CHAPTER EIGHT: PHYSICAL EFFECTS—WATER INTAKE AND DISCHARGE FACILITIES

Introduction

Water intake and discharge facilities are typically municipal or industrial operations that use water for some processing purpose and/or release effluent water into the aquatic environment. Increased water diversion is associated with human population growth and development (Gregory and Bisson 1997). Some examples of facilities that use and discharge water include fossil-fuel and nuclear power plants, sewage treatment facilities, industrial manufacturing facilities, and domestic and agricultural water supply facilities. The construction and operation of water intake and discharge facilities can have a wide range of physical effects on the aquatic environment including changes in the substrate and sediments, water quality and quantity, habitat quality, and hydrology. Most facilities that use water depend upon freshwater or water with very low salinity for their needs. Reductions in the quality and quantity of freshwater to bays and estuaries have led to serious damage to estuaries in the northeast US region and worldwide (Deegan and Buchsbaum 2005). This chapter discusses the physical impacts associated with water discharge and intake facilities. Refer to the chapter on Chemical Affects: Water Discharge Facilities for information on chemical impacts.

Intake Facilities

Introduction

Water intake facilities can be located in riverine, estuarine, and marine environments and can include domestic water supply facilities, irrigation systems for agriculture, power plants, and industrial process users. Nearly half of US water withdrawals are attributed to thermoelectric power facilities, and about one-third are used for agriculture irrigation (Markham 2006). In freshwater riverine systems, water withdrawal for commercial and domestic water use supports the needs of homes, farms, and industries that require a constant supply of water. Freshwater is diverted directly from lakes, streams, and rivers by means of pumping facilities or is stored in impoundments or reservoirs. Water withdrawn from estuarine and marine environments may be used to cool coastal power generating stations, as a source of water for agricultural purposes, and more recently, as a source of domestic water through desalinization facilities. In the case of power plants and desalinization plants, the subsequent discharge of water with temperatures higher than ambient levels can also occur.

Water intake structures can interfere or disrupt ecosystem functions in the source waters, as well as downstream water bodies such as estuaries and bays. The volume and the timing of freshwater delivery to estuaries have been substantially altered by the production of hydropower, domestic and industrial use, and agriculture (Deegan and Buchsbaum 2005). Long-term water withdrawal may adversely affect fish and shellfish populations by adding another source of mortality to the early life-stage, which affects recruitment and year-class strength (Travnichek et al. 1993). Water intake structures can result in adverse impacts to aquatic resources in a number of ways, including: (1) entrainment and impingement of fishes and invertebrates; (2) alteration of natural flow rates and hydroperiod; (3) degradation of shoreline and riparian habitats; and (4) alteration of aquatic community structure and diversity.

Entrainment and impingement

Entrainment is the voluntary or involuntary movement of aquatic organisms from the parent water body into a surface diversion or through, under, or around screens and results in the loss of the organisms from the population. Impingement is the involuntary contact and entrapment of aquatic organisms on the surface of intake screens caused when the approach velocity exceeds the swimming capability of the organism (WDFW 1998). Most water-intake facilities have the potential to cause entrainment and impingement of some aquatic species when they are located in areas that support those organisms. Facilities that are known to entrain and impinge marine animals include power plants, domestic and agricultural water supplies, industrial manufacturing facilities, ballast water intakes, and hydraulic dredges. Some of these types of facilities need very large volumes and intake rates of water. For example, conventional 1,000-megawatt fossil fuel and nuclear power plants require cooling water rates of approximately 50 and 75 m^3/s, respectively (Hanson et al. 1977). Water diversion projects have been identified as a source of fish mortality and injury, and egg and larval stages of aquatic organisms tend to be the most susceptible (Moazzam and Rizvi 1980; NOAA 1994; Richkus and McLean 2000). Entrainment can subject these life stages to adverse conditions such as increased heat, antifouling chemicals, physical abrasion, rapid pressure changes, and other detrimental effects. Although some temperate species of fish are able to tolerate exposure to extreme temperatures for short durations (Brawn 1960; Barker et al. 1981), fish and invertebrates entrained into industrial and municipal water intake structures experience nearly 100% mortality from the combined stresses associated with altered temperatures, toxic effects of chemical exposure, and mechanical and pressure-related injuries (Enright 1977; Hanson et al. 1977; Moazzam and Rizvi 1980; Barker et al. 1981; Richkus and McLean 2000).

Both entrainment and impingement of fish and invertebrates in power plant and other water intake structures have immediate as well as future impacts to the riverine, estuarine, and marine ecosystems. Not only is fish and invertebrate biomass removed from the aquatic system, but the biomass that would have been produced in the future would not become available to predators (Rago 1984). Water intake structures, such as power plants and industrial facilities, are a source of mortality for managed-fishery species and play a role as one of the factors driving changes in species abundance over time (Richkus and McLean 2000).

Various physical impacts to fish traversing low-head, tidal turbines in the Bay of Fundy, Canada, were reported by Dadswell and Rulifson (1994) and included mechanical strikes with turbine blades, shear damage, and pressure- and cavitation-related injuries/mortality. They found 21-46% mortality rates for experimentally tagged American shad (*Alosa sapidissima*) passing through the turbine. NOAA (1994) reported fish diverted into power turbines experience up to 40% mortality, as well as injury, disorientation, and delay of migration. An entrainment and impingment study for a once-through cooling system of an 848-megawatt electric generating plant on the East River (NY) concluded the reduction in biomass of spawners from an unfished stock in the Long Island Sound and New York-New Jersey estuary to be extremely small (i.e., 0.01% for Atlantic menhaden [*Brevoortia tyrannus*] and 0.09% for winter flounder [*Pseudopleuronectes americanus*]) compared to fishing mortality (Heimbuch et al. 2007).

Organisms that are too large to pass through in-plant screening devices become stuck or impinged against the screening device or remain in the forebay sections of the system until they are removed by other means (Hanson et al. 1977; Langford et al. 1978; Helvey 1985; Helvey and Dorn 1987; Moazzam and Rizvi 1980). They are unable to escape because the water flow either pushes them against the screen or prevents them from exiting the intake tunnel. This can cause injuries such as bruising or descaling, as well as direct mortality. The extent of physical damage to organisms is directly related to the duration of impingement, techniques for handling impinged fish, and the intake water velocity (Hanson et al. 1977). Similar to entrainment, the withdrawal of water can entrap particular species, especially when visual acuity is reduced (Helvey 1985) or when the ambient water temperature and the metabolism of individuals are low (Grimes 1975). This condition reduces the suitability of the source waters to provide normal habitat functions necessary for subadult and adult life stages of managed living marine resources and their prey. Increased predation can also occur. Intakes can stress or disorient fish through nonlethal impingement or entrainment in the facility and by creating conditions favoring predators such as larger fish and birds (Hanson et al. 1977; NOAA 1994).

Ballast water and vessel operations intake

Vessels take in and release water in order to maintain proper ballast and stability, which is affected by the variable weight of passengers and cargo and sea conditions. In addition, water is used for cooling engines and other systems. While the discharge of ballast water can cause significant impacts on the aquatic environment, particularly through the introduction of invasive species as discussed below, the intake of water for ballast and vessel cooling can also cause entrainment and impingement impacts on aquatic organisms.

Depending upon the size of the vessel, millions of gallons of water and its associated aquatic life, particularly eggs and larvae, can be transferred to the ballast tanks of a ship at a rate of tens of thousands of gallons per minute. For example, large ships, such as those constructed to transport liquefied natural gas (LNG), need to take on ballast water to stabilize the ship during offloading of the LNG. A 200,000-m^3 capacity LNG carrier would withdraw approximately 19.8 million gallons of water over a 10-hour period at an intake rate of 2 million gallons per hour (FERC 2005). The use of water for ballast and vessel cooling at these volumes and rates has the potential to entrain and impinge large numbers of fish eggs and larvae. For example, a proposed offshore LNG degasification facility using a closed-loop system near Gloucester, MA, would have estimated annual mortality of eggs and larvae from vessel ballast and cooling water for Atlantic mackerel (*Scomber scombrus*), pollock (*Pollachius virens*), yellowtail flounder (*Limanda ferruginea*), and Atlantic cod (*Gadus morhua*) of 8.5 million, 7.8 million, 411,000, and 569,000, respectively (USCG 2006). Refer to the chapters on Energy-related Activities and Marine Transportation for additional information on vessel entrainment and impingement impacts.

Alteration of hydrological regimes/flow restrictions

Water withdrawals for industrial or municipal water needs can have a number of physical effects to riverine systems, including altering stream velocity, channel depth and width, turbidity, sediment and nutrient transport characteristics, dissolved oxygen concentrations, and seasonal and diel temperature patterns (Christie et al. 1993; Fajen and Layzer 1993). These physical changes can have ecological impacts, such as a reduction of riparian vegetation that affects the availability of fish habitat and prey (Christie et al. 1993; Fajen and Layzer 1993; Spence et al. 1996). Alteration of freshwater flows is one of the most prevalent problems facing coastal regions and has had profound effects on riverine, estuarine, and marine fisheries (Deegan and Buchsbaum 2005). For example, water in the Ipswich River in Massachusetts has been reduced to 10% of historic natural flows because of increased water withdrawals, such as irrigation water during the growing season, power plant cooling water, and potable water for a growing human population (Bowling and Mackin 2003). Approximately one-half of the 45-mile long Ipswich River was reported to have gone completely dry in 1995, 1997, 1999, and 2002, and nearly one-half of the native fish populations have either been extirpated or severely reduced in size (Bowling and Mackin 2003). Many estuarine and diadromous species, such as American eel (*Anguilla rostrata*), striped bass (*Morone* *saxatilis*), white perch (*Morone americana*), Atlantic herring (*Clupea harengus*), blue crab (*Callinectes sapidus*), American lobster (*Homarus americanus*), Atlantic menhaden (*Brevoortia tyrannus*), cunner (*Tautogolabrus adspersus*), Atlantic tomcod (*Microgadus tomcod*), and rainbow smelt (*Osmerus mordax*), depend upon the development of a counter current flow set up by freshwater discharge to enter estuaries as larvae or early juveniles; reductions in the timing and volume of freshwater entering estuaries can reduce this counter current flow and disrupt larval transport (Deegan and Buchsbaum 2005).

Increased need for dredging

The alteration of the hydrological regimes and reductions in flow in riverine and estuarine systems caused by water intake structures can result in the build-up of sediments and increase the need to dredge around the intake facilities in order to prevent the sediments from negatively affecting the operations of the facility. Dredging can cause direct mortality of the benthic organisms within the area to be dredged, result in turbidity plumes of suspended particulates that can reduce light penetration, interfere with respiration and the ability of site-feeders to capture prey, impede the migration of anadromous fishes, and affect the growth and reproduction of filter feeding organisms. For more detailed discussion on the impacts of dredging, refer to the chapters on Marine Transportation and Offshore Dredging and Disposal Activities.

Habitat impacts

The operation of water intake facilities can have a broad range of adverse effects on fishery habitats, including the conversion and loss of habitat and the alteration of the community structure resulting from changes in the hydrological regimes, salinities, and flow patterns. Large withdrawals of freshwater from riverine systems above the tidal water influence can cause an upstream "relocation" of the salt wedge, altering an area's suitability for some freshwater species and possibly altering benthic community structure. In addition, reductions in the volume of freshwater entering estuaries can alter vertical and longitudinal habitat structure and disrupt larval transport (Deegan and Buchsbaum 2005). Water withdrawals during certain times of the year, such as the use of irrigation water during the growing season of crops, power plant cooling water used during high energy-demand periods, or for domestic water usage during dry, summer months can severely impact the ecological health of riverine systems. For example, the water withdrawal from the Ipswich River in Massachusetts increases by two-fold or more during summer months when natural river flows are lowest (Bowling and Mackin 2003). This has led to one-half of the river going completely dry in some years and has caused fish kills and habitat degradation (Bowling and Mackin 2003).

Construction-related impacts

Impacts to aquatic habitats can result from construction-related activities (e.g., dewatering, dredging) as well as routine operation and maintenance activities for water intake facilities. Generally, these impacts are similar in nature to both water intake and discharge structures and facilities. There is a broad range of impacts associated with these activities depending on the specific design and needs of the system. For example, dredging activities associated with construction of pipelines, bulkheads and seawalls, and buildings for a facility can cause turbidity and sedimentation in nearby waters, degraded water quality, noise, and substrate alterations. Filling of the aquatic habitat may also be needed for the construction of the facilities. Excavation of sediments in subtidal and intertidal habitats during construction may have at least short-term impacts, but the recovery of the aquatic habitat for spawning and egg deposition is uncertain

(Williams and Thom 2001). Many of these impacts can be reduced or eliminated through the use of various techniques, procedures, or technologies such as careful siting of the facility, timing restrictions on in-water work, and the use of directional drilling for the installation of pipelines. Some impacts may not be fully eliminated except by eliminating the activity itself.

Turbidity plume and sedimentation effects incidental to facility construction commonly produce a range of direct and indirect effects to living aquatic resources and their habitats. However, not all of the ecological implications of sediment resuspension and transport result in adverse effects to aquatic organisms (Blaber and Blaber 1980). The life history and ecological strategies characteristic of different species also are important considerations in assessing potential physical impacts from facility installation. For instance, while highly motile adult and juvenile life stages of most fishes could flee when construction is ongoing, egg and larval stages as well as nonmotile benthic organisms will likely not be able to avoid impacts. As a general rule, the severity of adverse effects tends to be greatest for early life stages and for adults of some highly sensitive species (Newcombe and Jensen 1996). The eggs and larvae of nonsalmonid estuarine fishes exhibit some of the most sensitive responses to suspended sediment exposures of all the taxa and life history stages for which data are available (Wilber and Clarke 2001). Reductions in the hatching success of white perch and striped bass eggs were reported at suspended sediment concentrations of 1,000 mg/L, and the survival of striped bass and yellow perch (*Perca flavescens*) larvae were reduced at concentrations greater than 500 mg/L and for American shad larvae at concentrations greater than 100 mg/L (Auld and Schubel 1978). Nelson and Wheeler (1997) found reduced hatching success for winter flounder eggs exposed to suspended sediment concentrations as low as 75 mg/L. While some species like the sessile life stages of eastern oyster (*Crassostrea virginica*) have adapted to withstand some acute habitat disturbances such as sedimentation and turbidity (Galtsoff 1964; Levinton 1982), most benthic and slow-moving species would not be able to escape exposure and instead would exhibit adaptive physiological and biochemical responses to counter adverse effects to water quality.

The area affected by water quality impacts from the construction of a water intake facility is largely dependent on the nature of the resuspended sediments, the duration the sediments are held in the water column, and the factors contributing to the transport of the sediments from the site. As benthic material is disturbed during facility installation and site preparation, resuspended particulate matter settles predominantly in the immediate vicinity of the project. Remaining waterborne fractions subsequently would be transported from the site and dispersed according to the grain size of disturbed sediments, the velocity of local water currents, and local wave action (Neumann and Pierson 1966).

The construction of water intake facilities can create adverse impacts within the immediate vicinity of the construction, including disrupting ambient sediment stratigraphy, cohesiveness, and geochemistry. These effects have geochemical consequences that may be particularly significant when construction activities are located in depositional or nutrient-enriched areas and where local sediments tend to be fine-grained. While important, it is essential to recognize that local sediment composition is not the only factor which affects resuspension during water intake facility installation. The type of construction equipment used to build an intake structure also has an important influence on the dispersion of dredge material. For traditional clamshell dredging, Tavolaro (1984) estimates a 2% loss of material through sediment resuspension at the dredge site. Dredge equipment that fluidizes sediments to facilitate their removal (e.g., hydraulic dredges or water jets) could result in a greater dispersion of resuspended sediment, especially when local waters are not quiescent or in situations where unfiltered return flow to the waterway is permitted. While sediment particles naturally exhibit cycles of exchange between the water column and materials composing the bottom substrate (Turner and Millward 2002), mechanized equipment used to remove sediments can reasonably be expected to disturb much deeper sediment horizons in a short period of time than would be expected from storms or in all but the most highly erosion prone coastal areas.

Additional discussions of the effects of dredging, dredged material disposal, and coastal development can be found in the Marine Transportation, Coastal Development, and Offshore Dredging and Disposal chapters.

Conservation measures and best management practices for water intake facilities (adapted from Hanson et al. 2003)

1. Locate facilities that rely on surface waters for cooling or ballast in areas other than estuaries, inlets, heads of submarine canyons, rock reefs, or small coastal embayments where important fishery species or their prey concentrate for spawning and migration.
2. Design and operate facilities to create flow conditions that provide for passage, water quality, proper timing of life history stages, and properly functioning channel, floodplain, riparian, and estuarine conditions.
3. Establish adequate instream flow conditions for anadromous fish.
4. Design intake structures to minimize entrainment or impingement. Velocity caps that produce horizontal intake/discharge currents should be employed, and intake velocities across the intake screen should generally not exceed 0.5 ft/s.
5. Use closed-loop cooling systems in facilities requiring water whenever practicable, especially in areas that would impinge and entrain large numbers of fish and invertebrates.
6. Screen water diversions on fish-bearing streams, as needed. In general, 2 mm wedge wire screens are recommended on intake facilities in areas that support anadromous fishes.
7. Incorporate juvenile and adult fish passage facilities on all water diversion projects (e.g., fish bypass systems).
8. Assess existing and potential aquatic vegetation, the volume and depth of the water body, the amount and timing of freshwater inflow, the presence of upland rearing and spawning habitat, and the relative salinity of the water body.
9. Assess the hydrology of the regulated land's tolerance for increased water exchange. The assessment should account for active management of the water intake facility to allow increased water exchange during critical periods.
10. Install intake pipes and facilities during low flow periods and tidal stage; incorporate appropriate erosion and sediment control best management practices, and have an equipment spill and containment plan and appropriate materials onsite.
11. Monitor facility operations to assess impacts on water temperatures, dissolved oxygen, and other applicable parameters. Adaptive management should be designed to minimize impacts.

Discharge Facilities

Introduction

Although there are a number of potential impacts to aquatic resources from point-source discharges, it is important to be aware that not all point-source discharge results in adverse impacts to aquatic organisms or their habitats. Most point-source discharges are regulated by the US Environmental Protection Agency (US EPA) under the National Pollutant Discharge Elimination System (NPDES), and the effects on receiving waters are generally considered under this permitting program. As authorized by the Clean Water Act, the NPDES permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States.

Industrial, municipal, and other facilities must obtain permits if their discharges go directly into surface waters. In most cases, the NPDES permit program is administered by authorized state agencies.

Point source discharges may modify habitat by creating adverse impacts to sensitive areas such as freshwater, estuarine, and marine wetlands; emergent marshes; and submerged aquatic vegetation beds and shellfish beds. Extreme discharge velocities of effluent may also cause scouring at the discharge point as well as entrain particulates and thereby create turbidity plumes.

Habitat conversion and exclusion

The discharge of effluent from point sources can cause numerous habitat impacts resulting from the changes in sediments, salinities, temperatures, and current patterns. These can include the conversion and loss of habitat as the salinities of estuarine areas decrease from the inflow of large quantities of freshwater or as areas become more saline through the discharge of effluent from desalinization plants. Temperature changes, increased turbidity, and the release of contaminants can also result in the reduced use of an area by marine and estuarine species and their prey and impede the migration of some diadromous fishes. Outfall pipes and their discharges may alter the structure of the habitats that serve as juvenile development habitat, such as eelgrass beds (Williams and Thom 2001). Power plants, for example, release large volumes of water at higher than ambient temperatures, and the area surrounding the discharge pipes may not support a healthy, productive community because of physical and chemical alterations of the habitat (Wilbur and Pentony 1999).

The accumulation of sediments at an outfall may alter the composition and abundance of infaunal or epibenthic invertebrate communities (Ferraro et al. 1991). These accumulated sediments can smother sessile organisms or force mobile animals to migrate from the area. If sediment characteristics are changed drastically at the discharge location, the benthic community composition may be altered permanently. This can lead to reductions in the biological productivity of the habitat at the discharge site for some aquatic resources as their prey species and important habitat types, such as aquatic vegetation, are no longer present. Outfall pipes can act as groins and interrupt sand transport, cause scour around the structures, and convert native sand habitat to larger course sediment or bedrock (Williams and Thom 2001). This can affect the spawning success of diadromous and estuarine species, many of which serve as prey species for other commercially or recreationally important species.

Alteration of sediment composition

As discussed above, outfall pipes and their discharges may alter the composition of sediments that serve as juvenile development habitat through scouring or deposition of dissimilar sediments (Williams and Thom 2001). Outfalls that typically release water at high velocities may scour sediments in the vicinity of the outfall and convert the substrate to course sediments or bedrock. Conversely, outfalls that release water at lower velocities that contain fine grained, silt-laden sediments may accumulate sediments near the outfall and increase the need to dredge to remove sediment buildup (Williams and Thom 2001). This can lead to a change in the community composition because many benthic organisms are sensitive to grain size. The chronic accumulation of sediments can also bury benthic organisms that serve as prey and limit an area’s suitability as forage habitat.

Substrate and sediment scouring

The discharge of effluent from point sources can result in a variety of benthic habitat and water quality impacts relating to scouring of substrate and sediments at the discharge point.

Changes to the substrate from scouring may impact benthic invertebrate and shellfish community, as well as submerged aquatic vegetation, such as eelgrass (Williams and Thom 2001).

Turbidity and sedimentation effects

Turbidity plumes of suspended particulates caused by the discharge of effluent, the scouring of the substrate at the discharge point, and even the repeated maintenance dredging of the discharge area can reduce light penetration and lower the rate of photosynthesis and the primary productivity of an aquatic area while elevated turbidity persists. Fish and invertebrates in the immediate area may suffer a wide range of adverse effects, including avoidance and abandonment of the area, reduced feeding ability and growth, impaired respiration, a reduction in egg hatching success, and resistance to disease if high levels of suspended particulates persist (Newcombe and MacDonald 1991; Newcombe and Jensen 1996; Wilber and Clarke 2001). Auld and Schubel (1978) reported reduced egg hatching success in white perch and striped bass at suspended sediment concentrations of 1,000 mg/L. They also found reduced survival of striped bass and yellow perch larvae at concentrations greater than 500 mg/L and for American shad at concentrations greater than 100 mg per liter (Auld and Schubel 1978). Short-term effects associated with an increase in suspended particles may include high turbidity, reduced light, and sedimentation, which may lead to the loss of benthic structure and disrupt overall productivity if elevated levels persist (USFWS and NMFS 1999; Newcombe and Jensen 1996). Other problems associated with suspended solids include reduced water transport rates and filtering efficiency of fishes and invertebrates and decreased foraging efficiency of sight feeders (Messieh et al. 1991; Wilber and Clarke 2001). Breitburg (1988) found the predation rates of striped bass larvae on copepods decreased by 40% when exposed to high turbidity conditions in the laboratory. In riverine habitats, Atlantic salmon (*Salmo salar*) fry and parr find refuge within interstitial spaces provided by gravel and cobble that can be potentially clogged by sediments, subsequently decreasing survivorship (USFWS and NMFS 1999).

Increased need for dredging

The release of sediment from water discharge facilities, as well as increased turbidity and sedimentation resulting from high velocity outfall structures, can lead to a build-up of sediments. Over time this may increase the need to dredge around the discharge facility in order to prevent the sediments from negatively affecting the operations of the facility or interfering with vessel navigation. Dredging can cause direct mortality of the benthic organisms within the area to be dredged, as well as create turbidity plumes of suspended particulates that can reduce light penetration, interfere with respiration and the ability of site-feeders to capture prey, impede the migration of anadromous fishes, and affect the growth and reproduction of filter feeding organisms (Wilber and Clarke 2001). For more detailed discussion on the impacts of dredging, refer to the chapters on Marine Transportation and Offshore Dredging and Disposal Activities.

Reduced dissolved oxygen

The contents of the suspended material can react with the dissolved oxygen in the water and result in oxygen depletion, which can impact submerged aquatic vegetation and benthos in the vicinity. Reduced dissolved oxygen (DO) can cause direct mortality of aquatic organisms or result in subacute effects such as reduced growth and reproductive success. Bejda et al. (1992) found that the growth of juvenile winter flounder was significantly reduced when DO levels were maintained at 2.2 mg/L or when DO varied diurnally between 2.5 and 6.4 mg/L for a period of 11 weeks.

Alteration of temperature regimes

Sources of thermal pollution from water discharge facilities include industrial and power plants. Temperature changes resulting from the release of cooling water from power plants can cause unfavorable conditions for some species while attracting others. Altered temperature regimes have the ability to affect the distribution, growth rates, survival, migration patterns, egg maturation and incubation success, competitive ability, and resistance to parasites, diseases, and pollutants of aquatic organisms (USEPA 2003). Increased water temperatures in the upper strata of the water column can result in water column stratification, which inhibits the diffusion of oxygen into deeper water leading to reduced (hypoxic) or depleted (anoxic) dissolved oxygen concentrations in estuaries (Kennedy et al. 2002). Because warmer water holds less oxygen than colder water does, increased water temperatures reduce the DO concentration in bodies of water that are not well mixed. This may exacerbate nutrient-enrichment and eutrophication conditions that already exist in many estuaries and marine waters in the northeastern United States. In addition, thermal stratification could also affect primary and secondary productivity by suppressing nutrient upwelling and mixing in the upper regions of the water column, potentially altering the composition of phytoplankton and zooplankton. Impacts to the base of the food chain would not only affect fisheries, but could impact entire ecosystems.

Elevated water temperature can alter the normal migration patterns of some species or result in thermal stress and mortality in individuals should the discharges cease during colder months of the year. Thermal effluents in inshore habitat can cause severe problems by directly altering the benthic community or killing marine organisms, especially larval fish. Temperature influences biochemical processes of the environment and the behavior (e.g., migration) and physiology (e.g., metabolism) of marine organisms (Blaxter 1969). Investigations to determine the thermal tolerances of larvae of Atlantic herring, smooth flounder (*Pleuronectes putnami*), and rainbow smelt suggests that these species can tolerate elevated temperatures for short durations which are near the upper limits of cooling systems of most normally operating nuclear power plants (Barker et al. 1981). However, a number of factors affected the survival of larvae, including the salinity the individuals were acclimated to and the age of the larvae.

Long-term thermal discharge may change natural community dynamics. For example, elevated water temperature has been identified as a potential factor contributing to harmful algae blooms (ICES 1991), which can lead to rapid growth of phytoplankton populations and subsequent oxygen depletion, sometimes resulting in fish kills. Some evidence indicates that elevated water temperatures in freshwater streams and rivers in the northeastern United States caused by anthropogenic impacts may be responsible for increased algal growth, which has been suggested as a possible factor in the diminished stocks of rainbow smelt (Moring 2005).

Alteration of salinity regimes

The discharge of water with elevated salinity levels from desalination plants may be a potential source of impacts to fishery resources. Waste brine is either discharged directly to the ocean or passed through sewage treatment plants. Although some studies have found desalination plant effluent to not produce toxic effects in marine organisms (Bay and Greenstein 1994), there may be indirect effects of elevated salinity on estuarine and marine communities, such as forcing juvenile fish into areas that could increase their chances of being preyed upon by other species. Conversely, treated freshwater effluent from municipal wastewater plants can produce localized reductions in salinity and could subject juvenile fish to conditions of less than optimal salinity for growth and development (Hanson et al. 2003).

Changes in local current patterns

In addition to changes in temperature and salinity, local current patterns can be altered by outfall discharges or by the structures themselves. These changes can be related to changes in the rate of sedimentation around the outfall, the volume of water discharged, and the size and location of the structures.

Release of radioactive wastes

Both natural and anthropogenic sources of radionuclides exist in the environment (ICES 1991). Potential sources of anthropogenic radioactive wastes include nonpoint sources, such as storm water runoff and atmospheric sources (e.g., coal-burning power plants) and point sources, such as industrial facilities (e.g., uranium mining and milling fuel lubrication) and nuclear power plant discharges (ICES 1991; NEFMC 1998). Fish exposed to radioactive wastes can accumulate radioisotopes in tissues, causing toxicity to other marine organisms and consumers (ICES 1991). The identification of radioactive wastes from industrial and nuclear power plant discharges was a focus of concern during the 1980s (ICES 1991). However, most studies since then have found trends of decreasing releases of artificial radionuclides from industrial and nuclear power plant discharges and reduced tissue-burdens in sampled fish and shellfish to levels similar to naturally occurring radionuclides (ICES 1991).

Ballast water discharges

Commercial cargo-carrying and recreational vessels are the primary type of vector that transports marine life around the world, some of which become exotic, invasive species that can alter the structure and function of aquatic ecosystems (Valiela 1995; Carlton 2001; Niimi 2004). Ballast water discharges, occurring when ships take on additional cargo while at a port, are one of the largest pathways for the introduction and spread of aquatic nuisance species (ANS). The introduction of ANS can have wide reaching impacts to the aquatic ecosystem, the economy, and human health. Many ANS species are transported and released in ballast in their larval stages, become bottom-dwelling as adults, and include sea anemones, marine worms, barnacles, crabs, snails, clams, mussels, bryozoans, sea squirts, and seaweeds (Carlton 2001). In addition, some species are transported and released as adults, including diatoms, dinoflagellates, copepods, and jellyfish (Carlton 2001). Invasive, exotic species can displace native species and increase competition with native species and can potentially alter nutrient cycling and energy flow leading to cascading and unpredictable ecological effects (Carlton 2001). Additional discussion of the effects of introduced species can be found in the chapters on Introduced/Nuisance Species and Aquaculture and Marine Transportation.

Behavioral effects

Discharge facility effluents have the potential to alter the behavior of riverine, estuarine, and marine species by changing the chemical and physical attributes of the habitat and water column in the vicinity of the outfall. These include attractions to the increase in flow velocity and altered temperature regimes at the discharge point and changes in predator/prey interactions. Changes in temperature regimes can artificially attract species and alter their normal seasonal migration behavior, resulting in cold shock and mortality of fishes when ambient temperatures are colder and the flow of heated water is ceased during a facility shutdown (Pilati 1976). Shorelines physically altered with outfall structures may also disrupt the migratory patterns and pathways of fish and invertebrates (Williams and Thom 2001).

Physiological effects

Point-source discharges can cause a wide range of physiological effects on aquatic resources including both lethal and sublethal effects. Alteration of temperature, salinity, and dissolved oxygen concentration regimes have been shown to effect the normal physiology of marine organisms and can retard or accelerate egg and larval development and time of hatching (Blaxter 1969). Fish subjected to abnormally cold or hot temperatures from water discharges will either leave the affected area or acclimate to the change if it is within the species' thermal tolerance zone (Pilati 1976). However, a sudden change in ambient temperature can cause thermal shock and result in death to the fish, or the thermal shock may debilitate a fish and make it susceptible to predation (Pilati 1976). Temperature plays an important role in determining the survival and fitness of coldwater species, such as Atlantic salmon, and can affect the normal growth and development of eggs and fry (Blaxter 1969; Spence et al. 1996).

Water intake and outfall facilities can also have widespread chemical effects on aquatic organisms. These effects are discussed in the Chemical Effects: Water Discharge Facilities chapter.

Construction-related impacts of water discharge facilities

The physical effects of constructing water discharge facilities can result from a number of activities, including releasing suspended sediments and associated pore-water in the construction zone; removal of bottom sediments and subsequent suspended sediments; turbidity and alteration of benthic habitats from dredging; releasing drill mud or cuttings from a directional drilling operation; and the loss or conversion of the existing benthic habitat and water column from placement of fill pipelines, and shoreline stabilization structures (e.g., riprap, headwalls). The impacts associated with constructing water intake and discharge structures and facilities are similar in nature and have been discussed in more detail in the Intake Facilities section of this chapter.

Conservation measures and best management practices for discharge facilities (adapted from Hanson et al. 2003)

1. Conduct a thorough environmental assessment of proposed site locations for water discharge facilities prior to granting any regulatory permits. The assessments should include detailed investigations on the utilization of the aquatic environment by resident and transient species, including the migratory pathways of marine and diadromous fishes. Physical and chemical parameters of the proposed site should be included, such as sediment and substrate characteristics, hydrological dynamics of tides and currents, and temperature and salinity regimes.
2. Develop outfall design (e.g., modeling concentrations within the predicted plume or likely extent of deposition within the zone of influence) by using site specific, hydrological data with input from appropriate resource agencies.
3. Select appropriate point-source discharge locations by using information on the concentrations of living marine resources based upon site-specific, biological assessments. Sensitive and highly productive areas and habitats, such as shellfish beds, sea grass beds, hardbottom reefs should be avoided. Reduce potentially high velocities by diffusing effluent to acceptable velocities.
4. Regulate discharge temperatures (both heated and cooled effluent) such that they do not appreciably alter ambient temperatures and cause a change in species assemblages and ecosystem function in the receiving waters. Strategies should be implemented to diffuse the heated effluent.

5. Use land-treatment and upland disposal/storage techniques where possible. Use of vegetated wetlands as natural filters and pollutant assimilators for large-scale discharges should be limited to those instances where other less damaging alternatives are not available and the overall environmental and ecological suitability of such an action has been demonstrated.
6. Avoid siting pipelines and treatment facilities in wetlands and streams. Since pipeline routes and treatment facilities should not necessarily be water-dependent with regard to positioning, the priority should be to avoid their placement in wetlands or other fragile coastal habitats. Avoiding placement of pipelines within streambeds and wetlands will also reduce inadvertent infiltration into conveyance systems and retain natural hydrology of local streams and wetlands.
7. Ensure that all discharge water from outfall structures meets state and federal water quality standards. Whenever feasible, discharge pipes should extend a substantial distance offshore and be buried deep enough to not affect shoreline processes. Buildings and associated structures should be set well back from the shoreline to preclude the need for bank armoring.

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