# CHAPTER FIVE: MARINE TRANSPORTATION

## Introduction

The demand for increased capacity of marine transportation vessels, facilities, and infrastructure is a global trend that is expected to continue in the future. This demand is fueled by a need to accommodate growing vessel operations for cargo handling activities and human population growth in coastal areas. As coastal areas continue to grow, there is a concomitant increase in the demand for water transportation services and recreational opportunities.

It is also important to note that coastal areas under high developmental pressure are often located adjacent to productive and sensitive aquatic environments. Historically, human settlements in the northeastern United States were probably established on the basis of availability to food resources and marine transportation. Coastal features such as estuaries and embayments satisfied these needs as they are highly productive ecosystems ideal for fishing, farming, or hunting and are sheltered waters that provide access to rivers and the ocean for transportation purposes. Today, urban growth and development in coastal areas are growing at a rate approximately five times that of other areas of the country and over one-half of all Americans live within 50 miles of the coast (Markham 2006). The continued demand on the coast today is likely attributed to the highly desirable aesthetic quality and recreational opportunities, including access to fishing, beaches, and boating.

The expansion of port facilities, vessel operations, and commercial and recreational marinas can have adverse impacts on fishery habitat. The growth of the marine transportation industry is accompanied by land-use changes, including over-water or in-water construction, filling of aquatic habitat and wetlands, and increased maintenance activities. Although some categories of habitat impacts resulting from activities related to port and marina construction and maintenance and vessel operations may be minimal and site specific, the cumulative effects of these activities over time can have substantial impacts on habitat.

The construction of new ports and marinas typically involves the removal of sediments by dredging from intertidal and subtidal habitats in order to create navigational channels, turning basins, anchorages, and berthing docks for the size and types of vessels expected to use the facilities. For existing ports and marinas, dredging is generally conducted on a routine basis in order to maintain the required depths as sediment is transported and deposited into the channels, basins, anchorages, and docks. The construction of new ports and marinas, or the expansion of existing facilities, is often referred to as "improvement" dredging; whereas, dredging existing ports and marinas in order to maintain an assigned or authorized depth is generally referred to as "maintenance" dredging. Because the chemical, physical, and biological impacts associated with both "improvement" and "maintenance" dredging are similar in nature, both types of dredging are discussed in the Navigation Dredging section of this chapter. Other impacts associated with newly constructed and expanded ports and marinas are covered under the Construction and Expansion of Ports and Marinas section of this chapter.

## Construction and Expansion of Ports and Marinas

Construction of ports and marinas can change physical and chemical habitat parameters such as tidal prism, depth, water temperature, salinity, wave energy, sediment transport, and current velocity. Alterations to physical characteristics of the coastal ecosystems can cause adverse effects to biological parameters, such as the composition, distribution, and abundance of shellfish and submerged aquatic vegetation (SAV). These changes can impact the distribution of nearshore habitats and affect aquatic food webs.

## *Loss and conversion of habitat*

Port and marina facilities are typically located in areas containing highly productive intertidal and subtidal habitats, including saltmarsh wetlands and SAV. Coastal wetlands provide a number of important ecological functions, including foraging, spawning/breeding, protection from predators, as well as nutrient uptake and release and retention of storm and floodwaters. Vegetated wetlands and intertidal habitats are some of the most highly productive ecosystems in the world, and support one or more life stages of important commercial and recreational fishery resources in the United States (Dahl 2006). One of the most obvious habitat impacts related to the construction of a port or marina facility is alteration or loss of physical space taken up by the structures required for such a facility. The construction of ports and marinas can alter or replace salt marsh, SAV, and intertidal mud flat habitat with “hardened” structures such as concrete bulkheads and jetties that provide relatively few ecological functions. Boston Harbor, MA, exemplifies a northeastern coastal port transformed by expansive dredging and filling of former shallow estuarine waters and salt marsh wetlands. Between 1775 and 1980, wetland filling within the harbor extensively altered the shoreline, with the airport alone amounting to 2,000 acres of filled intertidal salt marsh wetlands (Deegan and Bushbaum 2005).

Over-water structures, such as commercial and residential piers and docks, floating breakwaters, barges, rafts, booms, and mooring buoys are associated with port and marina facilities and are constructed over both subtidal and intertidal habitats. Although they generally have less direct physical contact with benthic habitats than in-water structures, float, raft, and barge groundings at low tides and the scouring of the substrate by the structures and anchor chains can be substantial. Piles and other in-water structures can alter the substrate below and adjacent to the structures by providing a surface for encrusting communities of mussels and other sessile organisms, which can create shell deposits and shift the biota normally associated with sand, gravel, mud, and eelgrass substrates to those communities associated with shell hash substrates (Penttila and Doty 1990; Nightingale and Simenstad 2001a).

Shoreline armoring is an in-water activity associated with the construction and operation of marinas and ports, intended to protect inland structures from storm and flood events and to prevent erosion that is often a result of increased boat traffic. Armoring of shorelines to prevent erosion and maintain or create shoreline development simplifies habitats, reduces the amount of intertidal habitat, and affects nearshore processes and the distribution of aquatic communities (Williams and Thom 2001). Hydraulic effect alterations to the shoreline include increased energy seaward of the armoring from reflected wave energy, which can exacerbate erosion by coarsening the substrate and altering sediment transport (Williams and Thom 2001). Installation of breakwaters and jetties can also result in community changes, including burial or removal of resident biota, changes in cover, preferred prey species, predator interaction, and the movement of larvae (Williams and Thom 2001). Chapman (2003) found a paucity of mobile species associated with seawalls in a tropical estuary, compared with surrounding areas.

## *Altered light regimes and loss of submerged aquatic vegetation*

Alteration of the light regimes in coastal waters can affect primary production, including the distribution and density of SAV, as well as the feeding and migratory behavior of fish. Over-water structures shade the surface of the water and attenuate the sunlight available to the benthic habitat under and adjacent to the structures. The height, width, construction materials used, and the orientation of the structure in relation to the sun can influence how large a shade footprint an over-water structure may produce and how much of an adverse impact that shading effect may have on the localized habitat (Fresh et al. 1995; Burdick and Short 1999; Shafer 1999; Fresh et al. 2001). High, narrow piers and docks produce more diffuse shadows which have been shown to reduce shading impacts to SAV (Burdick and Short 1999; Shafer 1999).

The density of pilings can also determine the amount of light attenuation created by dock structures. Piling density is often higher in larger, commercial shipping ports than in smaller recreational marinas, as larger vessels and structures often require a greater number of support structures such as fenders and dolphin piles. Light limitations caused by pilings can be reduced through adequate spacing of the pilings and the use of light reflecting materials (Thom and Shreffler 1996; Nightingale and Simenstad 2001a). In addition, piers constructed over solid structures, such as breakwaters or wooden cribs, would further limit light transmittance and increase shading impacts on SAV.

Although shading impacts are greatest directly under a structure, the impacts on SAV may extend to areas adjacent to the structure as shadows from changing light conditions and adjacent boats or docks create light limitations (Burdick and Short 1999; Smith and Mezich 1999). A decrease in SAV and primary productivity can impact the nearshore food web, alter the distribution of invertebrates and fish, and reduce the abundance of prey organisms and phytoplankton in the vicinity of the over-water structure (Kahler et al. 2000; Nightingale and Simenstad 2001a; Haas et al. 2002).

The sharp light contrasts created by over-water structures because of shading during the day and artificial lighting at night can alter the feeding, schooling, predator avoidance, and migratory behaviors of fish (Nightingale and Simenstad 2001a; Hanson et al. 2003). Fish, especially juveniles and larvae, rely on visual cues for these behaviors. Shadows create a light-dark interface which may increase predation by ambush predators and increase starvation through limited feeding ability (Able et al. 1999; Hanson et al. 2003). In addition, the migratory behavior of some species may favor deeper waters away from shaded areas during the day and lighted areas may affect migratory movements at night, contributing to increased risk of predation (Nightingale and Simenstad 2001a).

### *Altered temperature regimes*

Shoreline modifications, including the construction of seawalls and bulkheads, can alter nearshore temperature regimes and natural communities. Modified shorelines invariably contain less shoreline vegetation than do natural shorelines, which can reduce shading in the nearshore intertidal zone and cause increases in water temperatures (Williams and Thom 2001). Conversely, seawalls and bulkheads constructed along north facing shorelines may unnaturally reduce light levels and reduce water temperatures in the water column adjacent to the structures (Williams and Thom 2001).

### *Siltation, sedimentation, and turbidity*

The construction of a new port or marina facility is usually associated with profound changes in land use and in-water activities. Because a large proportion of the shoreline associated with a port is typically replaced with impervious surfaces such as concrete and asphalt, stormwater runoff is exacerbated and can increase the siltation and sedimentation loads in estuarine and marine habitats. The upland activities related to building roads and buildings may cause erosion of topsoil which can be transported through stormwater runoff to the nearshore aquatic environment, increasing sedimentation and burying benthic organisms. Construction and expansion of ports and marinas generally include dredging channels, anchorages, and berthing areas for larger and greater numbers of vessels, which contribute to localized sedimentation and turbidity. In addition, the use of underwater explosives to construct bulkheads, seawalls, and concrete docks may temporarily resuspend sediments and cause excessive turbidity in the water column and impact benthic organisms. Refer to the section on Navigation Dredging later in this chapter for information on channel dredging.

Impacts associated with increased suspended particles in the water column include high turbidity levels, reduced light transmittance, and sedimentation which may lead to reductions or loss of SAV and other benthic habitats. Elevated suspended particles have also been shown to adversely affect the respiration of fish, reduce filtering efficiencies and respiration of invertebrates, reduce egg buoyancy, disrupt ichthyoplankton development, reduce the growth and survival of filter feeders, and decrease the foraging efficiency of sight-feeders (Messieh et al. 1991; Barr 1993).

Structures such as jetties and groins may be constructed to reduce the accretion of sediment in navigable channels, so by design they alter littoral sediment transport and change sedimentation rates. These structures may reduce sand transport, cause beach and shoreline erosion to down drift areas, and may also interfere with the dispersal of larvae and eggs along the coastline (Williams and Thom 2001). Substrate disturbance from pile driving and removal can increase turbidity, interfere with fish respiration, and smother benthic organisms in adjacent areas (Mulvihill et al. 1980). In addition, contaminants in the disturbed sediments may be resuspended into the water column, exposing aquatic organisms to potentially harmful compounds (Wilbur and Pentony 1999; USEPA 2000; Nightingale and Simenstad 2001b). Refer to the Coastal Development chapter for a more detailed discussion on impacts related to pile driving and removal.

### *Contaminant releases*

The construction of ports and marinas can alter natural currents and tidal flushing and may exacerbate poor water quality conditions by decreasing water circulation. Bulkheads, jetties, docks, and pilings can create water traps that accumulate contaminants or nutrients washed in from land based sources, vessels, and facility structures. These conditions may create areas of low dissolved oxygen, dinoflagellate blooms, and elevated toxins.

Contaminants can be released directly into the water during construction activities associated with new ports and marinas or indirectly through storm water runoff from land-based operations. Accidental and incidental spills of petroleum products and other contaminants, such as paint, degreaser, detergents, and solvents, can occur during construction operations of a facility. Large amounts of impervious surfaces at ports and marinas can increase, and in some cases direct, stormwater runoff and contaminants into aquatic habitats. The use of certain types of underwater explosives to construct bulkheads, seawalls, and concrete docks may release toxic chemicals (e.g., ammonia) in the water column that can impact aquatic organisms.

Wood pilings and docks used in marina and port construction are often treated with chemicals such as chromated copper arsenate, ammoniacal copper zinc, and creosote to help extend the service of the structures in the marine environment. These preservatives can leach harmful chemicals into the water that have been shown to produce toxic affects on fish and other organisms (Weis et al. 1991). Creosote-treated wood for pilings and docks has also been used in marine environments and has been shown to release polycyclic aromatic hydrocarbons (PAH) continuously and for long periods of time after installation or treatment; whereas other chemicals that are applied to the wood, such as ammoniacal copper zinc arsenate (ACZA) and chromated copper arsenate (CCA), tend to leach into the environment for shorter durations (Poston 2001). Affects from exposure of aquatic organisms to PAH include carcinogenesis, phototoxicity, immunotoxicity, and disturbance of hormone regulation (Poston 2001). The rate and duration that these preservatives can be leached into marine waters after installation are highly variable and dependent on many factors, including the length of time since the treatment of the wood and the type of compounds used in the preservatives. The toxic effects of metals such as copper on fish are well known and include body lesions, damage to gill tissue, and interrupted cellular functions (Gould et al. 1994). These chemicals can become available to marine organisms through uptake by wetland vegetation, adsorption by adjacent sediments, or directly through the water column (Weis and Weis 2002). The presence of CCA in the food chain may cause localized reductions in species richness and diversity (Weis and Weis 2002). Concrete, steel, or nontreated wood are relatively inert and generally do not leach contaminants into the water.

Dredging and filling of intertidal and subtidal habitats can resuspend sediments into the water column that may have been contaminated by nearby industrial activities. Information on contaminant releases from dredging can be found in the Navigation Dredging section of this chapter and the Chemical Effects: Water Discharge Facilities chapter of the report.

### *Altered tidal, current, and hydrologic regimes*

One of the primary functions of a marina or port is to shelter and protect boats from wave energy. In-water structures of ports and marinas such as bulkheads, breakwaters, jetties, and piles result in localized changes to tidal and current patterns. These alterations may exacerbate poor water quality conditions in these facilities by reducing water circulation. In addition, in-water structures interfere with longshore sediment transport processes resulting in altered substrate amalgamation, bathymetry, and geomorphology. Changing the type and distribution of sediment may alter key plant and animal assemblages, starve nearshore detrital-based foodwebs, and disrupt the natural processes that build spits and beaches (Nightingale and Simenstad 2001a; Hanson et al. 2003).

The protected, low energy nature of marinas and ports may alter fish behavior as juvenile fish show an affinity to structure and may congregate around breakwaters or bulkheads (Nightingale and Simenstad 2001a). These alterations in behavior may make them more susceptible to predation and may interfere with normal migratory movements.

### *Underwater blasting and noise*

Noise from underwater blasting and in-water construction generates intense underwater sound pressure waves that may adversely affect marine organisms. These pressure waves have been shown to injure and kill fish (Caltrans 2001; Longmuir and Lively 2001; Stotz and Colby 2001). Fish are known to use sound for prey and predator detection as well as social interaction (Richard 1968; Myrberg 1972; Myrberg and Riggio 1985; Hawkins 1986; Kalmijn 1988), and underwater blasting and noise may alter the their distribution and behavior (Feist et al.1996).

Generally, aquatic organisms that possess air cavities (i.e., lungs and swim bladders) are more susceptible to underwater blasts than those without (Keevin et al. 1999). In addition, smaller fish are more likely to be impacted by the shock wave of underwater blasts than are larger fish, and the eggs and embryos tend to be particularly sensitive; however, fish larvae tend to be less sensitive to blasts than eggs or post-larvae fish, probably because the larvae stages do not yet possess air bladders (Wright 1982; Keevin et al. 1999).

Blasting may be used for dredging new navigation channels and boat basins or expanding existing channels in areas containing rock substrates, boulders, and ledges. The construction of new in-water structures, such as bulkheads, seawalls, and concrete docks also may involve blasting. Blasting represents a single point of disturbance with a restricted, and often predictable, mortality zone. In addition, blasting engineers purposefully focus the blast energy towards fracturing rock substrate and prevent excess energy from being released into the water column (Keevin et al. 1999). Techniques used to prevent blasting damage to structures in the vicinity of a project, such as bubble curtains, may be effective mitigation measures for reducing blasting impacts on aquatic biota (Keevin et al. 1999). Although the use of bubble curtains have been shown to be effective at minimizing pressure wave impacts on fish (Keevin et al. 1997; Longmuir and Lively 2001), the difficulty of deploying bubble curtains in field conditions may reduce the efficacy of this technology in mitigating these effects (Keevin et al. 1997).

Unlike blasting, pile driving is a repeating sound disturbance that can last for extended periods of time during construction. There are several factors which affect the type and intensity of sound pressure waves during pile driving, including the size and material of the piling, the firmness of the substrate, and the type of pile-driving hammer that is used (Hanson et al. 2003). Wood and concrete piles produce lower sound pressures than do steel piles. Pile driving in firmer substrate, which requires more energy, will produce more intense sound pressures (Hanson et al. 2003). Both impact hammers and vibratory hammers are commonly used when driving pilings into the substrate. Vibratory hammers produce sounds with more energy in the lower frequencies (15-26 Hz), compared to higher frequency noise generated by impact hammers (100-800 Hz) (Carlson et al. 2001). The behavioral response elicited by fish differs in these two ranges of sound frequencies. Fish respond to sounds similar to vibratory hammers by consistently displaying an avoidance response and not habituating to the sound despite repeated exposure (Dolat 1997; Knudsen et al. 1997; Sand et al. 2000). In contrast to vibratory hammers, fish may be initially startled by an impact hammer but eventually become habituated and no longer respond to the stimuli. Acclimation to the sound may place fish in more danger as they remain in range of potentially harmful sound pressure waves (Dolat 1997). Refer to the chapter on Global Effects and Other Impacts for additional information on underwater noise impacts to aquatic organisms.

### *Conservation recommendations and best management practices for construction and expansion of ports and marinas*

1. Encourage federal, state, and local authorities to assist port authorities and marinas in developing management plans that avoid and minimize impacts to the coastal environment and that are consistent with coastal zone management plans.
2. Encourage implementation of environmental management systems for ports and marinas that incorporate strong operational controls and best management practices (BMPs) into existing job descriptions and work instruction.
3. Encourage marinas to participate in NOAA/US EPA’s Coastal Nonpoint Program and the Clean Marina Initiative.
4. Explore alternative port developments such as satellite ports and offshore terminals, which may decrease some impacts associated with traditional inshore port facility developments.
5. Conduct site suitability analyses for new or proposed expansion of port and marina facilities to reduce and avoid habitat degradation or loss. Some of the analyses that should be conducted include identifying alterations to current and circulation patterns, water quality, bathymetric and topographic features, fisheries utilization and species distributions, and substrate features.
6. Conduct pre- and post-project biological surveys over multiple growing seasons to assess impacts on submerged and emergent aquatic vegetation communities.
7. Site new or expansions of port and marina facilities in deep-water areas to the maximum extent practicable to avoid the need for dredging. Areas that are subject to rapid shoaling or erosion will likely require more frequent maintenance dredging and should be avoided.

8. Avoid areas identified as supporting high abundance and diversity of species (e.g., SAV beds, intertidal mudflats, emergent wetlands, fish spawning areas) when locating new or expanded port and marina facilities.
9. Encourage the use of preproject surveys by qualified biologists/botanists to identify and map invasive plants within the proposed project area, and develop and implement an eradication plan for nonnative species.
10. Consider excavating uplands as a less-damaging alternative for new or expanded port and marina facilities instead of dredging intertidal or shallow subtidal habitat. However, water quality modeling should be conducted to evaluate potential impacts associated with enclosed and poorly flushed marinas.
11. Retain and preserve marine riparian buffers to maintain intertidal microclimate, flood and stormwater storage capacity, and nutrient cycle.
12. Consider low-wake vessel technology and appropriate vessel routes in the facility design and permitting process to minimize impacts to shorelines and shallow water habitats. Vessel speeds should be adapted to minimize wake damage to shorelines, and no-wake zones should be considered in highly sensitive areas, such as fish spawning habitat and SAV beds.
13. Do not locate new port and marina facilities in areas that have reduced tidal exchange and/or shallow water habitats, such as enclosed bays, salt ponds, and tidal creeks.
14. Implement construction designs for new ports and marinas to facilitate good tidal exchange and surface water movement and provide an adequate migratory corridor for fish. When possible, structures that impede tidal exchange and that may interfere with the movement of marine organisms, such as solid breakwaters, should be avoided.
15. Ensure that new ports and marinas incorporate BMPs in the construction operation plans that prevent and minimize the release of contaminants and debris caused by construction equipment and activities. The plan should include a spill response plan and training, and spill response equipment should be installed and maintained properly on-site.
16. Implement seasonal restrictions when necessary to avoid construction-related impacts to habitat during species' critical life history stages (e.g., spawning and egg development periods).
17. For structures located over SAV, the amount of light reaching vegetation below the dock should be maximized by providing adequate height over the water, minimizing the width of the dock, and orienting the length of the dock in a north-south direction.
18. The use of wood preservatives, such as creosote, ACZA and CCA should be avoided, where possible. If CCA treated wood must be used, the wood can be presoaked for several weeks or the wood can be coated with plastic sheath to reduce/eliminate leaching. Concrete and steel pilings are generally considered to be less damaging, since they reflect light more than wood docks and generally do not release contaminants into the aquatic environment. However, concrete pilings and docks generally increase the overall size of the overwater structure and may not be preferable in areas containing SAV.
19. Site floating docks, which limit light transmittance more than elevated structures, only in nonvegetated areas. When used, floating docks should either be located in areas of adequate depth so that adequate clearance between the float and the bottom is maintained, or fitted with structures (i.e., float stops) that prevent the float from contacting the bottom. Float stops should be designed to provide a minimum of 2 feet of clearance between the float and substrate to prevent hydraulic disturbances to the bottom. Greater clearances may be necessary in higher energy environments that experience strong wave action.
20. Orient night lighting such that illumination of the surrounding waters is avoided.

21. Reduce sound pressure impacts during pile installation by using wood or concrete piles, rather than hollow steel piles which produce intense, sharp spikes of sound that are more damaging to fish.
22. Use technologies that have been designed to reduce the adverse effects of underwater sound pressure waves such as air bubble curtains and metal or fabric sleeves to surround the pile. Air bubble systems must have adequate airflow, and the pile should be fully contained to ensure that sound attenuation is successful.
23. Conduct pile driving during low tides in intertidal and shallow subtidal areas.
24. Employ vibratory hammers when removing old piles to help minimize the release of suspended sediments, silt, and contaminants into the water column; these may be preferable over direct pull or the use of a clamshell dredge.
25. Reduce or eliminate the amount of sediment released into the water column by cutting the pile off below the mudline and leaving the stub in place when removing old piles.
26. Mitigate impacts to marine organisms, particularly those with air cavities (i.e., swim bladders and lungs), from underwater blasting by employing BMPs such as focusing the blast energy towards a solid rock substrate rather than towards the water column; installing noise attenuating devices such as air curtains; conducting the blasting during periods of low-water or low-tide; using delayed blasts that produce sequenced, lesser-charged explosions that reduce the shockwave; stemming (capping) the charge bore hole with material that contains the blast; and repelling charges that frighten fish from the blast area prior to blasting (Keevin 1998).
27. Consult federal and state resource agencies prior to work that involves blasting to assess the marine resource utilization of the area. Biological surveys may be required to assess the presence of fishery resources. Time-of-year restrictions should be employed to avoid impacting sensitive species and life history stages that use the area. Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
28. Integrate measures to reduce nonpoint source (NPS) pollution, such as a stormwater management plan into the design, maintenance, and operation of a port or marina. Some examples of BMPs for stormwater management include (adapted from Amaral et al. 2005):
    a. Minimize the amount of impervious surfaces surrounding the port or marina facility and maintain a buffer zone between the coastal zone and upland facilities.
    b. Implement runoff control strategies to decrease the amount of contaminants entering marine waters from upland sources. This can be accomplished by using alternative surface materials such as crushed gravel, decreasing the slope of surfaces towards the waters' edge, and installing filtering systems or settling ponds.
    c. Designate specific enclosed areas for maintenance activities such as sanding, painting, engine repairs. Use tarp enclosures or spray booths for abrasive blasting to prevent residue from reaching surface waters.
    d. Provide and maintain appropriate storage, transfer, containment, and disposal facilities for liquid hazardous material, such as solvents, antifreeze, and paints.
29. Address the cumulative impacts of past, present, and foreseeable future development activities on aquatic habitats by considering them in port and marina review processes.

## Operation and Maintenance of Ports and Marinas

Existing ports and marinas can be a source of impacts to fishery resources and habitat that may differ from those relating to construction and expansion of new facilities. These impacts may be associated with the operation of the facilities, equipment impacts, and stormwater runoff. Examples of port or marina impacts include chronic pollution releases, underwater noise, altered light regimes, and repeated physical disturbances to benthic habitats.

### *Contaminant release and storm water runoff*

Ports and marinas can be a source of contaminants directly associated with facility activities and by stormwater runoff from the facility and the surrounding urbanized areas. The long-term operation of a marina or port can provide a chronic presence of contaminants to the localized area that can have an adverse effect on the quality of fishery habitat and population dynamics (Wilbur and Pentony 1999).

The oil and fuel that accumulates on dock surfaces, facilities properties, adjacent parking lots, and roadways may enter coastal waters through stormwater runoff and snowmelt. Oil and fuel contains PAH and other contaminants that are known to bioaccumulate in marine organisms and impact the marine food web (Nightingale and Simenstad 2001a; Amaral et al. 2005). In addition, these contaminants can persist in bottom sediments where they can be resuspended through a variety of activities such as propeller scouring and dredging. Marina activities such as vessel refueling, engine repair, and accidental vessel sinking may increase the risk of fuel and oil contamination of the surrounding environment (Amaral et al. 2005).

Marina facilities such as storage areas for paint, solvents, detergents, and other chemicals may pose a risk of introducing additional contaminants to the marine environment resulting in both acute and chronic toxicity to marine biota (Amaral et al. 2005). These products are often a routine and essential part of marina or port operations, and if handled and stored improperly they can increase the risk of accidental spillage. Various port and vessel maintenance activities may contribute to metal contamination to the surrounding waters. For example, elevated levels of copper are often associated with ports and marinas, especially those with a high density of recreational boats because of the type of antifouling paints used on those boats. A number of other metals have been detected in the sediments and surface waters of marinas, including arsenic (used in paints and wood preservatives), zinc (leached from anodes used to reduce corrosion of boat hulls and motors), mercury (used in float switches for bilge and other storage tank pumps), lead (used in batteries), nickel, and cadmium (used in brake linings) (USEPA 2001). However, stormwater runoff may be the primary source of copper in most marinas in urban areas (Warnken et al. 2004).

Wooden pilings and docks in marinas and ports are typically treated with some type of preservative, such as chromated copper arsenate, ammoniacal copper zinc, and creosote. These preservatives can leach harmful chemicals into the water that have been shown to have toxic effects on fish and other organisms (Weis et al. 1991). Concrete, steel, or nontreated wood are relatively inert and do not leach contaminants into the water. Refer to this chapter's section on Construction and Expansion of Ports and Marinas and the Coastal Development chapter for more information on the affects of copper and other wood preservatives on aquatic resources.

Because marinas and ports typically contain large areas of impervious surfaces and are located at the interface between land and water, stormwater runoff can be greater at these facilities compared with other types of land uses. The organic particulates that are washed into marine waters from the surrounding surfaces can add nutrients to the water and cause eutrophication in bays and estuaries. A number of sources of organic matter from ports and marinas can degrade water quality and reduce dissolved oxygen concentrations, including sewage discharges from recreational and commercial boats, trash tossed overboard, fish wastes disposed of into surface waters, pet wastes, fertilizers, and food wastes (USEPA 2001). Eutrophication often leads to abnormally high phytoplankton populations, which in turn can reduce the available light to SAV beds. Changes in water quality caused by eutrophication can sometimes have a more severe impact on seagrass populations than shading from over-water structures or physical uprooting by vessel and float groundings (Costa et al. 1992; Burdick and Short 1999).

### *Release of debris*

Solid waste is another problematic issue associated with port and marina operations. A great deal of solid waste is generated through daily operations of a commercial port as well as the recreational activities of a marina. This waste may include plastics such as fishing line, bottles, tarps, food containers, and shopping bags, or paper products and other materials, which can be released as debris into the surface waters through accidental loss from vessels or through stormwater runoff from upland facilities. Activities such as sanding, pressure washing, sand blasting, and discarding rags and oil/fuel filters can contribute to marine debris if improper handling and disposal is allowed (USEPA 2001). If this waste is collected and disposed of properly the impacts to the environment can be minimized (Amaral et al. 2005). Plastics are a large component of the trash released into marine waters, accounting for 50-60% of marine debris collected from the Gulf of Maine (Hoagland and Kite-Powell 1997). Plastics contain toxic substances that can persist in the environment and bioaccumulate through the food web, impairing metabolic functions in fish and invertebrates that use habitats polluted by plastic debris. Some chemicals found in plastics, known as "endocrine disruptors," may interfere with the endocrine system of aquatic organisms (Kavlock et al. 1996; Kavlock and Ankley 1996). These chemicals act as "environmental hormones" that may mimic the function of the sex hormones androgen and estrogen (Thurberg and Gould 2005). Adverse effects include reduced or altered reproductive functions, which could result in population-level impacts.

Marine debris can directly affect fish and invertebrates that may consume or become entangled by the debris. Plastic debris may be ingested by seabirds, fish and invertebrates, sea turtles, and marine mammals, which can cause infections and death of the animal (Cottingham 1988). Debris can be transported by currents to other areas where it can become snagged and attached to benthic habitat, damaging sensitive reef habitat. Additional information on impacts associated with marine debris can be found under Operation and Maintenance of Vessels section of this chapter and in the Coastal Development chapter of this report.

### *Underwater noise*

The ambient noises emanating from ports and marinas are from a combination of boat propellers, engines, pumps, generators, and other equipment within vessels and shore-side equipment. In coastal areas the sounds of cargo and tanker traffic are multiplied by complex reflected paths from scattered and reverberated noises caused by littoral geography. Commercial and private fishing boats, pleasure craft, personal watercraft (i.e., jet skis), industrial vessels, public transport ferries, and shipping safety and security services such as tugs boats, pilot boats, enforcement vessels, and coastal agency support craft generate sounds that can impact marine organisms, particularly fish and marine mammals. Exposure to continuous noise may also create a shift in hearing thresholds for marine organisms resulting in hearing losses at certain frequency ranges (Jasny et al. 1999). Refer to the Global Effects and Other Impacts chapter and the Operation and Maintenance of Vessels and the Construction and Expansion of Ports and Marinas sections in this chapter for more information on underwater noise.

## *Derelict structures*

Increased vessel activity in and around port and marina operations increase the probability of the grounding of vessels, which may not always be removed immediately from the aquatic environment. In addition to being public health and navigational hazards, derelict or abandoned vessels can cause various impacts to coastal habitats. Grounded vessels can physically damage and smother benthic habitats, create changes in wave energy and sedimentation patterns, and scatter debris across sensitive habitats (Precht et al. 2001; Zelo and Helton 2005). However, the most common environmental threat of a derelict or abandoned vessel is the release of oil or other pollutants. These hazardous materials may be part of a vessel's cargo, fuel and oil related to vessel operations, or chemicals contained within the vessel's structure which may be released over time through decay and corrosion. Refer to the Operation and Maintenance of Vessels section of this chapter for more information on impacts associated with derelict structures and grounded vessels.

## *Mooring and floating dock impacts*

Vessel mooring impacts, although localized, can reduce habitat quality and complexity. Accidental vessel groundings can smother or crush shellfish, scour vegetation, and disturb substrates (Nightingale and Simenstad 2001a). Disturbance of substrates can lead to increased turbidity, reduced light penetration, decreased dissolved oxygen levels, and the possible resuspension of contaminants. In addition, moored vessels contacting the bottom during low tides can cause the bottom habitat in the area of the mooring to be unavailable for fish and other marine biota during the time the vessel is resting on the bottom. Vessels that contact the bottom can create scouring of the substrate and result in permanent alteration or loss of benthic habitats, such as eelgrass. Demersal eggs (e.g., Atlantic herring [*Clupea harengus*]) and larvae that utilize an area can also be destroyed from the impact of the vessel or shading. Floating piers and docks may also alter wave energy, current patterns, and longshore sediment transport, especially in areas that experience strong current velocities (Nightingale and Simenstad 2001a).

Depending upon the type and configuration, the mooring tackle itself may cause impacts to substrate and benthos, including SAV. Typical vessel moorings consist of an anchor connected to a surface buoy by a long length of heavy chain. In most moorings, some portion of the anchor chain drags and often scours the bottom and forms a depression in the sediment surface (Walker et al. 1989). In areas influenced strongly by tides and currents or wind, the bottom scouring takes on a circular or "V" configuration when the anchor chain is allowed to drag along the bottom as the vessel or buoy swings with the tide or wind (Nightingale and Simenstad 2001a). The resulting scour holes allow further erosion and loss of the physical integrity of the habitat, which can lead to fragmentation of seagrass meadows (Walker et al. 1989; Hastings et al. 1995). Hastings et al. (1995) attributed an approximate 18% direct loss of seagrass habitat from boat moorings in one bay in Western Australia. Refer to the Coastal Development chapter of this report for a more detailed discussion on impacts from overwater structures.

## *Alteration of light regimes*

As discussed in other sections of this chapter, overwater structures shade the surface of the water and attenuate the light available to benthic habitat under and adjacent to the structures. The height, width, construction materials used, and orientation of the structure in relation to the sun can influence how large a shade footprint an over-water structure may produce and how much of an adverse impact that shading effect may have on the benthic habitat (Burdick and Short 1999; Shafer 1999; Fresh et al. 2001; Nightingale and Simenstad 2001a). Refer to the chapter on Coastal

Development and the Construction and Expansion of Ports and Marinas section of this chapter for more information on docks structures and light attenuation.

### *Conservation recommendations and best management practices for the operation and maintenance of ports and marinas (adapted from Amaral et al. 2005; Hanson et al. 2003)*

1. Consider environmental impacts through port development and operations plans, including:
   a. assess all activities at facility and identify potential environmental impacts
   b. determine compatibility with port environmental practices and assess available control technologies
   c. evaluate and monitor effectiveness of control technologies
   d. develop and implement environmental management
2. Encourage marinas to participate in NOAA/US EPA's Coastal Nonpoint Program and the Clean Marina Initiative.
3. Ensure that marina and port facility operations have an oil spill response plan in place, which has been shown to improve the response and recovery times of oil spills.
4. Ensure that marina or port facilities have adequate oil spill response equipment accessible and clearly marked. Oil spill response equipment may include oil booms, absorbent pads, and oil dispersant chemicals.
5. Use dispersants that remove oils from the environment, rather than those that simply move them from the surface to the ocean bottom.
6. Install automatic shut-off nozzles at fuel dispensing sites and require the use of fuel/air separators on air vents or tank stems of inboard fuel tanks to reduce the amount of fuel oil spilled into surface waters by vessels using fuel stations.
7. Promote the use of oil-absorbing materials in the bilge areas of all boats with inboard engines.
8. Place containment berms around fixed pieces of machinery that use oil and gas within the facility.
9. Encourage public education and signage to promote proper disposal of solid debris and polluting materials.
10. Encourage the proper disposal of materials produced and used by the operation, cleaning, maintenance, and repair of boats to limit the entry of solid and contaminated waste into surface waters.
11. Recommend the placement of garbage containers to supervised areas and use containers that have lids in order to reduce the potential for litter to enter the marine environment.
12. Promote the use of pumpout facilities and restrooms at marinas and ports to reduce the release of sewage into surface waters. Ensure that these facilities are maintained and operational, and provide these services at convenient times, locations, and reasonable cost. In addition, promote the use of these facilities through public education and signage.
13. Develop a harbor management plan which addresses the maintenance and operation of pumpout facilities.
14. Prevent the disposal of fish waste or other nutrient laden material in marina or port basins through the use of public education, signage, and by providing alternate fish waste management practices.
15. Ensure that measures to reduce NPS pollution, such as a stormwater management plan, are integrated into the maintenance and operation of a port or marina.

16. Recommend site-specific solutions to NPS pollution by considering the frequency of marina operations and potential pollution sources. Management practices should be tailored to the specific issues of each marina.
17. Encourage the removal of unnecessary impervious surfaces surrounding the port or marina facility and maintain a buffer zone between the aquatic zone and upland facilities.
18. Ensure that stormwater runoff from parking lots and other impervious surfaces is collected and treated to remove contaminants prior to delivery to any receiving waters. This can be accomplished by using alternative surface materials such as crushed gravel, decreasing the slope of surfaces towards the water's edge, and installing filtering systems or settling ponds.
19. Recommend that specific, enclosed areas are designated for maintenance activities such as sanding, painting, engine repairs. Using tarp enclosures or spray booths for abrasive blasting will also prevent residue from reaching surface waters.
20. Ensure that facilities provide for appropriate storage, transfer, containment, and disposal facilities for harmful liquid material, such as solvents, antifreeze, and paints.
21. Recommend that facilities provide a containment system and a filtering and treatment system for vessel wash down wastewater.
22. Ensure that floating structures, including barges, mooring buoys, and docks are located in adequate water depths to avoid propeller scour and grounding of vessel and floating structures. When floating docks cannot be located in adequate depth to avoid contact on the bottom at low tides, recommend that float stops (structural supports to prevent the float from resting on the bottom) are installed. Float stops should be designed to provide a minimum of 2 feet of clearance between the float and substrate to prevent hydraulic disturbances to the bottom. Greater clearances may be necessary in higher energy environments that experience strong wave action.
23. Recommend anchoring techniques and mooring designs that avoid scouring from anchor chains. For example, anchors that do not require chains (e.g., helical anchors) or moorings that use subsurface floats to prevent anchor chains from dragging the bottom are some designs that should be considered.
24. When moorings with anchor chains cannot be avoided, recommend that areas prone to high current and wind velocity be avoided, where the sweep of the anchor chain on the bottom can cause the greatest damage.
25. Recommend the use of concrete, nontreated wood or steel dock materials to avoid the leaching of contaminants associated with wood preservatives.

## Operation and Maintenance of Vessels

Vessel activity in coastal waters is generally proportional to the degree of urbanization and port and harbor development within a particular area. Benthic, shoreline, and pelagic habitats may be disturbed or altered by vessel use, resulting in a cascade of cumulative impacts in heavy traffic areas (Barr 1993). The severity of boating-induced impacts on coastal habitats may depend on the geomorphology of the impacted area (e.g., water depth, width of channel or tidal creek), the current velocity, the sediment composition, the vegetation type and extent of vegetative cover, as well as the type, intensity, and timing of boat traffic (Yousef 1974; Karaki and vanHoften 1975; Barr 1993). Recreational boating activity mainly occurs during the warmer months which coincide with increased biological activity in east coast estuaries (Stolpe and Moore 1997; Wilbur and Pentony 1999). Similarly, frequently traveled routes such as those traveled by ferries and other transportation vessels can impact fish spawning, migration, and recruitment behaviors through noise and direct disturbance of the water column (Barr 1993).

Other common impacts of vessel activities include vessel wake generation, anchor chain and propeller scour, vessel groundings, the introduction of invasive or nonnative species, and the discharge of contaminants and debris (Hanson et al. 2003).

## *Impacts to benthic habitat*

Vessel operation and maintenance activities can have a wide range of impacts to benthic habitat, ranging from minor (e.g., shading of SAV) to potentially large-scale impacts (e.g., ship groundings and fuel or toxic cargo spills). Direct disturbances to bottom habitat can include propeller scouring and vessel wake impacts on SAV and other sensitive benthic habitats and direct contact by groundings or by resting on the bottom at low tides while moored. Propeller scarring can result in a loss of benthic habitat, decrease productivity, potentially fragment SAV beds, and lead to further erosion and degradation of the habitat (Uhrin and Holmquist 2003). Eriksson et al. (2004) found that boating activities can have direct and indirect impacts on SAV, including drag and tear on plant tissues resulting from increased wave-action, reduction in light availability caused by elevated turbidity and resuspension of bottom sediments, and altered habitat and substrate that causes plants to be uprooted and can inhibit recruitment. The disturbance of sediments and rooted vegetation decreases habitat suitability for fish and shellfish resources and can effect the spatial distribution and abundance of fauna (Nightingale and Simenstad 2001a; Uhrin and Holmquist 2003; Eriksson et al. 2004).

## *Resuspension of bottom sediments/turbidity*

The degree of sediment resuspension and turbidity that is produced in the water column from vessel activity is complex but is generally dependent upon the wave energy and surge produced by the vessel, as well as the size of the sediment particles, the water depth, and the number of vessels passing through an area (Karaki and vanHoften 1975; Barr 1993). These activities typically increase turbidity and sedimentation on SAV and other sensitive benthic habitats (Klein 1997; Barr 1993; Nightingale and Simenstad 2001a; Eriksson et al. 2004). Studies investigating sedimentation impacts on eelgrass have found that experimental burial of 25% of the plant height can result in greater than 50% mortality (Mills and Fonseca 2003). Klein (1997) reported that turbidity generated by boats operating in shallow waters can exceed safe levels by up to 34-fold.

The resuspension of sediments can affect habitat suitability for fish and shellfish resources and effect the spatial distribution and abundance of fauna (Nightingale and Simenstad 2001a; Uhrin and Holmquist 2003; Eriksson et al. 2004). The egg and larval stages of marine and estuarine fish are generally highly sensitive to suspended sediment exposures (Wilber and Clark 2001), and juvenile fish may be susceptible to gill injury when suspended sediment levels are high (Klein 1997). Sedimentation and turbidity impacts associated with boating may be more pronounced in areas that contain shallow water habitat where the bottom is composed of fine sediments (Klein 1997).

## *Shoreline erosion*

Wave energy caused by industrial and recreational shipping and transportation can have substantial impacts on aquatic shoreline and backwater areas which can eventually cause the loss and disturbance of shoreline habitats (Karaki and vanHoften 1975; Barr 1993; Klein 1997). Vessel wakes along frequently traveled routes can cause shoreline erosion, damage aquatic vegetation, disturb substrate, and increase turbidity. Wave energy and surge produced by vessels are dependent upon a number of factors, including the size and configuration of the vessel hull, the size of the vessel, and the speed of the vessel (Karaki and vanHoften 1975; Barr 1993). The degree of erosion on shorelines caused by vessels is complex, but it is generally dependent upon the wave energy and surge produced by the vessel and the slope of the shoreline, the type of sediment (e.g., clay, sand), and the type and amount of shoreline vegetation, as well as the characteristics of the water body (e.g., water depth and bottom topography) and distance between the vessel and shoreline (Karaki and vanHoften 1975; Barr 1993).

### *Contaminant spills and discharges*

A variety of substances can be discharged or accidentally spilled into the aquatic environment, such as gray water (i.e., sink, laundry effluent), raw sewage, engine cooling water, fuel and oil, vessel exhaust, sloughed bottom paint, boat washdown water, and other vessel maintenance and repair materials that may degrade water quality and contaminate bottom sediments (Cardwell et al. 1980; Cardwell and Koons 1981; Krone et al. 1989; Waite et al. 1991; Hall and Anderson 1999; Hanson et al. 2003).

Industrial shipping and recreational boating can be sources of metals such as arsenic, cadmium, copper, lead, and mercury (Wilbur and Pentony 1999). Metals are known to have toxic effects on marine organisms. For example, laboratory experiments have shown high mortality of Atlantic herring eggs and larvae at copper concentrations of 30 µg/L and 1,000 µg/L, respectively, and impairment of vertical migration for larvae at copper concentrations greater than 300 µg/L (Blaxter 1977). Copper may also bioaccumulate in bacteria and phytoplankton (Milliken and Lee 1990). Metals may enter the water through various vessel maintenance activities such as bottom washing, paint scraping, and application of antifouling paints (Amaral et al. 2005). For example, elevated copper concentrations in the vicinity of shipyards have been associated with vessel maintenance operations such as painting and scraping of boat hulls (Milliken and Lee 1990). Studies have shown a positive relationship between the number of recreational boats in a marina and the copper concentrations in the sediments of that marina (Warnken et al. 2004). Copper and an organotin, called tributyltin (TBT), are common active ingredients in antifouling paints (Milliken and Lee 1990). The use of TBT is primarily used for large industrial vessels to improve the hydrodynamic properties of ship's hulls and fuel consumption, while recreational vessels typically use copper-based antifouling paints because of restrictions introduced in the Organotin Antifouling Paint Control Act of 1988 (33 U.S.C. 2401), which bans its use on vessels less than 25 m in length (Milliken and Lee 1990; Hofer 1998).

Herbicides are also used in some antifouling paints to inhibit the colonization of algae and the growth of seaweeds on boat hulls and intake pipes (Readman et al. 1993). Similar to copper, the highest concentrations of herbicides in nearshore waters are associated with recreational marinas, which may be because of a higher frequency of use of these types of antifouling paints for pleasure boats compared to commercial vessels (Readman et al. 1993). The leaching of these chemicals into the marine environment could affect community structure and phytoplankton abundance (Readman et al. 1993).

Fuel and oil spills can affect animals directly or indirectly through the food chain. Fuel, oil, and some hydraulic fluids contain PAH which can cause acute and chronic toxicity in marine organisms (Neff 1985). Toxic effects of exposure to PAH have been identified in adult finfish at concentrations of 5-50 ppm and the larvae of aquatic species at concentrations of 0.1-1.0 ppm (Milliken and Lee 1990). Small, but chronic oil spills are a potential problem because residual oil can build up in sediments and affect living marine resources. Even though individual releases are small, they are also frequent and when combined they contribute nearly 85% of the total input of oil into aquatic habitats from human activities (ASMFC 2004). Incidental fuel spills involving small vessels are probably common events, but these spills typically involve small amounts of material and may not necessarily adversely affect fishery resources. Larger spills may have significant acute adverse affects, but these events are relatively rare and usually involve small geographic areas.

Outboard engines, as opposed to inboard engines that are generally used for larger, commercial vessels, are unique in that their exhaust gases cool rapidly and leave some hydrocarbon components condensed and in the water column rather than being released into the atmosphere (Moore and Stolpe 1995). Outboard engine pollution, particularly from two-cycle engines, can contribute to the concentrations of hydrocarbons in the water column and sediment (Milliken and Lee 1990). Two-cycle outboard engines accomplish fuel intake and exhaust in the same cycle and tend to release unburned fuel along with the exhaust gases. In addition, two-cycle engines mix lubricant oil with the fuel, so this oil is released into the water along with the unburned fuel. There are over 100 hydrocarbon compounds in gasoline, including additives to improve the efficiency of the fuel combustion (Milliken and Lee 1990). Once discharged into the water, petroleum hydrocarbons may remain suspended in the water column, concentrate on the surface, or settle to the bottom (Milliken and Lee 1990).

Any type of fuel or oil spill has the potential to cause impacts to organisms and habitats in the water column, on the bottom, and on the shoreline, but it is unknown to what extent these effects are individually or cumulatively significant. Effects on fish from low-level chronic exposure may increase embryo mortality, reduce growth, or alter migratory patterns (Heintz et al. 2000; Wertheimer et al. 2000). For more details on the impacts of oil or fuel spills, see the chapter on Energy-related Activities.

Gray water and sewage discharge from boats may impact water quality by increasing nutrient loading and biological oxygen demand of the local area and through the release of disease causing organisms and toxic substances (Thom and Shreffler 1996; Klein 1997). Positive correlations between boating activity levels and elevated levels of fecal coliform bacteria in nearshore coastal waters have been reported (Milliken and Lee 1990). Although the Clean Water Act (CWA) of 1972 makes it illegal to discharge untreated wastes into coastal waters and the Federal Water Pollution Control Act requires recreational boats be equipped with marine sanitation devices (MSDs), it is legal to discharge treated wastes, and illegal discharges of untreated waste may be common (Milliken and Lee 1990; Amaral et al. 2005). Despite these laws, many vessels may not be equipped with MSDs and on-shore pumpout stations are not common (Amaral et al. 2005). Impacts from vessel waste discharges may be more pronounced in small, poorly flushed waterways where pollutant concentrations can reach unusually high levels (Klein 1997).

### *Underwater noise*

The noise generated by vessel operations is usually concentrated in ports, marinas, and heavily used shipping lanes or routes and may impact fish spawning, migration, and recruitment behaviors (Hildebrand 2004). Exposure to continuous noise may also create a shift in hearing thresholds for marine organisms resulting in hearing losses at certain frequency ranges (Jasny et al. 1999). Reducing vessel noise is a difficult task because of the economic incentives that encourage the expansion of commercial shipping and the lack of alternatives for efficient global transport of large and high tonnage material (Hildebrand 2004).

Small craft with high-speed engines and propellers (e.g., recreational boats with outboard engines) typically produce higher frequency noise than do larger vessels that generate substantial low-frequency noise because of their size and large, slow-speed engines and propellers (Kipple and

Gabriele 2004). A noise study of three size-classes of vessels (i.e., small, 17-30 feet; medium, 50-100 feet; and large, >100 feet) in Glacier Bay, AK, found that, on average, overall sound levels were higher for the larger vessel categories (Kipple and Gabriele 2004). However, vessel sound levels in this study were generally measured at vessel speeds less than 10 knots, and the investigators found increasing sound levels with greater vessel speed (Kipple and Gabriele 2004). Scholik and Yan (2002) reported significant elevation of the auditory threshold of the fathead minnow (*Pimephales promelas*), after exposure to noise from an idling 55 horsepower outboard motor. Furthermore, the frequencies of the noise from the outboard engine corresponded to the frequencies of the fish's auditory threshold shifts, specifically in this species' most sensitive hearing range (1.0-2.0 kHz).

Commercial shipping vessels are a major source of low frequency (5-500 Hz) noise in the marine environment and may be one of the most pervasive sources of anthropogenic ocean noise (Jasny et al. 1999; Stocker 2002; Hildebrand 2004). Low frequencies travel long distances in the marine environment, which is probably why these frequencies are also used by marine mammals for communication (Jasny et al. 1999). Ship noise is generated from the use of engines and other on-board mechanical devices such as pumps, cooling systems, and generators, as well as movement of water across the hull and propellers (Stocker 2002; Hildebrand 2004). These sounds are amplified and transferred to the water through the ship's hull (Stocker 2002). The size and frequency of use for commercial vessels traversing the ocean and nearshore waters may explain why they are considered a major source of noise impacts compared to the more numerous fishing and pleasure craft found in coastal waters (Hildebrand 2004).

There are several factors which influence sound attenuation in shallow coastal waters including temperature variations or thermoclines, bottom geography, and sediment composition. Vessel noise may reverberate or scatter off geological features and anthropogenic structures in the water (Stocker 2002).

Sonar is another source of anthropogenic noise attributed to vessel operation. It is used for various purposes such as depth sounding and fish finding and can vary in range depending on the use (15-200 kHz for commercial navigation, 1-20 kHz for other positioning and navigation, and 100-3,000 Hz for long range sonar) (Stocker 2002). Refer to the Global Effects and Other Impacts chapter of this report for more information on ocean noise.

### *Release of debris*

As discussed in the Operation and Maintenance of Ports and Marinas section of this chapter, the release of solid waste in coastal waters is a considerable concern. Billions of pounds of debris are dumped into the oceans each year (Milliken and Lee 1990), and vessel traffic is a significant source of this waste because of accidental loss, routine practices of dumping waste, and illegal dumping activities (Cottingham 1988). Entanglement in or ingestion of this debris can cause fish, marine mammals, and sea birds to become impaired or incapacitated, leading to starvation, drowning, increased vulnerability to predators, and physical wounds (Milliken and Lee 1990). Marine debris can also cause direct physical damage to habitat features through smothering or physical disturbance.

Plastics are an especially persistent form of solid waste. Plastics tend to concentrate along coastal areas because they float on the surface and can be transported by ocean currents (Milliken and Lee 1990). Commercial fishing, merchant vessel, cruise ship, and recreational boats are major contributors to marine plastic debris (Cottingham 1988; Milliken and Lee 1990). Cottingham (1988) estimated that merchant vessels are the primary source of plastic refuse in New England. Refer to the Operation and Maintenance of Ports and Marinas section in this chapter for information on plastic debris and the Coastal Development chapter of this report for more information on general marine debris.

## *Abandoned and derelict vessels*

Derelict or abandoned vessels can cause a variety of impacts to habitats and are public health and navigational hazards. Grounded vessels may physically damage and smother benthic habitats, create changes in wave energy and sedimentation patterns, and scatter debris across sensitive habitats (Precht et al. 2001; Zelo and Helton 2005). The potential impact footprint of a grounded vessel can be much larger than the vessel itself as vessels move or break up during storm events, which can scour bottom habitat, amplify impacts, and complicate removal (Zelo and Helton 2005). The physical impacts of a grounded vessel can be greater in shallow water since the wreck is more likely to be unstable and move, may break up more rapidly because of wave and current forces, and is more likely to need urgent removal because of navigation concerns which may lead to additional resource impacts (Michel and Helton 2003). Refer to the Offshore Dredging and Disposal Activities chapter of this report for information regarding intentional sinking of vessels for disposal and creation of artificial reefs.

The most common environmental threat of a derelict or abandoned vessel is the release of oil or other pollutants. These hazardous materials may be part of a vessel's cargo, fuel and oil related to vessel operations, or chemicals contained within the vessel's structure which may be released through decay and corrosion over time. Rusting vessel debris can also cause iron enrichment in enclosed areas, which has been associated with harmful algal blooms (Helton and Zelo 2003; Michel and Helton 2003).

The historical focus of laws regarding derelict or abandoned vessels was the protection of the property rights of shipowners and the recovery of cargo (Michel and Helton 2003). Existing federal laws and regulations do not provide clear authority or funding to any single agency for the removal of grounded or abandoned vessels that harm natural resources but which are not otherwise obstructing or threatening to obstruct navigation or threatening a pollution discharge (Helton and Zelo 2003). In many cases vessels are abandoned and are left to continually damage the marine environment because a responsible party cannot be identified or a funding source for removal cannot be secured (Zelo and Helton 2005). Physical impacts, in particular, can persist for decades when vessels are left in the marine environment, and in some cases simply removing a vessel is enough to allow natural recolonization of benthic organisms (Zelo and Helton 2005).

Removal of a derelict vessel will ensure that the vessel does not become a navigation hazard to other ships and that hazardous materials are not released during storms which can damage the wreckage further. It also ensures that abandoned vessels do not become illegal dumpsites for oil, industrial waste, and other hazardous materials, including munitions (Helton and Zelo 2003). Salvage and wreck removal activities can result in unintended habitat impacts. For example, fuel spillage may occur during salvage operations of a wrecked vessel. The potential for collateral impacts should be considered when planning a salvage operation (Michel and Helton 2003). Wrecks in shallow water are often removed and scuttled in deep water to prevent further damage to more vulnerable, nearshore benthic habitats and to avoid the risks involved in bringing an unstable vessel into port (Michel and Helton 2003).

Although many of the habitat impacts described above can be averted if derelict vessels are removed while still afloat, abandoned and neglected floating vessels can also create habitat impacts (Zelo and Helton 2005). These vessels may shade seagrass beds, scour subtrates with anchor chains, or release pollutants from decaying hull materials and paints (Sunda 1994; Negri et al. 2002; Smith et al. 2003; Zelo and Helton 2005).

## Nonnative and invasive species

Nonnative species, some of which are invasive, have been introduced to coastal areas through industrial shipping and recreational boating (Omori et al. 1994; Wilbur and Pentony 1999; Hanson et al. 2003; Pertola et al. 2006). These introductions can be in the form of fouling organisms on the bottom of vessels as they are transported between water bodies or through the release of ballast water from large commercial vessels. Modern ships can carry 10 to 200 thousand tons of ballast water at a time and transport marine organisms across long distances and in relatively short time periods (Hofer 1998). This expeditious travel increases the risk that the organisms taken up in ballast water will be viable when introduced into a distant port or marina during deballasting (Wilbur and Pentony 1999). Pertola et al. (2006), in an investigation of dinoflagellates and other phytoplankton from the ballast tank sediments of ships at ports in the northeastern Baltic Sea, found a large assemblage of germinated dinoflagellate cysts in 90% of all ships and at all ports sampled. Ship traffic can transport, in large numbers, nonnative and invasive species of phytoplankton that can be harmful to native aquatic species (Pertola et al. 2006). The nonnative green algae (*Codium fragile*), is an example of a species that has invaded the northeastern US coast, the eastern Atlantic Ocean, Mediterranean Sea, and New Zealand and has displaced native species of *Codium* (Walker and Kendrick 1998; Tyrrell 2005). Shipping has been implicated as the major agent of spread of this species (Walker and Kendrick 1998), as well as of the zebra mussel (*Dreissena polymorpha*) (Strayer et al. 2004). This invasive species has been shown to have had an adverse effect on the populations of some native species of fish (e.g., *Alosa* spp.), as well as phytoplankton, zooplankton, aquatic vegetation, water chemistry, and zoobenthos (Strayer et al. 2004).

Introduced species can adversely impact habitat qualities and functions by altering the community structure, competing with native species, and introducing exotic diseases (Omori et al. 1994; Wilbur and Pentony 1999; Carlton 2001). Additional discussion of the effects of introduced species can be found in the chapters on Introduced/Nuisance Species and Aquaculture and Physical Effect: Water Intake and Discharge Facilities.

## Conservation recommendations and best management practices for vessel operation and maintenance

1. Encourage marinas to participate in NOAA/US EPA's Coastal Nonpoint Program and the Clean Marina Initiative.
2. Ensure that commercial ships and port facilities have oil-spill response plans in place which improve response and recovery in the case of accidental spillage.
3. Ensure that commercial ships and or port facilities have adequate oil-spill response equipment accessible and clearly marked.
4. Use dispersants that remove oils from the environment rather than dispersants that simply move them from the surface to the ocean bottom.
5. Promote the use of oil-absorbing materials in the bilge areas of all boats with inboard engines.
6. Promote the use of fuel/air separators on air vents or tank stems of inboard fuel tanks to reduce the amount of fuel and oil spilled into surface waters during fueling of boats.
7. Encourage recreational boats to be equipped with marine sanitation devices (MSDs) to prevent untreated sewage to be pumped overboard.
8. Encourage ship designs that include technologies capable of reducing noise generated and transmitted to the water column, such as the use of muffling devices already required for land-based machinery that may help reduce the impacts of vessel noise.

9. The effects of proposed and existing vessel traffic and associated underwater noise should be assessed for potential impacts to sensitive areas such as migration routes and spawning areas for marine animals.
10. Exclude vessels or limit specific vessel activities such as high intensity, low-frequency sonar, to known sensitive marine areas if evidence indicates that these activities have a substantial adverse effect to marine organisms.
11. Promote education and signage on all vessels to encourage proper disposal of solid debris at sea.
12. Encourage the use of innovative cargo securing and stowing designs that may reduce solid debris in the marine environment from the transportation of commercial cargo.
13. Use appropriate equipment and techniques to salvage and remove grounded vessels and follow all necessary state and federal laws and regulations. If possible, avoid using the propulsion systems of salvage tugs that can cause propeller wash and scour the bottom. Instead, moor the tugs and use a ground tackle system to provide maneuvering and pull.
14. Minimize additional seafloor damage when a derelict vessel has to be dragged across the seafloor to deep water by following the same ingress path. Alternatively, identify the least sensitive, operationally feasible towpath. Dismantling derelict vessels in place when stranded close to shore may cause less environmental impact than dredging or dragging a vessel across an extensive shallow habitat.
15. Reduce the risk of a sudden release of the entire cargo when a submerged derelict vessel contains hazardous aqueous solutions that pose limited environmental risks, such as mild acids and bases, by allowing the release of the cargo under controlled conditions. The controlled release plan can include water-quality monitoring to validate the calculated dilution rates and plume distance assumptions. All applicable state and federal laws and regulations regarding the release of chemicals into the water should be followed.
16. Develop a contingency plan for uncontrolled releases during vessel salvage operations. The salvage plan should include a risk assessment to determine the most likely release scenarios and use the best practices of the industry.
17. Schedule nonemergency salvage operations while including environmental considerations to minimize potential impacts on natural resources. Environmental considerations include periods when few sensitive species are present, avoidance of critical reproductive periods, and weather patterns that influence the trajectory of potential releases during operations
18. Choose a scuttling site for a derelict vessel in a deep-water location in federal or Exclusive Economic Zone (EEZ) waters that does not contain any sensitive resources or geological hazards. Ensure that all proposed disposal of vessels in the open ocean adheres to state and federal guidance and regulations, including section 102(a) of the Marine Protection, Research, and Sanctuaries Act (Ocean Dumping Act), and under 40 CFR § 229.3 of the US EPA regulations. Refer to the Offshore Dredging and Disposal Activities chapter for additional recommendations and BMPs for the disposal of vessels.

## Navigation Dredging

### *Introduction*

Channel dredging is a ubiquitous and chronic maintenance activity associated with port and harbor operation and vessel activity (Barr 1987; NEFMC 1998). Navigational dredging occurs in rivers, estuaries, bays, and other areas where ports, harbors, and marinas are located (Messieh and El-Sabh 1988). The locations of these facilities often coincide with sensitive aquatic habitats that are vital for supporting fishery production (Newell et al. 1998).

For the purposes of navigation, dredging can be generally classified as either creating new or expanded waterways with greater profiles, depths, and scope or as maintenance of existing waterways for the purpose of maintaining established profiles, depths, and scope. Although the latter category represents the most common dredging scenario, new construction, or "improvement" dredging as it is sometimes called, has become increasingly common at larger ports and harbors throughout the United States. Several corresponding factors have likely led to greater need for navigational "improvements" and increases in the operating depths and the sizes of existing ports and harbors, including: (1) increased demand for marine cargo and transportation; (2) expansion of commercial fleets; (3) increased demand for larger capacity commercial and recreational vessels; and (4) increased urbanization and infrastructure development along the coast (Messieh et al. 1991; Wilbur and Pentony 1999; Nightingale and Simenstad 2001b). In particular, this demand for larger capacity commercial cargo vessels has led to an increased competition among the major coastal ports to provide facilities to accommodate these vessels. Improvement dredging may occur in areas that have not previously been subjected to heavy vessel traffic and dredging activities, such as new commercial marinas or the creation of a new channel or turning basin in an existing port or marina facility. Because improvement dredging is often conducted in areas that have been less affected by previous dredging and vessel activities, the impacts are generally more severe than the impacts associated with regular maintenance dredging activities unless the sediments involved in the maintenance dredging contain high levels of contaminants (Allen and Hardy 1980).

Maintenance dredging is generally required in most navigation channels and port and marina facilities because of the continuous deposition of sediments from freshwater runoff or littoral drift. Navigation channels require maintenance dredging to remove accumulated sediments, typically conducted on a temporal scale of one to ten years (Nightingale and Simenstad 2001b). Alterations in sedimentation patterns of estuaries resulting from increased coastal development and urbanization often increases the sediment influx and the frequency for maintaining existing channels and ports. Dredging for other purposes, such as aggregate mining for sand and gravel, conveyance of flood flows, material for beach nourishment, and removal of contaminated sediments or construction of subtidal confined disposal of contaminated sediments, may be done separately or in conjunction with navigation dredging (Nightingale and Simenstad 2001b). Refer to the Offshore Dredging and Disposal Activities chapter of this report for more information on offshore aggregate mining and to the Coastal Development chapter of this report contains information on the affects of beach nourishment and other coastal development activities.

There is a variety of methods and equipment used in navigation dredging, and a detailed explanation and assessment is beyond the scope of this report. However, one can categorize dredging activities as either using hydraulic or mechanical equipment. The type of equipment used for navigation dredging primarily depends on the nature of the sediments to be removed and the type of disposal required. Some of the factors that determine the equipment type used are the characteristics of the material to be dredged, the quantities of material to be dredged, the dredging depth, the distance to the disposal area, the physical environmental factors of the dredging and disposal area, the contamination level of sediments, the methods of disposal, the production (i.e., rate of material removed) required, and the availability of the dredge equipment (Nightingale and Simenstad 2001b).

Hydraulic dredging involves the use of water mixed with sediments that forms a slurry, which is pumped through a pipeline onto a barge or a hopper bin for off-site disposal. To increase the productivity of the dredging operation (i.e., maximizing the amount of solid material transported to the disposal site), some of the water in the sediment slurry may be allowed to overflow out of the hopper which can increase the turbidity in the surrounding water column. If the disposal site is relatively close to the dredge site, the slurry may be pumped through a pipeline directly to the disposal site (e.g., beach disposal).

Mechanical dredging typically involves the use of a clamshell dredge, which consists of a bucket of hinged steel that is suspended from a crane. The bucket, with its jaws open, is lowered to the bottom and as it is hoisted up, the jaws close and carry the sediments to the surface. The sediments are then placed in a separate barge for transport to a disposal site. Bucket dredges tend to increase the suspended sediment concentrations compared to hydraulic dredges because of the resuspension created as sediment spills through the tops and sides of the bucket when the bucket contacts the bottom, during withdrawal of the bucket through the water column, and when it breaks the water's surface (Nightingale and Simenstad 2001b). Closed or "environmental" buckets are designed to reduce the sediment spill from the bucket by incorporating modifications such as rubber seals or overlapping plates and are often used in projects involving contaminated sediments.

The location and method of disposal for dredged material depends on the suitability of the material determined through chemical, and often, biological analyses conducted prior to the dredging project. Generally, sediments determined to be unacceptable for open water disposal are placed in confined disposal facilities or contained aquatic disposal sites and capped with uncontaminated sediments. Sediments that are determined to be uncontaminated may be placed in open-water disposal sites or used for beneficial uses. Beneficial uses are intended to provide environmental or other benefits to the human environment, such as shoreline stabilization and erosion control, habitat restoration/enhancement, beach nourishment, capping contaminated sediments, parks and recreation, agriculture, strip mining reclamation and landfill cover, and construction and industrial uses (Nightingale and Simenstad 2001b). Open water disposal sites can be either predominantly nondispersive (i.e., material is intended to remain at the disposal site) or dispersive (i.e., material is intended to be transported from the disposal site by currents and/or wave action (Nightingale and Simenstad 2001b). The potential for environmental impacts is dependent upon the type of disposal operation used, the physical characteristics of the material, and the hydrodynamics of the disposal site. Refer to the chapter on Offshore Dredging and Disposal Activities for more detailed information on dredge material disposal.

Dredging to deepen or maintain ports, marinas, and navigational channels involves a number of environmental effects to fishery habitats, including the direct removal or burial of demersal and benthic organisms and aquatic vegetation, alteration of physical habitat features, the disturbance of bottom sediments (resulting in increased turbidity), contaminant releases in the water column, light attenuation, releases of oxygen consuming substances and nutrients, entrainment of living organisms in dredge equipment, noise disturbances, and the alteration of hydrologic and temperature regimes. Dredging is often accompanied by a significant decrease in the abundance, diversity, and biomass of benthic organisms in the affected area and an overall reduction in the aquatic productivity of the area (Allen and Hardy 1980; Newell et al. 1998). The rate of recovery of the benthic community is dependent upon an array of environmental variables which reflect interactions between sediment particle mobility at the sediment-water interface and complex associations of chemical and biological factors operating over long time periods (Newell et al. 1998).

### *Loss or conversion of benthic habitat and substrate*

Alterations in bathymetry, benthic habitat features, and substrate types caused by navigational dredging activities may have long-term effects on the functions of estuarine and other aquatic environments. The effects of an individual project are proportional to the scale and time required for a project to be completed, with small-scale and short-term dredging activities having less impact on benthic communities than long-term and large-scale dredging projects (Nightingale and Simenstad 2001b). Dredging can have cumulative effects on benthic communities, depending upon the dredging interval, the scale of the dredging activities, and the ability of the environment to recover from the impacts. The new exposed substrate in a dredged area may be composed of material containing more fine sediments than before the dredging, which can reduce the recolonization and productivity of the benthos and the species that prey upon them.

The impacts to benthic communities vary greatly with the type of sediment, the degree of disturbance to the substrate, the intrinsic rate of reproduction of the species, and the potential for recruitment of adults, juveniles, eggs, and larvae (Newell et al. 1998). Following a dredging event, sediments may be nearly devoid of benthic infauna, and those that are the first to recolonize are typically opportunistic species which may have less nutritional value for consumers (Allen and Hardy 1980; Newell et al. 1998).

In general, dredging can be expected to result in a 30-70% decrease in the benthic species diversity and 40-95% reduction in number of individuals and biomass (Newell et al. 1998). Recovery of the benthic community is generally defined as the establishment of a successional community which progresses towards a community that is similar in species composition, population density, and biomass to that previously present or at nonimpacted reference sites (Newell et al. 1998). The factors which influence the recolonization of disturbed substrates by benthic infauna are complex, but the suitability of the postdredging sediments for benthic organisms and the availability of adjacent, undisturbed communities which can provide a recruitment source are important (Barr 1987; ICES 1992). Rates of benthic infauna recovery for disturbed habitats may also depend upon the type of habitat being affected and the frequency of natural and anthropogenic disturbances. Benthic infauna recovery rates may be less than one year for some fine-grained mud and clay deposits, where a frequent disturbance regime is common, while gravel and sand substrates, which typically experience more stability, may take many years to recover (Newell et al. 1998). Post-dredging recovery in cold waters at high latitudes may require additional time because these benthic communities can be comprised of large, slow-growing species (Newell et al. 1998).

### *Loss of submerged aquatic vegetation*

Submerged aquatic vegetation provides food and shelter for many commercially and recreationally important species, attenuates wave and current energy, and plays an important role in the chemical and physical cycles of coastal habitats (Thayer et al. 1997). The loss of vegetated shallows results in a reduction in important rearing and refugia functions utilized by migrating and resident species. Seagrass beds are more difficult to delineate and map than some other subtidal habitats because of their spatial and temporal dynamic nature, making these habitats more vulnerable to being inadvertently dredged (Thayer et al. 1997; Deegan and Buchsbaum 2005). Dredging causes both direct and indirect impacts to SAV. The physical removal of plants through dredging is a direct impact, while the reduction in light penetration and burial or smothering that is a result of the turbidity plumes and sedimentation created by the dredge are indirect impacts (Deegan and Buchsbaum 2005). While SAV may regrow in a dredged area if the exposure to excessive suspended sediments is not protracted and most of the accumulated sediments are removed by currents and tides after dredging ceases (Wilber et al. 2005), the recolonization by SAV may be limited if the bottom sediments are destabilized or the composition of the bottom sediments is altered (Thayer et al. 1997). Even when bottom sediments are stabilized and are conducive to SAV growth, channel deepening may result in the area having inadequate light regimes necessary for the recolonization of SAV (Barr 1987).

Dredge and fill operations require a permit review process which is regulated by state and federal agencies. Advancement in understanding the physical impacts of dredging on SAV and recognition of the ecological significance of these habitats has allowed special consideration for SAV beds during the permit review process. Most reviewing agencies discourage dredging activities in or near SAV beds as well as in areas that have been historically known to have SAV and areas that are potential habitats for SAV recruitment (Orth et al. 2002).

While the physical disturbance to SAV beds from dredge activities may have significant localized effects, water quality problems such as eutrophication, pollution and sedimentation have resulted in large-scale declines to SAV in some areas of the northeastern US coast (Goldsborough 1997; Deegan and Buchsbaum 2005; Wilber et al. 2005). The small, localized disturbance of SAV associated with dredging may be viewed as a significant impact in the context of diminished regional health and distribution resulting from stressors such as poor water quality and cumulative effects such as dredging, boating (propeller scour), and shoreline alteration (Goldsborough 1997; Thayer et al. 1997; Deegan and Buchsbaum 2005). The environmental effects of excess nutrients and sediments are the most common and significant causes of SAV decline worldwide (Orth et al. 2006).

### *Loss of intertidal habitat and wetlands*

Intertidal habitats (e.g., mud and sand flats) and wetlands (e.g., salt marsh) are valuable coastal habitats which support high densities and diversities of biota by supporting biological functions such as breeding, juvenile growth, feeding, predator avoidance, and migration (Nightingale and Simenstad 2001b). These valuable habitats are also some of the most vulnerable to alterations through coastal development, urbanization, and the expansion of ports and marinas.

The loss of intertidal habitat and the deepening of subtidal habitat during dredging for marina development and for navigation can alter or eliminate the plant and animal assemblages associated with these habitats, including SAV and shellfish beds (Nightingale and Simenstad 2001b; MacKenzie 2007). Dredging in intertidal habitats can alter the tidal flow, currents, and tidal mixing regimes of the dredged area as well as other aquatic habitats in the vicinity, leading to changes in the environmental parameters necessary for successful nursery habitats (Barr 1987). Dredging in tidal wetlands can also encourage the spread of nonnative invasive organisms by removing or disturbing the native biota and altering the physical and chemical properties of the habitat (Hanson et al. 2003; Tyrrell 2005).

Navigational dredging converts shallow subtidal or intertidal habitats into deeper water environments through the removal of sediments (Nightingale and Simenstad 2001b, Deegan and Buchsbaum 2005). The historical use of dredged materials was to infill wetland, salt marshes, and tidal flats in order to create more usable land. The Boston Harbor, MA, area is a prime example of this historical trend, where thousands of acres of salt marsh and intertidal wetlands have been filled over time (Deegan and Buchsbaum 2005). Filling wetlands eliminates the biological, chemical, and physical functions of intertidal habitat such as flood control, nutrient filter or sink, and nursery habitat. Although direct dredging and filling within intertidal wetlands are relatively rare in recent times, the lost functions and values of intertidal wetlands and the connectivity between upland and subtidal habitat is difficult and costly to create and restore (Nightingale and Simenstad 2001b).

### *Underwater noise*

Fish can detect and respond to sounds for many life history requirements, including locating prey and avoiding predation, spawning, and various social interactions (Myrberg 1972; Myrberg and Riggio 1985; Kalmijn 1988). The noise generated by pumps, cranes, and by the mechanical action of the dredge itself has the ability to alter the natural behavior of fish and other aquatic organisms. Feist et al. (1996) reported that pile-driving operations had an affect on the distribution and behavior of juvenile pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta*). Fish may leave an area for more suitable spawning grounds or may avoid a natural migration path because of noise disturbances.

The noise levels and frequencies produced from dredging depend on the type of dredging equipment being used, the depth and thermal variations in the surrounding water, and the topography and composition of the surrounding sea floor (Nightingale and Simenstad 2001b; Stocker 2002). However, dredging activities from both mechanical and hydraulic dredges produce underwater sounds that are strongest at low frequencies and because of rapid attenuation of low frequencies in shallow water, dredge noise normally is undetectable underwater at ranges beyond 20-25 km (Richardson et al. 1995). Although the noise levels from large ships may exceed those from dredging, single ships usually do not produce strong noise in one area for a prolonged period of time (Richardson et al. 1995). The noise created during dredging can produce continuous noise impacts for extended periods of time (Nightingale and Simenstad 2001b).

### *Siltation, sedimentation, and turbidity*

Dredging degrades habitat quality through the resuspension of sediments which creates turbid conditions and can release contaminants into the water column, in addition to impacting benthic organisms and habitat through sedimentation. Turbidity plumes ranging in the hundreds to thousands mg/L are created and can be transported with tidal currents to sensitive resource areas. Alterations in bottom sediments, bottom topography, and altered circulation and sedimentation patterns related to dredge activities can lead to shoaling and sediment deposition on benthic resources such as spawning grounds, SAV, and shellfish beds (Wilber et al. 2005; MacKenzie 2007). Early life history stages (eggs, larvae, and juveniles) and sessile organisms are the most sensitive to sedimentation impacts (Barr 1987; Wilber et al. 2005). Some estuarine and coastal habitats are prone to natural sediment loads and sediment resuspension because of the relatively dynamic nature of the ecosystems; therefore, most organisms adapted to these environments have tolerance to some level of suspended sediments and sedimentation (Nightingale and Simenstad 2001b).

The reconfiguration of sediment type and the removal of biogenic structure during dredging may decrease the stability of the bottom and increase the ambient turbidity levels (Messieh et al. 1991). This increased turbidity and sedimentation can reduce the light penetration of the water column which then can adversely affect SAV and reduce primary productivity (Cloern 1987; Dennison 1987; Wilbur and Pentony 1999; Mills and Fonseca 2003; Wilbur et al. 2005). The combination of decreased photosynthesis and the interaction of the suspended material with dissolved oxygen in the water may result in short-term oxygen depletion (Nightingale and Simenstad 2001b).

If suspended sediment loads remain high, fish may experience respiratory distress and reduced feeding ability because of sight limitations, while filter feeders may suffer a reduction in growth and survival (Messieh et al.1991; Barr 1993; Benfield and Minello 1996; Nightingale and Simenstad 2001b). Prolonged exposure to suspended sediments can cause gill irritation, increased mucus production, and decreased oxygen transfer in fish (Nightingale and Simenstad 2001b; Wilber et al. 2005). Reduced dissolved oxygen concentrations and increased water temperatures may be cumulative stressors that exacerbate the effects of respiratory distress on fish from extended exposure to suspended sediments (Nightingale and Simenstad 2001b). In addition, mobile species may leave an area for more suitable feeding or spawning grounds, or avoid migration paths because of turbidity plumes created during navigational dredging.

Increased turbidity and sedimentation may also bury benthic organisms and demersal fish eggs. The depth of burial and the density of the substrate may limit the natural escape response of some organisms that are capable of migrating vertically through the substrate (Barr 1987; Wilber et al. 2005). In addition, anoxic conditions in the disturbed sediments may decrease the ability of benthic organisms to escape burial (Barr 1987). Short-term burial, where sediment deposits are promptly removed by tides or storm events, may have minimal effects on some species (Wilber et al. 2005). However, even thin layers of fine sediment have been documented to decrease gas exchange in fish eggs and adversely affect the settlement and recruitment of bivalve larvae (Wilber et al. 2005). An in-situ experiment with winter flounder (*Pseudopleuronectes americanus*) eggs exposed to sediment deposition from a navigational dredging project found a slightly lower larval survival rate compared to control sites, but the differences were not statistically significant (Klein-MacPhee et al. 2004). However, the viability of the larvae in this experiment was not monitored beyond burial escapement. Similarly, laboratory experiments with winter flounder eggs buried to various depths (i.e., control, <0.5 mm, and up to 2 mm) indicated a decreased hatch success and delayed hatch with increasing depth; but differences were not statistically significant (Berry et al. 2004). The same study also exposed winter flounder eggs to both clean, fine-grained sediment and highly contaminated, fine-grained sediment at various depths from 0.5-6.0 mm. The investigators found that eggs buried to depths of 4 mm with clean sediments did not hatch, while eggs buried to depths of 3 mm with contaminated sediments had little or no hatching success (Berry et al. 2004). Although there are clearly adverse effects to sessile benthic organisms and life stages from sedimentation from dredging activities, additional investigations are needed to assess lethal and sublethal thresholds for more species and under different sediment types and quality. In addition, better understanding about the relationship between natural and anthropogenic sources of suspended sediments and population-level effects is needed.

The use of certain types of dredging equipment can result in greatly elevated levels of fine-grained particles in the water column. Mechanical dredging techniques such as clam shell or bucket dredges usually increase suspended sediments at the dredge site more than hydraulic dredge techniques such as hopper or cutterheads, unless the sediment and water mixture (slurry) removed during hydraulic dredging is allowed to overflow from the barge or hopper and into the water column, a technique often used to reduce the number of barge trips required (Wilber and Clarke 2001). Mechanical dredges are most commonly used for smaller projects or in locations requiring maneuverability such as close proximity to docks and piers or in rocky sediments (Wilber et al. 2005), although small hydraulic dredges can be used to reduce suspended sediment concentrations in the dredging area and minimize impacts on adjacent benthic habitats, such as SAV or shellfish beds.

Seasonal or time-of-year (TOY) restrictions to dredging activities are used to constrain the detrimental affects of dredging to a timeframe that minimizes impacts during sensitive periods in the life history of organisms, such as spawning, egg development, and migration (Nightingale and Simenstad 2001b; Wilber et al. 2005). Segregating dredging impacts by life history stages provides a means for evaluating how different impacts relate to specific organisms and life history strategies (Nightingale and Simenstad 2001b). The application of TOY restrictions should be based upon the geographic location, species and life history stages present, and the nature and scope of the dredging project. Because the employment of TOY restrictions may have some negative effects, such as extending the overall length of time required for dredging and disposal, increasing the impacts on less economically valuable or poorly studied species, and increasing the economic costs of a project, the benefits of TOY restrictions should be evaluated for each individual dredging project (Wilber et al. 2005; Nightingale and Simenstad 2001b).

### Contaminant release and source exposure

Contaminated sediments are a concern because of the risk of transport of the contaminants and the exposure to aquatic organism and humans through bioaccumulation and biomagnification (Nightingale and Simenstad 2001b). Navigation dredging can create deep channels where currents are reduced and fine sediments may be trapped. Nutrients and contaminants can bind to fine particles such as those that may settle in these deep channels (Newell et al. 1998; Messiah et al. 1991). Dredging and disposal causes resuspension of the sediments into the water column and the contaminants that may be associated with the sediment particles. The disturbance of bottom sediments during dredging can release metals (e.g., lead, zinc, mercury, cadmium, copper), hydrocarbons (e.g., PAH), hydrophobic organics (e.g., dioxins), pesticides, pathogens, and nutrients into the water column and allow these substances to become biologically available either in the water column or through trophic transfer (Wilbur and Pentony 1999; USEPA 2000; Nightingale and Simenstad 2001b). Generally, the resuspension of contaminated sediments can be reduced by avoiding dredging in areas containing fine sediments. In addition, the biological and/or chemical testing requirements under the Marine Protection, Research, and Sanctuaries Act and the Clean Water Act are designed to minimize adverse effects of dredge material disposal on the environment. For additional information regarding the affects of contaminants associated with resuspended sediments, refer to the chapters on Offshore Dredging and Disposal Activities and Chemical Affects: Water Discharge Facilities in this report.

### Release of nutrients/eutrophication

Dredging can degrade water quality through resuspension of sediments and the release of nutrients and other contaminants into the water column. Nutrients and contaminants may adhere to these fine particles (Newell et al. 1998; Messieh et al. 1991). The resuspension of this material creates turbid conditions and decreases photosynthesis. The combination of decreased photosynthesis and the release of organic material with high biological oxygen demand can result in short-term oxygen depletion to aquatic resources (Nightingale and Simenstad 2001b). Long-term anoxia can occur if highly organic sediments are dredged or discharged into estuaries, particularly in enclosed or confined bodies of water. The loss of SAV is linked to poor water quality from increased turbidity and nutrient loading (Deegan and Buchsbaum 2005; Wilber et al. 2005).

### Entrainment and impingement

Entrainment is the direct uptake of aquatic organisms by the suction field created by hydraulic dredges. Benthic infauna are particularly vulnerable to entrainment by dredging, although some mobile epibenthic and demersal species such as shrimp, crabs, and fish can be susceptible to entrainment as well (Nightingale and Simenstad 2001b). Elicit avoidance responses to suction dredge entrainment has been reported for some demersal and pelagic mobile species (Larson and Moehl 1990; McGraw and Armstrong 1990). The susceptibility to entrainment for some pelagic species may be related to the degree of waterway constriction in the area of the dredging, which makes it more difficult for fish to avoid the dredge operation (Larson and Moehl 1990; McGraw and Armstrong 1990).

### *Altered tidal, current, and hydrologic regimes*

Large channel deepening projects can potentially alter ecological relationships through a change in freshwater inflow, tidal circulation, estuarine flushing, and freshwater and saltwater mixing (Nightingale and Simenstad 2001b). Dredging may also modify longshore current patterns by altering the direction or velocity of water flow from adjacent estuaries. These changes in water circulation are often accompanied by changes in the transport of sediments and siltation rates resulting in alteration of local habitats used for spawning and feeding (Messieh et al. 1991).

Altered circulation patterns around dredged areas can also lead to changes in sediment composition and deposition and in the stability of the seabed. The deep channels created during navigational dredging may experience reduced current flow that allows the area to become a sink for fine particles as they settle out of the water column or slump from the channel walls (Newell et al. 1998). In some cases this may change the sediment composition from sand or shell substrate to a substrate consisting of fine particles which flocculate easily and are subject to resuspension by waves and currents (Messieh et al. 1991). This destabilization of the seabed can lead to changes in sedimentation rates and a reduction in benthic resources, such as shellfish beds and SAV (Wilber et al. 2005). In addition, changes in substrate type can smother demersal eggs, affect larval settlement, and increase predation on juveniles adapted to coarser bottom substrates (Messieh et al. 1991; Wilber et al. 2005).

Navigational dredging can remove natural benthic habitat features, such as shoals, sand bars, and other natural sediment deposits. The removal of such features can alter the water depth, change current direction or velocity, modify sedimentation patterns, alter wave action, and create bottom scour or shoreline erosion (Barr 1987). Channel dredging can alter the estuarine hydrology and the mixing zone between fresh and salt water, leading to accelerated upland run-off, lowered freshwater aquifers, and greater saltwater intrusion into aquifers, as well as reduce the buffering capabilities of wetlands and shallow water habitats (Barr 1987; Nightingale and Simenstad 2001b).

Navigational channels that are substantially deeper than surrounding areas can become anoxic or hypoxic as natural mixing is decreased and detrital material settles out of the water column and accumulates in the channels. This concentration of anoxic or hypoxic water can stress nearshore biota when mixing occurs from a storm event (Allen and Hardy 1980). The potential for anoxic conditions can be reduced in areas that experience strong currents or wave energy, and sediments are more mobile (Barr 1987; Newell et al. 1998).

### *Altered temperature regimes*

Channel and port dredging can alter bottom topography, increase water depths, and change circulation patterns in the dredged area, which may increase stratification of the water column and reduce vertical mixing. This thermal layering of water may create anoxic or hypoxic conditions for benthic habitats. Deepened or new navigation channels may create deep and poorly flushed areas that experience reduced light penetration and water temperatures. Temperature influences biochemical processes and deep channels may create zones of poor productivity that can serve as barriers to migration for benthic and demersal species and effectively fragment estuarine habitats.

### *Conservation recommendations and best management practices for navigational dredging*

1. Avoid new dredging to the maximum extent practicable. Activities that would likely require dredging (such as placement of piers, docks, marinas, etc.) should instead be located in deep water or designed to alleviate the need for maintenance dredging.
2. Reduce the area and volume of material to be dredged to the maximum extent practicable.

3. Ensure that the volumes of dredge material are appropriately considered and that the identified disposal sites are adequate in containing the material. For example, the volume of material removed for the allowable over-depth dredging (usually 2 feet below the authorized or target depth) should be included in the disposal volume calculations.
4. Ensure that areas proposed for dredging are necessary in order to maintain the necessary and authorized target depths of the channel. Recent bathymetric surveys should be reviewed to evaluate the existing depths of the area proposed for dredging. Areas within the proposed dredge area that are at or deeper than the target depths should be avoided, whenever practicable.
5. Identify sources of erosion in the watershed that may be contributing to excessive sedimentation and the need for regular maintenance dredging activities. Implement appropriate management techniques to ensure that actions are taken to curtail those causes.
6. Use settling basins to act as sediment traps to prevent accretion of sediments in the navigational channel, when appropriate. This reduces the need for frequent maintenance dredging of the entire channel.
7. Consider the effects of increased boat traffic to an area when assessing a new dredging project or expanding existing channels. Increases in the speed, size, and density of boat traffic in an area may require increased frequency of maintenance dredging and produce a number of secondary impacts, such as shoreline erosion, sedimentation, and turbidity.
8. Identify the user group during the planning process to ensure that the dredging project meets the basic needs of the target user without exceeding an appropriate size and scope, or encouraging inappropriate use.
9. Consider time-of-year dredging restrictions, which may reduce or avoid impacts to sensitive life history stages, such as migration, spawning, or egg and young-of-year development. Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
10. Avoid projects that involve dredging intertidal and wetland habitat.
11. Avoid dredging in areas with SAV, areas which historically supported SAV, and areas which are potential habitat for recolonization by SAV.
12. Conduct both historic surveys of the area and predredge surveys because of the spatial and temporal dynamic nature of SAV beds.
13. Avoid dredging in areas supporting shellfish beds.
14. Consider beneficial uses for uncontaminated sediments when practicable and feasible. Priority should be given to beneficial uses of material that contributes to habitat restoration and enhancement, landscape ecology approach, and includes pre- and post-disposal surveys.
15. Avoid beneficial use projects that impose unnatural habitats and features and involve habitat trade-offs (substituting one habitat type for another).
16. Ensure that sediments are tested for contaminants and meet or exceed US EPA requirements and standards prior to dredging and disposal.
17. Assess cumulative impacts for current activities in the vicinity of a proposed dredging project, as well as for activities in the past and foreseeable future.
18. Ensure that bankward slopes of the dredged area are slanted to acceptable side slopes (e.g., 3:1 ratio) to ensure that sloughing of the channel side slopes does not occur.
19. Avoid placing pipelines and accessory equipment used in conjunction with dredging operations close to algae beds, eelgrass beds, estuarine/salt marshes, and other high value habitat areas.
20. Use silt curtains in some locations to reduce impacts of suspended sediments on adjacent benthic resources.
21. Avoid dredging in fine sediments when possible to reduce turbidity plumes and the release of nutrients and contaminants which tend to bind to fine particles.

22. Include information on control sites and predredging sampling for comparison and monitoring of impacts in environmental assessments for dredging projects.
23. Ensure that disposal sites are properly sited (i.e., avoid sensitive resources and habitats) and are appropriate for the type of dredge material proposed for disposal.
24. Ensure that disposal sites are being properly managed (e.g., disposal site marking buoys, inspectors, the use of sediment capping and dredge sequencing) and monitored (e.g., chemical and toxicity testing, benthic recovery) to minimize impacts associated with dredge material.

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