CHAPTER THREE: ENERGY-RELATED ACTIVITIES

Petroleum Exploration, Production, and Transportation

Introduction

The exploration, production, and transportation of petroleum have the potential to impact riverine, estuarine, and marine environments on the northeastern US coast. Petroleum exploration, production, and transportation are a particular concern in areas such as the Gulf of Maine and Georges Bank, which support important fishery resources and represent significant value to the US economy. Although petroleum exploration and production do not currently occur within the northeast coastal and offshore region, the transportation of oil and gas (i.e., pipelines and tankers) and the associated infrastructure are widespread. It is expected that issues relating to petroleum development will continue to gain importance as world energy costs and demands rise. The Energy Policy Act of 2005 (Pub. L. 109-58, § 357, 42 U.S.C. §15912) authorizes the Minerals Management Service (MMS) to perform surveys (exploration) for petroleum reserves on the Outer Continental Shelf (OCS) of the United States. The OCS is the submerged lands, subsoil, and seabed lying between the United States' seaward jurisdiction and the seaward extent of federal jurisdiction.

Petroleum exploration involves seismic testing, drilling sediment cores, and test wells in order to locate potential oil and gas deposits. Petroleum production includes the drilling and extraction of oil and gas from known reserves. Oil and gas rigs are placed on the seabed and as oil is extracted from the reservoirs, it is transported directly into pipelines. While rare, in cases where the distance to shore is too great for transport via pipelines, oil is transferred to underwater storage tanks. From these storage tanks, oil is transported to shore via tanker (CEQ 1977). According to the MMS, there are 21,000 miles of pipeline on the United States OCS. According to the National Research Council (NRC), pipeline spills account for approximately 1,900 tonnes per year of petroleum into US OCS waters, primarily in the central and western Gulf of Mexico (NRC 2003).

The major sources of oil releases as a result of petroleum extraction include accidental spills and daily operational discharges. The NRC estimates the largest anthropogenic source of petroleum hydrocarbon releases into the marine environment is from petroleum extraction-related activities. Approximately 2,700 tonnes per year in North America and 36,000 tonnes per year worldwide are introduced to the marine environment as a result of "produced waters" (NRC 2003). "Produced waters" are waters that are pumped to the surface from oil reservoirs which cannot be separated from the oil. Produced waters are either injected back into reservoirs or discharged into the marine environment (NRC 2003). Over 90% of the oil released from extraction activities is from produced water discharges which contain dissolved compounds (i.e., polycyclic aromatic hydrocarbons, PAH) and dispersed crude oil (NRC 2003). These compounds stay suspended in the water column and undergo microbial degradation or are sorbed onto suspended sediments and are deposited on the seabed. Elevated levels of PAH in sediments are typically found up to 300 m from the discharge point (NRC 2003).

While petroleum extraction and transportation can result in impacts to the marine environment, it is important to note that natural seeps contribute to approximately 60% of all petroleum hydrocarbons that are released into the marine environment (NRC 2003). In addition, land-based runoff and discharges by two–stroke recreational boating engines account for nearly 22% of the total petroleum released into the marine environment in North America (NRC 2003).

Underwater noise

Oil and gas activities generate noise from drilling activities, construction, production facility operations, seismic exploration, and supply vessel and barge operations that can disrupt or damage living marine resources. The effects of oil exploration-related seismic energy may cause fish to disperse from the acoustic pulse with possible disruption to their feeding patterns (Marten et al. 2001). Larvae and young fish are particularly sensitive to noise generated from underwater seismic equipment. Noise in the marine environment may adversely affect marine mammals by causing them to change behavior (e.g., movement and feeding), interfering with echolocation and communication, or injuring hearing organs (Richardson et al. 1995). Noise issues related to petroleum tanker traffic can adversely affect fishery resources within the marine environment, particularly within estuarine areas which host much of the nation's petroleum land-based port activities. Refer to the chapters on Marine Transportation and Global Effects and Other Impacts for information regarding impacts to fishery resources from underwater noise.

Habitat conversion and loss

Petroleum extraction and transportation can lead to a conversion and loss of habitat in a number of ways. Activities such as vessel anchoring, platform or artificial island construction, pipeline laying, dredging, and pipeline burial can alter bottom habitat by altering substrates used for feeding or shelter. Disturbances to the associated epifaunal communities, which may provide feeding or shelter habitat, can also result. The installation of pipelines associated with petroleum transportation can have direct and indirect impacts on offshore, nearshore, estuarine, wetland, beach, and rocky shore coastal zone habitats. The destruction of benthic organisms and habitat can occur through the installation of pipelines on the sea floor (Gowen 1978). Benthic organisms, especially prey species, may recolonize disturbed areas, but this may not occur if the composition of the substrate is drastically changed or if facilities are left in place after production ends.

The discharge of drilling cuttings (i.e., crushed sedimentary rock) during petroleum extraction operations can result in varying degrees of change to the sea floor and affect feeding, nursery, and shelter habitat for various life stages of marine organisms. Cuttings may adversely affect bottom-dwelling organisms at the site by burial of immobile forms or forcing mobile forms to migrate. The accumulation of drill cuttings on the ocean floor can alter the benthic sedimentary environment (NRC 2003).

Physical damage to coastal wetlands and other fragile areas can be caused by onshore infrastructure and pipelines associated with petroleum production and transportation. Physical alterations to habitat can occur from the construction, presence, and eventual decommissioning and removal of facilities such as islands or platforms, storage and production facilities, and pipelines to onshore common carrier pipelines, storage facilities, or refineries. For additional information regarding impacts of pipelines associated with petroleum production, refer to the section on Cables and Pipelines in this chapter of the report.

Contaminant discharge

A variety of contaminants can be discharged into the marine environment as a result of petroleum extraction operations. Waste discharges associated with a petroleum facility include drilling well fluids, produced waters, surface runoff and deck drainage, and solid-waste from wells (i.e., drilling mud and cuttings) (NPFMC 1999). In addition to crude oil spills, chemical, diesel, and other contaminant spills can occur with petroleum-related activities (NPFMC 1999).

Produced waters contain finely dispersed oil droplets that can stay suspended in the water column or can settle out into sediments. Produced waters are generally more saline than seawater and contain elevated concentrations of radionuclides, metals, and other contaminants. Elevated levels of contaminated sediments typically extend up to 300 m from the discharge point (NRC 2003). In estuarine waters, higher saline produced waters can affect the salt wedge and form dense saltwater plumes.

The discharge of oil drilling mud can change the chemical and physical characteristics of benthic sediments at the disposal site by introducing toxic chemical constituents. The addition of contaminants can reduce or eliminate the suitability of the water column and substrate as habitat for fish species and their prey. The discharge of oil-based drill cuttings are currently not permitted in US waters; however, where oil-based drill cuttings have been discharged, there is evidence that sediment contamination and benthic impacts can occur up to 2 km from the production platform (NRC 2003).

The petroleum refining process converts crude oil into gasoline, home heating oil, and other refined products. The process of refining crude oil into various petroleum products produces effluents, which can degrade coastal water quality. Oil refinery effluents contain many different chemicals at different concentrations including ammonia, sulphides, phenol, and hydrocarbons. Toxicity tests have shown that most refinery effluents are toxic, but to varying extents. Some species are more sensitive and the toxicity may vary throughout the life cycle. Experiments have shown that not only can the effluents be lethal, but they can often have sublethal effects on growth and reproduction (Wake 2005). Field studies have shown that oil refinery effluents often have an adverse impact on aquatic organisms (i.e., an absence of all or most species), which is more pronounced in the area closest to the outfall (Wake 2005).

The operation of oil tankers can discharge contaminants into the water column and result in impacts to pelagic and benthic organisms. Older tankers that do not have segregated ballast tanks (i.e., completely separated from the oil cargo and fuel systems) can discharge ballast water containing contaminants (NRC 2003).

Discharge of debris

Petroleum extraction and transportation can result in the discharge of various types of debris, including domestic wastewater generated from offshore facilities, solid-waste from wells (i.e., drilling mud and cuttings), and other trash and debris from human activities associated with the facility (NPFMC 1999). Debris, either floating on the surface, suspended in the water column, covering the benthos, or along the shoreline can have deleterious impacts on fish and shellfish within riverine habitat, as well as in benthic and pelagic habitats in the marine environment (NEFMC 1998). Debris from petroleum extraction and transportation activities can be ingested by fish (Hoagland and Kite-Powell 1997). Reduction and degradation of habitat by debris can alter community structure and affect the sustainability of fisheries.

Oil spills

In even moderate quantities, oil discharged into the environment can affect habitats and living marine resources. Accidental discharge of oil can occur during almost any stage of exploration, development, or production on the OCS and in nearshore coastal areas and can occur from a number of sources, including equipment malfunction, ship collisions, pipeline breaks, other human error, or severe storms (Hanson et al. 2003). Oil spills can also be attributed to support activities associated with product recovery and transportation and can also involve various contaminants including hazardous chemicals and diesel fuel (NPFMC 1999).

Oil, characterized as petroleum and any derivatives, can be a major stressor to inshore fish habitats. Oil can kill marine organisms, reduce their fitness through sublethal effects, and disrupt the structure and function of the marine ecosystem (NRC 2003). Short-term impacts include interference with the reproduction, development, growth and behavior (e.g., spawning and feeding) of fishes, especially at early life-history stages (Gould et al. 1994). Petroleum compounds are known to have carcinogenic and mutagenic properties (Larsen 1992). Various levels of toxicity have been observed in Atlantic herring (*Clupea harengus*) eggs and larvae exposed to crude oil in concentrations of 1-20 ml/L (Blaxter and Hunter 1982). Oil spills may cover and degrade coastal habitats and associated benthic communities or may produce a slick on the surface waters which disrupts the pelagic community. These impacts may eventually lead to disruption of community organization and dynamics in affected regions. Oil can persist in sediments for years after the initial contamination (NRC 2003), interfering with physiological and metabolic processes of demersal fishes (Vandermeulen and Mossman 1996).

Oil spills can have adverse effects to both subtidal and intertidal vegetation. Direct exposure to petroleum can lead to die off of submerged aquatic vegetation (SAV) in the first year of exposure. Certain species which propagate by lateral root growth rather than seed germination may be less susceptible to oil in the sediment (NRC 2003). Oil has been demonstrated to disrupt the growth of vegetation in estuarine habitats (Lin and Mendelssohn 1996). Kelp located in low energy environments can retain oil in their holdfasts for extended periods of time. Oil spills are known to cause severe and long-term damage to salt marshes through the covering of plants and contamination of sediments. Lighter and more refined oils such as No. 2 fuel oil are extremely toxic to smooth cordgrass (*Spartina alterniflora*) (NRC 2003). Impacts to salt marsh habitats from oil spills depend on type, coverage, and amount of oil. Oil spills within salt marshes will likely have a greater impact in the spring growing season, compared to the dormant periods in the fall and winter.

Habitats that are susceptible to damage from oil spills include the low-energy coastal bays and estuaries where heavy deposits of oil may accumulate and essentially smother intertidal and salt marsh wetland communities. High-energy cobble environments are also susceptible to oil spills, as oil is driven into sediments through wave action. For example, many of the beaches in Prince William Sound, AK, with the highest persistence of oil following the *Exxon Valdez* oil spill were high-energy environments containing large cobbles overlain with boulders. These beaches were pounded by storm waves following the spill, which drove the oil into and well below the surface (Michel and Hayes 1999). Oil contamination in sediments may persist for years. For example, subsurface oil was detected in beach sediments of Prince William Sound twelve years after the *Exxon Valdez* oil spill, much of it unweathered and more prevalent in the lower intertidal biotic zone than at higher tidal elevations (Short et al. 2002).

Oil can have severe detrimental impacts on offshore habitats, although the effects may not be as acute as in inshore, sheltered areas. Offshore spills or wellhead blowouts can produce an oil slick on surface waters which can disrupt entire pelagic communities (i.e., phytoplankton and zooplankton). The disruption of plankton communities can interfere with the reproduction, development, growth, and behavior of fishes by altering an important prey base.

Physical and biological forces act to reduce oil concentrations (Hanson et al. 2003). Generally, the lighter fraction aromatic hydrocarbons evaporate rapidly, particularly during periods of high wind and wave activity. Heavier oil fractions typically pass through the water column and settle to the bottom. Suspended sediments can adsorb and carry oil to the seabed. Hydrocarbons may be solubilized by wave action which may enhance adsorption to sediments, which then sink to the seabed and contaminate benthic sediments (Hanson et al. 2003). Tides and hydraulic gradients allow movement of soluble and slightly soluble contaminants (e.g., oil) from beaches to surrounding streams in the hyporheic zone (i.e., the saturated zone under a river or stream, comprising substrate with the interstices filled with water) where pink salmon (*Oncorynchus* *gorbuscha*) eggs incubate (Carls et al. 2003). Oil can reach nearshore areas and affect productive nursery grounds, such as estuaries that support high densities of fish eggs and larvae. An oil spill near a particularly important hydrological zone, such as a gyre where fish or invertebrate larvae are concentrated, could also result in a disproportionately high loss of a population of marine organisms (Hanson et al. 2003). Epipelagic biota, such as eggs, larvae and other planktonic organisms, would be at risk from an oil spill. Planktonic organisms cannot actively avoid exposure, and their small size means contaminants may be absorbed quickly. In addition, their proximity to the sea surface can increase the toxicity of hydrocarbons several-fold and make them more vulnerable to photo-enhanced toxicity effects (Hanson et al. 2003).

Many factors determine the degree of damage from a spill, including the composition of the petroleum compound, the size and duration of the spill, the geographic location of the spill, and the weathering process present (NRC 2003). Although oil is toxic to all marine organisms at high concentrations, certain species and life history stages of organisms appear to be more sensitive than others. In general, the early life stages (i.e., eggs and larvae) are most sensitive, juveniles are less sensitive, and adults least so (Rice et al. 2000). Some marine species may be particularly susceptible to hydrocarbon spills if they require specific habitat types in localized areas and utilize enclosed water bodies, like estuaries or bays (Stewart and Arnold 1994).

Small but chronic oil spills may be a particular problem to the coastal ecosystem because residual oil can build up in sediments. Low-levels of petroleum components from such chronic pollution have been shown to accumulate in fish tissues and cause lethal and sublethal effects, particularly at embryonic stages. Effects on Atlantic salmon (*Salmo salar*) from low-level chronic exposure to petroleum components and byproducts (i.e., polycyclic aromatic hydrocarbons [PAH]) have been shown to increase embryo mortality, reduce growth (Heintz et al. 2000), and lower the return rates of adults returning to natal streams (Wertheimer et al. 2000).

As spilled petroleum products become weathered, the aromatic fraction of oil is dominated by PAH as the lighter aromatic components evaporate into the atmosphere or are degraded. Because of its low solubility in water, PAH concentrations probably contribute little to acute toxicity (Hanson et al. 2003). However, lipophilic PAH (those likely to be bonded to fat compounds) may cause physiological injury if they accumulate in tissues after exposure (Carls et al. 2003; Heintz et al. 2000). Even concentrations of oil that are diluted sufficiently to not cause acute impacts in marine organisms may alter certain behavior or physiological patterns. For example, “fatty change,” a degenerative disease of the liver, can occur from chronic exposure to organic contaminants such as oil (Freeman et al. 1981).

Sublethal effects that may occur with exposure to PAH include impairment of feeding mechanisms for benthic fish and shellfish, growth and development rates, energetics, reproductive output, juvenile recruitment rates, increased susceptibility to disease and other histopathic disorders (Capuzzo 1987), and physical abnormalities in fish larvae (Urho and Hudd 1989). Effects of exposure to PAH in benthic species of fish include liver lesions, inhibited gonadal growth, inhibited spawning, reduced egg viability and reduced growth (Johnson et al. 2002). Gould et al. (1994) summarized various toxicity responses to winter flounder (*Pseudopleuronectes americanus*) exposed to PAH and other petroleum-derived contaminants, including liver and spleen diseases, immunosuppression responses, tissue necrosis, altered blood chemistry, gill tissue clubbing, mucus hypersecretion, altered sex hormone levels, and altered reproductive impairments. For Atlantic cod (*Gadus morhua*) exposed to various petroleum products, responses included reduced growth rates, gill hyperplasia, increased skin pigmentation, hypertrophy of gall bladder, liver disease, delayed spermatogenesis, retarded gonadal development and other reproductive impairments, skin lesions, and higher parasitic infections (Gould et al. 1994).

Oil spill clean-up activities

There are a number of oil spill response and cleanup methods available. Chemical dispersants are used primarily in open water environments. Dispersants contain surfactant chemical that under proper mixing conditions and concentrations attach to oil molecules and reduce the interfacial tension between oil molecules (NOAA 1992). This allows oil molecules to break apart and thus break down the oil slick. Depending on the environmental conditions and biological resource present, dispersants can result in acute toxicity. Exposure to high concentrations of oil dispersants has been shown to block the fertilization of eggs and induce rapid cytolysis of developing eggs and larvae in Atlantic cod (Lonning and Falk-Petersen 1978). Other methods of cleanup for open water spills include in-situ burning and nutrient and microbial remediation. In each case, impacts are dependent on the resources present in the particular location. Other forms of shoreline cleanup include the use of sorbents, trenching, sediment removal, and water flooding/pressure washing. Sediment removal and pressure washing will result in direct impact to the benthos. Trampling and cutting of salt marsh vegetation during cleanup activities can be severe, causing damage to plants and forcing oil into the sediments. However, impacts associated with the cleanup activities need to be weighed against the impacts created by the the spill itself.

Siltation, sedimentation, and turbidity

Exploratory and construction activities may result in resuspension of fine-grained mineral particles, usually smaller than silt, in the water column. Fish and invertebrate habitat may be adversely affected by elevated levels of suspended particles (Arruda et al. 1983), which can result in both lethal and sublethal impacts to marine organisms (Newcombe and MacDonald 1991; Newcombe and Jensen 1996). Short-term impacts from increases in suspended particles may include high turbidity, reduced light, and sedimentation which may lead to the loss or complexity of benthic habitat (USFWS and NMFS 1999). Suspended particles can reduce light penetration and lower the rate of photosynthesis and the primary productivity of the aquatic area, especially if the turbidity is persistent (Gowen 1978). Groundfish and other fish species can suffer reduced feeding ability and limited growth if high levels of suspended particles persist in the water column. Other problems associated with suspended solids include disrupted respiration and water transport rates in marine organisms, reduced filtering efficiencies in invertebrates, reduced egg buoyancy, disrupted ichthyoplankton development, reduced growth and survival of filter feeders, and decreased foraging efficiency of sight-feeders (Gowen 1978; Messieh et al. 1991; Barr 1993). Demersal eggs of fish and invertebrates can be adversely impacted by sediment deposition and suffocation. For example, hatching is delayed for striped bass (*Morone saxatilis*) and white perch (*Morone americana*) exposed to sediment concentrations as low as 100 mg/L for 1 day (Wilber and Clarke 2001). Berry et al. (2004) reported a decreased hatching success for winter flounder eggs with increasing depth of burial by sediment. No hatching occurred at burial depths of approximately 2 mm. Breitburg (1988) found the predation rates of striped bass larvae on copepods to decrease by 40% when exposed to high turbidity conditions in the laboratory. Anadromous fish passage in estuarine and riverine environments can also be adversely impacted by increased turbidity. For example in laboratory experiments, rainbow smelt (*Osmerus mordax*) showed signs of increased swimming activity at suspended sediment concentrations as low as 20 mg/L, suggesting fish responded to increased sediment concentrations with an “alarm reaction” (Chiasson 1993).

Shallow water environments, rocky reefs, nearshore and offshore rises, salt and freshwater marshes (wetlands), and estuaries are more likely to be adversely impacted than are open-water habitats. This is due, in part, to their higher sustained biomass and lower water volumes, which decrease their ability to dilute and disperse suspended sediments (Gowen 1978).

Conservation recommendations and best management practices for petroleum exploration, production, and transportation (adapted from Hanson et al. 2003)

1. Conduct preconstruction biological surveys in consultation with resource agencies to determine the extent and composition of biological populations or habitat in the proposed impact area. Construction should be sited to minimize impacts to fishery resources.
2. Avoid the discharge of produced waters into marine and estuarine environments. Reinject produced waters into the oil formation whenever possible.
3. Avoid discharge of drilling mud and cuttings into the marine, estuarine, and riverine environment.
4. Avoid placing roads and bridges and structures associated with petroleum exploration and production in the nearshore marine environment. Particular care should be made to avoid SAV, intertidal flats, and salt marsh habitat.
5. Use methods to transport oil and gas that limit the need for handling in sensitive fishery habitats.
6. Use horizontal directional drilling for installation of pipelines in areas containing sensitive habitats, whenever possible.
7. Provide for monitoring and leak detection systems at oil extraction, production, and transportation facilities that preclude oil from entering the environment.
8. Evaluate impacts to habitat during the decommissioning phase, including impacts during the demolition phase.
9. Schedule dredging and excavation activities when the fewest species and least vulnerable life stages are present. Appropriate work windows can be established based on the multiple season biological sampling. Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
10. Ensure that oil extraction, production, and transportation facilities have developed and implemented adequate oil spill response plans. Assist government agencies responsible for oil spills (e.g., US Coast Guard, state and local resource agencies) in developing response plans and protocols, including identification of sensitive marine habitats and development and implementation of appropriate oil spill-response measures.
11. Potential adverse impacts to marine resources from oil spill clean-up operations should be weighed against the anticipated adverse affects of the oil spill itself. The use of chemical dispersants in nearshore areas where sensitive habitats are present should be avoided.
12. Address the cumulative impacts of past, present, and foreseeable future development projects on aquatic habitats by considering them in the review process for petroleum exploration, production, and transportation projects.

Liquefied Natural Gas (LNG)

Introduction

Liquefied Natural Gas (LNG) is expected to provide a large proportion of the future energy needs in the northeastern United States. In recent years there has been an increase in proposals for new LNG facilities, including both onshore and offshore facilities from Maine to Delaware. In the northeastern United States, there are currently onshore LNG facilities operating in Everett, MA, and Cove Point, MD, and two offshore LNG facilities have been approved to operate in Massachusetts Bay.

The LNG process cools natural gas to its liquid form at approximately -260 degrees Fahrenheit (F). This reduces the volume of natural gas to approximately 1/600th of its gaseous state volume, making it possible for economical transportation with tankers. Upon arrival at the destination, the LNG is either regasified onshore or offshore and sent out into an existing pipeline infrastructure, or transported onshore for storage and future regasification. The process of regasification occurs when LNG is heated and converted back to its gaseous state. LNG facilities can utilize either "open loop," "closed loop," or "combined loop" systems for regasification. Open loop systems utilize warm seawater for regasification, and closed loop systems generally utilize a recirculating mixture of ethylene glycol for regasification. Combined loop systems utilize a combination of the two systems.

Onshore LNG facilities generally include a deepwater access channel, land-based facilities for regasification and distribution, and storage facilities. Offshore facilities generally include some type of a deepwater port with a regasification facility and pipelines to transport natural gas into existing gas distribution pipelines or onshore storage facilities. Deepwater ports require specific water depths and generally include some form of exclusion zone for LNG vessel and/or port facility security.

Habitat conversion and loss

The conversion of habitat and/or the loss of benthic habitats can occur from the construction and operation of LNG facilities. The placement of pipelines and associated structures on the seafloor can impact benthic habitats from physical occupation and conversion of the seafloor. The installation of pipelines can impact shellfish beds, hard-bottomed habitats, and SAV (Gowen 1978). Plowing or trenching for pipeline installation and side-casting of material can lead to a conversion of substrate and habitat. Placement of anchors for the construction of the deepwater port facilities can have direct impact to the substrate and benthos.

Because of the large size of LNG tankers, dredging may need to occur in order to access onshore terminals. The deepening of channel areas and turning basins can result in permanent and temporary dredging impacts to fishery habitat, including the loss of spawning and juvenile development habitat caused by changes in bathymetry, suitable substrate type, and sedimentation. Disruption of the areas from dredging and sedimentation may cause spawning fish to leave the area for more suitable spawning conditions. Dredging, as well as the equipment used in the process such as pipelines, may damage or destroy other sensitive habitats such as emergent marshes and SAV, including eelgrass beds (Mills and Fonseca 2003) and macroalgae beds. The stabilization and hardening of shorelines for the development of upland facilities can lead to a direct loss of SAV, intertidal mudflats, and salt marshes that serve as important habitat for a variety of living marine resources. See the Marine Transportation, Offshore Dredging and Disposal, and Coastal Development chapters for more detailed information on impacts from dredging.

Discharge of contaminants

Discharge of contaminants can occur as a result of spills during offloading procedures associated with either onshore or offshore facilities. There is limited information and experience regarding the aquatic impacts resulting from an LNG spill; however, because of the toxic nature of natural gas, acute impacts to nearby resources and habitats can be expected.

Biocides (e.g., copper and aluminum compounds) are often utilized in the hydrostatic testing of pipelines. LNG tankers utilize large amounts of seawater for regasification purposes (i.e., open-loop system), for engine cooling, and for ship ballast water. Biocides are commonly utilized to prevent pipeline and engine fouling from marine organisms and are subsequently discharged into surrounding waters. 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 vertical migration of larvae was impaired at copper concentrations of greater than 300 µg/L (Blaxter 1977). The release of contaminants can reduce or eliminate the suitability of water bodies as habitat for fish species and their prey. In addition, contaminants, such as copper and aluminum, can accumulate in sediments and become toxic to organisms contacting or feeding on the bottom.

Discharge of debris

LNG facilities can result in the discharge of debris, including domestic waste waters generated from the offshore facility, and other trash and debris from human activities associated with the facility (NPFMC 1999). Impacts from the discharge of debris from LNG are similar to those described in the Petroleum Exploration, Production, and Transportation section of this chapter.

Siltation, sedimentation, and turbidity

LNG construction activities may result in increased suspended sediment in the water column caused by dredging, the installation of pipelines, anchors and chains, and the movement of vessels through confined areas, and upland site development. Impacts from siltation and sedimentation from LNG are similar to those described in the Petroleum Exploration, Production, and Transportation section of this chapter.

Entrainment and impingement

Intake structures for traditional power plants can result in impingement and entrainment of marine organisms through the use of seawater for cooling purposes (Enright 1977; Helvey 1985; Callaghan 2004). Likewise, intake structures utilized for the LNG regasification process can result in impingement and entrainment of living marine resources. “Open-loop” LNG regasification systems utilize seawater for warming into a gaseous state and are typically utilized when ambient water temperatures are greater than about 45°F. In addition, “combined loop” systems can utilize seawater for partial regasification. Depending on the geographic location and the water depth of the intake pipe, phytoplankton, zooplankton, and fish eggs and larvae can be entrained into the system. Juvenile fish can also be impinged on screens of water intake structures (Hanson et al. 1977; Hanson et al. 2003). Normal ship operations utilize intake structures for ballast water and engine cooling and can result in additional impingement and entrainment of resources, as well.

The entrainment and impingement impacts on aquatic organisms from LNG facilities have the potential to be substantial. For example, an assessment of impacts of a proposed LNG facility in the Gulf of Mexico determined that an open-loop regasification system could utilize 176 million gallons of water per day, which may entrain 1.6 billion fish and 60 million shrimp larvae per year, 3.3 billion fish eggs per year, and 500 billion zooplankton per year (R. Ruebsamen, pers. comm.). Additional entrainment and impingement impacts were expected for vessel ballast and cooling water uses. In the northeastern United States, an offshore LNG regasification facility approved in Massachusetts Bay with a closed-loop system has estimated annual mortality rates caused by vessel ballast and cooling water for the eggs and larvae for Atlantic mackerel (*Scomber scombrus*), pollock (*Pollachius virens*), yellowtail flounder (*Limanda ferruginea*), and Atlantic cod of 8.5 million, 7.8 million, 411,000, and 569,000, respectively (USCG 2006).

Alteration of temperature regimes

The operation of LNG facilities can result in the alteration of temperature regimes. Discharge of water from engine cooling operations can be at temperatures up to 10°F higher than surrounding waters. Water utilized for the purposes of regasification could be discharged at temperatures colder than the surrounding water by about 10-15°F. Changes in water temperatures can alter physiological functions of marine organisms, including respiration, metabolism, reproduction, and growth. In riverine and estuarine environments, changes to water temperatures can impact the egg and juvenile life stages of Atlantic salmon (USFWS and NMFS 1999). Thermal effluent in inshore habitat can cause severe problems by directly altering the benthic community or adversely affecting marine organisms, especially egg and larval life stages (Pilati 1976; Rogers 1976). For example, the seaward migration of juvenile American shad (*Alosa sapidissima*) are cued to water temperatures (Richkus 1974; MacKenzie et al. 1985), and temperature influences biochemical processes of the environment and the behavior (e.g., migration) and physiology (e.g., metabolism) of marine organisms (Blaxter 1969; Stanley and Colby 1971).

Alteration of hydrological regimes

The operation of LNG facilities can affect the hydrology of confined waterbodies, waterbodies with limited flows such as streams and rivers, and estuaries fed by streams and rivers. Depending upon the characteristics of the waterbody and the nature of the water intake and discharge, altered stream flow can result in reductions in stream flow and subsequent degradation of ecosystem functions (Reiser et al. 2004).

Alteration of salinity regimes

The operation of LNG tankers can result in the alteration of hydrological regimes caused by the discharge of brine from onboard desalination operations. For example, the operation of LNG tankers within riverine and estuarine environments can impact anadromous fish by altering salinity regimes (Dodson et al. 1972; Leggett and O’Boyle 1976) and affecting the ability of fish to access migration corridors.

Underwater noise

Underwater noise sources generate sound pressure that can disrupt or damage marine life. LNG activities generate noise from construction, production facility operations, and tanker traffic. Larvae and young fish are particularly sensitive to noise generated from underwater seismic equipment. It is also known that noise in the marine environment may adversely affect marine mammals by causing them to change behavior (e.g., movement, feeding), interfering with echolocation and communication or injuring hearing organs (Richardson et al. 1995). Noise issues related to LNG tanker traffic may adversely affect fishery resources in the marine environment, particularly in estuarine areas where some LNG port activities are located or proposed. A more thorough review of underwater noise can be found in the chapter on Global Effects and Other Impacts.

Exclusion zones

Because of security concerns, LNG tankers and terminals include safety and exclusion areas. Different types of restrictions are put in place based on the distance from the facility. However, restrictions on commercial and recreational fishing activities around the LNG facilities can lead to a displacement of fishing effort to other/adjacent areas. This in turn, may increase fishing effort and habitat impacts to more ecologically sensitive areas.

Introduction of invasive species

Introductions of nonnative invasive species into marine and estuarine waters are a significant threat to living marine resources in the United States (Carlton 2001). Nonnative species can be released unintentionally when ships release ballast water (Hanson et al. 2003; Niimi 2004). Hundreds of species have been introduced into United States waters from overseas and from other regions around North America, including finfish, shellfish, phytoplankton, bacteria, viruses, and pathogens (Drake et al. 2005). LNG tankers entering US waters are generally loaded with cargo and do not need to release large amounts of ballast water. However, even small amounts of released ballast water have the potential to contain invasive exotic species. In addition, as vessels are unloaded and ballast is taken on in US waters, the water may contain species that are potentially invasive to other locations. The transportation of nonindigenous organisms to new environments can have severe impacts on habitat (Omori et al. 1994), change the natural community structure and dynamics, lower the overall fitness and genetic diversity of natural stocks, and pass and/or introduce exotic lethal disease. Refer to the chapters on Marine Transportation and Introduced/Nuisance Species and Aquaculture for more information on invasive species and shipping.

Conservation recommendations and best management practices for LNG facilities

1. Conduct preconstruction biological surveys in consultation with resource agencies to determine the extent and composition of biological populations or habitat in the proposed impact area.
2. Recommend the use of “closed loop” systems, which minimize the volume of water utilized for regasification, over “open loop” systems. This will serve to minimize the level of impingement and entrainment of living marine resources.
3. Locate facilities that use surface waters for regassification and engine cooling purposes away from areas of high biological productivity, such as estuaries.
4. Design intake structures to minimize entrainment or impingement.
5. Regulate discharge temperatures (both heated and cooled effluent) such that they do not appreciably alter the temperature regimes of the receiving waters, which could cause a change in species assemblages and ecosystem function. Strategies should be implemented to diffuse the heated effluent.
6. Avoid the use of biocides (e.g., aluminum, copper, chlorine compounds) to prevent fouling where possible. The least damaging antifouling alternatives should be implemented.
7. Implement operational monitoring plans to analyze impacts resulting from intake and discharge structures and link them to a plan for adaptive management.
8. Provide for monitoring and leak detection systems at natural gas production and transportation facilities that preclude gas from entering the environment.
9. Schedule dredging and excavation activities when the fewest species and least vulnerable life stages are present. Appropriate work windows can be established based on the multiple season biological sampling. Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
10. Address cumulative impacts of past, present, and foreseeable future development projects on aquatic habitats by considering them in the project review process of LNG facilities construction and operations. Based on evaluation of the foreseeable impacts to fishery habitats, a determination can be made regarding the most suitable location and operational procedures for LNG facilities. Ideally, such an analysis would be done at the regional or national level based on natural gas usage and need.

11. Ensure that gas production and transportation facilities have developed and implemented adequate gas spill response plans. Assist government agencies responsible for gas spills (e.g., US Coast Guard, state and local resource agencies) in developing response plans and protocols, including identification of sensitive marine habitats and development and implementation of appropriate gas spill-response measures.

Offshore Wind Energy Facilities

Introduction

Offshore wind energy facilities (windmills) convert wind energy into electricity through the use of turbines. An offshore facility generally consists of a series of wind turbine generators, an inner-array of submarine electric cables that connect each of the turbines, and a single electric service platform (ESP). Electricity is transmitted from the ESP to an onshore facility through one or a series of submarine cables.

While there are no operating offshore wind facilities in the United States at the writing of this report, there is an increasing number of proposals to develop offshore wind facilities within the northeast region. The construction and operation of offshore wind facilities has the potential to adversely affect fishery habitats.

Habitat conversion and loss

The construction of offshore wind turbines and support structures can result in benthic habitat conversion and loss because of the physical occupation of the natural substrate. Scour protection around the structures, consisting of rock or concrete mattresses, can also lead to a conversion and loss of habitat. For example, the total seafloor area occupied by 130 wind turbines, ESP and associated scour mats for an offshore wind farm proposed in Nantucket Sound, MA, is expected to be approximately 3.21 acres (USACE 2004). Should scour around cables and the base of structures occur, subsequent substrate stabilization activity would lead to additional impact on benthic habitat. Likewise, the burial and installation of submarine cable arrays can impact the benthic habitat through temporary disturbance from plowing and from barge anchor damage. In some cases, plowing or trenching for cable installation can permanently convert benthic habitats when top layers of sediments are replaced with new material. The installation of cables and associated barge anchor damage can adversely affect SAV, if those resources are present in the project area. Cable maintenance, repairs, and decommissioning can also result in impacts to benthic resources and substrate.

Siltation, sedimentation, and turbidity

The construction of wind turbine and support structures can cause increased turbidity in the water column and sedimentation impacts on adjacent benthic habitats. Likewise, the subsurface installation of underwater cables can result in similar impacts. Most of these impacts are relatively short-term and should subside after construction is completed. Maintenance and repairs of wind turbines and submarine electric cables can be expected to persist during the operation of the wind generator facilities. Increased sedimentation and turbidity during the decommissioning of wind energy facilities could be greater than the construction impacts if all submarine structures were to be removed. Siltation, sedimentation, and turbidity impacts related to the construction and maintenance activities from offshore wind energy projects are similar to those described in the Petroleum Exploration, Production, and Transportation section of this chapter.

Alteration of hydrological regimes

The placement of wind energy facilities, especially large arrays or "farms," in marine and estuarine habitats may affect hydrological regimes by altering tidal and current patterns. Altered current patterns could affect the distribution of eggs and larvae and the distribution of species within estuaries and bays, as well as the migration patterns of anadromous fishes.

Alteration of electromagnetic fields

Background direct current electric fields originate from the metallic core of the Earth and the electric currents flowing in the upper layer of the Earth's crust. The strength of this geomagnetic field is highest at the magnetic poles and the lowest at the equator. Marine fishes, such as elasmobranches and anadromous fishes, utilize natural electromagnetic fields (EMFs) for navigation and migratory behavior (Gill et al. 2005). Studies have shown sharks and rays are capable of detecting artificial EMFs (Meyer et al. 2005), and some species have a remarkable sensitivity to electric fields in seawater (Kalmijn 1982). Some species of fish have shown sensitivity to underwater EMFs, including several species of sharks (i.e., *Scyliorhinus canicula, Mustelus canis,* and *Prionace glauca)* and thornback skate (*Raja clavata*) (Kalmijn 1982); and sea lamprey (*Petromyzon marinus*), eels (*Anguilla sp.*), Atlantic cod, plaice (*Pleuronectes platessa*), yellowfin tuna (*Thunnus albacares*) and Atlantic salmon (Gill et al. 2005). Electrical cables associated with offshore wind energy facilities produce EMFs (and induced electric fields) which could interfere with fish behavior. However, at the present time there is no conclusive evidence that EMFs have an adverse effect on marine species (Gill et al. 2005).

Underwater noise

Underwater noise during construction of turbines may have impacts to hearing in fish and may cause fish to disperse with possible disruption to their feeding and spawning patterns. Underwater noise from the operation of wind turbines may decrease the effective range for sound communication in fish and mask orientation signals (Wahlberg and Westerberg 2005). Atlantic salmon and cod have been shown to detect offshore windmills at a maximum distance of about .04 km to 25 km at high wind speeds (i.e., >13 m/s), and noise from turbines can lead to permanent avoidance by fish within ranges of about 4 m (Wahlberg and Westerberg 2005). Noise from construction of wind farms (e.g., pile driving) could have significant effects on fish (Hoffmann et al. 2000). It is also known that noise in the marine environment may adversely affect marine mammals by causing them to change behavior (e.g., movement, feeding), interfering with echolocation and communication or injuring hearing organs (Richardson et al. 1995). A more thorough review of underwater noise can be found in the chapter on Global Effects and Other Impacts.

Alteration of community structure

Offshore wind energy facilities have the potential to alter the local community structure of the marine ecosystem. There is significant debate as to whether the presence of underwater vertical structures (e.g., oil platforms) contribute to new fish production by providing additional spawning and settlement habitat or simply attract and concentrate existing fishes (Bohnsack et al. 1994; Pickering and Whitmarsh 1997; Bortone 1998). The aggregation of fish in the vicinity of the wind turbine structures may subject certain species to increased fishing. Additive and synergistic effects of multiple stressors, such as the presence of electric cables on the seafloor and underwater sound generated by the turbines, could have cumulative effects on marine ecosystem and community dynamics (e.g., predator-prey population densities, migration corridors).

Discharge of contaminants

An ESP serves as a connection point for the inner-array of cables as well as a staging area for maintenance activities. Hazardous materials that may be stored at the ESP include fluids from transformers, diesel fuel, oils, greases and coolants for pumps, fans and air compressors. Discharge of these contaminants into the water column can affect the water quality in the vicinity of the offshore wind facility. Further information regarding the impacts of oil spills and contaminants can be found in the Petroleum Exploration, Production, and Transportation section of this chapter, and the chapters on Coastal Development and Chemical Affects: Water Discharge Facilities of the report.

Conservation recommendations and best management practices for offshore wind energy facilities

1. Conduct preconstruction biological surveys in consultation with resource agencies to determine the extent and composition of biological populations or habitat in the proposed impact area.
2. Avoid placing cables associated with offshore wind facilities near sensitive benthic habitats, such as SAV.
3. Use horizontal directional drilling to avoid impacts to sensitive habitats, such as salt marshes and intertidal mudflats.
4. Make contingency plans and response equipment available to respond to spills associated with service platforms.
5. Use scour protection for turbines and associated structures and cables to the minimum practicable in order to avoid alteration and conversion of benthic habitat.
6. Bury cables to an adequate depth in order to minimize the need for maintenance activities and to reduce conflicts with other ocean uses.
7. Time construction of facilities to avoid impacts to sensitive life stages and species. Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
8. Address the cumulative impacts of past, present, and foreseeable future development activities on aquatic habitats in the review process for offshore wind energy facilities construction and operations.

Wave and Tidal Energy Facilities

Introduction

Wave power facilities involve the construction of stationary or floating devices that are attached to the ocean floor, the shoreline, or a marine structure like a breakwater with exposure to adequate "wave climate." Ocean wave power systems can be utilized in the offshore or nearshore environments. Offshore systems can be situated in deep water, typically in depths greater than 40 m (131 ft). Some examples of offshore systems include the Salter Duck, which uses the bobbing motion of the waves to power a pump that creates electricity. Other offshore devices use hoses connected to floats that move with the waves. The rise and fall of the float stretches and relaxes the hoses, which pressurizes the water, which in turn rotates a turbine. In addition, some seagoing vessels can be built to capture the energy of offshore waves. These floating platforms create electricity by funneling waves through internal turbines.

Wave energy can be utilized to generate power from the nearshore area in three ways:

1. Floats or pitching devices generate electricity from the bobbing or pitching action of a floating object. The object can be mounted to a floating raft or to a device fixed on the ocean floor. A

similar device, the pendulor, is a wave-powered device consisting of a rectangular box, which is open to the sea at one end. A flap is hinged over the opening and the action of the waves causes the flap to swing back and forth. The motion powers a hydraulic pump and a generator.
2. Oscillating water columns generate electricity from the wave-driven rise and fall of water in a cylindrical shaft. The rising and falling water column drives air into and out of the top of the shaft, powering an air-driven turbine.
3. Wave surge or focusing devices, also called "tapered channel" or "tapchan" systems, rely on a shore-mounted structure to channel and concentrate the waves, driving them into an elevated reservoir. Water flow out of this reservoir is used to generate electricity by using standard hydropower technologies (USDOE 2003).

Tidal energy facilities are designed to generate power in tidal estuaries through the use of turbines. A barrage, or dam, can be placed across a tidal river or estuary. This design utilizes a build-up of water within a headpond to create a differential on either side (depending on the tide), and then the water is released to turn the turbines. While less efficient, tidal power facilities can also utilize water currents to turn turbines. Turbines can be designed in a number of ways and include the "helical-type" turbines, as well as the "propeller-type" turbines. Turbines are generally placed within areas of fast moving water with strong currents to take advantage of both ebb and flow tides. For impacts associated with conventional hydropower facilities, refer to the chapter on Alteration of Freshwater Systems.

Habitat conversion and loss

The construction of tidal and wave energy facilities includes the placement of structures within the water column, thus converting open water habitat to anthropogenic structure. The placement of support structures, transmission lines, and anchors on the substrate will result in a direct impact to benthic habitats which serve as feeding or spawning habitats for various species. Large-scale tidal power projects which utilize a barrage can cause major changes in the tidal elevations of the headpond which can affect intertidal habitat. Alterations in the range and duration of tide flow can adversely affect intertidal communities that rely on specific hydrological regimes. Mud and sand flats may be converted to subtidal habitat, while high saltmarsh areas that may be normally flooded only on the highest spring tides can become colonized by terrestrial vegetation and invasive species (Gordon 1994).

Siltation, sedimentation, and turbidity

Construction of tidal facilities in riverine and estuarine areas can result in increased sedimentation. Structures placed within riverine and estuarine habitats can reduce the natural transport of sediments and cause an accretion of silt and sediments within impoundments. Deposition of sediments can adversely impact benthic spawning habitats of various anadromous fish species, including riffle and pool complexes. Clean gravel substrates, which are preferred by rainbow smelt and Atlantic salmon, can be subjected to increased siltation from alterations in the sediment transport. Shallow water environments, rocky reefs, nearshore and offshore rises, salt, and freshwater marshes (wetlands), and estuaries are more likely to be adversely impacted than open-water habitats. This is due, in part, to their higher sustained biomass and lower water volumes, which decrease their ability to dilute and disperse suspended sediments (Gowen 1978). Impacts from siltation and sedimentation from wave and tidal power facilities are similar to those described in the Petroleum Exploration, Production, and Transportation section of this chapter.

Alteration of hydrological regimes

Water circulation patterns and the tidal regimes can be altered during the operation of a barrage-type tidal facility. This can result in poor tidal flushing of the headwaters of estuaries and rivers and can lead to decreased water quality and increases in water temperature (Rulifson and Dadswell 1987). Altered current patterns could affect the distribution of eggs and larvae and the distribution of species within estuaries and bays as well as the migration patterns of anadromous fishes. Hydrological regimes may also be impacted by flows passing through and around tidal turbines and support structures.

Entrainment, impingement, and other impacts to migration

Water control structures, such as dams, alter the flow, volume, and depth of water within impoundments and below the structures. Water impoundments tend to stratify the water column, increasing water temperatures and decreasing dissolved oxygen levels. Projects operating as "store and release" facilities can drastically affect downstream water flow and depth, resulting in dramatic fluctuations in habitat accessibility, acute temperature changes and an overall decline in water quality (NEFMC 1998). The construction of dams, with either inefficient or nonexistent fish bypass structures, has been a major cause of the population decline of US Atlantic salmon (USFWS and NMFS 1999). Tidal energy facilities located within estuaries or riverine environments have the potential to directly impact migrating fish (Dadswell et al. 1986). Dadswell and Rulifson (1994) reported various physical impacts to fish traversing low-head, tidal turbines in the Bay of Fundy, Canada, including mechanical strikes with turbine blades, shear damage, and pressure- and cavitation-related injuries/mortality. They found between 21-46% mortality rates for tagged American shad passing through the turbine. The physical presence of tidal power facilities can impact the return of diadromous fishes to natal rivers (Semple 1984). Refer to the chapter on Alteration of Freshwater Systems for further information on impacts from water control structures.

Alteration of electromagnetic fields

Electrical distribution cables associated with ocean wave-power facilities produce EMFs similar to offshore wind energy facilities and may interfere with fish behavior (Gill et al. 2005). Refer to the discussion under the Offshore Wind Energy Facilities in this chapter for information on the affects of EMFs.

Conservation recommendations and best management practices for wave and tidal energy facilities

1. Do not permit the construction of barrage-type tidal energy facilities because of the potential for large impacts to the ecosystem and migratory fishery resources.
2. Require preconstruction assessments for analysis of potential impacts to fishery resources for all projects. Assessments should include comprehensive monitoring of the timing, duration, and utilization of the area by diadromous and resident species, potential impacts from the project, and contingency planning using adaptive management.
3. Do not site projects in areas that may result in adverse effects to sensitive marine and estuarine resources and habitats.
4. Avoid project siting of any wave or tidal energy facility within riverine, estuarine, and marine ecosystems utilized by diadromous species.
5. Time construction of facilities to avoid impacts to sensitive life stages and species. Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.

6. Include impacts associated with the decommissioning and/or dismanteling of wave or tidal energy facility as part of the environmental analyses. Contingency for removal of structures should be required as part of any permits or licenses.
7. Address the cumulative impacts of past, present, and foreseeable future development activities on aquatic habitats in the review process for wave and tidal facilities construction and operations.

Cables and Pipelines

Introduction

With the continued development of coastal regions comes greater demand for the installation of cables, utility lines for power and other services, and pipelines for oil and gas. The installation of pipelines, utility lines, and cables can have direct and indirect impacts on the offshore, nearshore, estuarine, wetland, beach, and rocky shore coastal zone habitats.

Habitat conversion and loss

The installation of cables and pipelines can result in the loss of benthic habitat from dredging and plowing through the seafloor. This can result in a direct loss of benthic organisms, including shellfish. Construction impacts can result in long-term or permanent damage, depending on the degree and type of habitat disturbance and best management practices employed for a project. The installation of pipelines can impact shellfish beds, hard-bottomed habitats, and SAV (Gowen 1978). Cables can damage complex habitats containing epifaunal growth during installation, if allowed to "sweep" along the bottom while being positioned into the correct location. Shallow water environments, rocky reefs, nearshore and offshore rises, salt and freshwater marshes (wetlands), and estuaries are more likely to be adversely impacted than are open-water habitats. This is due to their higher sustained biomass and lower water volumes, which decrease their ability to dilute and disperse suspended sediments (Gowen 1978). Benthic organisms, especially prey species, may recolonize disturbed areas, but this may not occur if the composition of the substrate is drastically changed or if pipelines are left in place after production ends.

Pipelines installed on the seafloor or over coastal wetlands can alter the environment by causing erosion and scour around the pipes, resulting in escarpments on coastal dune and salt marshes, and on the seafloor. Alterations to the geomorphology of coastal habitats from pipelines can exacerbate shoreline erosion and fragment wetlands. Because vegetated coastal wetlands provide forage and protection to commercially important invertebrates and fish, marsh degradation caused by plant mortality, soil erosion, or submergence will eventually decrease productivity.

Pipelines are generally buried below ground by digging trenches or canals. Digging trenches may change the coastal hydrology by: (1) facilitating rapid drainage of interior marshes during low tides or low precipitation; (2) reducing or interrupting freshwater inflow and associated littoral sediments; and (3) allowing saltwater to move farther inland during periods of high tides (Chabreck 1972). Saltwater intrusion into freshwater marsh often causes a loss of salt-intolerant emergent plants and SAV (Chabreck 1972; Pezeshki et al. 1987). Soil erosion and a net loss of organic matter may also occur (Craig et al. 1979).

Conversion of benthic habitat can occur if cables and pipelines are not buried sufficiently within the substrate. Conversion of habitats can also occur in areas where a layer of fine sediment is underlain with coarser materials. Once these materials are plowed for pipeline/cable installation, they can be mixed with underlying coarse sediment, and thus, alter the substrate composition. This can adversely affect the habitat of benthic organisms which rely on soft sand or mud habitats. The armoring of pipeline with either rock or concrete can result in permanent habitat alterations if placed within soft substrate. The placement of cables and pipelines often necessitates removal of hard bottom or rocky habitats in the pipeline corridor. These habitats are removed by using explosives or mechanical fracturing and can result in a reduction of available hard bottom substrate and habitat complexity.

Subsea pipelines that are placed on the substrate have the potential to create physical barriers to benthic invertebrates during migration and movement. In particular, the migration of American lobster (*Homarus americanus*) between inshore and offshore habitats can be adversely affected if pipelines are not buried to sufficient depths (Fuller 2003). Furthermore, erosion around buried pipelines and cables can lead to uncovering of the structure and the formation of escarpements. This, in turn, can interfere with the migratory patterns of benthic species.

Siltation, sedimentation, and turbidity

The installation of cables and pipelines can lead to increased turbidity and subsequent sedimentation, caused by either the plowing or jetting method of installation. Elevated siltation and turbidity during cable and pipeline installation is typically short-term and restricted to the area surrounding the cable and pipeline corridor. However, pipelines that are left unburied and exposed can cause erosion of the substrate and cause persistent siltation and turbidity in the surrounding area. Maintenance activities related to cables and pipelines, as well as removal for decommissioned cables and pipelines, can release suspended sediments into the water column. Long-term effects of suspended sediment include reduced light penetration and lowered photosynthesis rates and the primary productivity of the area (Gowen 1978). Impacts from siltation, sedimentation, and turbidity from cables and pipelines are similar to those described in the Petroleum Exploration, Production, and Transportation section of this chapter.

Release of contaminants

Petroleum products can be released into the environment if pipelines are broken or ruptured by unintentional activities, such as shipping accidents or deterioration of pipelines. A review of impacts from petroleum spills can be found in the Petroleum Exploration, Production, and Transportation section of this chapter. In addition, resuspension of contaminants in sediments, such as metals and pesticides, during pipeline installation can have lethal and sublethal effects to fishery resources (Gowen 1978). Contaminants may have accumulated in coastal sediments from past industrial activities, particularly in heavily urbanized areas. Metals may initially inhibit reproduction and development of marine organisms, but at high concentrations they can directly or indirectly contaminate or kill fish and invertebrates. The early life-history stages of fish are the most susceptible to the toxic impacts associated with metals (Gould et al. 1994). The release of contaminants can reduce or eliminate the suitability of water bodies as habitat for fish species and their prey. In addition, contaminants, such as copper and aluminum, can accumulate in sediments and become toxic to organisms contacting or feeding on the bottom.

Impacts to sensitive wetland and subtidal habitats can be avoided during pipeline and cable installation using horizontal directional drilling techniques, which allow the pipe or cable to be installed in a horizontal drill hole below the substrate. “Frac-outs” (i.e., releases of drilling mud or other lubricants, such as bentonite mud) can occur during the drilling process, and material can escape through fractures in the underlying rock. This typically happens when the drill hole encounters a natural fracture in the rock or when insufficient precautions are taken to prevent new fractures from occurring. Fishery habitats can be adversely affected if a “frac-out” occurs during the installation process and discharges drilling mud or other contaminants into the surrounding area.

Cranford et al. (1999) found that chronic intermittent exposure to sea scallops (*Placopecten magellanicus*) of dilute concentrations of operational drilling wastes, characterized by acute lethal tests as practically nontoxic, can affect growth, reproductive success, and survival.

Maintenance of cables and pipelines can also result in subsequent impacts to the aquatic environment. The maintenance of pipelines includes the "pigging" of pipelines to clean out residual materials from time-to-time. The release of these materials into the surrounding environment can lead to water quality impacts and contamination of adjacent benthic habitats. For example, biocides (e.g., copper and aluminum compounds) are often utilized in the hydrostatic testing of pipelines and are subsequently discharged into surrounding waters. 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 vertical migration of larvae was impaired at copper concentrations of greater than 300 µg/L (Blaxter 1977).

Alteration of electromagnetic fields

Underwater electrical distribution cables produce EMFs that may interfere with fish behavior (Gill et al. 2005). However, at the present time there is no conclusive evidence that EMFs have an adverse effect on marine species (Gill et al. 2005). See also the discussion of underwater EMFs in the Offshore Wind Energy Facilities section of this chapter and the Global Effects and Other Impacts chapter of the report.

Underwater noise

The installation of cables and pipelines can produce underwater noise that may disrupt or damage fishery resources. Noise from construction activities (e.g., pile driving) can have significant effects on fish (Hoffmann et al. 2000). Larvae and young fish are particularly sensitive to noise generated from underwater explosives during blasting. It is also known that noise in the marine environment may adversely affect marine mammals by causing them to change behavior (movement, feeding), interfering with echolocation and communication, or injuring hearing organs (Richardson et al. 1995).

Alteration of community structure

The construction of pipelines and other underwater structures has the potential to alter the local community structure of the marine ecosystem. There is significant debate as to whether the presence of underwater vertical structures (e.g., oil platforms) contribute to new fish production by providing additional spawning and settlement habitat or simply attract and concentrate existing fish within an area (Bohnsack et al. 1994; Pickering and Whitmarsh 1997; Bortone 1998). Underwater pipelines are anthropogenic structures that could have similar attraction and production issues relating to fishery management. As with wind turbines and offshore LNG facilities, aggregation of fishes in the vicinity of pipeline structures may subject certain species to increased fishing pressure. By altering the age and species composition in the area around pipelines, predator/prey interactions and reproduction can be altered, and these changes may have community-level affects on fisheries.

Conservation recommendations and best management practices for cables and pipelines (adapted from Hanson et al. 2003)

1. Align crossings along the least environmentally damaging route. Sensitive habitats such as hard-bottom (e.g., rocky reefs), SAV, oyster reefs, emergent marsh, and mud flats should be avoided.

2. Use horizontal directional drilling where cables or pipelines would cross sensitive habitats, such as intertidal mudflats and vegetated intertidal zones, to avoid surface disturbances. Measures should be employed to avoid/minimize impacts to sensitive fishery habitats from potential frac-outs, including:
    a. The use of nonpolluting, water-based lubricants should be required.
    b. Drill stem pressures should be monitored closely so that potential frac-outs can be identified.
    c. Drilling should be halted, if frac-outs are suspected.
    d. Above ground monitoring should be employed to identify potential frac-outs.
    e. Spill clean-up plan and protocols should be developed, and clean-up equipment should be on-site to quickly respond to frac-outs.
3. Avoid construction of permanent access channels since they disrupt natural drainage patterns and destroy wetlands through excavation, filling, and bank erosion.
4. Backfill excavated wetlands with either the same or comparable material capable of supporting similar wetland vegetation. Original marsh elevations should be restored.
5. Use existing rights-of-way whenever possible to lessen overall encroachment and disturbance of wetlands.
6. Bury pipelines and submerged cables where possible. Unburied pipelines or pipelines buried in areas where scouring or wave activity eventually exposes them can result in impacts to invertebrate migratory patterns.
7. Use silt curtains or other types of sediment control in order to protect sensitive habitats and resources.
8. Limit access for equipment to the immediate project area avoid access through sensitive resources.
9. Avoid the use of open trenching for installation. Methods in which the trench is immediately backfilled reduce the impact duration and should therefore be employed when possible.
10. Conduct construction during the time of year that will have the least impact on sensitive habitats and species. Appropriate work windows can be established based on the multiple season biological sampling. Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
11. Evaluate impacts to habitat during the decommissioning phase, including impacts during the demolition phase and impacts resulting from permanent habitat losses.
12. Address the cumulative impacts of past, present, and foreseeable future development activities on aquatic habitats in the review process for cable and pipeline construction and operations.
13. Ensure that oil and gas pipeline systems include leak detection capabilities to minimize potential impacts from spills.

References for Energy-related Activities

Arruda JA, Marzolf GR, Faulk RT. 1983. The role of suspended sediments in the nutrition of zooplankton in turbid reservoirs. Ecology 64(5):1225-35.

Barr BW. 1993. Environmental impacts of small boat navigation: vessel/sediment interactions and management implications. In: Magoon OT, editor. Coastal Zone '93: proceedings of the eighth Symposium on Coastal and Ocean Management; 1993 Jul 19-23; New Orleans, LA. American Shore and Beach Preservation Association. p 1756-70.

Berry WJ, Hinchey EK, Rubinstein NI, Klein-MacPhee G. 2004. Winter flounder, *Pseudopleuronectes americanus*, hatching success as a function of burial depth in the laboratory. In: Ninth flatfish biology conference- poster presentation; 2004 Dec 1-2; Westbrook, CT. Woods Hole (MA): Northeast Fisheries Science Center Reference Document 04-13.

Blaxter JHS. 1969. Development: eggs and larvae. In: Hoar WS, Randall DJ, editors. Fish physiology: Vol. 3, reproduction and growth, bioluminescence, pigments, and poisons. New York (NY): Academic Press. p 177-252.

Blaxter JHS. 1977. The effect of copper on the eggs and larvae of plaice and herring. Journal of the Marine Biological Association of the United Kingdom 57:849-59.

Blaxter JHS, Hunter JR. 1982. The biology of the clupeoid fishes. In: Blaxter JHS, Russel FS, Yonge M, editors. Advances in marine biology – Vol. 20. New York (NY): Academic Press. p 187-91.

Bohnsack JA, Harper DE, McClellan DB, Hulsbeck M. 1994. Effects of reef size on colonization and assemblage structure of fishes at artificial reefs off southeastern Florida, U.S.A. Bulletin of Marine Science 55(2-3):796-823.

Bortone SA. 1998. Resolving the attraction-production dilemma in artificial reef research: Some yeas and nays. Fisheries 23(3):6-10.

Breitburg DL. 1988. Effects of turbidity on prey consumption by striped bass larvae. Transactions of the American Fisheries Society 117(1):72-7.

Callaghan TP. 2004. Entrainment and impingement of organisms in power plant cooling. In: Cleveland CJ, editor. Encyclopedia of Energy, Vol. 2. Amsterdam (The Netherlands): Elsevier. p 447-57.

Capuzzo JM. 1987. Biological effects of petroleum hydrocarbons: assessment of experimental results. In: Boesch DF, Rabalais NN, editors. Long-term environmental effects of offshore oil and gas development. London (England): Elsevier Applied Science. p 343-410.

Carls MG, Thomas RE, Lilly MR, Rice SD. 2003. Mechanism for transport of oil-contaminated groundwater into pink salmon redds. Marine Ecology Progress Series 248:245-55.

Carlton JT. 2001. Introduced species in U.S. coastal waters: environmental impacts and management priorities. Arlington (VA): Pew Oceans Commission. 28 p.

Chabreck RH. 1972. Vegetation, water, and soil characteristics of the Louisiana coastal region. Baton Rouge (LA): LSU Agricultural Experimental Station.

Chiasson AG. 1993. The effects of suspended sediment on rainbow smelt (*Osmerus mordax*): a laboratory investigation. Canadian Journal of Zoology 71:2419-24.

[CEQ] Council on Environmental Quality. 1977. Oil and gas in coastal lands and waters. Washington (DC): US Government Printing Office. 153 p.

Craig NJ, Turner RE, Day JW Jr. 1979. Land Loss in coastal Louisiana (U.S.A.). Environmental Management 3(2):133-44.

Cranford PJ, Gordon DC Jr, Lee K, Armsworthy SL, Tremblay GH. 1999. Chronic toxicity and physical disturbance effects of water- and oil-based drilling fluids and some major constituents on adult sea scallops (*Placopecten magellanicus*). Marine Environmental Research 48(3):225-56.

Dadswell MJ, Rulifson RA. 1994. Macrotidal estuaries: A region of collision between marine animals and tidal power development. Biological Journal of the Linnean Society 51(1-2):93-113.

Dadswell MJ, Rulifson RA, Daborn GR. 1986. Potential impact of large-scale tidal power developments in the upper Bay of Fundy on fisheries resources of the northwest Atlantic. Fisheries 11(4):26-35.

Dodson JJ, Leggett WC, Jones RA. 1972. The behavior of adult American shad (*Alosa sapidissima*) during migration from salt to fresh water as observed by ultrasonic tracking techniques. Journal of the Fisheries Research Board of Canada 29(10):1445-9.

Drake LA, Jenkins PT, Dobbs FC. 2005. Domestic and international arrivals of NOBOB (no ballast on board) vessels to lower Chesapeake Bay. Marine Pollution Bulletin 50(5):560-5.

Enright JT. 1977. Power plants and plankton. Marine Pollution Bulletin 8(7):158-61.

Freeman HC, Uthe JF, Sangalang GB, Garside ET. 1981. Contaminant/liver histopathology in Canadian Atlantic cod (*Gadus morhua*). Copenhagen (Denmark): ICES CM-1981/ E: 50.

Fuller C. editor. 2003. A workshop on the potential effects of the construction and operation of subsea pipelines on lobster movement and behavior. Blue Atlantic Lobster Workshop Proceedings; 2003 Jun 24; Providence, RI. Willington (CT): ENSR International. 152 p.

Gill AB, Gloyne-Phillips I, Neal KJ, Kimber JA. 2005. The potential effects of electromagnetic fields generated by sub-sea power cables associated with offshore wind farm developments on electrically and magnetically sensitive marine organisms-a review. Final Report: Collaborative Offshore Wind Energy Research into the Environment. London (England): COWRIE 1.5 Electromagnetic Fields Review. 128 p.

Gordon DC Jr. 1994. Intertidal ecology and potential power impacts, Bay of Fundy, Canada. Biological Journal of the Linnean Society 51(1-2):17-23.

Gould E, Clark PE, Thurberg FP. 1994. Pollutant effects on dermersal fishes. In: Langton RW, Pearce JB, Gibson JA, editors. Selected living resources, habitat conditions, and human perturbations of the Gulf of Maine: environmental and ecological considerations for fishery management. Woods Hole (MA): NOAA Technical Memorandum NMFS-NE-106. p 30-41.

Gowen AW. 1978. The environmental effects of outer continental shelf (OCS) pipelines. Initial findings. Boston (MA): New England River Basins Commission 4:24-43.

Hanson CH, White JR, Li HW. 1977. Entrapment and impingement of fishes by power plant cooling water intakes: an overview. Marine Fisheries Review 39:7-17.

Hanson J, Helvey M, Strach R. editors. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. Long Beach (CA): National Marine Fisheries Service (NOAA Fisheries) Southwest Region. Version 1. 75 p.

Heintz RA, Rice SD, Wertheimer AC, Bradshaw RF, Thrower FP, Joyce JE, Short JW. 2000. Delayed effects on growth and marine survival of pink salmon *Oncorhynchus gorbuscha* after exposure to crude oil during embryonic development. Marine Ecology Progress Series 208:205-16.

Helvey M. 1985. Behavioral factors influencing fish entrapment at offshore cooling-water intake structures in southern California. Marine Fisheries Review 47:18-26.

Helvey M. 2002. Are southern California oil and gas platforms essential fish habitat? ICES Journal of Marine Science 59(Suppl.):S266-S271.

Hoagland P, Kite-Powell HL. 1997. Characterization and mitigation of marine debris in the Gulf of Maine. A report prepared for the U.S. Gulf of Maine Association under contract no. GM97-13. Gulf of Maine Council on the Marine Environment. 41 p.

Hoffman E, Astrup J, Larsen F, Munch-Petersen S. 2000. Effects of marine windfarms on the distribution of fish, shellfish, and marine mammals in the Horns Rev Area. Lyngby (Denmark): Danish Institute for Fisheries Research. Report to ELSAMPROJEKT A/S. Report No. Baggrundsrapp 24. 42 p.

Johnson LL, Collier TK, Stein JE. 2002. An analysis in support of sediment quality thresholds for polycyclic aromatic hydrocarbons (PAH) to protect estuarine fish. Aquatic Conservation: Marine and Freshwater Ecosystems 12(5):517-38.

Kalmijn AJ. 1982. The electric and magnetic field detection in Elasmobranch fishes. Science 218(4575):916-18.

Larsen PF. 1992. An overview of the environmental quality of the Gulf of Maine. In: The Gulf of Maine. Silver Spring (MD): NOAA Coastal Ocean Program Synthesis Series No. 1. p 71-95.

Leggett WC, O'Boyle RN. 1976. Osmotic stress and mortality in adult American shad during transfer from saltwater to freshwater. Journal of Fish Biology 8(6):459-69.

Lin Q, Mendelssohn IA. 1996. A comparative investigation of the effects of south Louisiana crude oil on the vegetation of fresh, brackish, and salt marshes. Marine Pollution Bulletin 32(2):202-9.

Lonning S, Falk-Petersen IB. 1978. The effects of oil dispersants on marine eggs and larvae. Astarte 11:135-8.

MacKenzie C, Weiss-Glanz LS, Moring JR. 1985. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates. Washington (DC): US Fish and Wildlife Service. Biological Report 82(11.37). 18 p.

Marten K, Herzing D, Poole M, Newman-Allman K. 2001. The acoustic predation hypothesis: Linking underwater observations and recordings during Odontocete predation and observing the effects of loud impulsive sounds on fish. Aquatic Mammals 27(1):56-66.

Messieh SN, Rowell TW, Peer DL, Cranford PJ. 1991. The effects of trawling, dredging and ocean dumping on the eastern Canadian continental shelf seabed. Continental Shelf Research 11(8-10):1237-63.

Meyer CG, Holland KN, Papastamatiou YP. 2005. Sharks can detect changes in the geomagnetic field. Journal of the Royal Society Interface 2(2):129-30.

Michel J, Hayes MO. 1999. Weathering patterns of oil residues eight years after the *Exxon Valdez* oil spill. Marine Pollution Bulletin 38(10):855-63.

Mills KE, Fonseca MS. 2003. Mortality and productivity of eelgrass *Zostera marina* under conditions of experimental burial with two sediment types. Marine Ecology Progress Series 255:127-34.

[NOAA] National Oceanic and Atmospheric Administration. 1992. An introduction to coastal habitats and biological resources for oil spill response. Seattle (WA): Hazardous Materials Response and Assessment Division. Report No. HMRAD 92-4.

[NRC] National Research Council. 2003. Oil in the sea III: inputs, fates and effects. Washington (DC): National Academy Press.

Newcombe CP, Jensen JO. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16(4):693-727.

Newcombe CP, MacDonald DD. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management 11(1):72-82.

[NEFMC] New England Fishery Management Council. 1998. Final Amendment #11 to the Northeast multispecies fishery management plan, Amendment #9 to the Atlantic sea scallop fishery management plan, Amendment #1 to the Monkfish fishery management plan, Amendment #1 to the Atlantic salmon fishery management plan, and components of the proposed Atlantic herring fishery management plan for essential fish habitat, incorporating the environmental assessment. Newburyport (MA): NEFMC Vol. 1.

Niimi AJ. 2004. Role of container vessels in the introduction of exotic species. Marine Pollution Bulletin 49(9-10):778-82.

[NPFMC] North Pacific Fisheries Management Council. 1999. Environmental Assessment for Amendment 55 to the Fishery Management Plan for the Groundfish Fishery of the Bering Sea and Aleutian Islands Area; Amendment 55 to the Fishery Management Plan for Groundfish of the Gulf of Alaska; Amendment 8 to the Fishery Management Plan for the King and Tanner Crab Fisheries in the Bering Sea and Aleutian Islands; Amendment 5 to the Fishery Management Plan for Scallop Fisheries off Alaska; Amendment 5 to the Fishery Management Plan for the Salmon Fisheries in the EEZ off the Coast of Alaska, Essential Fish Habitat. Anchorage (AK): NPFMC. 367 p.

Omori M, VanderSpoel S, Norman CP. 1994. Impact of human activities on pelagic biogeography. Progress in Oceanography 34(2-3):211-9.

Pezeshki SR, Delaune RD, Patrick WH Jr. 1987. Response of the freshwater marsh species, *Panicum hemitomon* Schult., to increased salinity. Freshwater Biology 17(2):195-200.

Pickering H, Whitmarsh D. 1997. Artificial reefs and fisheries exploitation: a review of the ‘attraction versus production’ debate, the influence of design and its significance for policy. Fisheries Research 31(1-2):39-59.

Pilati DA. 1976. Cold shock: biological implications and a method for approximating transient environmental temperatures in the near-field region of a thermal discharge. Science of the Total Environment 6(3):227-37.

Reiser DW, Chapin D, DeVries P, Ramey MP. 2004. Flow regime and ecosystem interactions in spring dominated streams: Implications for selecting instream flow methods. Hydroecologie Appliquee 14(1):93-104.

Rice SD, Short JW, Heintz RA, Carls MG, Moles A. 2000. Life-history consequences of oil pollution in fish natal habitat. In: Catania P, editor. Energy 2000: the beginning of a new millennium. Lancaster (PA): Technomic Publishers. p 1210-5.

Richardson WJ, Greene CR, Malme CI, Thomas DH. 1995. Marine mammals and noise. San Diego (CA): Academic Press. 576 p.

Richkus WA. 1974. Factors influencing the seasonal and daily patterns of alewife (*Alosa pseudoharengus*) migration in a Rhode Island river. Journal of the Fisheries Research Board of Canada 31:1485-97.

Rogers CA. 1976. Effects of temperature and salinity on the survival of winter flounder embryos. Fisheries Bulletin 74(1):52-8.

Rulifson RA, Dadswell MJ. 1987. Mortality of fish passing through tidal, low-head hydropower turbines and possible mitigation strategies. In: Proceedings of Ocean 87: the ocean-an international workplace; 1987 Sep 28-Oct 1; Halifax, Nova Scotia. Columbia (MD): Marine Technology Society and IEEE Ocean Engineering Society. p 944-9.

Semple JR. 1984. Possible effects of tidal power development in the upper Bay of Fundy on anadromous fish passage. In: Update on the environmental consequences of tidal power in the upper reaches of the Bay of Fundy. Dartmouth (Nova Scotia): Canadian Technical Report of the Fisheries and Aquatic Sciences No. 1256:565-75.

Short JW, Lindeberg MR, Harris PM, Maselko J, Rice SD. 2002. Vertical oil distribution within the intertidal zone 12 years after the *Exxon Valdez* oil spill in Prince William Sound, Alaska. Proceedings of the 25th Arctic and Marine Oilspill Program Technical Seminar. Ottawa (Ontario): Minister of Supply and Services Canada. p 57-72.

Stanley JG, Colby PJ. 1971. Effects of temperature on electrolyte balance and osmoregulation in the alewife (*Alosa pseudoharengus*) in fresh and sea water. Transactions of the American Fisheries Society 100(4):624-38.

Stewart PL, Arnold SH. 1994. Environmental requirements Atlantic herring (*Clupea harengus harengus*) in eastern Canada and its response to human impacts. Dartmouth (Nova Scotia): Canadian Technical Report of Fisheries and Aquatic Sciences 2003: ix + 37p.

Urho L, Hudd R. 1989. Sublethal effects of an oil spill on fish (herring) larvae in the northern Quark, in the Baltic. In: Blaxter JHS, Gamble JC, Westernhagen HV, editors. The early life history of fish; 1988 Oct 3-5; Bergen, Norway. Third ICES Symposium: Rapports et Proces-Verbaux Des Reunions 191. Copenhagen (Denmark): International Council for the Exploration of the Sea. p 494.

[USACE] US Army Corps of Engineers. 2004. Cape Wind Energy Project Draft Environmental Impact Statement (Cape Wind DEIS). Vol. 1. Concord (MA): US Army Corp of Engineers, New England District.

[USCG] US Coast Guard. 2006. Environmental impact statement/environmental impact report for the Neptune LNG deepwater port license application. Washington (DC): USCG-2005-22611.

[USDOE] US Department of Energy. 2003. A consumer's guide to energy efficiency and renewable energy: Ocean wave power. [Internet]. [updated 2003 Feb 7; cited 2007 Dec 19]. Available from: http://www.eere.energy.gov/consumer/renewable_energy/ocean/index.cfm/mytopic=50009.

[USFWS], [NMFS] US Fish and Wildlife Service, National Marine Fisheries Service. 1999. Status review of anadromous Atlantic salmon in the United States. Hadley (MA): USFWS. p 1-131.

Vandermeulen JH, Mossman D. 1996. Sources of variability in seasonal hepatic microsomal oxygenase activity in winter flounder (*Pleuronectes americanus*) from a coal tar contaminated estuary. Canadian Journal of Fisheries and Aquatic Sciences 53:1741-53.

Wahlberg M, Westerberg H. 2005. Hearing in fish and their reactions to sounds from offshore wind farms. Marine Ecology Progress Series 288:295-309.

Wake H. 2005. Oil refineries: a review of their ecological impacts on the aquatic environment. Estuarine, Coastal and Shelf Science 62:131-40.

Wertheimer AC, Heintz RA, Thedinga JF, Maselko JM, Rice SD. 2000. Straying of adult pink salmon from their natal stream following embryonic exposure to weathered *Exxon Valdez* crude oil. Transactions of the American Fisheries Society 129(4):989-1004.

Wilber DH, Clarke DG. 2001. Biological effects of suspended sediments: A review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries. North American Journal of Fisheries Management 21(4):855-75.