Tetra Tech 2009). Lipid content of tilapia samples ranged from 3.3 to 5.1 mg/kg total lipids and 13.9 to 21.3 percent lipid. Total moisture in tilapia samples ranged from 71.3 to 74.3 percent. Detected constituents included the following:
    - *Inorganic Constituents:* Aluminum, Antimony, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Mercury, Methyl Mercury, Selenium, Silver, Thallium, Vanadium, and Zinc
    - *Organic Constituents:* Dioxins/furans, Acetone, m+p-Xylenes, Bis(2-ethylhexyl)phthalate, di-n-Butylphthalate, beta-BHC, delta-BHC, gamma-BHC, 4,4'-DDT, Heptachlor epoxide, and Perchlorate

Conservation Status: Invasive nonindigenous species.

Other Notes: Tilapia are considered threats to native species such as the mullet (*Mugil cephalus*) based on competition for food (Randall 1987).

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Photo Credit: Blue tilapia (*Oreochromis aureus*) by Leonard Lovshin, US Army Corps of EngineersLicensed under Public domain via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Blue_tilapia_identification_ASACE.jpg

SPECTACLED PARROTFISH (*CHLORURUS PERSPICILLATUS*) AND YELLOWBAR PARROTFISH (*CALOTOMUS ZONARCHUS*)

Spectacled parrotfish Uhu Uliuli, Uhu 'ahu'ula
and
Yellowbar parrotfish ponuhunuhu

Spectacled parrotfish

Yellowbar parrotfish (Terminal Phase)

Native Hawaiian Species: Both species are native to the Hawaiian Islands. The spectacled parrotfish also occurs at Johnston Atoll; otherwise, both species are endemic to Hawaii (Bishop Museum 1997, Hawaii DLNR 2005).

Habitat: Like all parrotfishes, these species are associated with coral reefs. Spectacled parrotfish occur in surface waters and range to more than 60 meters (200 feet) deep. The yellowbar parrotfish is not known from shallow surface waters, but occur in waters at least 10 meters (35 feet) deep (Hawaii DLNR 2005).

Locations: The spectacled parrotfish is widely distributed across Hawaii. The yellowbar parrotfish occurs from O'ahu through the Northwestern Hawaiian Islands (Hawaii DLNR 2005).

Cultural Use (historical and current): None reported.

Recreational Harvest: Both species are fished recreationally, and are especially vulnerable to nighttime spearfishing (Hawaii DLNR 2005).

Commercial Harvest: Parrotfishes are harvested commercially, although landings are not tracked by species. DLNR (2011) reported that 72,000 pounds of uhu were landed in Hawaii in that year.

Home Range: The mean home for the redlip parrotfish (*Scarus rubroviolaceus*) ranges from 382 to 834 m^2 at 5 m depth and 1,043 to 2,279 m^2 at 15 m depth, depending on the phase of the fish.

Size/Body Weight: These parrotfishes typically grow to about 30 centimeters (1 foot) in total length in the MHI (Hawaii DLNR 2005). Larger individuals have been reported from the NWHI. The size at which individuals become terminal phase males varies among islands, possibly in response to differential predation from sharks and other large piscivorous fishes such as trevallies (Family Carangidae). Terminal phase males on Midway were longer than 50 cm (about 22 inches) (deMartini et al. 2005). No body weight data were found.

Diet/Ingestion Rates: Parrotfishes are herbivorous and graze algae from rock and coral surfaces (Hawaii DLNR 2005). No food or sediment ingestion rates were found.

Predators: In the NWHI, apex predators such giant trevally (*Caranx ignobilis*) and bluefin trevally (*C. melampygus*), feed heavily on parrotfishes (DeMartini et al. 2005). In the MHI, where stocks of apex predators have been reduced by harvest, humans are the predominant predator on parrotfishes (Friedlander and DeMartini 2002).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation factors: No tissue data or bioaccumulation factors were found.

Conservation Status: No special status (Russel et al. 2012)

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MORAY EEL (*MURAENIDAE*)

Native Hawaiian Species: Several species are native to Hawaii. Forty-two species of moray eel have been found in the Hawaiian Islands (Böhlke and Randall, 2000). Common species include the yellow margin moray (*G. flavimarginatus*) and undulated moray (*G. undulates*). Some species of moray eel are endemic to the Hawaiian Islands, including the Atoll moray (*Gymnothorax atolli*), Nutting's moray (*G. nuttingi*), brown speckled eel (*G. steindachneri*), and possibly the manyvertebrate moray (G. polyspondylus) (Böhlke and Randall, 2000).

Habitat: Moray eels occur in shallow to moderately deep tropical and subtropical seas. They are frequently observed in coral reefs or lagoons. They tend to hide in reefs or rocky bottoms (Böhlke and Randall 2000).

Locations: Throughout the Hawaiian Islands.

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): None identified.

Recreational Harvest: Moray eels are harvested and consumed throughout the Indo-Pacific region, including the Hawaiian Islands. However ciguatera poisoning may result from eating large piscivorous reef fishes, such as large morays (greater than 4 kg), particularly the yellow margin moray, undulated moray, giant moray (*G. javanicus*), and white mouth moray (*G . meleagris*) (Böhlke and Randall, 2000).

Commercial Harvest: Some species may be harvested.

Home Range: The yellow margin moray and undulated moray occupy reefs and rocky substrates from depths of 1 to 150 meters (Reece et al. 2011). Other morays have a more restricted range. For example, the snowflake moray (*Echidna nebulosa)* and zebra moray (*Gymnomuraena zebra)* occur between 0 and 15 meters, but are most common at less than 2 meters (Hiatt & Strasburg 1960, Yukihira et al. 1994 [as cited in Reece et al. 2011]). The average depths where eels were captured for a study across the Indian Ocean and Pacific Ocean were 22 meters for the yellow margin moray, 24 meters for the undulated moray, 1.9 meters for the zebra moray, and 1.8 meters for the snowflake moray (Reece et al. 2011).

Size/Body Weight: The yellow margin moray and undulated moray are large fish. The undulated moray ranged from 312 to 628 mm (females) and 282 to 756 mm (males) (Böhlke and Randall 2000). The yellow margin moray ranged from 230 to 1175 mm. The zebra moray ranged from 427 to 920 mm (females) and 425 to 734 mm (males). All three of these species may reach 1500 mm. The snowflake moray ranged from 273 to 570 mm (females) and 302 to 703 (males), with a maximum length of 750 mm (Böhlke and Randall 2000).

Diet/Ingestion Rates: Moray eels in Hawaii are generally separated into two groups based on their diet. The species with fang-like teeth, including the yellow margin moray and undulated moray, feed on fishes and soft-bodied invertebrates (e.g., octopus). The species with pebble-like teeth, such as the snowflake moray and zebra moray, feed on crustaceans (e.g., crabs and molluscs) (Waikiki Aquarium 2014).

Predators: Humans and large fish species (e.g., grouper)

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors: The conger eel (*Conger cinereus*), undulated moray eel (*Gymnothorax undulates*), whitemouth moray eel (*Gymnothorax meleagris*), and yellowmargin moray eel (*Gymnothorax flavimarginatus*) collected from French Frigate Shoals were analyzed for PCBs and metals (arsenic, cadmium, chromium, copper, lead, mercury, selenium, and zinc) (Miao et al. 2000, Miao et al. 2001). The results indicated that the undulated moray eel bioaccumulated high levels of arsenic compared with the other eel species (Miao et al. 2001). The other metal concentrations varied little among species.

Conservation Status: Not threatened.

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Moray Eel

Photo Credit: Jon Hanson Licensed under Public domain via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Yellow_Margined_Moray_Eel.jpg

WEDGE-TAILED SHEARWATER (*PUFFINUS PACIFICUS*)

Native Hawaiian Species: Yes

Habitat: Occurs over the open ocean most of the year. Nests in burrows, which may be concealed or in the open. Shearwater burrows at Mālaekahana ranged from concealment under thickets of naupaka, at the base of ironwood and heliotrope trees, to bare sand under clumps of ‘aki’aki grass (Smith et al. 2002).

Locations: This bird occurs throughout most of the tropical and subtropical Pacific and Indian Oceans, including the Hawaiian Islands (Harrison 1983, Harrison 1990, Whittow 1997 [as cited in Smith et al. 2002). It is a common breeder on almost every island in Hawaii and on many small offshore islets (Pyle and Pyle 2009).

Seasonality (year-round resident or migrant): Migrant. The wedge-tailed shrearwater spends much of the year on the open ocean but returns to coastal areas to breed (Smith et al. 2002). It returns to nesting areas on O‘ahu in April (Smith et al. 2002). In November, the fledglings fly out to sea (Smith et al. 2002).

Cultural Use (historical and current): None identified.

Recreational Harvest: None.

Commercial Harvest: None. Seabirds in Hawai‘i are protected by the federal Migratory Bird Treaty Act (50 CFR 10) and by State law under Title 13, Part 2, Chapter 125 of the Hawai‘i Administrative Rules, which prohibit the hunting, capturing, killing, possession, shipping, etc., of migratory birds, unless authorized by a permit (Smith et al. 2002).

Home Range: Not identified. It remains close to its burrow during nesting.

Size/Body Weight: The wedge-tailed shearwater was reported to weigh from 0.30 to 0.57 kg (sample size = 576 birds) (Bull, 2006).

Diet/Ingestion Rates: An adult shearwater consumes an average 35.01 ± 1.34 grams per day, based on a study in Australia (Peck and Congdon 2005 [as cited in McDuie et al. 2013]). A study in the NWHI reported that fish comprised 67.0% and cephalopods 28.6% by volume of stomach contents. By number

of items, fish comprised 73.3% and cephalopods 23.1%. The remaining small portions consisted of crustaceans, insects, and coelenterates. Typical prey size was approximately 5.7 cm in length. Common fish prey include Mullidae and Carangidae, especially shortfin scad (*Decapterus macrosoma*); cephalopods were mostly Ommastrephidae (Marchant and Higgins 1990 [as cited in Australian Department of the Environment 2014]).

Predators: Humans and introduced mammals, such as dogs, cats, mongooses, and rats (Olson and James 1982, Steadman 1995 [as cited in Smith et al. 2002]). Predation by feral cats was reported to reduce reproductive success to near at Mālaekahana, and pedestrian traffic can collapse nesting burrows (Smith, et al., 2002). Invasive ants were observed to injure nesting shearwaters on windward Oahu (Plentovich et al. 2009).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- Feathers from wedge-tailed shearwaters from Midway Atoll were analyzed for metals (arsenic, cadmium, chromium, manganese, mercury, lead, selenium, and tin) (Burger and Gochfeld 2000). Chromium was high in the wedge-tailed shearwaters compared to other sea birds.

- Feathers from flesh-footed shearwaters (*Puffinus carneipes*) from New Zealand, Lord Howe Island, and Australia were analyzed for metals (Bond and Lavers 2011). Mercury, and potentially arsenic and cadmium were noted as toxicological concerns for the species.

Conservation Status: Not threatened. Another species, Newell Shearwater (*Puffinus newelli*) is threatened.

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BLACK-CROWNED NIGHT HERON (*NYCTICORAX NYCTICORAX HOACTLI*)

Native Hawaiian Species: yes

Habitat: The night herons is frequently found in permanent freshwater wetlands, lowland streams, and man-made wetlands. It is also known to occur in lagoons, reefs, and lava benches exposed during low tide (Engilis and Pratt 1993).

Locations: It occurs on every continent except Australia and Antarctica (U.S. Army Center for Health Promotion and Preventive Medicine 2004). Within the Hawaiian Islands, it is observed commonly on Kaua'i, O'ahu, Moloka'i, Maui, and Hawai'i and reported less often on Ni'ihau, Lana'i, and Kaho'olawe (Pyle and Pyle 2009).

Seasonality (year-round resident or migrant): Year-round resident.

Cultural Use (historical and current): None identified.

Recreational Harvest: None.

Commercial Harvest: None.

Home Range: Most colonies of the black-crowned night heron are in the vicinity of large wetlands. During nesting, both the male and female defend a territory around a large nest (approximately 8 ft wide and 4 ft high. Adults often return to previously used nests (Davis 1993 [as cited in U.S. Army Center for Health Promotion and Preventive Medicine 2004]; Custer et al. 1980 [as cited in USGS 2010]). Individuals disperse widely after nesting is completed.

Size/Body Weight: Adult black-crowned night herons are approximately 58 to 65 cm in length, with an average mass of 883 grams (Dunning 1993 [as cited in USGS 2010]). Body mass in four males ranged from 785 to 1014 grams with an average mass of 913 grams; four females ranged from 727 to 862 grams with an average mass of 827 grams (Gross 1923 [as cited in U.S. Army Center for Health Promotion and Preventive Medicine 2004])

Diet/Ingestion Rates: While fish are the primary food source, the black-crowned night heron is an opportunistic feeder (Davis 1993 [as cited in U.S. Army Center for Health Promotion and Preventive Medicine, 2004]). Its diet varies by habitat and regional, but is typically about 50 percent fish, 40 percent insects and crustaceans, and 10 percent amphibians and reptiles (Palmer 1962 [as cited in

Madenjian and Gabrey 1995]). The black-crowned night heron may prey upon Hawaiian coot chicks (Brisbin et al. 2002 [as cited in USFWS 2011]). This heron may consume fish at a rate of 0.15 kg/day (Alberta Agriculture and Rural Development 1999). A food consumption rate of 0.061 kg/kg body weight/day was estimated using a mean body weight of 0.87 kg and assuming a diet of 59 percent fish, 37 percent invertebrates, 7 percent amphibians, and 1.7 percent mammals with respective water contents of 75, 76, 85, and 68 percent. Using the same body weight, a water ingestion rate of 0.062 L/kg BW/day was calculated (U.S. Army Center for Health Promotion and Preventive Medicine 2004). The heron may ingest soil or sediment when feeding on burrowing crustaceans. U.S. Army Center for Health Promotion and Preventive Medicine (2004) estimated that a soil/sediment ingestion rate of 2 percent, as reported in Beyer et al. (1994), was appropriate.

Predators: Not identified.

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- See Pearl Harbor BERA for use of black-crowned night heron as assessment endpoint (Navy 2007).

Conservation Status: Not threatened.

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Photo Credit: "Black-crowned night heron. 'Auku'u. Nycticorax nycticorax hoactii" Photo taken by Tom Fake, National Park Service.

HAWAIIAN COOT (*FULICA ALAI*)

'Alae Ke'oke'o

Native Hawaiian Species: Yes

Habitat: Low elevations in wetland habitats with both emergent plant growth and open water (USFWS 2011). The coot prefers freshwater wetlands, but will use brackish wetlands.

Locations: Currently on all of the main Hawaiian Islands except Kaho`olawe, which lacks suitable wetland habitat (USFWS 2011). It is present on Lāna`i in artificial wetland areas near water treatment sites (USFWS 2011).

Seasonality (year-round resident or migrant): Year-round resident (USFWS 2011).

Cultural Use (historical and current): None identified.

Recreational Harvest: Hunted in early twentieth century, but now protected (Reed et al. 2011).

Commercial Harvest: None.

Home Range: The coot typically feeds and nests in the same area, but will travel long distances when food is not locally available (Shallenberger 1977 [as cited in USFWS 2011]).

Size/Body Weight: Adult Hawaiian coots weigh approximately 0.53 ± .08 kilograms (n = 231) (Desrochers et al. 2010). The Pearl Harbor BERA used an adult body weight of 0.56 kg (Navy 2007).

Diet/Ingestion Rates: The coot forages near the surface of the water or deeper; it will dive for food and forage in submerged mud or sand. It also grazes on upland grassy sites, such as golf courses adjacent to wetland (USFWS 2011). Food items include aquatic plants, particularly seeds and leaves; invertebrates such as snails, crustaceans, and insects; and small fish (Schwartz and Schwartz 1949 [as cited in USFWS 2011]).

No food or sediment ingestion rates were found. A large-scale study of the American coot, a closely related species (formerly considered another subspecies) common on the U.S. mainland, reported that the stomach held up to 30 percent sand or sediment (Jones 1940). The Pearl Harbor BERA

calculated a normalized food ingestion rate of 0.071 kg food/kg body weight-day) using methods in EPA (1993) and an incidental sediment ingestion rate of 3 percent for the coot (Navy 2007).

Predators: Non-native cats, rats, mongooses, dogs, and to a lesser extent wild pigs, barn owls, cattle egrets, predatory fish, and bullfrogs prey on eggs, young, or adult birds (Underwood et al. 2013). The native black-crowned night heron may prey upon Hawaiian coot chicks (Brisbin et al. 2002 [as cited in USFWS 2011]).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation factors: See Pearl Harbor BERA for use of Hawaiian coot as assessment endpoint (Navy 2007).

Waiakea Pond (Hilo) ERA provides life history parameters for food chain modeling and toxicity reference values for arsenic.

Conservation Status: Endangered. The main cause of decline of the Hawaiian coot is loss of wetland habitat (USFWS 2011).

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Photo Credit: "Hawaiian coot. 'Alae ke'oke'o. Fulica alai" Photo taken by Bryan Harry, National Park Service.
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GREEN SEA TURTLE (*CHELONIA MYDAS*)

honu

Native Hawaiian Species: yes

Habitat: The green sea turtle forages in seagrass beds, shallow patch reefs, and coral-covered areas; it rests on deep mud bottom channels and in small caves and crevices in the sides of reefs (Brill et al. 1995). Immature green turtles stay in the open ocean, moving inshore as adults (Parker et al. 2011).

Locations: The green sea turtle occurs in tropical waters worldwide and is the most common sea turtle in Hawaii, occurring throughout the islands. Most nesting is at French Frigate Shoals (Balazs 1980).

Seasonality (year-round resident or migrant): Year-round resident

Cultural Use (historical and current): Historically, the green sea turtle was used as a food source and harvest was often restricted to special occasions. Certain parts of the green turtle, such as the fat, were also used for medicinal purposes. In addition, parts of the turtle were used as containers, tools, and ornaments (NOAA 1998).

Recreational Harvest: Sea turtles and their eggs are harvested for food (NOAA, 1998).

Commercial Harvest: Incidental harvest by commercial fisheries (NOAA, 1998).

Home Range: Telemetry tracing the journeys of male and female turtles between breeding and foraging areas found some individuals traveled 1050 to 1200 km (Balazs and Ellis, undated). Adults feed in areas less than 10 meters deep, typically only 3 meters deep (Balazs 1980).

Size/Body Weight: The straight carapace length of the green sea turtle turtles is ≤65 cm for juveniles; 65-81 cm for sub-adults, and >81 cm for adults. The mean body weight of adult females is 110 kg (range 68-148 kg) based on a sample size of 69 turtles (Balazs 1980).

Diet/Ingestion Rates: Algae is the dominant food, supplemented by jellyfish, salps, mollusks, sponges, and tubeworms (NOAA Fisheries http://www.fpir.noaa.gov/PRD/prd_green_sea_turtle.html). An adult green sea turtle consumes the equivalent of only 0.24 to 0.33 % of its body weight each day (dry weight to wet weight ratio) (Bjorndal 1980). Juvenile turtles in the pelagic phase (which lasts from 5

to 10 years) are carnivorous or omnivorous, consuming zooplankton, pelagic crustaceans, and mollusks (Parker et al. 2011).

Predators: Sea turtle eggs are eaten by feral dogs and cats, rats, mongooses, and ghost crabs. Hatchlings may be taken by large crabs and fishes. Humans and tiger sharks prey on juvenile and adult turtles (Balazs 1980, NOAA Fisheries http://www.fpir.noaa.gov/PRD/prd_green_sea_turtle.html).

Tissue Data (or other use in ecological or human health risk assessment)/Bioaccumulation Factors:

- Arsenic concentrations were measured in green turtle tissues (liver, kidney, muscle, and stomach contents) collected in Japan (Agusa et al. 2008). Concentrations of arsenic in the stomach versus tissues were reported to indicate bioaccumulation of arsenic.

- Toxicity reference values were derived for sea turtles on Tern Island using terrestrial bird laboratory toxicological studies (USCG 2000).

Conservation Status: Threatened; Hawaiian population is under review for delisting (77 FR 45571).

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Photo Credit: Andy Bruckner, NOAA (http://www.nmfs.noaa.gov/pr/species/turtles/photos.htm

MONK SEAL (*MONACHUS SCHAUINSLANDI*)

ilio-holo-i-ka-uaua or **na mea hulu**

Native Hawaiian Species: Yes. Endemic to Hawaii (NOAA Fisheries Pacific Island Regional Office: http://www.fpir.noaa.gov/PRD/prd_hms_index.html)

Habitat: The Hawaiian monk seal uses shallow water reef habitat for pupping, weaning and foraging, sandy beach areas for resting, and deeper reef areas for foraging (Kittinger et al. 2011). It forages in various habitats such as coral reefs, sandy bottom, rubble flats, and sub-photic slopes (Sprague et al. 2013). Most foraging dives are 200 meters or less (Sprague et al. 2013).

Locations: The largest population of Hawaiian monk seal occurs in the NWHI (approximately 1,400); a second population of about 200 seals occurs on the MHI (Sprague et al. 2013). The NWHI population is declining, while the number of seals in the MHI is increasing (Lopez et al. 2012, Johanos et al. 2014).

Seasonality (year-round resident or migrant): Year-round resident; some movement between the two populations occurs.

Cultural Use (historical and current): The Hawaiian monks seal is seen by some native Hawaiians as an interloper from the NWHI that competes with local subsistence fishing communities. Other people report strong positive cultural associations and a feeling of stewardship toward the seal (Kittinger et al. 2011).

Recreational Harvest: Monk seals may have been harvested historically for meat and fur but harvest is illegal now under the Endangered Species Act (Kittinger et al. 2011).

Commercial Harvest: The monk seal was hunted historically but is now protected from harvest.

Home Range: The species ranges over 2500 km throughout the Hawaiian Islands (Baker et al. 2012). Although individual monk seals may move between the NWHI and the MHI, most do not. Pups tend to stay on their natal island, but adults may visit adjacent islands throughout the year (Johanos et al. 2014). Foraging trips may extend to 322 km from the island of origin (Stewart 2004, Stewart et al. 2006 [as cited in Johanos et al. 2014]).

Size/Body Weight: The average body mass for monk seals is 170 kg for an adult (>5 years), 140 kg for a subadult (3-5 years), and 66 kg for a juvenile (weaning to 3 years) (Sprague et al. 2013).

Diet/Ingestion Rates: The Hawaiian monk seal consumes more than 22 families of fish and marine invertebrates. Principal prey items include triggerfish, moray and white eels, large crustaceans, and surgeonfishes (Sprague et al. 2013). Generally, the monk seal does not eat apex predators such as tuna or mahi, preferring the slower reef fishes that are easier to catch (Baker et al. 2012).

Life Stage	Daily food ingestion (kg/day)[1]	Food Ingestion Rate (% body mass/day)[1]	Sediment Ingestion (grams/day)[2]
Adult	5.89	3.5	3 to 10
Subadult	7.61	5.5	No data
Juvenile	5.01	7.6	No data
Nursing Pup	No data	No data	10 (for 5 weeks)

Source:
[1] Sprague et al. 2013
[2] Woodward-Clyde Consultants 1994.

Predators: Monk seal pups may be taken by sharks or injured by adult male seals (Baker et al. 2012).

Tissue Data/Bioaccumulation Factors:
Mean concentrations of persistent organic pollutants (POP) in monk seal blubber were similar in seals in the Main Hawaiian Islands and the Northwestern Hawaiian Islands; however, some individuals from the main Hawaiian Islands had high contaminant levels (Lopez et al. 2012). Adult males generally have higher blubber and serum concentrations of POPs than do adult females or juveniles (Ylitalo et al. 2008; Lopez et al. 2012). POPs in monk seals from NWHI were generally equal to or lower than those reported for other pinniped species in the North Pacific Ocean (Ylitalo et al. 2008). Monk seals from French Frigate Shoals were analyzed for PCBs, DDT and DDT metabolites (Willcox et al 2004). Correlations were noted between concentrations of DDE and PCBs in blubber or blood and body mass, age, or condition (Willcox et al 2004).

<u>Blood and Blubber Concentrations:</u>
Organochlorine Compounds (DDTs and dioxin-like PCBs): Health effect levels and reference levels in North Pacific Ocean; safe upper PCB concentration of 8700 ng/g, lw for marine mammal blood; 17,000 ng/g, lw for PCBs in blubber

<u>Sediment Preliminary Remediation Goals (PRG) protective of monk seal:</u>
Lead: 270 to 890 mg/kg lead at Kure Atoll (NWHI) (Woodward-Clyde Consultants 1994)
PCBs: 250 to 849 mg/kg in sand on the island at Kure Atoll (NWHI) (Woodward-Clyde Consultants 1994)
PCBs: 3 mg/kg PCB soil cleanup level, based on target action level of 0.165 mg/kg in sediment. Tern Island, French Frigate Shoals (NWHI) (USCG 2000).

<u>Toxicity Reference Value (no effect daily dose) for monk seal:</u>
Lead = 0.02 mg/kg-body weight/day at Kure Atoll (NWHI) (Woodward-Clyde Consultants 1994)
PCBs = 0.0190 mg/kg-body weight/day at Kure Atoll (NWHI) (Woodward-Clyde Consultants 1994)

Conservation Status: Federally Endangered

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Photo Credit: "*Monachus schauinslandi*. Hawaiian monk seal" Photo taken by Tom Fake, National Park Service.
http://www.botany.hawaii.edu/basch/uhnpscesu/htms/kahomamm/fish_pops/phocidae/seal02.htm

APPENDIX 21-B
ECOLOGICAL RISK ASSESSMENT SCOPING CHECKLIST

ECOLOGICAL RISK ASSESSMENT SCOPING CHECKLIST

The purpose of this *Ecological Risk Assessment (ERA) Scoping Checklist* is to determine whether the target site requires an ERA based on known or suspected release of chemicals in sensitive coastal/marine habitat. The *Checklist* is intended to guide the preparer to assemble available data on conditions at the site and identify complete and potentially significant ecological exposure pathways. It is important that the *Checklist* be completed early in the investigation process to ensure coordination with the HEER Office on the need for additional data collection to support an ERA. This *Checklist* cross-references the HEER Office Technical Guidance Manual (TGM) for specific information on sampling design and other general topics, as needed.

Instructions for Completing the *ERA Scoping Checklist*:

When completing the *ERA Scoping Checklist*, all available relevant information/analytical data on known or suspected chemical releases to soil, groundwater, surface water, or sediment should be considered. Refer to the HEER Office TGM, particularly Section 21.0 (ERA Guidance), for information on sediment quality guidelines (SQG) and other screening levels, bioaccumulative chemicals, conceptual site models (CSM), typical habitats, and other components of this *Checklist*. Submit the completed *ERA Scoping Checklist* to the HEER Office for review. Note that the preparer is responsible for providing complete information to support the Checklist, including associated data tables, and must advise the HEER Office of any new data or information that becomes available during the review process that could alter the findings or conclusions of the *ERA Scoping Checklist*.

Ecological Risk Assessment Scoping Checklist
(Coastal and Marine Sites)

1. **Site Name:**_____

2. **Location (County, City or Lat/Long):**

   _____

3. **Describe site history: List past uses, any known or suspected releases, visible signs of contamination, or other evidence that the site may be contaminated. Include any onshore area considered a source to the coastal/ marine site.**

   _____

   _____

   _____

   _____

   _____

   _____

Note: *Attach applicable site maps and photographs; a topographical map; a diagram of any adjacent on-shore facilities (if applicable) showing site boundaries and structures. Include a CSM identifying potential ecological receptors, release mechanisms, and exposure pathways. (See TGM Section 21.3.3 [Step 1b, Task 5] for example CSMs.)*

4. **List previous studies/investigations conducted at the site and summarize their findings (add rows as needed):**

Study/Investigation (Date)	Findings

5. **Indicate the approximate size of the potentially affected area:**
   Acres:

   _____

   Linear feet of shoreline:

   _____

Distance seaward from the shoreline:

_____

6. **Indicate whether the potentially affected area is in an erosional or depositional zone. Provide literature or site-specific data to support the designation.** Data on coastal erosion and accretion (of shorelines) is available at http://pubs.usgs.gov/of/2011/1051/ (Fletcher et al. 2012)

7. **Indicate analytical data available at site:**

Sediment:	No	Yes	(Number of samples: _____)
Surface water:	No	Yes	(Number of samples: _____)
Soil (source area):	No	Yes	(Number of samples: _____)
Groundwater:	No	Yes	(Number of samples: _____)
Sediment Pore Water:	No	Yes	(Number of samples: _____)
Organisms/Tissue:	No	Yes	(Number of samples: _____)

Briefly describe the available data for any "Yes" answer above. Complete Table 21B-1 (attached; add rows as needed) and attach figures showing sample locations.

_____

_____

_____

_____

_____

8. **Complete Table 21B-2 (attached). In the notes section below the table, indicate the relative abundance of various habitat types, if known. Describe any potential offsite migration pathways.**

9. **Have the following site media been impacted or potentially impacted by site-related contamination?**

Sediment:	No	Yes	If Yes, complete **Table 21B-3**.
Surface water:	No	Yes	If Yes, complete **Table 21B-4**.
Groundwater:	No	Yes	If Yes, complete **Table 21B-4**.
Sediment Pore Water:	No	Yes	If Yes, complete **Table 21B-4**.
Soil (source area):	No	Yes	Explain in notes below.
Tissue/Organisms:	No	Yes	Explain in notes below.

Provide notes below to identify any soil or tissue contamination:

_____

_____

_____

_____

10. Is any threatened, endangered or special status species known or suspected to occur at the site?

No Yes If yes, list below:

Scientific Name	Common Name	Hawaiian Name	Federal/State Status	Habitat

11. Check all of the statements below that are true at the site:

1. ☐ A known release of chemicals occurred at the site.
2. ☐ Signs of adverse effects are obvious at the site (diseased, deformed, dying, or dead organisms).
3. ☐ Bioaccumulating chemicals are present at the site.
4. ☐ Chemical concentrations at the site exceed screening levels and/or background concentrations.
5. ☐ Sensitive habitat (e.g. threatened or endangered species, spawning or nursery areas) occurs within or immediately adjacent to the site.

If any one of #1 through #4 are true, AND #5 is true, then the site is recommended for the ERA Program.

12. Recommendation

Is an ERA recommended for the site? No Yes

Please list any additional factors supporting this recommendation:-

_____

_____

_____

_____

13. **Preparer**

Name:

_____

Organization / Position or Role:

_____

Address:

_____

Email:

_____

Phone:

_____

Table 21B-1
Potentially Site-Related Contaminants

Chemical Name	CAS No.	Bioaccumulative[1]		Potentially Affected Offshore Media		
		Yes	No	Sediment	Surface Water	Organisms

[1] See Table 21-7 and Appendix 21-E

TABLE 21B-2
Potential Contaminants in Marine Habitats

Habitat	Habitat Present at Site		Presence of Site-Related Contamination				Source of Potential Contamination			
	No	Yes	Documented	Suspected	Not Expected	Unknown	Direct Release	Migration from Soil	Migration from Groundwater	Other
Young Volcanic Substrate; Little Sediment										
Deep Channels										
Mixed Sediment Bays and Harbors										
Soft Sediment Bays										
Sandy Beach										
Anchialine Pools										
Stream-fed Estuarine Wetlands										
Coastal Fishponds										
Lagoon/Coastal Wetland										
Seagrass Beds										
Mangroves (Introduced)										
Mudflats										
Rocky Intertidal / Tidepools										
Subtidal Hardbottom										
Coral Reef										
Other:										
Other:										

Notes:

Table 21B-3
Initial Sediment Screening

Chemical	Frequency of Detection	Minimum Detected Concentration	Maximum Detected Concentration	Location of Maximum Detection[1]	Mean Concentration	Sediment Quality Guideline[1]		Maximum Hazard Quotient[2]	Is Chemical Bioaccumulative[4]
						Value	Source		Yes/No/ Basis[4]

1 Sediment Quality Guidelines (SQG) for selected chemicals are in Table 21-7. For chemicals not listed in Table 21-7, the preparer may recommend SQG from the literature and provide a source document.
2 Hazard Quotient (HQ) = Maximum detected concentration / SQG
3 List of common bioaccumulative chemicals are in Table 21-7.
4 Cite Table 21-7 or other basis (e.g. log K_{ow}, tissue concentrations, other)

Table 21B-4
Initial Surface Water, Groundwater, or Pore Water Screening

Chemical	Frequency of Detection	Minimum Detected Concentration	Maximum Detected Concentration	Location of Maximum Detection[1]	Mean Concentration	Water Quality Criterion[2]		Maximum Hazard Quotient[3]	Is Chemical Bioaccumulative[4]
						Value	Source		Yes/No/ Basis[5]

[1] For groundwater results, provide depth of well, if known.
[2] USEPA Water Quality Criteria (WQC) are available on-line at http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm#altable
[3] Hazard Quotient (HQ) = Maximum detected concentration / WQC
[4] List of common bioaccumulative chemicals are in Table 21-6.
[5] Cite Table 21-7 or other basis (e.g. log K_{ow}, tissue concentrations, other)

APPENDIX 21-C
DEFINING ECOLOGICALLY-BASED DECISION UNITS

An important step in the DQO process is to define the study boundaries, which includes defining decision units (DUs). A general discussion of DUs is presented in Section 3.4 of the Hawaii HEER TGM. As discussed above, The HEER Office has adopted the use of Multi Increment sampling (MIS) sampling for specific applications and suggests that the size and shape of a DU is primarily controlled by the environmental concerns posed by the contaminants present at the site. The December 2008 Issue Paper (Navy, 2008), "Defining the Minimum Spatial Resolution Needed for a Multi-Increment Sampling Event in Order to Evaluate the Risk to Ecological Receptors," presents draft guidelines for selecting the size, shape, and depth for terrestrial and aquatic (sediment) DUs. Ecological DUs should be based on: (1) the phase of ecological risk assessment being planned (SLERA or BERA); (2) the assessment endpoints and receptors of interest; and (3) the available habitat and its contiguity with site.

As described in Navy (2008), ecological DUs must be defined both laterally and vertically. The approach to defining the lateral extent of a DU should consider the following factors:

- **The ERA process, particularly problem formulation, conceptual site model (CSM) development, and the resulting assessment endpoints** (EPA 1992, 1997, 1998, 1999, Chief of Naval Operations 1999, NAVFAC 2003; Wentsel et al. 1996, Simini et al. 2000). The assessment endpoints selected for the site, and the receptors selected to represent them, are the critical first step in defining the lateral extent of a DU.

- **Population versus individual exposures.** With the exception of special status species (those listed as rare, threatened, or endangered) or migratory birds is that risk management decisions for vertebrates should be based upon protecting local receptor populations. Lower trophic level receptors, such as benthic invertebrates, are typically assessed at the community level. However, ERAs for upper trophic level wildlife species (e.g., birds and mammals) are typically based on effects to individuals. Individual-level responses are then used to estimate population-level responses for management purposes (Sample et al. 2000). It can be assumed that there is a distinct (local) population of the receptor of interest on the site so that the exposure of the population is represented by the exposure of all of the individuals, which are assumed to experience equivalent exposure. This assumption is appropriate for organisms with relatively small home ranges.

  It is thus critical to define the population and address questions of scale. The size of a typical sediment site is generally too small to support viable populations of most upper trophic level receptors. However, many sites can support populations and communities of lower trophic level species such as sediment invertebrates, coral, and aquatic plants. Confined aquatic habitats (Anchialine Pools, tidepools, etc.) may support distinct populations and communities of benthic invertebrates and fish. For tidal creeks, bays, harbors, etc., portions of the water body may be capable of supporting populations or communities of receptors, but they are not isolated and may "exchange" organisms with off-site areas. This may confound attempts to determine if there are impacts, since immigration from surrounding, uncontaminated areas may mask the effects of site-associated contaminants.

  Fish and other aquatic communities in streams and rivers should be generally be defined by reach, which is the appropriate scale at which to address effects (Suter et al. 1995). The size of the reaches (which could correspond to DUs) may be defined based upon changes in physical attributes (such as habitat shifts represented by sediment grain size distribution, marine influence, and wave energy) and habitat attributes.

For mobile vertebrates, such as birds and mammals, the population is generally defined as a function of individual spatial use patterns (home range). Sites sufficiently large to contain multiple home ranges for a given species can be said to support a "local population" of that species provided that the habitat is suitable. Home ranges can be defined in a number of ways, depending upon receptor. During the breeding season, some species defend territories that contain all life requisite needs (food, breeding sites, etc.). Others may defend small breeding sites but forage (nonexclusively) over larger areas. Because ingestion of food is the greatest exposure pathway for these receptors, the foraging range strongly influences site-related exposure. For species with home ranges smaller than the area of suitable habitat present on a site, it is typically assumed that exposures (on a spatially averaged basis) of individuals can be extrapolated to the population level. For species whose home range size exceeds the area of suitable habitat at a site, a site use factor (SUF), calculated as the area of suitable habitat on the site divided by the home range, is typically used to adjust the exposure.

- **Seasonal considerations**. Some species are migratory and only spend a portion of the year in an area. Upper trophic level receptors are typically selected and exposures calculated based upon the breeding season. This is because reproduction is often emphasized as the toxicological endpoint in ERAs, and reproductive effects are generally most relevant to population-level effects (especially when extrapolated from individual-level responses).

- **Bioaccumulation and bioavailability considerations.** Bioaccumulation and bioavailability may vary across the site based upon variability in factors that influence these functions, such as pH, total organic carbon (TOC), grain size, and acid-volatile sulfide/simultaneously extracted metals (AVE/SEM). The influence may be direct (through binding or otherwise limiting bioavailability) or indirect (by influencing the form of the chemical to a species that is less toxic). Although most receptors are not expected to perceive or respond directly to differences in bioavailability of chemicals, the will respond to physical or chemical features of the habitat that known to influence bioavailability. For example, a given receptor may prefer a certain range of pH, TOC, or grain size, and so may indirectly increase or decrease exposure to chemicals in microhabitats.

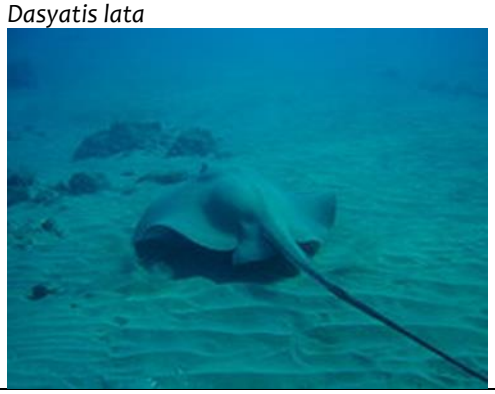
- Depositional or Accretional Areas. The processes of erosion and deposition of sediment creates a patchwork of unconsolidated substrates throughout coastal Hawaii. Physical characteristics of the sediment particles, such as grain size and associated organic carbon, play a substantial role in the fate and transport, bioavailability, and toxicity of contaminants in the marine environment. Many chemicals that cause ecological effects (such as metals, pesticides, PCBs) are known to be associated most strongly with finer-grained sediment, especially silts and clays (also called “muds”) (Morrison et al. 2011). Fine-grained sediments generally accumulate in coastal bays and other sites where wave energy is low or absent. Contaminant concentrations are expected to be highest in such depositional areas where particles smaller than 62.5 µm accumulate (NRC 1989, Grabe and Barron 2003). In contrast, sites with predominantly sand or gravel are less likely to contain toxic levels of contaminants (Morrison et al. 2011). The U.S. Geological Survey (USGS) has conducted numerous studies of natural processes that affect erosion and deposition in Hawai‘i. Geophysical processes affect not only where sediments accumulate, but also how receptors are exposed to contaminated sediments. See Fletcher et al. 2012 for a summary of discussion of depositional and erosional areas in Hawaii.

The vertical extent of a DU is defined by the depth to which ecological receptors are typically exposed (Navy 2008). For sediment, the depth of samples to evaluate ecological exposures should generally be from the sediment surface down to the redox boundary, which generally defines the biologically active zone. This is generally no deeper than 5 to 15 cm in marine systems.

[Additional guidance on defining DUs for ERAs in Hawaii is under development.]

APPENDIX 21-D
HABITAT PROFILES

Table 21-Key Habitats and Species in Hawai‘i: Mudflats/Coastal Wetlands/Lagoons

Habitat Type	**Mudflats/Coastal Wetlands/Lagoon (freshwater and brackish)** 		
Representative Location	Kāne‘ohe Bay (represented above); other principal mudflats occur in Mamala Bay and Pearl Harbor		
Sediment Characteristics	Well-sorted, fine-grained		
Wave Energy	Low		
Typical Species	Common Name	Hawaiian Name	Scientific Name
Birds	Black-crowned night-heron<link>	‘Auku‘u	*Nycticorax nycticorax hoactli*
Fish	Scalloped hammerhead shark (nursery)	Manō kihikihi	*Sphyrna lewini*
	Broad stingray (nursery)	lupe	*Dasyatis lata* 
	Gobies	not known	Gobiidae
Benthic Invertebrates	Alpheid shrimps	not known	*Alpheus malabaricus*
	Portunid crabs	not known	*Podophthalmus vigil, Libystes villosus*
	Stomatopods	not known	*Oratosquilla oratoria, Gonodactylaceus falcatus, Pseudosquilla ciliata*
	Polychaetes<link>	not known	*Neanthes* spp.
Plants	Bulrushes	not known	*Schoenoplectus spp.*
	Panic grass (invasive)	not known	*Panicum purpurascens*
	Pickleweed (invasive)	not known	*Batis maritima*
	Green algae<link	limu	*Ulva, Enteromorpha*

	Seagrasses	not known	*Halophila hawaiiana and H. decipiens*
Threatened or Endangered Species			
Sea Turtles	Green turtle<link>	Honu	*Chelonia mydas*
Birds	Hawaiian stilt	Ae'o	*Himantopus mexicanus knudseni*
	Hawaiian coot<link>	'Alae Ke'oke'o	*Fulica alai*
	Hawaiian duck	Koloa maoli	*Anas wyvilliana*
	Hawaiian common moorhen	'Alae 'Ula	*Gallinula chloropus sandvicensis*

Photo Credits:
Kaneohe Mudflat: http://lovelyhawaii.blogspot.com/2009/05/kaneohe-bay-low-tide-sunrise.html
Dasyatis lata: http://en.wikipedia.org/wiki/Broad_stingray

Key Habitats and Species in Hawai‘i: Rocky Intertidal and Tide Pools

	
High Wave Energy	**Low Wave Energy**

Representative Location	Shorelines of all islands where constant wave action, currents, steep submarine slopes, and a lack of offshore sand reservoirs limit the accumulation of sand. Ilio Point on Hawai‘i is a typical high-energy tide pool habitat.		
Sediment Characteristics	Little sediment where wave energy is high; accumulation of fine sediment may occur where wave energy is low		
Wave Energy	Various		
Typical Species	Common Name	Hawaiian Name	Scientific Name
Birds	Black-crowned night-heron<link>	‘Auku‘u	*Nycticorax nycticorax hoactli*
Fish	Hawaiian Flagtail <link>	Aholehole	Kuhlia sandvicensis
	Convict Tang <link>	Manini	Acanthurus triostegus
	Zebra rockskipper	Pao ‘o	*Istiblennius zebra*
	Gobies	not known	Gobiidae
Benthic Invertebrates	Hawaiian Limpet <link>	opihi	*Cellana exarata*
	Helmet Urchin <link>	haukeuke kaupali	*Colobocentrotus atratus*
	Gastropods	not known	*Littoraria pintado, Siphonaria normalis, Nerita picea, and Morula granulata*
	Samoan crab <link>	Not known	*Scylla serrata*
	Day Octopus	Not known	*Octopus cyanea*
	Polychaetes<link>	not known	*Neanthes* spp.
Plants/Algae	Sea lettuce <link>	not known	*Ulva fasciata; Ulva reticulata*
	Green Algae	not known	*Halimeda, Neomeris, Caulerpa*
	Red algae	not known	*Hydrolithon, Melanamansia, Pterocladiella, Jania*
	Brown algae	Not known	*Padina, Turbinaria, Dictyota*
Threatened or Endangered Species			
Sea Turtles	Green turtle<link>	Honu	*Chelonia mydas*
Birds	Hawaiian stilt	Ae'o	*Himantopus mexicanus knudseni*

Photo Credits:
Low Wave Energy:

Tidepools at Maui, Puhilele Pt Haleakala National Park by Forest & Kim Starr. Licensed under Public domain via Wikimedia Commons. https://commons.wikimedia.org/wiki/File:Starr_040423-0115_Scaevola_taccada.jpg
High Wave Energy:
Exposed wave-cut platform in bedrock.
ftp://ftp.nodc.noaa.gov/pub/data.nodc/coris/data/NOAA/nos/EnvironmentalSensitivityIndices/Hawaii/ESI_DATA/INTRO.PDF

Key Habitats and Species in Hawai‘i: Coastal Fishponds

He’eia Fish Pond

Moli’i Fishpond

Representative Location	Mamala Bay, Pearl Harbor, several around Kāne‘ohe Bay (above), and three on the southwestern coast of Kaua‘i		
Sediment Characteristics	Surface layer of fine-grained sediment and underlying coarse grains.		
Wave Energy	Low		
Typical Species	Common Name	Hawaiian Name	Scientific Name
Birds	Black-crowned night-heron<link>	‘Auku‘u	*Nycticorax nycticorax hoactli*
	Northern Shovelers	Koloa Moha	*Anas clypeata*
Fish	Striped Mullet	Ama ama	*Mugil cephalus*
	Milkfish	Awa	*Chanos chanos*
	Hawaiian Flagtail <link>	Aholehole	Kuhlia sandvicensis
Benthic Invertebrates	Hawaiian Oysters	not known	*Dendrostrea sandvicensis*
	Anchialine shrimp	Opae ‘ula	*Halocaridina rubra*
	Samoan Crab <link>		*Scylla serrata*
Plants	Seaweed	Limu	Numerous species
	Rock-dwelling algae		
	Seagrasses	not known	*Halophila hawaiiana and H. decipiens*
	Red Mangrove (invasive)	not known	*Rhizophora mangle*
	Red Algae (invasive)	not known	*Acanthophora spicifera*
	Pickleweed (invasive)	not known	*Batis maritima*
Threatened or Endangered Species			
Sea Turtles	Green turtle<link>	Honu	*Chelonia mydas*
Birds	Hawaiian stilt	Ae'o	*Himantopus mexicanus knudseni*
	Hawaiian coot<link>	'Alae Ke'oke'o	*Fulica alai*
	Hawaiian duck	Koloa maoli	*Anas wyvilliana*
	Hawaiian common moorhen	'Alae 'Ula	*Gallinula chloropus sandvicensis*

Photo Credits:
Moli’i Fishpond by Joel Bradshaw. Licensed under Public domain via Wikimedia Commons.
https://commons.wikimedia.org/wiki/Category:Molii_Fishpond#/media/File:Oahu-Moliifishpond-rockwall.JPG
He’eia Fishpond: https://fishpondfever.wordpress.com/about/

Key Habitats and Species in Hawai‘i: Seagrass Beds

Representative Location	inner reef flats of south Moloka‘i; ‘Anini (Kaua‘i); near Mamala Bay and Kāne‘ohe Bay		
Sediment Characteristics	Seagrass can inhabit various sediment types including silt, mud, sand, gravel, rock		
Wave Energy	Various		
Typical Species	Common Name	Hawaiian Name	Scientific Name
Birds	Black-crowned night-heron<link>	‘Auku‘u	*Nycticorax nycticorax hoactli*
Fish	Hawaiian Flagtail <link>	Aholehole	Kuhlia sandvicensis
	Striped Mullet	Ama ama	*Mugil cephalus*
Benthic Invertebrates	Sea cucumbers	loli okuhi kuhi	*Holothuria atra*
	Hawaiian gastropod	not known	*Smaragdia bryanae*
	Polychaetes<link>	not known	*Neanthes* spp.
Plants	Seagrasses	not known	*Halophila hawaiiana and H. decipiens*
	Green Algae/Mudweed (invasive)	not known	*Avrainvillea amadelpha*
	Sea lettuce	not known	*Ulva reticulata*
	Green Algae	not known	*Halimeda discoidea*
	Red algae	not known	*Spyridia filamentosa*
Threatened or Endangered Species			
Sea Turtles	Green turtle<link>	Honu	*Chelonia mydas*
Birds	Hawaiian coot<link>	'Alae Ke'oke'o	*Fulica alai*
	Hawaiian common moorhen	'Alae 'Ula	*Gallinula chloropus sandvicensis*

Photo Credits:
Left: Seagrass. Halophila hawaiiana. LIMU Species List 2005. University of Hawaii's Marine Option Program Summer Course Quantitative Underwater Ecological Surveying Techniques (QUEST). LIMU Species List 2005. http://www.kmec.uhh.hawaii.edu/QUESTInfo/limujs/Limulist/LIMU%20Species%20List%202005JS.htm
Right: http://coconutislandnews.blogspot.com/2012/03/hawaiian-seagrass-not-your-average.html

Key Habitats and Species in Hawai‘i: Mixed Sediment Bays and Harbors

Representative Location	Pearl Harbor		
Sediment Characteristics	Soft sediment overlaid on limestone platform of fossil reef origin; soft sediments often composed of carbonate grains derived from coralline algae, coral, mollusk fragments, foraminiferans, and tests of bryozoans and echinoderms		
Wave Energy	low		
Typical Species	Common Name	Hawaiian Name	Scientific Name
Birds	Black-crowned night-heron<link>	‘Auku‘u	*Nycticorax nycticorax hoactli*
	Bristle-thighed curlew	Kioea	*Numenius tahitiensis*
	Pacific golden plover	*klea*	*Pluvialis dominica fulva*
	Brown booby	Not known	*Sula leucogaster plotus*
	Black noddy	noio, `eki`eki	*Anous minutus melanogenys*
Fish	Hawaiian Flagtail <link>	Aholehole	Kuhlia sandvicensis
	yellowfin goatfish <link>	Weke, weke'ula	*Mulloidicthyes vanicolensis*
	Mozambique Tilapia (invasive) <link>	Not known	*Oreochromis mossambicus*
	Gobies	Not known	Gobiidae
	Hawaiian anchovy	Nehu	*Enchasicholina purpurea*
	striped mullet	`Ama`Ama	*Mugil cephalus*
Benthic Invertebrates	White crab <link>	Kuahonu	*Portunus sanguinolentus*
	Samoan crab <link>	Not known	*Scylla serrata*
	Hooded oyster *(invasive)*	Not known	*Saccostrea cucullata*
	Hawaiian rock oyster	Not known	*Ostrea sandvichensis*
	Soft bodied sea cucumber	Not known	*Ophiodesoma spectabilis,*
	Day Octopus	he‘e	*Octopus cyanea*
	Polychaetes<link>	not known	*Neanthes* spp.
Plants	Pickleweed (invasive)	not known	*Batis maritima*
	Red Mangrove (invasive)	not known	*Rhizophora mangle*
	Sea lettuce <link>	limu	*Ulva*
Threatened or Endangered Species			
Sea Turtles	Green turtle<link>	Honu	*Chelonia mydas*
Birds	Hawaiian stilt	Ae'o	*Himantopus mexicanus knudseni*
	Hawaiian coot<link>	'Alae Ke'oke'o	*Fulica alai*

	Hawaiian duck	Koloa maoli	*Anas wyvilliana*
	Hawaiian common moorhen	'Alae 'Ula	*Gallinula chloropus sandvicensis*
	white tern	Manu-o-Kū	*Gygis alba rothschildi*

Photo Credits: Aerial view of Pearl Harbor. https://en.wikipedia.org/wiki/Pearl_Harbor

APPENDIX 21-E
EVALUATING BIOACCUMULATIVE CHEMICALS

Evaluation of Risks of Bioaccumulative Chemicals

A bioaccumulative chemical is one that is taken up and retained for some duration by a living organism; the chemical may or may not have a measurable adverse effect on the organism in which it is measured. Once an organism incorporates a chemical into its tissues, the organism becomes a secondary source of contamination to other organisms that feed on it.

The terms bioconcentration, bioaccumulation, and biomagnification are sometimes used interchangeably in the literature; however, each describes a specific process, as described below (based on USEPA [2000]).

- ***Bioconcentration*** - the process by which there is a net accumulation of a chemical directly from water into aquatic organisms resulting from simultaneous uptake (e.g., by gill or epithelial tissue) and elimination.
- ***Bioaccumulation*** - the accumulation of a chemical in the tissue of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, or sediment pore water.
- ***Biomagnification*** - the net result of the process of bioconcentration and bioaccumulation by which tissue concentrations of bioaccumulated chemicals increase as the chemical passes up through two or more trophic levels. The term implies an efficient transfer of chemicals from food to consumer, so that residue concentrations increase systematically from one trophic level to the next. (The movement of contaminants from prey to predator is called trophic transfer.)

Chemicals known to bioaccumulate may also cause direct toxicity to organisms exposed through simple ingestion or direct contact with sediment or water. For example, some invertebrates are adversely affected by direct exposure to copper in water and sediment. Organisms that are less susceptible to direct effects may survive and grow, incorporating the copper into their tissues. At some tissue concentration, which may be well above the sediment concentration the organism was initially exposed to, the accumulated copper may begin to exert a toxic effect on the organism. Additionally, the organism (and its tissue burden of copper) has become a concentrated source of copper to its predator. Thus, copper must be evaluated for both its direct effects and as a bioaccumulating chemical. The relative importance of direct effects versus effects resulting from bioaccumulation varies by species and chemical, as some species are capable of regulating, transforming, or eliminating come chemicals.

Most sources agree on the basic list of bioaccumulative chemicals derived from decades of empirical evidence (see Table 21-7). Several metals (arsenic, copper, lead, mercury, and zinc); most if not all organochlorine pesticides (DDT, chlordane, endrin, dieldrin); PCBs; dioxins/furan; and some PAHs are considered bioaccumulative under most circumstances, and are included as such in this guidance.

These bioaccumulative chemicals share several traits: (1) hydrophobicity (excluding metals); (2) log $K_{ow} > 3.5$; (3) documented tissue concentrations under many environmental conditions; and (4) empirical evidence of toxicological effects of tissue concentrations (ODEC 2007; ACOE et al. 2009). Note that it is possible, although unlikely, to measure elevated concentrations of a bioaccumulative chemical in tissues without detecting the chemical in collocated sediment or water samples. This could occur under conditions of high bioavailability of the chemical in the sediment or water, coupled with

high laboratory detection limits. Alternatively, the organism could have accumulated the chemical from a different location. The HEER Office ERA Guidance is designed to identify areas where risk is likely, and so focuses on sediment sites with measurable concentrations of target contaminants.

Predicting the bioaccumulative potential of a chemical not listed in any of the references cited below is less straightforward and subject to nuances of chemistry and physiology. The risk assessor is responsible for designating the bioaccumulation potential of each chemical detected at the site, and providing rationale for the designation. Generally, all chemicals on Table 21-7 are considered bioaccumulators, and any other chemical with a log K_{ow} greater than 3.5 must be discussed with the HEER Office. (Note that log K_{ow} is not a reliable predictor of bioaccumulation for organotins.) Suggested references for developing a list of bioaccumulative chemicals are listed below:

Beyer, W. N. and J. P. Meador. 2011. *Environmental Contaminants in Biota: Interpreting Tissue Concentrations*, Second Edition. CRC Press. 768 pages.

Hoffman, E. 2007. The Technical Basis for Revisions to the Dredged Material Management Program's Bioaccumulative Contaminants of Concern List. Prepared for the Agencies of the Dredged Material Management Program. January. http://www.nws.usace.army.mil/Portals/27/docs/civilworks/dredging/Updates/2007-Final_BCOC_Technical_Appendix_010807.pdf

U.S. Army Corps of Engineers, Environmental Protection Agency (Region 10), Washington Department of Ecology, Washington Department of Natural Resources, Oregon Department of Environmental Quality, Idaho Department of Environmental Quality, National Marine Fisheries Service, and U.S. Fish and Wildlife Service. 2009. *Sediment Evaluation Framework for the Pacific Northwest.* May 2009. Portland, Oregon, 138 pp. http://www.nwp.usace.army.mil/Portals/24/docs/environment/sediment/2009_SEF_Pacific_NW.pdf

U.S. EPA. 2000. *Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment: Status and Needs.* Office of Water. February. EPA-823-R-00-001. http://water.epa.gov/polwaste/sediments/cs/upload/bioaccum.pdf

Steps for Evaluating Risks of Bioaccumulative Chemicals

The SLERA (described in TGM Section 21) evaluated direct effects of bioaccumulating chemicals. If the direct effects are nonlethal and the organism incorporates the chemical into its tissues, indirect effects may occur. This section describes the process of evaluating risk of bioaccumulating chemicals within the tissues of living organisms, both to the organism itself and to its predators. The evaluation of such indirect effects of bioaccumulating chemicals is more complex because the physiology of the target organisms must be taken into account.

The HEER Office encourages the risk assessor to use existing information to the extent possible, and to conduct a focused field investigation when necessary to fill gaps in essential data. Close coordination with the HEER Office will ensure that data collection efforts are appropriate to support

an ERA. The eight steps below describe essential components of the ERA for bioaccumulating chemicals. However, each ERA is necessarily tailored to an individual site.

- Step 1 – Identify Potential Bioaccumulative Chemicals
- Step 2 - Determine Likely Exposure Pathways
- Step 3 – Compare Site-Specific Concentrations with Background/Reference/Ambient Concentrations
- Step 4 – Compile Screening Level Data for Bioaccumulating Chemicals
- Step 5 – Compile Toxicity Reference Values (TRV)
- Step 6 – Identify Chemicals of Potential Ecological Concern (COPEC)
- Step 7 - Determine the Need for Additional Information
- Step 8 – Conduct a Site-Specific Bioaccumulation Investigation

Step 1 – Identify Potential Bioaccumulative Chemicals

The *ERA Scoping Checklist* requests information on chemicals detected or suspected at the site, and asks whether any of the chemicals are bioaccumulative. If any chemicals listed in Tables 21B-1 or 21B-3 are known to bioaccumulate (based on Table 21-7 or other source), then it is necessary to complete this evaluation.

If the bioaccumulative status of any chemical at the site is unknown, the risk assessor should use the published literature to determine the potential bioaccumulative properties of the chemical. For example, the *Technical Support Document for Revision of the Dredged Material Management Program Bioaccumulative Chemicals of Concern List* (Hoffman 2007) provides four groups of chemicals with shared bioaccumulative properties:

- List 1 – Primary Bioaccumulative Chemicals of Concern (Table 9 in Hoffman [2007])
- List 2 – Candidate Bioaccumulative Contaminants (Table 10 in Hoffman [2007])
- List 3 – Potentially Bioaccumulative Contaminants (Table 11 in Hoffman [2007])
- List 4 – Not Currently Considered Bioaccumulative Contaminants (Table 12 in Hoffman [2007])

Although some of the discussion of chemicals in Hoffman (2007) pertains to regional ambient concentrations, most of the logic for identifying bioaccumulating chemicals is relevant to marine sediments sites in Hawaii.

The U.S. ACOE Seattle District modified the lists in Hoffman (2007) to remove some of the metals that are not known to occur in organic forms (ACOE et al. 2009). The chemicals on Lists 1, 2, and 3 in ACOE et al. (2009) provide a reasonable starting point for evaluating chemicals not on Table 21-7 of the HEER Office guidance. New chemicals should be considered bioaccumulative based on the following considerations:

- A site-related chemical not included on any of the lists discussed above should be considered bioaccumulative if
    - its Log K_{ow} is greater than 3.5; or
    - it has been demonstrated to bioaccumulate in living organisms.

Step 2 - Determine Likely Exposure Pathways

The exposure pathways should have been described in the conceptual site model (CSM) during a previous phase of the ERA. The exposure pathways for bioaccumulating chemicals may be refined at this time to focus on the likely routes of uptake by target receptors. Note that some information on diet and sediment ingestion is included in the species profiles in appendix 21A. The risk assessor should supplement the information using the published literature as needed.

Step 3 – Compare Site-Specific Concentrations with Background/Reference/Ambient Concentrations

The uncertainty associated with evaluating bioaccumulating chemicals stems in part from the complexity of trophic transfer, which includes processes that are difficult to measure or observe, including uptake, biotransformation, sequestration, depuration, and excretion. In most cases, measuring in-situ trophic transfer is beyond the scope of an ERA. Modeling necessarily relies on conservative assumptions, which drives the protective screening level toward zero. It is not uncommon for a calculated screening level to be lower than background/ambient/reference concentrations, calling into question the legitimacy of the ERA. Rather than allow conservative exposure assumptions of BCFs, BSAFs, and toxicity thresholds to drive the ERA, the HEER Office recommends first refining the list of bioaccumulative chemicals by comparing site concentrations with background/ambient/reference concentrations.

The HEER Office is currently compiling background/ambient/reference concentrations of sediment and tissue from published reports across Hawaii. Ideally, the risk assessor will be able to search the database by habitat, chemical, species, and other variable to locate sediment and tissue concentrations considered representative of background/ambient/reference concentrations. Until that database is available, the risk assessor should discuss the need for collecting background/ambient/reference samples as part of the ERA.

In general, a minimum of three background/ambient/reference samples should be collected during the site-specific investigation. The samples should be collected from an area with similar sediment and wave energy that is believed not to be impacted by the chemicals under investigation at the site or any direct chemical release. The proposed reference locations should be discussed with the HEER Office early in the process to ensure that the samples are acceptable and representative.

Step 4 – Compile Screening Level Data for Bioaccumulating Chemicals

Evaluation of bioaccumulating chemicals may include comparing site-specific concentrations in tissue, sediment, and water with regional reference areas and/or toxicity-based screening levels, as described below. The risk assessor should compile information relevant to the site based on habitat, species, and chemicals. Include bioaccumulation factors, laboratory bioaccumulation tests, and other available information to provide regional context for the site.

Tissue Screening Level: Critical Body Residues

A critical body residue is a chemical concentration in a tissue (or whole body) that is considered protective of the receptor that accumulates the chemicals through exposure to sediment, water, and/or prey. As described below for sediment screening levels for bioaccumulating chemicals, CBRs taken from the published literature may or may not be appropriate for use at coastal marine sites in Hawaii. The use of CBRs in ERAs is relatively undeveloped and heavily reliant on temperate North American species and locations. The process of deriving CBRs described in Appendix D of ACOE et al.

(2009) is technically sound, but the resulting values are not necessarily appropriate for sites in Hawaii. Moreover, in many cases back-calculating protective sediment concentrations from CBRs yields sediment screening levels that are lower than ambient concentrations. The HEER Office does not support any method that results in suggesting remediation of sediments that are already within background concentrations.

In lieu of adopting CBRs from temperate sites, the HEER Office recommends that site-specific tissue concentrations be compared with concentrations from either a pre-approved local reference location or from published studies in Hawaii. The species profiles presented in Appendix 21A provide some data on tissue concentrations reported in other studies. The HEER Office continues to collect and compile relevant data from across the state to support this element of the ERA Program.

Sediment Screening Levels for Bioaccumulating Chemicals

The sediment screening level for a bioaccumulating chemical is a concentration in sediment considered to pose little to no risk to ecological receptors exposed to the sediment. At concentrations less than the screening level, bioaccumulation is expected to be low enough to allow the receptor to live in the sediment without experiencing adverse effects caused by bioaccumulation of the chemical In principle, the screening level concentrations in sediment should ensure that the receptor would not bioaccumulate the chemical to concentrations greater than the CBR of any target receptor.

Development of a sediment screening level for a bioaccumulating chemical requires that a biota-sediment accumulation factor (BSAF) be used to model the accumulation of the chemical in an organism based on the sediment concentration. Although theoretically possible, development of BSAFs is a complicated process that is influenced by numerous factors such as the developmental stage, age, sex, reproductive state, and condition of the receptor; physico-chemical features of the sediment such as organic carbon content, pH, salinity, redox, and temperature); and the form of the chemical present in the sediment. BSAFs reported in the literature can vary widely, and are not reliably transferred from one site to another, especially from temperate fluvial habitats to tropical marine habitats. Few BSAFs are available for species and habitats in Hawaii. For these reasons, the HEER Office does not recommend the use of literature-based BSAFs to estimate tissue concentrations unless the BSAF was derived from a regionally-appropriate study. Therefore, the HEER Office is not providing sediment screening levels for bioaccumulating chemicals at this time. The risk assessor may conduct studies as needed to develop site-specific BSAFs or measure tissue concentrations directly at the site.

Surface Water Screening Levels

Surface water screening levels for bioaccumulating chemicals are similar to the sediment screening levels described above. Development of a surface water screening levels for a bioaccumulating chemical requires that a bioconcentration factor (BCF) be used to model the accumulation of the chemical in an organism based on the concentration in surrounding water. However, species and site-specific water quality conditions (pH, temperature, conductivity, and other water quality parameters) influence the value of the BCF. Moreover, most bioaccumulative chemicals are hydrophobic (not water soluble), and are not often detected in surface water. The dynamic movement of water, especially in coastal Hawaii, further complicates the link between water concentrations and tissue concentrations. Finally, chemical concentrations in surface water are spatially and temporally more variable than in sediment, as water is influenced by rainfall, suspended and dissolved solids, and other

factors. The HEER Office does not provide surface water screening levels for bioaccumulating chemicals. The risk assessor may provide literature supporting the use of existing BCFs at the site or propose site-specific studies in support of BCF derivation.

Step 5 – Compile Toxicity Reference Values

A TRV is a chemical dose, given in mg of chemical per kg body weight per day; it is used to evaluate risk to a receptor ingesting bioaccumulative chemicals in sediment, water, and prey. Most TRVs are derived from laboratory studies of a few standard test species measuring effects on growth, reproduction, and mortality. Although the ideal TRV is specific to a chemical-receptor pair that occurs at the site, data limitations generally require the risk assessor to apply a general TRV to an entire class of receptors, such as birds or mammals. The HEER Office has compiled TRVs for some receptors and chemicals<link>. The risk assessor is responsible for reviewing the available information and supplementing it as needed with current toxicological data from the published literature. The risk assessor should prepare a list of proposed TRVs, with rationale, for review by the HEER Office.

Step 6 – Identify Chemicals of Potential Ecological Concern (COPEC)

The decision process below should be applied to each chemical separately to identify which bioaccumulating chemicals will be retained as chemicals of potential ecological concern (COPEC) for further evaluation in the ERA.

- Are site sediment concentrations greater than background/ambient/reference concentrations?
    - If no, the chemical is not retained as a COPEC.
    - If yes, the chemical is retained as a COPEC.
    - If no background/ambient/reference concentrations are available, the chemical is retained as a COPEC and additional investigation may be required. Consult with the HEER Office.

- Are site tissue concentrations greater than background/ambient/reference concentrations?
    - If no, the chemical is not retained as a COPEC.
    - If yes, the chemical is retained as a COPEC.
    - If no background/ambient/reference concentrations are available, the chemical is retained as a COPEC and additional investigation may be required. Consult with the HEER Office.

- Are site tissue concentrations greater than all CBRs?
    - If no, the chemical is not retained as a COPEC.
    - If yes, the chemical is retained as a COPEC.
    - If no CBRs are available, the chemical is retained as a COPEC and additional investigation may be required. Consult with the HEER Office.

Note that this decision process will be modified if and when screening levels for bioaccumulating chemicals in sediment and surface water become available.

Step 7 - Determine the Need for Additional Information

To proceed with the ERA for bioaccumulating chemicals, the following information is required:

- List of COPECs (specific to each receptor or group of receptors)
- Exposure point concentration for each COPEC in each medium (sediment, prey items)
- CBRs for target receptors
- TRVs for target species-chemical pairs (for example marine mammal – PCBs)
- Values for key exposure parameters for target receptors, such as body weight, ingestion rates for food and sediment, diet, site use factors, and others (see Step 2, Task 3 in HEER Office ERA Guidance, Section 21)

If any of the information above is unavailable, and cannot be estimated using literature values relevant to Hawaii, additional site-specific work may be required before the ERA can be completed.

Step 8 – Conduct a Site-Specific Bioaccumulation Investigation

When a bioaccumulating chemical is present at a site at concentrations greater than regional background/ambient/reference concentrations, the most efficient way to evaluate risk of the chemical is to measure its bioaccumulation in target receptors at the site that have small home ranges (if the receptors are not legally protected). If site-specific tissue cannot be obtained, tissue concentrations may be estimated using concentrations in sediment and BSAFs, when available. Alternatively, laboratory bioaccumulation tests of site sediment samples can provide tissue concentrations and BSAFs for benthic invertebrates. A detailed sampling and analysis plan should be submitted to the HEER Office for review to ensure that any field sampling effort addresses the necessary requirements for an ERA. At a minimum, the following components of field sampling should be addressed in the sampling and analysis plan:

Sediment Sampling

- Depth of samples (should reflect exposure of target receptors)
- Number of sediment samples (minimum = 5)
- Multi Increment sampling (MIS) and decision unit (DU) design (see Appendix 21-C and TGM <LINK>)

Biota Sampling

- Target receptors (should be relevant to CSM and linked to existing reference data, if possible)
- Rationale for selection of species (e.g. small home range, known to accumulate the chemical, availability of background/ambient/reference tissue concentrations, etc.)
- Number of samples (minimum = 5 site; 3 reference)
- Sample composition: composite vs individuals; age; sex; size/length; reproductive condition
- Sample processing methods (e.g. whole body, specific organs, muscle only, etc.)
- Seasonal considerations
- MIS and DU considerations
- Chemical/physical analyses; percent moisture; percent lipid

Laboratory Bioaccumulation Study

- Number of samples (minimum = 7 site)
- Method for selecting samples (ensure a concentration gradient)
- Tests species relevant to Hawaii (e.g. *Neanthes arenaceodentata* polychaete)
- Method for calculating the BSAF
- Duration of test
- Sample processing methods (depuration)
- MIS and DU considerations
- Chemical/physical analyses of sediment and tissue; percent moisture and percent lipid in tissue

APPENDIX 21-F

- Background/Ambient/Reference Concentrations
    - Evaluating Bioavailability

Background/Ambient/Reference Concentrations

This section is under development.

Evaluating Bioavailability

In the initial steps of the SLERA, it is assumed that chemicals are 100 percent bioavailable. Refinement of this conservative assumption requires site-specific information. Total organic carbon (TOC) and grain size distribution data should be collected during the site investigation so the potential bioavailability of the chemicals can be evaluated in the refinement step (Step 3a). These parameters should also be evaluated during the background comparison to determine whether the background sediment has similar physical characteristics as the site sediment because TOC and grain size can influence the amount of chemicals accumulating in sediment, as discussed below.

Very little debate remains over the role of grain size in influencing bioavailability. In general, finer-grained sediments have a proportionately higher number of binding sites (based strictly on increased surface area) than coarser-grained sediments. When fine-grained particles are ingested by an organism, a relatively higher dose of the chemical is also ingested.

The other hand, there are conflicting views on whether toxicity to sediment invertebrates is correlated with TOC. The tendency of PCBs, PAHs, and other organic chemicals (including mercury) to sorb to the organic carbon fraction of is well documented, and is used in equilibrium partitioning models to predict bioavailable fractions. However, the relationship between TOC and concentration of organic compounds is not as straightforward as the EqP models assume. For example, some studies have concluded that TOC normalization had little if any influence on the outcome of the screening process using the low sediment quality guidelines (McCready et al. 2006). Not all organic carbon is equally capable of binding organic chemicals; the type of organic carbon (humic matter particles, humic matter sorbed on mineral surfaces, animal and plant matter, combustion by-products) may also determine the strength of the association with organic compounds (Ghosh et al. 2003). Remediation engineers take advantage of the tendency of organic carbon to bind PCBs and apply specific types of activated organic carbon to sediments contaminated with PCBs, PCDD/Fs, and mercury as a means of reducing the bioavailability of chemicals to organisms (Millward Et al. 2005; Patmont et al. 2015; Gilmour et al. 2014).

It is recommended that TOC and grain size be analyzed in sediment ERAs in so that the relationship can be independently tested in Hawaii. If similar results are confirmed over time, this requirement may be modified or eliminated. Additional discussion of methods for measuring and interpreting results of grain size and TOC analyses is available in Opel et al. (2011);

Under some conditions, chemical analysis of field-collected organisms can provide site-specific evidence of bioavailability of chemicals in sediment. Organisms should be resident at the site, relatively sessile, and exposed to sediment either through direct contact or ingestion of sediment (or both). Note that tissue concentrations will reflect exposure to chemicals in overlying water as well as sediment, potentially confounding data interpretation.

If tissue data are not available, chemical concentrations in food items can be calculated using sediment-to-fish and sediment-to-invertebrate BSAFs, as follows:

$$C_f \text{ (for metals)} = C_{sd} * BSAF$$

Where:

C_f = Contaminant concentration in food (mg/kg)
C_{sd} = Contaminant concentration in sediment (mg/kg)
BSAF = Biota-sediment bioaccumulation factor (unitless)

$$C_f \text{ (for organics)} = C_{sd} * \left(BSAF * \frac{\%L}{\%TOC} \right)$$

Where:

C_f = Contaminant concentration in food (mg/kg)
C_{sd} = Contaminant concentration in sediment (mg/kg)
BSAF = Biota-sediment bioaccumulation factor (for organics) (unitless)
%L = Percent lipids [species-specific value (dry weight)]
%TOC = Percent total organic carbon (site-specific value)

For the SLERA, conservative exposure assumptions should be used for food chain models, such as:

- Maximum sediment concentrations
- Conservative receptor body weight and ingestion rates
- Assume that receptors obtain all of their food from the site (home range factor of 1.0)

TABLE 21F-1. BIOTA-SEDIMENT ACCUMULATION FACTORS FOR FISH AND INVERTEBRATES

Analyte	Sediment Invertebrate Bioaccumulation Factors			Fish Bioaccumulation Factors		
	Conservative	Average	Source	Conservative	Average	Source
Metals						
Arsenic	0.69	0.143	ORNL (1998)	-		-
Copper	5.25	1.556	ORNL (1998)	-		-
Lead	0.607	0.071	ORNL (1998)	-		-
Mercury	2.868	1.136	ORNL (1998)	-		-
Zinc	7.527	1.936	ORNL (1998)	-		-
Pesticides/PCBs/Dioxins						
4,4'-DDD	-		-	0.28		EPA (2004)
4,4'-DDE	-		-	7.7		EPA (2004)
Total DDTs	-		-	7.7		EPA (2004)
Total Chlordanes	-		-	4.77		EPA (2004)
Dieldrin	-		-	1.8		EPA (2004)
Endrin	-		-	1.8		EPA (2004)
Total PCBs	6.41E+01	3.62E+01	ORNL (1998)	EPA (2004)		EPA (2004)
2,3,7,8-TCDD	-		-	0.025		EPA (2004)
Semivolatile Organic Compounds						
Acenaphthene	-		-	0.29		EPA (2004)
Acenaphthylene	-		-	0.29		EPA (2004)
Anthracene	-		-	0.29		EPA (2004)
Benzo(a)anthracene	-		-	0.29		EPA (2004)
Benzo(a)pyrene	-		-	0.29		EPA (2004)
Chrysene	-		-	0.29		EPA (2004)
Dibenzo(a,h)anthracene	-		-	0.29		EPA (2004)
Fluoranthene	-		-	0.29		EPA (2004)
Fluorene	-		-	0.29		EPA (2004)
Naphthalene	-		-	0.29		EPA (2004)
Phenanthrene	-		-	0.29		EPA (2004)
Pyrene	-		-	0.29		EPA (2004)
Sum HMW PAHs	-		-	0.29		EPA (2004)
Sum LMW PAHs	-		-	0.29		EPA (2004)
Total PAHs	-		-	0.29		EPA (2004)

- no data

ORNL (1998). *Biota Sediment Accumulation Factors for Invertebrates: Review and Recommendations for the Oak Ridge Reservation*. BJC/OR-112. August.

EPA (2004). *The Incidence and Severity of Sediment Contamination in Surface Waters of the United States, Volume 1: National Sediment Quality Survey*: Second Edition. Office of Science and Technology. Washington, D.C. EPA 823-R-04-007. November.

Calculating Biota-Sediment Accumulation Factors

A BSAF is a unitless ratio of the lipid-normalized wet weight concentration in tissue to the organic carbon-normalized concentration in surface sediment. BSAFs are transfer coefficients that relate chemical concentrations in biota to chemical concentrations in sediment (USEPA 2004). In the BERA, site-specific tissue data (either from field-collected organisms or tissue samples from laboratory bioaccumulation tests) can be used to develop site-specific BSAFs. BSAFs are the ratio of chemical concentrations in tissue and chemical concentration in collocated sediment, as follows:

$$\text{BSAF(metals)} = \frac{\text{tissue concentraton}}{\text{sedimentconcentraton}}$$

Where: BSAF(metals) = Biota-sediment accumulation factor for metals (unitless)
Tissue Concentration = Chemical concentration in tissue (mg/kg or µg/kg)
Sediment Concentration = Chemical concentration in sediment (mg/kg or µg/kg)

$$\text{BSAF(organics)} = \frac{\text{tissue concentraton/\%lipids}}{\text{sedimentconcentraton/\%TOC}}$$

Where: BSAF(organics) = Biota-sediment accumulation factor for organics (unitless)
Tissue Concentration = Chemical concentration in tissue (mg/kg or µg/kg)
Percent Lipids = Percent lipids in tissue sample (%)
Sediment Concentration = Chemical concentration in sediment (mg/kg or µg/kg)
Percent TOC = Percent total organic carbon of the sediment (%)

Normalizing the tissue and sediment concentrations for the organic chemicals to percent lipids and TOC, respectively, is done because organic chemicals have a tendency to bind to lipids and organic carbon.

When field-collected invertebrate tissue concentrations are not available, BSAFs can be calculated using site-specific sediment concentrations and tissue concentrations measured in laboratory bioaccumulation tests. The BSAFs can then be used to estimate the concentrations of chemicals that could occur in invertebrates exposed to maximum concentrations in sediment in each DU. BSAFs incorporate the percent lipid in tissue and total organic carbon (TOC) in sediment to predict the total concentration in the prey tissue. Although separate site-specific BSAFS for each species of interest would be ideal, application of BSAFs derived for one laboratory invertebrate test species to other invertebrates within the study area is considered appropriate because BSAFs for benthic invertebrates have been shown to be relatively insensitive to interspecific variability (Tracey and Hansen 1996; Burkhard et al. 2010).

Differences in BSAFs in site samples and other sites reported in the literature may be explained by numerous physical, chemical, and biological factors. Bioaccumulation of PCBs and other compounds

with high log K_{ow} may differ from what is predicted by equilibrium partitioning because sediment ingestion by the organism may enhance bioavailability in ways not accounted for by log K_{ow} and similar physico-chemical models (Sormunen et al. 2008). Empirical BSAFs derived from site-specific samples are considered a reliable indicator of bioavailability of chemicals in sediment and a direct measure of bioaccumulation under laboratory conditions. The differences between estimated and field-derived BSAFs are lowest between the same species at different locations within a site, or different species at a single site. The extrapolation of BSAFs within or among species at distant unrelated sites decreases the reliability of the estimated BSAF (Burkhard et al. 2010).

Evidence for chemical uptake from sediment includes BSAFs greater than 1.0.

Numerous sources of uncertainty are associated with the derivation, application, and interpretation of benthic invertebrate BSAFs. Judd et al. (2014) concluded a review of more than 200 BSAFs with words of caution against the over-reliance on BSAFs. In particular, BSAFs should not be extrapolated beyond the chemical concentration on which they were based because the relationship may not be linear. Likewise, the BSAF curve intercept may not be zero. Lastly, one of two outlier concentrations can skew the BSAFs. While an understanding of the influence of lipid concentration on BSAFs may improve the interpretation of bioavailability for some lipophilic compounds, in wild populations lipid concentrations can vary dramatically with season, diet, and reproductive stage (Beckvar and Lotufo 2011). Lipid-adjusted tissue concentrations are not reliably more predictive than standard wet weights for interpreting bioaccumulation processes or toxicity in wild organisms (Wenning et al. 2011). Nevertheless, investigators require some approach to measuring bioaccumulation, and BSAFs can be useful within the limits of these known liabilities (Judd et al. 2014).

A review of BCF and BAF publications encompassing hundreds of organic compounds and test species concluded that field-derived BAFs may be higher than laboratory-derived BAFs (Arnot and Gobas 2006). Conversely, a more directly relevant side-by-side laboratory and in-situ comparison of BSAFs and BAFs using *Lumbriculus* reported that the two measures were comparable for PCBs (Beckingham and Ghosh 2010).

BSAFs based on field collected data will typically be less accurate that BSAFs derived from laboratory studies because the exposure point concentration for field collected organisms is less certain than it is for laboratory studies. For example, even though non-mobile organisms like mollusks live in the sediment, they are filter feeders and get their exposure from chemicals in the overlying water. While some of the contaminants in the overlying water may be from the adjacent sediment, in aquatic systems, water and sediment are transient so exposure will change over time. Therefore, sediment that is co-located with organisms collected in the field may not accurately represent exposure of the organisms. This is a much greater source of uncertainty with mobile organisms such as crabs and fish.

DOH recommends that BSAFs should generally only be calculated for detected and non-rejected data. Non-detected data can be used to calculate average sediment concentrations over an exposure area, however, non-detected data should not be used to calculate BSAFs if either the tissue or sediment concentrations were non-detect.

APPENDIX 21-G

SAMPLE TABLE OF CONTENTS

BASELINE ECOLOGICAL RISK ASSESSMENT (BERA) WORK PLAN/SAMPLING AND ANALYSIS PLAN (WP/SAP) AND BERA REPORT

CONTENTS OF A BERA WORK PLAN/SAMPLING AND ANALYSIS PLAN

(see Section 21 for guidance on preparing the BERA WP/SAP)

CONTENTS OF A BERA REPORT

TABLES (THESE ARE EXAMPLES – REVISE AS APPROPRIATE FOR YOUR SITE)

CHAPTER 2 TABLES

CHAPTER 3 TABLES

CHAPTER 4 TABLES

CHAPTER 5 TABLES

CHAPTER 6 TABLES

- BERA SUMMARY: DU-1
- BERA SUMMARY: DU-2
- BERA SUMMARY: DU-3
- SUMMARY OF COECS BY DU
- SPATIAL DISTRIBUTION OF TOXIC SEDIMENTS AT THE SITE
- LOCATIONS WARRANTING FURTHER INVESTIGATION

FIGURES (THESE ARE EXAMPLES – REVISE AS APPROPRIATE FOR YOUR SITE)

- LOCATION OF DECISION UNITS
- ECOLOGICAL CONCEPTUAL SITE MODEL (PER DU, IF APPROPRIATE)
- FOOD WEB OF SELECTED RECEPTORS
- SURFACE SEDIMENT SAMPLING REFERENCE LOCATIONS
- RESULTS OF SEDIMENT TOXICITY TESTS

APPENDICES (THESE ARE EXAMPLES – REVISE AS APPROPRIATE FOR YOUR SITE)

- BERA WP/SAP
- SPECIES KNOWN OR EXPECTED TO OCCUR AT THE SITE (WITH STATUS OF LEGAL PROTECTION)
- ALL SCREENING AND DATA SUMMARIES
- BIRD AND MAMMAL FOOD CHAIN MODELING
    - SPECIES PROFILES
    - DOSE PARAMETERS FOR EACH RECEPTOR
    - HAZARD QUOTIENT SUMMARIES FOR EACH RECEPTOR (SITE AND REFERENCE LOCATION)