Chapter 3
Habitat Characterization

Biological assessment in estuaries and coastal marine waters is built around assessing two separate ecosystem components: the habitat and the biota. The biota are the resident plant and animal assemblages in the water body. The condition of the biota depends in part on the quality of the physical-chemical environment of estuaries and coastal marine waters; i.e., habitat. Habitat is in turn influenced by natural and catastrophic events, climate, and human activities. These include:

- Seasonal variations in precipitation, temperature shifts, and wind or wave patterns;
- Introduced or extirpated species able to influence the habitat (such as burrowing organisms, plants, or diseases/parasites;
- Shifts in sedimentation or scouring patterns;
- Dredging and filling;
- Shoreline or basin construction;
- Bulkheading and jetty construction;
- A variety of land use and navigational practices.

This conceptual model is based on an understanding of the causal mechanisms of natural and anthropogenic stress effects in estuarine and coastal marine ecosystems.

Estuaries integrate processes because they receive and retain matter and energy released in the watershed. Many human activities directly affect aquatic habitat including discharges, agriculture, and urban land use which contribute materials (sediment, nutrients, contaminants) to the water body. Biological communities are directly affected by their physical habitat and water quality conditions, and also by direct human activities such as stocking or harvesting.

Components of biota are the biological assemblages, such as algae, aquatic macrophytes, benthos, epibenthos, plankton, and fish. Habitat components for the biological assessment of these assemblages are hierarchical, and include the watershed, the nearshore zone, the water column, and the sediment. An integrated assessment evaluates the condition of estuaries and coastal marine waters by aggregating data on components of both habitat and biota. The habitat component may be damaged by physical stress or chemical degradation from pollution. Thus, habitat studies may help identify causes of biological decline as well as being the important determinant of the types of biotic communities to be expected. This classification function is crucial to proper biocriteria development.

Habitat characterization is essential to the proper classification of sites. Although estuaries are by definition transitional zones between fresh water and the sea, and both estuaries and coastal marine waters incorporate many environmental gradients (e.g., salinity, sediment grain size, depth), individual locations and conditions are often defined categorically. Thus, a site may be characterized as oligohaline or mesohaline with respect to salinity, or sand or mud with respect to sediment grain size. The composition of biological assemblages can vary dramatically along these habitat gradients, and valid comparisons of estuarine and coastal marine biological assemblages require that their habitats be correctly classified.

3.1 Flow and Hydrography

The type of estuarine ecosystem in a specific area is primarily controlled by the physical environment; i.e., geomorphology, climate, salinity, and the availability of fresh water. The absolute values of the abiotic factors are not as important as the degree of fluctuation of factors such as the microclimate, water movement, chemical cycling, and physical structure (Day et al. 1989). In addition, the residence time of water in an estuary can influence overall water column pollutant concentrations.

The abiotic features thought to be important in determining the specific nature of estuaries as proposed by Day et al. (1989) are:

- The degree of protection and buffering from direct oceanic forces;

- The quantity of freshwater input and associated dissolved and suspended materials;

- The water circulation patterns that are determined by riverine and tidal currents, geomorphology and wind. Tides play a critical role in influencing circulation, and biochemical and biological processes. In many coastal regimes, the wind-driven currents are more predominant than tidal and geomorphologically-induced currents;

- Depth—stronger interactions between the water column and the bottom occur in shallow estuaries, thereby expediting the release of sediment nutrients for use by the phytoplankton;

- Variability of salinity and the sharpness and pattern of the salinity gradient from the mouth to the headwaters. Water circulation influences the salinity gradient and the distribution of biological assemblages;

- The rate of geomorphological change generated by various physical forces that control sediment transport within the estuary.

These controlling abiotic features are discussed in more detail in the following sections.

3.1.1 Circulation and Tidal Regime

Circulation is the physical process that influences or controls many of the ecological processes occurring in an estuary, including the degree to which an estuary is dominated or modified by hydrodynamics. The three major driving forces behind the circulation patterns in estuaries are: (1) gravitational circulation; (2) tidal circulation; and (3) wind-driven circulation. Geostrophic forcing; i.e., the Coriolis effect, can significantly alter estuarine circulation patterns as does bathymetry. A notable example is the Chesapeake Bay, where lower salinities extend further south along the Bay's western shore in comparison to its eastern shore.

Gravitational circulation is induced by water masses of differing densities and the layering of fresh water inflow on top of more saline waters. These density differences cause the lighter fresh water to flow over top of the saltwater to form what is commonly termed the "salt wedge". In what is termed the "classical" estuarine gravitational circulation, the pressure surfaces of the fresh water are tilted seaward and the pressure surfaces of the saltwater are tilted toward the head of the estuary. The shear stress forces that occur at the interface of these two water masses cause vertical mixing and an eventual equalizing of the pressure surfaces somewhere near mid-depth. The fresh water surface layer has a net seaward movement, the saltwater layer on the bottom has a net movement upward into the estuary and the interface is a zone of no net movement.

Typically, density differences and the resulting circulation are determined by salinity and the circulation as is described above. However, in arctic or subarctic estuaries, the fresh water inflow may be substantially colder than the saltwater causing the fresh water inflow to sink below the saltwater, reversing the expected circulation pattern. In shallow lagoons that receive little or no fresh water input such as Florida Bay or Laguna Madre, the evaporation rate can cause the salinity of the water within the lagoon to rise higher than the ocean waters. When this happens, the ocean water flows into the estuary on the surface and the estuarine water flows out on the bottom, resulting in reverse circulation. Most often, though, shallow lagoons are well-mixed by the wind and reverse circulation is only observed at the mouth of the lagoon.

Tidal circulation occurs when the ebb and flow of the tides becomes the driving force behind circulation. This is known to occur in estuaries with steep constrictions or with shallow depths and large tidal ranges (e.g., Puget Sound), and in the absence of density gradients or wind stress. In many estuarine systems, gravitational and tidal effects coexist.

Wind circulation is common in estuaries with open water, shallow water depths, a small tidal range, and low fresh water input. Although the effects of wind may be overshadowed by gravitational or tidal forces, periods of sustained wind can have dramatic ecological effects. In the Ten Thousand Islands region of the Florida Everglades, sustained northern winds virtually drain the water out of large portions of the estuary for extended periods of time, exposing large areas of mudflats. Winds that blow into an estuary can create a net flood flow and result in the inundation of marshes and grass lands. In lagoons as well, water can pile up on one side of the lagoon creating a seiche or a sloshing of the water back and forth within the lagoon.

Attention to these diverse, often variable, and always significant circulation patterns is essential to understanding the biotic distribution of coastal and estuarine environments. This must always be addressed before attempting to attribute such distribution to anthropogenic influences.

3.2 Habitat Types

Use of a single habitat to characterize biological assemblage condition would minimize the requirements for expenditure of time and resources. However, estuaries and coastal marine waters are inherently heterogeneous systems. By definition, a salinity gradient is present in any estuary. Greater numbers of species are typically observed at the marine end of the salinity gradient, with the fewest numbers observed in about 3-7-ppt (Weisberg et al. 1993). This may be due to the unpredictable nature with which the brackish water zone varies along the length of the estuary; driven by the strength and intervals of freshwater inflow.

In addition to a salinity gradient, estuarine habitats vary in bottom substrates, and in the predominance of erosional versus depositional environments. The variations in these characteristics will lead to differences in the way pollutants and other stressors will effect the biota. For example, depositional environments occur where large amounts of terrigenous sediments are transported by rivers to embayments and where the water is sufficiently quiescent that fine-grained sediments settle out. Metals, synthetic organic pollutants, and other contaminants adsorb to fine-grained sediments (Holland 1990) and low-density organic detritus. Thus, the prevalence of depositional areas may reduce the likelihood of water column exposure of estuarine organisms to toxic materials, but may increase the exposure to burrowing organisms. Conversely, the water column of erosional zones is often highly enriched as resuspended phosphorus is episodically mobilized.

Habitats in estuaries and coastal marine waters can be classified into nine major categories. These habitats are summarized below in a progression from open, deep waters to decreasing depths near the shoreline. The choice to sample one or more of these nine habitats will be dictated by their areal extent and the nature of the problems being addressed.

3.2.1 Open Water

Sampling in open water may demonstrate phytoplankton blooms which might be symptomatic of eutrophication from anthropogenic inputs of phosphorus or nitrogen. It should be noted that not all phytoplankton blooms (e.g., red tides) result from anthropogenic stresses. Increases in the standing stocks of bacteria associated with fecal material can be used to identify the presence of sewage effluent. Open water (plankton and nekton) studies also allow assessment of pelagic food webs. Sampling of pelagic finfish also occurs in open estuarine and marine waters. Limitations of sampling in open water include a high degree of patchiness in the plankton and finfish assemblages, which necessitates the sampling of large volumes and areas of water before results can be described with acceptable precision. Because of the transitory residence time of water parcels moving through estuaries and the short life cycles of planktonic flora and fauna, a relatively high sampling frequency is necessary to distinguish signals from noise in this area.

3.2.2 Soft Bottom Substrates

A "soft bottom" deposit may be dominated by mud or fine- to relatively coarse-grained, hard-packed sand. All of these sediments can be sampled with appropriate grabs. Soft bottom substrates provide habitat for economically valuable clams, shrimp, and juvenile flatfishes. Muds have a high surface area-to-volume ratio, providing a large surface area for the adsorption of metals and organic pollutants. Also, fine-grained deposits are often rich in biogenic adhesives (mucopolysaccharide secreted by microbes and meio- and macrofauna), to which organic pollutants may adhere. Under anoxic conditions, these deposits are often called "black ma yonnaise." Conversely, sands have a lower surface area-to-volume ratio. Thus, there is less surface area available in the deposit to which pollutants may adsorb.

A limitation of sampling in soft substrates is that the samples must be sieved before individuals can be counted and identified. With medium or coarse sands this also means large volumes of sediment are retained on the sieves for subsequent processing. Thus, measurements cannot be readily made in the field. This is especially true for samples in which an abundance of organic debris (wood chips, seagrass leaves) masks the presence of small, cryptic organisms.

3.2.3 Hard Bottom Substrates

Hard bottom substrates can include offshore rocky outcrops; oyster, relic shell, and worm tube reefs; and relic limestone and coral outcrops. Oyster and mussel beds are major habitats supporting a complex community of various species essential to the biological diversity of estuaries such as Chesapeake, Florida, and Tampa Bays. In fjords the predominant subtidal habitat may be the rocky walls extending below the water line. An advantage of sampling these areas is that the macroalgae growing along these walls may be relatively sensitive to stress and can be used in bioassays or tested for bioaccumulation (Levin and Kimball 1984).

Hard bottom substrates frequently occur in high-energy environments common in portions of Alaska, Washington, Oregon, and northern California, as well as New England. For example, gravel/cobble beaches are typically subject to high incident wave energy. Accumulations of fine-grained sediments or organic detritus are not expected on hard substrates either because there is no riverine source or because the energy of the environment prevents their accumulation. In addition, subtidal rocky bottoms are difficult to sample remotely. A grab sampler cannot be used, for example, as it can in soft-bottom habitats. Typically, divers conduct transect observations and take photos.

Another limitation of sampling hard substrate is that the larvae and spores of rocky substrate organisms are typically planktonic; therefore, recruitment may be strongly influenced by factors outside the estuary. Sampling and analysis methods must be appropriate both to the specific type of hard substrate as well as regional characteristics due to the fact that hard bottom substrates can exist from rocky, high energy regions in California to carbonate sediment, low energy regions in Florida.

3.2.4 Aquatic Macrophytes

Macrophyte beds are among the most important estuarine habitats, both ecologically and economically. Seagrasses (in this text, used to describe macrophytes existing from tidal fresh to marine conditions) create an environment with a high degree of structural complexity. Ecological niches exist within the sediment, between the rhizomes, along the surfaces of the leaves, and in the protected portion of the water column within the bed. Thus, a seagrass bed is capable of supporting a highly diverse fauna. Seagrass beds are among the most productive aquatic habitats. In western Florida, *Thalassia testudinum* beds produce 8,100-gm^{-2} dry weight of leaves at maximum standing crop (Hillman et al. 1989). Seagrass beds provide "nursery areas" for juvenile fishes and decapod crustaceans, including many of economic importance. Seagrass leaves are known to bioaccumulate and possibly to bioconcentrate metals (Ward 1989).

The right mix of nutrients and water clarity are key in seagrass growth and survival in estuarine systems. A study by Stevenson et al. (1993) demonstrated regrowth of SAV in the Choptank River of the Chesapeake Bay (mesohaline salinity regime) was associated with mean DIN <10-µM, mean DIP <0.35-µM; mean SPM (suspended particulate matter) <20-mgL^{-1}; mean chlorophyll *a* (in water column) <15-µgL^{-1}; and mean light attenuation coefficient (Kd)<2-m^{-1}.

In addition to serving as habitat for invertebrates and fish, macrophytes are also a biological assemblage in their own right and appear to be relatively sensitive to stress. These beds can be monitored from historical photos and other records (Shepard et al. 1989). Areal reductions are often attributed to shading, which may result from a variety of anthropogenic factors including turbidity (from ship traffic, dredging, or harbor construction which may stir fine-grained material up into the water column) and eutrophication (where inputs of nutrients stimulate increases in the density of phytoplankton and of epiphytic macro- and microscopic algae on leaf surfaces).

A limitation of sampling in seagrass habitats is that because of their ecological complexity, multiple sampling strategies are required to survey the various components of the fauna (Howard et al. 1989), increasing the expenditure of time and resources by investigating agencies.

3.2.5 Beaches

Beaches are accumulations of unconsolidated sediment (e.g., sand, cobble) extending shoreward from the near low-tide line to some demarcation such as a sea cliff or dune field, or to the point where permanent vegetation is established (Komar 1976). High energy beaches typically consist of shingle or cobble due to the removal of finer sediments by high incident wave energy. These beaches may be commonly found on the Atlantic coast north of Cape Cod and along the Pacific coast. High energy beaches of southeastern Florida are composed of sand and are protected by sabellariid reefs offshore. Low energy beaches consist of sand and finer sediments and are widely located on the Atlantic coast south of Cape Cod, the Gulf of Mexico, and along the southern Pacific coast, and along the shorelines of most estuaries and their tidal tributaries.

Distinct zones occur across the beach profile, proceeding from the subtidal offshore and inshore zones, through the foreshore that lies between the upper current of wave swash at high tide and the low water mark of the backrush of the wave swash at low tide, to the subaerial backshore (Komar 1976). These zones contain a gradation of faunal communities in response to varying conditions of wave energy, sediment size, and inundation by water. Sampling across the beach profile can be problematic, particularly on high energy beaches, due to the rapidly-varying wave conditions and distribution patterns of beach infauna and epifauna. If attempted, core samplers can be used on low energy beaches but quadrat surface sampling may be required on high energy beaches.

3.2.6 Sandflats

Deposits described as "fine sand" contain some silts and clays and harbor rich communities of both deposit- and suspension-feeding invertebrates. "Coarse sands," found in higher energy environments, are expected to be dominated by suspension-feeding invertebrates. If a sufficient erosional force is applied to a sandy bed by the overlying flow, sand waves form. Sand waves indicate a physically stressful habitat, typified by a relatively depauperate fauna. It should be noted that coarse sands generally contain relatively low faunal densities and biomass. However, when coarse sands are colonized by surf clams and echinoderms (sand dollars), densities and biomass can be very high. Compared to mudflats, relatively little organic material and few associated pollutants are expected to accumulate in coarse sands. Calcareous deposits in Puerto Rico and Hawaii may provide an exception to this in that they have high organic matter content and many pollutants (Dossis and Warren 1981).

3.2.7 Mudflats

Mudflats provide habitat for commercially important clams and other invertebrates and feeding habitat for fishes and shorebirds. Fine-grained sediments (i.e., clay) and organic detritus accumulate on mudflats. These materials provide a large surface-to-volume ratio adsorb metals and organic pollutants. This same expanse of usually nutrient and oxygen rich habitat also supports diverse primary producers, bacteria, plankton, and fish and invertebrate species in a complex community.

3.2.8 Emergent Marshes

Where present, emergent marshes may be extremely important components of estuaries and coastal marine embayments and lagoons because they filter storm water runoff from cities, forests, and agricultural areas. Emergent marshes may also provide flood protection by attenuating peaks in storm water flow and reducing the erosive energy of wave action.

Traditionally, the ecological health of a marsh has been characterized by measuring changes in its areal extent and the abundance and diversity of its fish and wildlife populations. Although "microelements" of the marsh community (e.g., terrestrial insect assemblages) may be more sensitive to perturbations, these studies may be more expensive and time-consuming to carry out. For example, insect populations are difficult to sample quantitatively because of their mobility and cyclic abundance.

3.2.9 Mangrove Forests

Low-lying tropical coasts are often bordered by dense mangrove forests. Temperature, particularly the frequency of freezes, and rainfall gradients restrict mangrove distribution. In the Gulf of Mexico, mangrove forests occur along the coasts south of Cedar Keys, Florida and generally south of Port Isabel, Texas. Isolated stands of black mangrove (*Avicennia germinans*) occur in the Mississippi deltaic plain (Day et al. 1989), but mangroves are otherwise absent from the northern Gulf coast, which is dominated by salt marshes. Significant mangrove stands also occur south of Cape Canaveral on the east coast of Florida (Odum and McIvor 1990). Mangrove forests and their associated waters provide valuable habitat for a range of invertebrates, fishes, amphibians, reptiles, birds, and mammals. Mangroves are also valuable as stabilizers of intertidal sediments, and the structural complexity of the prop-roots provides habitat for many commercially and recreationally important fishes.

3.3 Water Column Characteristics

Many chemical and biological processes in the environment are affected—directly or indirectly—by the physical characteristics of that environment (Thomann and Mueller 1987). Therefore, collection of physicochemical data such as salinity, temperature, dissolved oxygen, pH, turbidity, nutrients, contaminants, and depth provides information necessary to evaluate biological data.

Although organisms living in estuaries are adapted for life in a physically dynamic system, many are living near the limit of their physiological tolerance range and any long-term alteration of physicochemical environmental conditions could force their permanent exclusion from the estuary. Even in minimally-impaired estuaries, causes of mass mortalities have been attributed to depletions of dissolved oxygen and changes in temperature, salinity, and excessive turbidity (Odum 1970). In areas subjected to anthropogenic stress, changes in physical and chemical parameters may occur too frequently, be increased in magnitude, or be sustained for periods of time that only the extremely tolerant organisms can endure.

The community composition of marine and estuarine fish assemblages is determined by the various species tolerances and preferences for environmental variables such as substrate, salinity, and temperature (Weinstein et al. 1980). These environmental variables are controlled by the quantity and direction of the flow of water; i.e., fresh water inflow, tidal cycles, circulation patterns, etc. The spatial and temporal distribution and abundance of fishes would typically be determined by these variables. Anthropogenic stress adds to the complexity by interfering with some aspects of the physiology of the fishes.

In the Chesapeake Bay, salinity is the major factor affecting the regional distribution of macrobenthos, while sediment characteristics have the most influence over local distributions (Carriker 1967). In the upper Chesapeake Bay, sedimentation, stratification, circulation, nutrient levels, and dissolved oxygen concentrations are all determined by the strength and variation of the fresh water inflow from the Susquehanna River.

Basic water quality parameters should always be monitored to provide a record of environmental conditions at the time of sampling and to provide information used in assessing the condition of biological assemblages. These parameters should be measured at the same time and location as the biological sampling. Such episodic data will only serve to provide a snapshot of the conditions at the time of sampling and will not characterize the habitat conditions in such dynamic ecosystems. To properly characterize many water quality conditions, long-term data sets are required, including data collected at short intervals over complete tidal cycles for each season.

Monitoring schemes for physicochemical water quality characteristics of the habitat usually involve *in situ* methods. Data on the water column's characteristics can be collected relatively inexpensively; the expense of different methods is generally governed by the level of automation. Nonetheless, it is essential to standardize the monitoring design in order to ensure the comparability of monitoring data throughout the program.

Measurements of temperature, salinity, and turbidity should be taken at a minimum of four depths in the vertical profile: (1) 1-m below the surface, (2) 1-m above the bottom, (3) 1-m above the pycnocline, and (4) 1-m below the pycnocline. If the waters are too shallow or no stratification occurs, it would be appropriate to take samples just below the surface, at mid-depth, and just above the bottom. However, features of water masses recorded in the historical data; i.e., historical profiles of salinity, temperature, and turbidity, and the collection of other data types (e.g., plankton community structure and water chemistry) should be considered when establishing sample depths (Pond and Pickard 1983).

When using *in situ* methods (e.g., a conductivity-temperature-depth meter [CTD], temperature, salinity and pH measurements should be taken at 1-m intervals with a maximum interval of ≤5-m in deeper coastal waters. The measurements should be made over the entire depth profile (to within 1-m of the surface and bottom). Little additional cost is incurred for this detailed characterization of the water column once the CTD is deployed. In areas of high stratification, a smaller interval would be appropriate. With some of the newer, more expensive probes, a continuous readout is possible and discussion of depth intervals is immaterial.

3.3.1 Salinity

Estuaries are transitional zones in which the chemical composition varies from that of freshwater to marine. Salinity is a key determinant in the distribution of estuarine flora and fauna, especially for benthic invertebrate communities (e.g., Engle et al. 1994, Holland et al. 1987, Summers et al. 1993, Weisberg et al. 1993). Taxa richness is most strongly affected by salinity, with relatively low richness in brackish waters compared to freshwater and seawater. Taxa richness metrics can be expressed as a "percent of expected" for a given salinity (Engle et al. 1994, Summers et al. 1993, Weisberg et al. 1993).

The best-known estuarine zonation system (the Venice system) is based on salinity and establishes five estuarine salinity zones:

- Limnetic (0-0.5-ppt)
- Oligohaline (0.5-5-ppt)
- Mesohaline (5-18-ppt)
- Polyhaline (18-30-ppt)
- Euhaline (>30-ppt).

Bulger et al. (1993) conducted a Principal Components Analysis (PCA) to derive estuarine salinity zones based on field data on the salinity ranges of 316 species or life stages in the mid-Atlantic region (primarily species found in the Chesapeake and Delaware Bays). The PCA showed that the data structure underlying the salinity distributions of the biota could be explained by five principal components corresponding to five overlapping salinity zones: 0-4 ppt; 2-14-ppt; 11-18-ppt; 16-27-ppt; and ≥24-ppt. This zonation scheme is similar to the Venice system, but is objectively derived from the salinity distribution of estuarine organisms. Measurement of the ionic strength of estuarine and marine waters is typically made using salinity. Salinity may be defined as the total solids in water after all carbonates have been converted to oxides, all bromide and iodide have been replaced by chloride, and all organic matter has been oxidized (APHA 1981), and is usually reported as grams per kilogram or parts per thousand. Salinity is most commonly measured electronically using a salinometer probe as part of a CTD unit.

A related measure of the ionic strength of water samples is the conductivity, which is the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions, their total concentration, mobility, valence, relative concentrations, and on the temperature of measurement.

Conductivity is a more useful measure in the tidal fresh water portion of estuaries than is salinity (or chlorinity). Conductivity is most frequently measured using a CTD meter.

The EMAP-Estuaries program collects point-in-time salinity measurements concurrently with the collection of biological and sediment samples using a CTD probe (Holland 1990). CTD-measured salinity is also incorporated in other estuarine monitoring programs; for example, the Chesapeake Bay (Holland et al. 1988, 1989), San Francisco Bay (ABAG 1991), and Puget Sound (PSWQA 1988, 1990, 1991). Monitoring guidance for the National Estuary Program (USEPA 1992) and procedural and monitoring guidance for the CWA §403 program (USEPA 1994a) both recommend CTD probes as the preferred method for collecting salinity data.

3.3.2 Temperature

Temperature is an important determinant of the rate of chemical reactions and biological processes. DO saturation is a function of water temperature. Temperature influences the spatial and seasonal distribution of benthic infauna (Kendall 1983 cited in Dardeau et al. 1992), microbial process rates (Christian 1989), and temporal and spatial distributions of fishes (e.g., Houde and Zastrow 1991). Estuarine water temperature in temperate regions is primarily a function of the temperatures of influent streams, rivers, the ocean, and tidal stage (Reid and Wood 1976). In the sub-tropical estuaries of Florida and Texas, estuarine temperature may be more closely related to incident sunlight and air temperature. Because most estuaries are shallow, there can be considerable diurnal and seasonal temperature variation. Estuarine temperature also varies with air temperature and depth, leading to vertical temperature gradients.

In addition to the potential influence of natural temperature variations on aquatic biota and chemical reactions, anthropogenic thermal inputs can lead to significant modifications of estuarine and coastal marine biological communities. A prime example is thermal loading via discharge of cooling water from power plants and other industrial facilities. The important influence of thermal discharges is recognized in §316 of the CWA, which allows USEPA or states to impose effluent limitations on thermal loading at point sources to ensure that balanced, indigenous populations of shellfish, fish, and wildlife in and on a water body will be maintained. Temperature should be measured at each sampling site with a CTD probe at 1-m intervals from the surface to within 1-m of the bottom concomitantly with the collection of salinity and DO data. Diel temperature measurements may also be needed.

3.3.3 Dissolved Oxygen

Dissolved oxygen (DO) is a basic physiological requirement for nearly all aquatic biota and for the maintenance of balanced populations (exceptions being anaerobic systems). Most estuarine populations can tolerate short exposures to reduced DO concentrations without adverse effects. Extended exposures to DO concentrations less than 60% oxygen saturation may result in modified behavior, reduced abundance and productivity, adverse reproductive effects, and mortality (Holland et al. 1989, Reish and Barnard 1960, Vernberg 1972). Low DO conditions can also increase the vulnerability of benthos to predation as they extend above the sediment surface to obtain more oxygen. Exposure to less than 30% saturation (~2-mgL^{-1}) for 1 to 4 days causes mortality to most species, especially during summer when metabolic rates are high. Some benthic macroinvertebrate species tolerate low DO conditions, and prolonged low DO concentrations frequently lead to changes in the composition of benthic macroinvertebrate assemblages in certain areas (Holland et al. 1989). Aquatic biota exposed to low DO may be more susceptible to adverse effects of other stressors (e.g., disease, toxic chemicals, habitat modification) (Holland 1990).

Because DO concentration throughout the water column can vary widely with tide, time of day, wind patterns, and biological activity, the EMAP-Estuaries program conducted extensive comparisons of point-in-time and continuous collections of DO data. In deeper areas of Chesapeake Bay, within EMAP's Virginian Province, bottom DO has a strong tidal signal; high tide corresponds to lower DO near the bottom. Significant serial autocorrelation of dissolved oxygen concentration persists for 6 to 8 days, indicating that consecutive measurements taken less than 8 days apart may not be independent (Holland 1990). In some EMAP Louisianian Province estuaries a strong diurnal cycle with lower DO occurs at night (Stickney 1984, Turner et al. 1987). Low DO in these shallow, often well-mixed estuaries may be highly variable both spatially and temporally (Sanford et al. 1990, Schroeder 1979, Rabalais et al. 1985). These conditions can lead to misclassification of the ecological condition of estuaries with respect to hypoxia.

Goals of the EMAP analyses comparing DO measurement approaches were to determine the best measure for representing DO exposure, to evaluate the stability of DO over the sampling (i.e., index) period, and to determine if the characteristics of exposure to extreme low DO can be predicted from short-term continuous DO records (Holland 1990). Analyses of the data for the Virginian Province showed that three instantaneous DO profile measurements best characterized the DO status of a site. In contrast, in the Louisianian Province the minimum DO measured over a 24-hour period was most successful in characterizing both low and high frequency hypoxia sites. These differences have logistical implications for bioassessment of estuarine and coastal marine waters in that instantaneous DO measurements can be made with CTD meters equipped with a DO probe; the 24-hour minimum DO measurements require the use of a continuous recording DO meter that must be deployed and subsequently retrieved. Consequently, dissolved oxygen is an important habitat parameter, but the manager must exercise care in both sampling design and data interpretation when attributing biotic responses to potential hypoxia.

Collection of DO in Tier 1 of these procedures should include an instantaneous measurement at the same stations and times as biological samples are collected. Tier 2 should include measurement of DO in the early morning at each station as a minimum. Tier 3 should include DO collected along a depth profile from surface to within 1-m of the bottom at 1-m intervals. For more detailed characterization of DO conditions, particularly at sites which may undergo hypoxia, recording DO meters may need be deployed in Tier 3. In any case, as the EMAP experiences indicate, careful DO profiles should be established for each region surveyed before any presumptions about community response are made.

3.3.4 pH

Another important indicator of the chemical condition of estuarine and coastal marine waters is pH. In estuaries, pH will usually be controlled by the mixing of seawater solutes with those in the fresh water inflow. A major factor influencing the pH of estuarine waters is the carbon dioxide solubility, which is a function primarily of salinity and secondarily of temperature. Seawater is a very stable buffering system containing excess bases, notably boric acid and borate salts, carbonic acid and carbonate. Surface seawater pH usually ranges between pH 8.1 and 8.3. River waters usually contain a lower concentration of excess bases than seawater; this shifts the carbonate buffering system toward a higher concentration of free carbon dioxide and lower pH in the upper reaches of rivers. Because fresh water inflow to estuaries is typically much less buffered than seawater, greater variation in pH is observed in the less saline portions of estuaries than near their mouths. The range of pH values observed in the upper reaches of estuaries can be 7.5 - 9.0.

Measurement of pH in estuaries and coastal marine waters can provide an indication of possible pollutant input (e.g., releases of acids or caustic materials) or high concentrations of phytoplankton (due to photosynthesis and respiration, pH varies inversely with the free carbon dioxide concentration and directly with DO).

3.3.5 Turbidity

The major component of turbidity in estuaries is silt. The volume of silt discharged into estuaries by streams and rivers varies seasonally, with the maximum discharge occurring during the wettest months. Silt may also be resuspended from sediments within estuaries. Turbidity has two primary effects in estuaries. First, light penetration is reduced, which directly affects primary production and abundance of aquatic macrophytes in the estuary. Second, settling of the particulate matter can result in deposition zones of mud, silt, other sediments, and detritus. This deposited material can cause changes in the composition of benthic invertebrate assemblages. For example, deposition of mud and silt can result in the clogging of gills of oysters and other filter-feeding species and a loss of a hard substrate required by these species. In coastal areas, the deposition of silt in pockets of uneven sandy bottom contributes to the "patchy" distribution of benthic invertebrate species, especially annelids, amphipods, and isopods. Deposited material can also contain particle-adsorbed contaminants; this can result in contaminated sediment "hot spots". In contrast to these negative effects on the benthic invertebrate assemblage, turbidity can have positive effects on the fish assemblage by increasing protection from predators by reduced visibility.

Turbidity can be easily assessed (as light penetration) using a Secchi disk, which is probably the most widely used method for estimating light penetration (USEPA 1992). Secchi disks are easy to use, the results are easy to interpret, and they are suitable for estimating light attenuation coefficients through the water column. Secchi disk measurements may vary somewhat because of interpersonal differences in visual acuity of observers, and, therefore, caution must be exercised when comparing Secchi disk readings taken by different investigators.

If measurement of turbidity *per se* is deemed necessary by a state, it may be accomplished *in situ* by using a transmissometer or turbidimeter as part of a CTD system. Nephelometry is the preferred method for measuring turbidity because it is more sensitive, effective over a wider range of turbidities, and less sensitive to particle size variations than other methods (USEPA 1992).

3.3.6 Nutrients

Nutrient fluxes are central in controlling the primary and secondary production of estuaries. Estuarine autotrophs (i.e., algae, diatoms, vascular plants) require numerous macro- and micronutrients and vitamins, including C, N, P, Si, S, K, Mg, Na, Ca, Fe, Mn, Zn, Cu, B, Mo, Co, V, thiamin, cyanocobalamin, and biotin (Hutchinson 1967 cited in Day et al. 1989). Higher trophic levels are influenced indirectly by nutrients through their dependence on a phytoplankton food base. Nitrogen, phosphorus, carbon, and silicon (used by diatoms) are the most studied of the nutrients in estuaries and coastal marine waters (Bricker and Stevenson 1996). This guidance document focuses particularly on nitrogen and phosphorus as the two key, potentially limiting and more manageable nutrients for the autotrophic assemblages; i.e., macrophytes, phytoplankton, to be incorporated in bioassessment procedures. The measurement of water column nutrient concentrations in Tiers 2 and 3 will aid in identifying possible sources of biological impairment. NOAA maintains a nationwide database on eutrophication and toxic algae blooms that can be cited to provide water column information.

It is a basic tenet of botany that multiple nutrients are necessary for plant growth, and that a shortage of any single nutrient will limit further growth. Thus, estuaries are sometimes referred to as "nutrient-limited." This concept is based on the finding that, under good growth conditions, algae have a relatively stable N:P atomic ratio of about 15-16:1. This ratio is frequently known as the Redfield ratio (Redfield 1958, Correll 1987, Malone et al. 1996). The Redfield ratio is an approximation and can vary depending on the stage of algal cell division, changes in light intensity or quality, or temperature (Correll 1987). Even considering these factors, measurement of nitrogen and phosphorus concentrations in estuarine and coastal marine waters provides a useful benchmark for evaluating the possible effects of increased loadings of these nutrients. Nutrient limitations in estuarine and coastal marine waters may change seasonally in response to temporal variations in nutrient loadings in the watershed and in hydrologic patterns. In the Chesapeake Bay, phytoplankton appear to be P-limited during spring when biomass reaches its annual maximum and N-limited during summer when phytoplankton growth rates are highest (Malone et al. 1996). In North Carolina estuaries, N-limitation occurs across a trophic gradient of highly productive (Pamlico), moderately productive (Neuse), and less productive systems (Beaufort, Morehead City area) (Mallin 1994). Phosphorus may be co-limiting in some of these areas during portions of the year (Mallin 1994). In the Florida Keys and adjacent Florida Bay, LaPointe and Clark (1992) determined that phosphorus is the primary limiting nutrient, with nitrogen being co-limiting. Smith and Hitchcock (1994) concluded that phosphorus (and silica) potentially limits phytoplankton growth in the Louisiana Bight during winter-spring, particularly at low salinities. In late summer nitrogen may be limiting in higher salinity waters of the Louisiana Bight.

Nitrogen and phosphorus occur in estuarine and coastal marine waters in many forms which can be variously described in terms of oxidation state, phase (solid-liquid-gas), chemical structure, or analytical method. Nitrogen forms are the most diverse, with nitrogen compounds ranging from NO_3^- to NH_4^+. Dissolved nitrogen species that could be incorporated into chemical analyses of this nutrient include total dissolved N (TDN), and dissolved inorganic nitrogen (DIN = $NH_4^+ + NO_3^- + NO_2^-$) (LaPointe and Clark 1992). Nitrate concentrations are typically controlled largely by external inputs to estuarine and coastal marine waters via land runoff. In some areas (e.g., Chesapeake Bay) atmospheric deposition may account for an important fraction of the nitrogen load to the water body (Dickerson 1995, Boynton et al. 1995). Ammonia concentrations are highest in waters receiving large inputs of sewage (Day et al. 1989). Dissolved organic nitrogen (DON) can be calculated as TDN minus DIN (LaPointe and Clark 1992).

Measurements of total dissolved P (TDP) and soluble reactive phosphorus (SRP) can be used to estimate dissolved organic phosphorus (DOP = TDP - SRP) (LaPointe and Clark 1992).

3.3.7 Contaminants

Measuring organic compounds and metals is particularly important because of the adverse effects they can have on aquatic life and on human health and recreation if these contaminants enter the food chain. Sources of organic and inorganic chemical contaminants include direct release to the water body, urban runoff, atmospheric deposition, industrial and municipal discharges, and upstream runoff (Velinsky et al. 1994, Wade et al. 1994). Organic and metals contaminants in the water column will usually be adsorbed onto sediment particles, settle to the bottom, and become a source of toxicity to organisms and bioaccumulation to the food chain. Contaminant analyses should be tailored to the types of substances known or suspected as chemicals of potential concern at a site. Chemical concentrations should be compared to applicable sediment quality guidance documents to aid in interpretation and to provide an effort-based assessment method. Results of any toxicity tests conducted should be compared against results from controls and against statistical standards to provide relative rankings. Chemical analyses, toxicity tests, and benthic analyses constitute the sediment quality triad, originally proposed by Long and Chapman (1985).

The Sediment Quality Triad approach, (SQT) (Long and Chapman 1985, Chapman et al. 1987, Long 1989, Chapman 1996) can be used to assess pollution-induced estuarine and coastal marine system degradation (Schlekat et al. 1994). In an analysis of sediment metals concentrations from 497 sites in Gulf of Mexico estuaries, Summers et al. (1996) normalized metals concentrations for extant concentrations of aluminum to identify the concentrations expected from natural sources versus anthropogenic sources. Krumgalz (1993) applied a "fingerprints" approach to estuarine and coastal marine pollutant source identification. This approach assumes that if anthropogenic pollutants in a particular area had originated from the same source, then pairwise relationships between the concentrations of these pollutants in sediments from various sampling sites in the contaminated area would be linear. The correlations between pollutants will depend on the origin of the contaminants and on the patterns of mixing contaminated sediments and contaminants with "pure" sediment. Thus, the "fingerprints" can be used to trace the distribution of contaminants from a source, or conversely, to identify potential sources.

3.3.8 Depth

Depth characterization is important for evaluating DO, temperature and salinity profiles, tidal regime consistency, and the percent of the water column that is photic. This may be especially significant in coastal areas where bathymetry changes can be great and other potentially related distinctions such as grain size are not as evident.

3.4 Bottom Characteristics

The SQT approach is generally the most comprehensive assessment of relative sediment quality. In this approach data are collected to determine concentrations of potentially toxic chemicals in sediments, to measure the relative bioavailability and toxicity of sediment-associated toxicants with laboratory bioassays, and to identify degradation of resident infauna possibly attributable to the contaminants.

Chemical data can be generated through analyses of the bulk sediments and compared to applicable sediment quality guidelines (SQGs), proposed or promulgated criteria or standards wherever they exist, and relevant sedimentological factors such as grain size, total organic carbon, or aluminum. Data analyses can be conducted to identify both sites and chemicals of potential concern. Chemicals of highest potential concern are those in which SQG or other applicable values were exceeded most frequently and by the largest amount. These chemicals also would be expected to show strong associations with measures of toxicity. Moreover, chemicals of highest concern may be those determined to be bioavailable and bioaccumulative in laboratory exposures (Chapman et al. 1988). If possible, historical data should be used to focus the chemical analyses.

Toxicity data can be generated through a battery of short-term tests performed under the controlled environment of the laboratory. Amphipod survival tests, which are most frequently used in North America, are done with exposures to solid-phase sediments and percent survival is measured after 10-days. These acute tests often are accompanied by tests of other sediment phases (e.g., pore waters and solvent extracts) with sublethal endpoints (Long et al. 1996). Data from the tests provide information for ranking and prioritizing sampling sites according to their potential for causing adverse effects among resident infauna. Confirmation of adverse effects among the infauna must be done with analyses of samples collected from the same locations tested for chemical concentrations and toxicity. Measures of species richness, total abundance, relative abundance of crustaceans (particularly infaunal amphipods) and/or other relatively sensitive taxa provide information on the degree to which resident biota have been adversely affected. Chapman (1996) provided useful guidance on the interpretation of the SQT data.

Measurements of bottom characteristics of estuaries and coastal marine waters provide important data for interpreting the condition of targeted biological assemblages. Sediment grain size influences the spatial distribution of benthic macroinvertebrates and fishes. Fine-grained sediments can adsorb contaminants, creating a source of potential impairment to bottom communities. Organic carbon found in these sediments can mediate the concentrations of DO, organic contaminants, and metals. Measuring the depth of the sediment oxidation-reduction potential discontinuity layer provides information on aerobic vs. anaerobic respiration in sediments. Sediment nutrients such as particulate nitrogen and phosphorus can be re-mobilized by physical disturbance or changes in the water column chemistry to become an additional nutrient source leading to potential eutrophication, phytoplankton blooms, and hypoxia of estuarine and coastal marine waters. Finally, sediment contaminant measurements can provide insights on factors that might limit biological assemblages and lead to potential human health effects.

3.4.1 Sediment Grain Size

The objective of measuring sediment grain size is to detect and describe spatial and temporal changes of the benthic habitat. The availability of sediment contaminants is often correlated with sediment grain size because more sediment contaminants are adsorbed onto small grained sediments due to their greater surface area. Likewise, grain size information may explain the temporal and spatial variability in biological assemblages related to an organism's ability to build tubes, capture food, and escape predation. Grain size data may be used to determine the extent of or recovery from environmental perturbations, to evaluate the condition of benthic habitats, and to assist in providing early warnings of potential impacts to the estuarine ecosystem (USEPA 1992). The most common measurements and classifications of sediment grain size are as follows:

- clay < 0.004-mm
- silt 0.004 - 0.064-mm
- sand 0.064 - 1.0-mm
- gravel > 1.0-mm

3.4.2 Total Organic Carbon, Total Volatile Solids, and Acid Volatile Sulfides

Total organic carbon (TOC) and acid volatile sulfides (AVS) are considered by some to be the most important sediment properties determining the bioavailability and toxicity of certain organic compounds and trace metals in sediments (DiToro et al. 1990, DiToro et al. 1991). The importance of these factors is based on an equilibrium partitioning approach. This approach assumes that the bioavailable fraction of chemicals in sediment is correlated to that fraction in the porewater rather than whole sediment concentrations. Therefore, factors that influence the partitioning of compounds between sediment and porewater will govern bioavailability. In addition, it is assumed that equilibrium exists among the phases (hence, the name "equilibrium partitioning"). For non-ionic hydrophobic organic chemicals, the primary factor influencing partitioning is TOC; for certain divalent cationic metals; i.e., cadmium, copper, nickel, lead, zinc, an important binding phase is the acid volatile sulfide fraction. The development of sediment quality criteria by USEPA is based on these assumptions and a comparison of predicted porewater concentrations to existing water quality criteria (DiToro et al. 1991, Ankley et al. 1996).

Normalization of non-ionic organic compounds is accomplished by calculating chemical concentrations per gram of sediment organic carbon rather than per gram of dry sediment. This approach allows comparisons of the potential bioavailability of non-ionic organic compounds across different sediment types and can be used to screen for chemicals of concern. For an explanation for how to apply this approach to calculate sediment quality criteria the reader is referred to DiToro et al. (1991).

Although SQGs (Sediment Quality Guidelines) derived for organic compounds and trace metals reported on a dry weight (bulk) basis have been shown to be reliable and predictive of both non-toxic and toxic conditions (Ingersoll et al. 1996, MacDonald et al. 1996, Long et al. 1998a); these values do not account for the relative bioavailability of sediment-associated chemicals. In areas in which high trace metal concentrations are known or suspected, or in which SQGs are exceeded, further evaluations of chemical contamination may be aided in subsequent analyses by use of the simultaneously extracted metals/acid volatile sulfides (SEM/AVS) tool to provide estimates of bioavailability.

The AVS normalization approach assumes that select trace metals bind to sediment sulfide, specifically the sulfide fraction soluble in cold acid, known as AVS (Allen et al. 1993). The bioavailability of trace metals capable of forming insoluble metal sulfides will be determined by the proportion of these metal ions not bound to sulfide. Hence, on a molar basis, if the concentration of SEM is less than the molar concentration of AVS, all of the metals should precipitate as metal sulfides and not be bioavailable. Conversely, if SEM exceeds AVS then free metal ions may exist in the porewater. This approach appears to work best in situations when the ratio of [SEM]/[AVS] is less than 1.0 or the difference between SEM and AVS concentrations is less than 0.0 (Hansen et al. 1996). That is, the SEV/AVS tool is primarily intended for use as a no-effects tool and caution is advised in using it as a predictor of toxicity or other effects. Long et al. (1998b) reported that the SEM/AVS tool and SQGs based upon bulk sediment chemistry for trace metals performed equally well in correctly predicting samples as either toxic or non-toxic. For an excellent discussion of the applicability, advantages and disadvantages of this approach, the reader is referred to several review papers in Environmental Toxicology and Chemistry, Volume 15, #12.

3.4.3 Sediment Oxidation-Reduction Potential

There are four oxidation-reduction (redox) processes related to biological respiration that occur in benthic sediments. These chemical reactions, which depend on the availability of electron acceptors; i.e., oxygen, nitrate, sulfate, and carbonate, stratify the sediments into four zones. Oxygen is the electron acceptor used for aerobic respiration and is the most important oxidizing agent at the surface of the sediments. Nitrate reduction occurs between 0- and 4-cm and produces elemental nitrogen. This is followed by sulfate reduction which produces hydrogen sulfide. Carbonate reduction occurs between 10- and 50-cm and results in the production of methane.

Aerobic respiration will be the dominant reaction as long as oxygen is available. The depth at which oxygen is fully depleted and the redox potential goes to zero has been termed the redox potential discontinuity (RPD) layer (Day et al. 1989). Burrowing organisms oxidize the sediments and hence will increase the zone of habitability as reflected in the depth of the RPD layer. Color changes in the substrate occur as a result of the oxidation and reduction of metals, such as iron, in the sediments. The upper few centimeters may appear brown from the formation of iron oxides and hydroxides, whereas the zone of reduction turns gray and eventually black in the deeper sediments from the formation of ferrous sulfide and pyrite. When examining a cross-section of a sediment core sample, the RPD layer is visibly noticeable by this change in color. The depth of this color change should be recorded because, as noted above, it indicates the zone of habitability for benthic infauna. The closer to the sediment surface this color change appears, the less available dissolved oxygen exists in the sediment porewater.

3.4.4 Sediment Contamination

Sampling the surface sediments for the presence of contaminants can provide insight on factors limiting the benthic community, as well as the potential for impacts to human health; i.e., by biomagnification or bioaccumulation in the food chain or by the contamination of shellfish. Metals and organic chemicals entering estuaries from fresh water inflows, point sources of pollution, and various nonpoint sources, including atmospheric deposition, generally are retained within estuaries and accumulate within the sediments (Forstner and Wittman 1981, Hinga 1988, Nixon et al. 1986, Schubel and Carter 1984, Turekian 1977) because of the affinity of most contaminants for particle adsorption (Hinga 1988; Honeyman and Santschi 1988). Chemical and microbial contaminants generally adsorb to fine-grained materials in the water and are deposited on the bottom, accumulating at deposition sites, including regions of upper tidal fresh water, low current velocity, deep basins, and the zone of maximum turbidity in the upper reaches of estuaries within which suspended sediment concentrations are greater than those either farther upstream or farther seaward (Schubel and Carter 1984). The concentration of contaminants in sediments is dependent upon interactions between natural (e.g., chemical and physical sediment characteristics) and anthropogenic factors (e.g., type and volume of contaminant loadings) (Sharpe et al. 1984).

Bottom sediments in some estuaries (e.g., harbors near urban areas and industrial centers) are so contaminated that they represent a threat to both human and ecological health (NRC 1989, OTA 1987, Weaver 1984), but contaminated sediments are not limited to these areas. Pollutant runoff from agricultural areas also is an important source of contaminant input to estuaries (Boynton et al. 1988, Pait et al. 1989).

The EMAP program uses the NOAA National Status and Trends (NS&T) suite of contaminants as the basis for measurements in homogenized subsamples of collected sediments (Figure 3-1). A useful citation for the NS&T Program list of chemicals is O'Connor et al. 1994. The NOAA suite includes chlorinated pesticides, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), major elements, and trace metals.

3.5 Proposed Habitat Parameters

Table 3-1 summarizes the proposed habitat measurements by survey tier and provides possible sources of information, methods, and equipment, as appropriate. Agency-specific objectives will determine the overall design of any sampling program. The following tier distribution is just one approach possible for gathering and organizing data. Habitat measurements are intended to be cumulative across tiers; that is, the desktop screening of Tier 0 should be incorporated into Tier 1, Tiers 0 and 1 parameters should be incorporated into Tier 2, and Tiers 0, 1,

Figure 3-1

Chemicals measured in sediments by the EMAP-Estuaries program. Refer also to the NS&T Program list of chemicals (O'Connor et al. 1994).

Polyaromatic Hydrocarbons (PAHs)

Acenaphthene
Anthracene
Benz(a)anthracene
Benzo(a)pyrene
Benzo(e)pyrene
Biphenyl
Chrysene
Dibenz(amh)anthracene
2,6-dimenhyulnaphthalene
Fluoranthene
Fluorene
2-methylnaphthalene
1-methylnaphthalene
1-methylphenanthrene
Naphthalene
Perylene
Phenanthrene
Pyrene
Benzo(b)fluoranthene
Acenaphthlyene
Benzo(k)fluoranthene
Benzo(g,h,i)perylene

Major Elements
Aluminum
Iron
Manganese
Silicon

Trace Elements
Antimony
Arsenic
Cadmium
Chromium
Copper
Lead
Mercury
Nickel
Selenium
Silver
Tin
Zinc

DDT and its metabolites

o,p'-DDD
p,p'-DDD
o,p'-DDE
p,p'-DDE
o,p'-DDT
p,p'-DDT

Chlorinated pesticides other than DDT
Aldrin
Alpha-Chlordane
Trans-Nonachlor
Dieldrin
Heptachlor
Heptachlor epoxide
Hexachlorobenzene
Lindane (gamma-BHC)
Mirex

18 PCB Congener

Congener Number	Location of Cls
8	2 4'
18	2 2' 5
28	2 4 4'
52	2 2' 5 5'
44	2 2' 3 5'
66	2 3' 4 4'
74	2 4 4' 5
99	2 2' 4 4' 5
101	2 2' 4 5 5'
118	2 3' 4 4' 5
153	2 2' 4 4' 5 5'
105	2 3 3' 4 4'
138	2 2' 3 4 4' 5'
187	2 2' 3 4' 5 5' 6
128	2 2' 3 3' 4 4'
180	2 2' 3 4 4' 5 5'
170	2 2' 3 3' 4 4' 5
195	2 2' 3 3' 4 4' 5 6
206	2 2' 3 3' 4 4' 5 5' 6
209	2 2' 3 3' 4 4' 5 5' 6 6'

Other measurements
Tributyltin
Acid volatile sulfides
Total organic carbon

and 2 parameters should be incorporated into Tier 3. The habitat tiers described here should be used with the corresponding biological survey tier.

3.5.1 Tier 0

The purpose of a Tier 0 assessment is to support the planning for monitoring and more detailed assessments. Tier 0 is a desktop screening assessment in which documented information for the estuary or coastal marine areas of concern is compiled from sources including databases, peer-reviewed and gray literature, state and federal agencies, universities, and local experts. A Tier 0 assessment should always precede any of the three subsequent tiers. Examination of long-term data records (e.g., salinity, DO, climate) is particularly important for identifying the variability which must be accounted for in the design of subsequent field monitoring. Habitat parameters to examine in Tier 0 include:

Area and Geomorphometric Classification

The size and classification of an estuary indicates its potential to respond to various impacts. Estuary types include coastal plain, lagoon, fjord, and tectonically-caused. Circulation type (e.g., gravitational, tidal, wind-induced) influences current patterns, salinity regimes, and thermal and dissolved oxygen patterns.

Habitat Type

Identifying and delineating the various habitat types (Section 3.3) that occur in the estuary or coastal marine waters will be necessary for partitioning the natural variability in the system. The extent of such a delineation will depend on the size of the area of concern and the nature of the environmental gradients present. Initial partitioning will probably be based on salinity, sediment type, and depth.

Watershed Land Use and Population

Land use and population data for the watershed will help to identify classes of contaminants and other stresses that may affect the water body. For example, agricultural areas located near an estuary might be expected to be sources of nonpoint loading of nutrients, pesticides, herbicides, and sediment. Urban areas may contribute toxic compounds via stormwater runoff. The pattern and magnitude of population density in the watershed can potentially provide clues regarding the potential for human-induced impacts to the water body.

Water Column and Bottom Characteristics

Historic data on water column and bottom characteristics is central for identifying system variability and to support the design of subsequent monitoring. This data can also be used by states to identify types and locations of potential impairment, for example, areas with high concentrations of water column nutrients, suspended sediment, or sediment contaminants.

3.5.2 Tier 1

Tier 1 is a basic field assessment that is used for screening purposes to identify potential reference and impaired sites. For biocriteria development purposes, it is adequate for only rudimentary habitat classifications and evaluations. It identifies the general physical characteristics of the estuary or coastal region, the habitats, and the potential sources of anthropogenic stress. Tier 1 relies heavily on existing information identified in Tier 0 and supplemented by one-time easily-measured field parameters, which are measured concomitantly with the collection of biological data. Much of the habitat information needed in this tier can be acquired from state or federal agency records. Depending on the needs of the state, Tier 1 habitat characterizations may include the following elements:

Estuary Characteristics

Information on estuary characteristics is essential for the development of appropriate sampling strategies. Data to be compiled in this category includes estuary area, geomorphometric classification (e.g., classical coastal plain estuary, lagoon), and habitat types present (e.g., hard bottom, soft bottom). These data can be obtained from USGS maps, NOAA charts, and reports and data archives at federal and state agencies and universities.

Watershed Characteristics

Knowledge of watershed characteristics can provide important information for determining appropriate sampling station locations and for evaluating possible sources and causes of biological and habitat impairment. Data to be compiled for this category include watershed land use, human population density, NPDES discharge locations, and vegetative cover. These data are likely to exist at federal, state, and local agencies and universities.

Water Column Characteristics

The characteristics in a water column play a key role in determining the biota present at a given location and their broader distribution patterns. Parameters to be measured in Tier 1 in the field include salinity and conductivity, DO, temperature, pH, turbidity and Secchi depth. Records of tidal stage and current velocity at the time of sampling at each station should be acquired from NOAA.

Bottom Characteristics

Characteristics of bottom sediments also are key determinants of aquatic biota present in estuaries and coastal marine waters. Parameters to be measured in Tier 1 include depth, dominant sediment type, total volatile solids, and sediment RPD layer depth.

3.5.3 Tier 2

Tier 2 provides the information necessary to develop a quantitative ranking of the sites that can be used to prioritize resources and sampling efforts. Habitat information collected in Tier 2 will be used in the development of biocriteria. In addition to Tier 1 habitat characterization, Tier 2 includes:

Water Column Nutrients

Nutrients in the water column determine the nutrient state of the area and may indicate possible sources of impairment, particularly nonpoint source runoff.

Sediment Characterization

The organisms closely associated with the bottom are strongly influenced by such sediment characteristics as the average grain size and the percent composition of silt, sand, and clay (Day et al. 1989). These characteristics determine the structure of the benthic community based on the preferences of the major groups of organisms. For example, suspension feeders are found more often in firmer, sandier substrates than are deposit feeders; interstitial meiofauna are predominant in sandy areas, whereas burrowing meiofauna prefer silty mud. Although a high organic content in the sediments can increase the rate of oxygen depletion, there are many organisms that require high concentrations of organic matter. Sediment characteristics to be measured in Tier 2 include percent sand vs. silt-clay, mean grain size, total volatile solids, and total organic carbon.

Shorezone Vegetative Cover Characterization

Shorezone vegetation provides stability for beaches, wetlands, banks, and cliffs, serving to reduce erosion and nonpoint source runoff to the water body. As such, evaluation of shorezone vegetative cover is important for identifying possible sources of impairment and remedial approaches. Terrestrial riparian vegetated areas to consider are uplands and the floodplain. Areas of emergent, intertidal, and submerged vegetation should also be characterized.

Shorezone vegetative cover is important for reducing nutrient and sediment loading to estuaries from nonpoint source runoff, attenuating incident wave energy and reducing shore erosion, and providing important nursery and feeding habitat for migratory species. Salt marshes and aquatic macrophytes have high gross primary productivity and provide a source of autochthonous organic matter for detrital feeders in adjacent waters. An assessment of the coverage and types of shorezone vegetation can contribute to the overall assessment of the condition of estuarine and coastal marine habitat. Evaluation of vegetative cover is most easily accomplished by aerial photography and mapping coupled with ground-truthing. Detailed procedures used for photography and mapping aquatic macrophytes are provided by Orth et al. (1993) (Chesapeake Bay), Ferguson and Wood (1994) (North Carolina estuaries), and USEPA (1992) (National Estuary Program) and can be adapted for use in other areas.

3.5.4 Tier 3

Tier 3 provides a detailed assessment with a high level of certainty of the biological or habitat condition of the estuarine and coastal marine environment. It is the definitive assessment level to distinguish habitat variation from anthropogenic impacts when the biocriteria have been exceeded. Tier 3 focuses on biological community level investigations and thoroughly integrates the physical, chemical and biological data to yield a detailed impact assessment. In addition to the habitat parameters compiled in Tier 0 and measured in Tiers 1 and 2, sediment oxidation-reduction potential, sand/silt/clay proportions, sediment contaminants, and water column pesticides, herbicides, and metals, nutrient speciation, and AVS/SEM as needed may be measured in this tier.

Tier 3 provides the detailed diagnostic information necessary for: (1) identifying specific problem sources in the drainage area; (2) delineating mitigation options for the identified problems; and (3) preparing written management plans for the estuary or coastal marine area of interest. Although the data collected in Tier 3 cannot prove cause-and-effect relationships between identified stressors and ecosystem responses, they can provide a strong correlation and a definitive assessment, with a high degree of certainty, of the biological integrity of the target waters and their habitats.

Table 3-1. Habitat measurements for estuaries and coastal marine waters.

Habitat Measurements	Assessment Tier 0	1	2	3	Information Source	Method(s) and Equipment
Historical Information						
Estuary area	✓	✓	✓	✓	USGS quad maps	Can be estimated from maps or using GIS
Geomorphometric classification (classical coastal plain estuary; salt marsh estuary; lagoon; fjord; tectonically-caused estuary)	✓	✓	✓	✓	USGS quad maps	
Habitat type (seagrass beds; hard bottom; soft bottom; water column; emergent marsh; mudflat; sandflat; gravel/cobble; rocky)	✓	✓	✓	✓	NOAA bathymetry charts; historic surveys by federal, state agencies and universities	
Watershed land use	✓	✓	✓	✓	USGS land use maps; state planning agencies; local zoning agencies	Can be estimated from maps or using GIS
Population density	✓	✓	✓	✓	US census data	
NPDES discharges	✓	✓	✓	✓	State water quality agency	
Vegetative cover	✓	✓	✓	✓	Historic surveys by federal, state agencies and universities	Can be estimated from maps or using GIS
Field-collected Information: Water Column Characteristics						
Salinity, conductivity	✓*	✓	✓	✓	Historic data from federal, state agencies and universities	Conductivity cells (CTD meters)
DO	✓*	✓	✓	✓	Historic data from federal, state agencies and universities	CTD meter equipped with O_2 probe, recording DO meters for Tier 3 may be needed
Temperature	✓*	✓	✓	✓	Historic data from federal, state agencies and universities	CTD meter, satellite remote sensing.
pH	✓*	✓	✓	✓	Historic data from federal, state agencies and universities.	CTD meter equipped with pH probe

Table 3-1 (Cont'd). Habitat measurements for estuaries and coastal marine waters.

Habitat Measurements	Assessment Tier 0	1	2	3	Information Source	Method(s) and Equipment
Turbidity, Secchi depth	✓*	✓	✓	✓	Historic data from federal, state agencies and universities	Secchi disk; transmissometer, nephelometer, turbidimeter if desired
Nutrients (nitrogen species, phosphorus)	✓*		✓	✓	Historic data from federal, state agencies and universities	Spectrophotometry
Organics, metals	✓*			✓	Historic data from federal, state agencies and universities	Standard methods for selected suite of contaminants
Field-collected Information: Bottom Characteristics						
Depth	✓*	✓	✓	✓	Historic data from federal, state agencies and universities	Meter wheel, fathometer, hydrostatic pressure sensor
Sediment grain size	✓*	✓	✓	✓	Historic data from federal, state agencies and universities	Sieving or separatory column combined with pipette analysis for silt-clay fraction
Total volatile solids	✓*	✓	✓	✓	Historic data from federal, state agencies and universities	Standard methods
Total organic carbon	✓*		✓	✓	Historic data from federal, state agencies and universities	Standard methods
Acid volatile sulfides	✓*			✓	Historic data from federal, state agencies and universities	Standard methods
Sediment reduction-oxidation potential	✓*	✓	✓	✓	Historic data from federal, state agencies and universities	Visual determination of the depth of change in sediment color in core
Sediment contamination	✓*			✓	Historic data from federal, state agencies and universities	Standard methods for contaminants selected

* Historic data should be included in Tier 0; the tier does not include any field collection of new data.