CHAPTER TEN: INTRODUCED/NUISANCE SPECIES AND AQUACULTURE

Introduced/Nuisance Species

Introduction

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 intentionally (i.e., fish stocking and pest control programs) or unintentionally during industrial shipping activities (e.g., ballast water releases), aquaculture operations, recreational boating, biotechnology, or from aquarium discharge (Hanson et al. 2003; Niimi 2004). Hundreds of species have been introduced into US waters from overseas and from other regions around North America, including finfish, shellfish, phytoplankton, bacteria, viruses, and pathogens (Drake et al. 2005). The rate of introductions has increased exponentially over the past 200 years, and it does not appear that this rate will level off in the near future (Carlton 2001).

In New England and the mid-Atlantic region, a number of fish, crabs, bryozoans, mollusks, tunicates, and algae species have been introduced since colonial times (Deegan and Buchsbaum 2005). New introductions continue to occur, such as *Convoluta convoluta*, a small carnivorous flatworm from Europe that has invaded the Gulf of Maine (Carlton 2001; Byrnes and Witman 2003); *Didemnum* sp., an invasive species of tunicate that has invaded Georges Bank and many coastal areas in New England (Pederson et al. 2005); the Asian shore crab (*Hemigrapsus sanguineus*) that has invaded Long Island Sound, NY/CT, (Carlton 2001) and other coastal areas; and *Codium fragile* spp. *tomentosoides,* an invasive algal species from Japan that has invaded the Gulf of Maine (Pederson et al. 2005).

Introduced species may thrive best in areas where there has been some level of environmental disturbance (Vitousek et al. 1997; USFWS and NMFS 1999; Minchinton and Bertness 2003). For example, in riverine systems alteration in temperature and flow regimes can provide a niche for nonnative species to invade and dominate over native species such as salmon (USFWS and NMFS 1999). Invasive species introductions can result in negative impacts to the environment and to society, with millions of dollars being expended for research, control, and management efforts (Carlton 2001).

The impacts associated with introduced/nuisance species can involve habitat, species, and genetic-level effects. Introduced/nuisance species can impact the environment in a variety of ways, including: (1) habitat alterations; (2) trophic alterations; (3) gene pool alterations; (4) alterations to communities and competition with native species; (5) introduced diseases; (6) changes in species diversity; (7) alteration in the health of native species; and (8) impacts to water quality. The following is a review of the potential environmental impacts associated with the introduction of nonnative aquatic invasive/nuisance species into marine, estuarine, and freshwater ecosystems.

Habitat alterations

Introduced species can have severe impacts on the quality of habitat (Deegan and Buchsbaum 2005). Nonnative aquatic plant species can infest water bodies, impair water quality, cause anoxic conditions when they die and decompose, and alter predator-prey relationships. Fish may be introduced into an area to graze and biologically control aquatic plant invasions. However, introduced fish may also destroy habitat, which can eliminate nursery areas for native juvenile fishes, accelerate eutrophication, and cause bank erosion (Kohler and Courtenay 1986).

Habitat has been altered by the introduction of invasive species in New England. For example, the green crab (*Carcinus maenus*) an exotic species from Europe, grazes on submerged aquatic vegeation and can interfere with eelgrass restoration efforts (Deegan and Buchsbaum 2005). *Didemnum* sp. is an invasive tunicate that has colonized the northern edge of Georges Bank, as well as many coastal areas in New England. This filter-feeding organism forms dense mats that encrust the seafloor, which can prevent the settlement of benthic organisms, reduce food availability for juvenile scallops and groundfish, and smother organisms attached to the substrate (e.g., Atlantic sea scallops [*Placopectin magellanicus*] in spat and juvenile stages) (Pederson et al. 2005; Valentine et al. 2007) and could have impacts to productive fishing grounds in New England and elsewhere. There is no evidence at this time that the spread of the tunicate on Georges Bank will be held in check by natural processes other than smothering by moving sediments; however, its offshore distribution may be limited by temperatures too low for reproduction (Valentine et al. 2007).

An invasive species of algae from Japan, *Codium fragiles* spp. *tomentosoides*, also referred to as deadman's fingers, has invaded subtidal and intertidal marine habitats in the Gulf of Maine and mid-Atlantic. Deadman's fingers can outcompete native kelp and eelgrass, thus destroying habitat for finfish and shellfish species (Pederson et al. 2005). The common reed (*Phragmites australis*) a nonnative marsh grass, has invaded coastal estuaries and can exclude native brackish and salt marsh plant species such as smooth cordgrass (*Spartina alterniflora*) from their historic habitat (Burdick et al. 2001; Minchinton and Bertness 2003; Deegan and Buchsbaum 2005). *Phragmites* invasions can increase the sedimentation rate in marshes and reduce intertidal habitat available for fish species in New England (Deegan and Buchsbaum 2005).

Trophic alterations and competition with native species

Introduced species can alter the trophic structure of an ecosystem via increased competition for food and space between native and nonnative species (Kohler and Courtenay 1986; Caraco et al. 1997; Strayer et al. 2004; Deegan and Buchsbaum 2005) as well as through predation by introduced species on native species (Kohler and Courtenay 1986). Competition may result in the displacement of native species from their habitat or a decline in recruitment, which are factors that can collectively contribute to a decrease in population size (Kohler and Courtenay 1986). For example, introductions of the invasive zebra mussel (*Dreissena polymorpha*) in the Hudson River, NY/NJ, estuary coincided with a decline in the abundance, decreased growth rate, and a shift in the population distribution of commercially and recreationally important species (Strayer et al. 2004). Zebra mussels have altered trophic structure in the Hudson River estuary by withdrawing large quantities of phytoplankton and zooplankton from the water column, thus competing with planktivorous fish. Phytoplankton is the basis of the food web, and altering the trophic levels at the bottom of the food web could have a detrimental, cascading effect on the aquatic ecosystem. Increased competition for food between the zebra mussel and open-water commercial and recreational species such as the American shad (*Alosa sapidissima*) and black sea bass (*Centropristis striata*) has been associated with large, pervasive alterations in young-of-the-year fish, which can result in interspecies competition and alterations in trophic structure (Strayer et al. 2004; Deegan and Buchsbaum 2005).

Predation on native species by nonnative species may increase the mortality of a species and could also alter the trophic structure (Kohler and Courtenay 1986). Whether the predation is on the eggs, juveniles, or adults, a decline in native forage species can affect the entire food web (Kohler and Courtenay 1986). For example, the Asian shore crab invaded Long Island Sound and has an aggressive predatory behavior and voracious appetite for crustaceans, mussels, young clams, barnacles, periwinkles, polychaetes, macroalgae, and salt marsh grasses. The removal of the forage base by this invasive crab could have a ripple effect throughout the food web that could restructure communities along the Atlantic coast (Tyrrell and Harris 2000; Brousseau and Baglivo 2005).

Alterations to communities

Introductions of nonnative species may result in alterations to communities and an increase in competition for food and habitat (Deegan and Buchsbaum 2005). For example, the green crab is an exotic species from Europe which preys on native soft-shelled clams and newly settled winter flounder (*Pseudopleuronectes americanus*) (Deegan and Buchsbaum 2005).

Nonnative marsh grass introductions can alter habitat conditions, resulting in changes in the fauna of salt marsh habitat. Alterations to communities have been noted in areas in which native marsh cordgrass habitat has been invaded by the invasive, exotic *Phragmites* (Posey et al. 2003). *Phragmites* has been implicated in alteration of the quality of intertidal habitats, including: lower abundance of nekton in *Phragmites* habitat; reduced utilization of this habitat by other species during certain life stages (Weinstein and Balletto 1999; Able and Hagan 2000); decreased density of gastropods, oligochaetes, and midges (Posey et al. 2003); decreased bird abundance and species richness (Benoit and Askins 1999); and avoidance of *Phragmites* by juvenile fishes (Weis and Weis 2000).

Gene pool alterations

Native species may hybridize with introduced species that have a different genetic makeup (Kohler and Courtenay 1986), thus weakening the genetic integrity of wild populations and decreasing the fitness of wild species via breakup of gene combinations (Goldburg et al. 2001). Aquaculture operations have the potential to be a significant source of nonnative introductions into North American waters (Goldburg and Triplett 1997; USCOP 2004). Escaped aquaculture species can alter the genetic characteristics of wild populations when native species interbreed with escaped nonnative or native aquaculture species (USFWS and NMFS 1999).

In the Gulf of Maine, the wild Atlantic salmon (*Salmo salar*) population currently exhibits poor marine survival and low spawning stock and is in danger of becoming extinct, which makes the species particularly vulnerable to genetic modification via interbreeding with escaped aquaculture species. Any genetic modification combined with other threats such as reduced water levels, parasites and diseases, commercial and recreational fisheries, loss of habitat, poor water quality, and sedimentation may threaten or potentially extirpate the wild salmon stock in the Gulf of Maine (USFWS and NMFS 1999). Refer to the Aquaculture section of this chapter for a more detailed discussion on impacts from aquaculture operations.

Introduced diseases

Introduced aquatic species are often vectors for disease transmittal that represent a significant threat to the integrity and health of native aquatic communities (Kohler and Courtenay 1986). Bacteria, viruses, and parasites may be introduced advertently or inadvertently and can reduce habitat quality (Hanson et al. 2003). The introduction of pathogens can have lethal or sublethal effects on aquatic organisms and has the potential to impair the health and fitness level of wild fish populations. Sources of introduced pathogens include industrial shipping, recreational boating, dredging activities, sediment disposal, municipal and agricultural runoff, wildlife feces, septic systems, biotechnology labs, aquariums, and transfer of oyster spat and other species to new areas for aquaculture or restoration purposes (ASMFC 1992; Boesch et al. 1997).

Parasite and disease introductions into wild fish and shellfish populations can be associated with aquaculture operations. These diseases have the potential to lower the fitness level of native species or contribute to the decline of native populations (USFWS and NMFS 1999). Examples include the MSX (multinucleated sphere unknown) oyster disease introduced through the Pacific oyster (*Crassostrea gigas*) which contributed to the decline of native oyster (*Crassostrea virginica*) populations in Delaware Bay, DE/NJ, and Chesapeake Bay, MD/VA, (Burreson et al. 2000; Rickards and Ticco 2002) and the Infectious Salmon Anemia (ISA) that has spread from salmon farms in New Brunswick, Canada, to salmon farms in Maine (USFWS and NMFS 1999). Refer to the Aquaculture section of this chapter for more information regarding diseases introduced through aquaculture operations.

Changes in species diversity

Introduced species can rapidly dominate a new area and can cause changes within species communities to such an extent that native species are forced out of the invaded area or undergo a decline in abundance, leading to changes in species diversity (Omori et al. 1994). For example, changes in species distribution have been seen in the Hudson River, where the invasion of zebra mussels caused localized changes in phytoplankton levels and trophic structure that favored littoral zone species over open-water species. The zebra mussel invasion resulted in a decline in abundance of open-water fishes (e.g., American shad) and an increase in abundance for littoral zone species (e.g., sunfishes) (Strayer et al. 2004). Shifts in the distribution and abundance of species caused by introduced species can effect the diversity of species in an area.

Alterations in species diversity have been noted in areas in which native *Spartina alterniflora* habitat has been invaded by the exotic haplotype, *Phragmites australis* (Posey et al. 2003). *Phragmites* can rapidly colonize a marsh area, thus changing the species of marsh grass present at that site. In addition, *Phragmites* invasions have been shown to change species use patterns and abundance at invaded sites, potentially causing a cascading of effects to the species richness and diversity of a community.

Benthic species diversity can be altered by the introduction of shellfish for aquaculture purposes (Kaiser et al. 1998) and for habitat restoration projects. Cultivation of shellfish such as hard clams often requires the placement of gravel or crushed shell on the substrate. Changes in benthic structure can result in a shift in the community at that site (e.g., from a polychaete to a bivalve and nemertean dominated benthic community) which may have the effect of reduced diversity (Simenstad and Fresh 1995; Kaiser et al. 1998). However, community diversity may be enhanced by the introduction of aquaculture species and/or the modification of the substrate (Simenstad and Fresh 1995). In addition, changes in species diversity may occur as a result of oyster habitat restoration. Oyster reefs provide habitat for a variety of resident and transient species (Coen et al. 1999), so restoration activities that introduce oysters into an area may result in localized changes in species diversity, as reef-building organisms and fish are attracted to the restoration site. Refer to the section on Aquaculture of this chapter for more information regarding altered species diversity caused by aquaculture activities.

Alterations in the health of native species

The health of native species can be impaired by the introduction of new species into an area. A number of factors may contribute to reduced health of native populations, including: (1) competition for food may result in a decrease in the growth rate and local abundance (Strayer et al. 2004) or the decline in the entire population (USFWS and NMFS 1999) of native species; (2) aggressive and fast growing nonnative predators can reduce the populations of native species (Pederson et al. 2005); (3) diseases represent a significant threat to the integrity and health of native aquatic communities and can decrease the sustainability of the native population (Kohler and

Courtenay 1986; USFWS and NMFS 1999; Rickards and Ticco 2002; Hanson et al. 2003); and (4) the genetic integrity of native species may be compromised through hybridization with introduced species (Kohler and Courtenay 1986), which can also decrease the fitness of wild species via breakup of gene combinations (Goldburg et al. 2001). The factors listed above, in combination with potential impact on the habitats of native species, can collectively result in long-term impacts to the health of native species (Burdick et al. 2001; Minchinton and Bertness 2003; Deegan and Buchsbaum 2005; Pederson et al. 2005).

Impacts to water quality

Invasive species can affect water quality in marine, estuarine, and riverine environments because they have the potential to outcompete native species and dominate habitats. For example, nonnative aquatic plant species, which may not have natural predators in their new environments, can proliferate within water bodies, impair water quality, and cause anoxic conditions when they die and decompose. Fish species such as grass carp (*Ctenopharyngodon idella*) and tilapia (Cichlidae), introduced to control noxious weeds, can accelerate eutrophication through fecal decomposition of nutrients previously stored in the plants (Kohler and Courtenay 1986). In addition, fish introduced to control invasive plant species can increase turbidity in the water column from the grazing behavior itself (Kohler and Courtenay 1986).

Introduced nonnative algal species from anthropogenic sources such as ballast water and shellfish transfer (e.g., seeding) combined with nutrient overloading may increase the intensity and frequency of algal blooms. An overabundance of algae can degrade water quality when they die and decompose, which depletes oxygen levels in an ecosystem. Oxygen depletion can result in ecological “dead zones,” reduced light transmittance in the water column, seagrass and coral habitat degradation, and large-scale fish kills (Deegan and Buchsbaum 2005).

Conservation measures and best management practices for impacts on aquatic habitats from introduced/nuisance species

1. Do not introduce exotic species for aquaculture purposes unless a thorough scientific evaluation and risk assessment is performed. Aquaculturist should be encouraged to only culture native species in open-water operations.
2. Prevent or discourage boaters, anglers, aquaculturists, traders, and other potential handlers of introduced species from accidental or purposeful introduction of species into ecosystems where these species are not native. In addition, measures should be taken to prevent the movement or transfer of exotic species into other waters.
3. Encourage vessels to perform a ballast water exchange in marine waters (in accordance with the US Coast Guard’s voluntary regulations) to minimize the possibility of introducing exotic species into estuarine habitats. Ballast water taken on in marine waters will contain fewer organisms, and these organisms will be less likely to become invasive in estuarine conditions than are species transported from other estuaries.
4. Discourage vessels that have not performed a ballast water exchange from discharging their ballast water into estuarine receiving waters.
5. Require vessels brought from other areas over land via trailering to clean any surfaces that may harbor nonnative plant or animal species (e.g., propellers, hulls, anchors, fenders). Bilges should be emptied and cleaned thoroughly with hot water or a mild bleach solution. These activities should be performed in an upland area to prevent introduction of nonnative species to aquatic environments during the cleaning process.

6. Encourage natural resource managers to provide outreach materials on the potential impacts resulting from releases of nonnative species into the natural environment.
7. Limit importation of ornamental fishes to licensed dealers.
8. Use only local, native fish for live seafood or bait.
9. Encourage natural resource managers to identify areas where invasive species have become established at an early time in the infestation and pursue efforts to remove them, either manually or by other methods.
10. Encourage natural resource managers to identify methods that eradicate or reduce the spread of invasive species (e.g., reducing *Phragmites* in coastal marshes by mitigating the effects of tidal restrictions).
11. Treat effluent from public aquaria displays, laboratories, and educational institutes that are using exotic species prior to discharge for the purpose of preventing the introduction of viable animals, plants, reproductive material, pathogens, or parasites into the environment.

Aquaculture

Introduction

Aquaculture is defined as the controlled cultivation and harvest of aquatic organisms, including finfish, shellfish, and aquatic plants (Goldburg et al. 2001, 2003). Aquaculture operations are conducted at both land and water facilities. Land-based aquaculture systems include ponds, tanks, raceways, and water flow-through and recirculating systems. Water-based aquaculture systems include netpens, cages, ocean ranching, longline culture, and bottom culture (Goldburg and Triplett 1997).

Aquaculture can provide a number of socio-economic benefits, including food provision, improved nutrition and health, generation of income and employment, diversification of primary products, and increased trade earnings through the export of high-value products (Barg 1992). Aquaculture can also provide environmental benefits by supporting stocking and release of hatchery-reared organisms, countering nutrient and organic enrichment in eutrophic waters from the culture of some mollusk and seaweed species, and because aquaculture operations relies on good water quality, the prevention and control of aquatic pollution (Barg 1992).

However, freshwater, estuarine, and marine aquaculture operations have the potential to adversely impact the habitat of native fish and shellfish species. The impact of aquaculture facilities varies according to the species cultured, the type and size of the operation, and the environmental characteristics of the site. Intensive cage and floating netpen systems typically have a greater impact because aquaculture effluent is released directly into the environment. Pond and tank systems are less harmful to the environment because waste products are released in pulses during cleaning and harvesting activities rather than continuously into the environment (Goldburg et al. 2001). The relative impact of finfish and shellfish aquaculture differs depending on the foraging behavior of the species. Finfish require the addition of a large amount of feed into the ecosystem, which can result in environmental impacts impacts from the introduction of the feed, but also from the depletion of species harvested to provide the feed. Bivalves are filter feeders and typically do not require food additives; however, fecal deposition can result in benthic and pelagic habitat impacts, changes in trophic structure (Kaspar et al. 1985; Grant et al. 1995), and nutrient and phytoplankton depletion (Dankers and Zuidema 1995).

Similar to the introduced/nuisance species section of this chapter, aquaculture activities can effect fisheries at both a habitat and species-level. Typical environmental impacts resulting from aquaculture production include: (1) impacts to the water quality from the discharge of organic wastes and contaminants; (2) seafloor impacts; (3) introductions of exotic invasive species; (4) food web impacts; (5) gene pool alterations; (6) changes in species diversity; (7) sediment deposition; (8) introduction of diseases; (9) habitat replacement or exclusion; and (10) habitat conversion. The following is a review of the known and potential environmental impacts associated with the cultivation and harvest of aquatic organisms in land- and water-based aquaculture facilities.

Discharge of organic wastes

Aquaculture operations can degrade the quality of the water column and the benthic environment via the discharge of organic waste and other contaminants (Goldburg et al. 2001; USCOP 2004). Organic waste includes uneaten fish food, urine, feces, mucus, and byproducts of respiration, which can have an adverse effect on both benthic and pelagic organisms when released into marine, estuarine, and riverine environments.

Uneaten fish food can contribute a significant amount of nutrients to the ecosystem at aquaculture sites (Kelly 1992; Goldburg and Triplett 1997). Farmed fish are typically fed "forage fish" of low economic value, such as anchovies (Engraulidae) and menhaden (*Brevoortia* sp.), which are either fed directly to aquaculture species or processed into dry feed pellets. However, these "forage fish," while having low economic value, may be highly important to other species and the aquatic ecosystem. A large percentage of nutrients contained in farmed fish food are lost to the environment through organic waste. As much as 80% of total nitrogen and 70% of total phosphorus fed to farmed fish may be released into the water column through fish wastes (Goldburg et al. 2001).

In New England, the majority of aquaculture operations are located in Maine, with Cobscook Bay being the primary site of finfish aquaculture operations. Recent research in Cobscook Bay and in neighboring waters of New Brunswick, Canada, has shown the primary sources of nutrients in the area are finfish aquaculture operations and the open ocean (Goldburg et al. 2001). Research conducted at an aquaculture facility with 200,000 salmon has revealed that the amount of nitrogen, phosphorus, and feces discharged from the facility are equivalent to that released from untreated sewage produced by 20,000, 25,000, and 65,000 people, respectively (Goldburg et al. 2001).

The release of high concentrations of nutrients can negatively affect an aquatic system through eutrophication. Eutrophication of an aquatic system can occur when nutrients, such as nitrogen and phosphorus, are released in high concentrations and over long periods of time. Eutrophication can stimulate the growth of algae and other primary producers and, in some cases, may develop into "algal blooms" (Hopkins et al. 1995; Goldburg et al. 2001; Deegan and Buchsbaum 2005). Although the effects of eutrophication are not necessarily always adverse, they are often extremely undesirable and include: (1) increased incidence, extent, and persistence of noxious or toxic species of phytoplankton; (2) increased frequency, severity, spatial extent, and persistence of low oxygen conditions; (3) alteration in the dominant phytoplankton species and the nutritional-biochemical "quality" of the phytoplankton community; and (4) increased turbidity of the water column because of the presence of algae blooms (O'Reilly 1994).

Oxygen can be depleted in the water column during bacterial degradation of algal tissue or when algal respiration exceeds oxygen production and can result in hypoxic or anoxic "dead zones," reduced water clarity, seagrass habitat degradation, and large-scale fish kills (Deegan and Buchsbaum 2005). Algal blooms may contain species of phytoplankton such as dinoflagellates that can produce toxins, cause toxic blooms (e.g., red tides), kill large numbers of fish, contaminate shellfish beds, and cause health problems in humans. Coastal and estuarine ecosystems in the United States are already moderately to severely eutrophic (Goldburg et al. 2001; Goldburg and

Triplett 1997) and are expected to worsen in 70% of all coastal areas over the next two decades (USEPA 2001). Consequently, the frequency and severity of toxic algal blooms could increase in the future. Refer to the Coastal Development and Chemical Effects: Water Discharge Facilities chapters for more information on eutrophication and harmful algal blooms.

Discharge of contaminants

In addition to organic waste, chemicals and other contaminants that are discharged as part of the aquaculture process can affect benthic and pelagic organisms (Hopkins et al. 1995; Goldburg and Triplett 1997). Chemicals are typically released directly into the water, including antibiotics that fight disease; pesticides that control parasites, algae, and weeds; hormones that initiate spawning; vitamins and minerals to promote fish growth; and anesthetics to ease handling of fish during transport. These chemical agents are readily dispersed into marine, estuarine, and freshwater systems and can be harmful to natural communities. Few chemicals have been approved for disease treatment in US aquaculture operations, although veterinarians can prescribe human and animal drugs use in food fish (Goldburg et al. 2001).

Antibiotics are given to fish and shrimp via injections, baths, and oral treatments (Hopkins et al. 1995; Goldburg and Triplett 1997). The most common method of oral administration is the incorporation of drugs into feed pellets, which results in a greater dispersion of antibiotics in the marine environment. Antibiotics, including those toxic to humans, typically bind to sediment particles, may remain in the environment for an extended period of time, can accumulate in farmed and wild fish and shellfish populations, and can harm humans when ingested.

Herbicides are chemicals used to control aquatic weeds in freshwater systems, and algicides are herbicides specifically formulated to kill algae; dissolved oxygen levels in ponds can be reduced when the algae die and decompose. A common ingredient in algicides is copper, which is toxic to aquatic organisms. Applications of herbicides or algicides must be carefully considered for their toxicity to aquaculture organisms and to humans, as well as their tendency to bioaccumulate in fish and shellfish tissues (Goldburg and Triplett 1997). While these chemicals may not be applied within riverine or estuarine systems, they may find their way there through stormwater runoff. Pesticides must also be carefully monitored for their effects on aquatic organisms and habitat. For example, antifouling compounds such as copper and organic tin compounds were historically used in the aquaculture industry to prevent fouling organisms from attaching to aquaculture structures. These chemicals accumulate in farmed and wild organisms, especially in shellfish species, and the use of organic tin compounds is now banned for use in both Washington and Maine. Aquaculturalists have used the insecticide, Sevin, for 35 years in Willapa Bay, WA, to control burrowing shrimp that destabilize sediment. Sevin kills other organisms such as the Dungeness crab (*Cancer magister*), and it should be used in moderation to minimize the impacts of the aquaculture industry on other important commercial fisheries (Goldburg and Triplett 1997). For additional information on the release of pesticides, refer to the Agriculture and Silviculture and Coastal Development chapters of this report.

Seafloor impacts

Aquaculture operations not only can cause environmental impacts through the discharge of contaminants and organic wastes, but these operations can also affect the seafloor as a result of the deposition of waste products, the placement of aquaculture structures on the seafloor, and the harvesting of aquaculture species.

Aquaculture operations can have a wide range of biological, chemical, and physical impacts on seafloor habitat stemming from organic material deposition, shading effects, damage to habitat from aquaculture structures and operations, and harvesting with rakes and dredges (USFWS and NMFS 1999; Goldburg et al. 2001). Organic material deposition beneath netpens and cages can smother organisms, change the chemical and biological structure of sediment, alter species biomass and diversity, and reduce oxygen levels. The physical and chemical conditions present at the aquaculture site will influence the degree to which organic waste affects the benthic community. At aquaculture sites with slower currents and softer sediments, benthic community impacts will generally be localized; whereas sites with stronger currents and coarser sediments will generally have widely distributed but less intense benthic community effects downstream of the site.

At both land-based and water-based aquaculture facilities, accumulations of large amounts of carbon and nutrient-rich sediment may produce anaerobic conditions in sediments and cause the release of hydrogen sulfide and methane, two gases toxic to fish (Goldburg and Triplett 1997). In Maine, seafloor impacts resulting from sediment deposition at salmon farms include the growth of the bacterial mold *Beggiatoa* sp., which degrades water quality and subsequently lowers species diversity and biomass beneath the pens (Goldburg and Triplett 1997).

Suspended shellfish culture techniques may cause changes in benthic community structure similar to those conditions found under netpens. Filter-feeding shellfish "package" phytoplankton and other food particles into feces and pseudofeces, which are deposited on the seafloor and may cause local changes in benthic community structure (Grant et al. 1995; Goldburg and Triplett 1997). In Kenepuru Sound, New Zealand, a mussel aquaculture site consistently showed a higher organic nitrogen pool than at the reference site, indicating that organic nitrogen was accumulating in the sediments below the mussel farm (Kaspar et al. 1985). The benthic community at the mussel farm was composed of species adaptable to low-oxygen levels that live in fine-textured, organically rich sediments, while the reference site consisted of species that typically reside in highly oxygenated water (Kaspar et al. 1985).

Aquaculture structures can have direct impacts on seafloor habitat, including shading of seafloor habitat by netpens and cages (NEFMC 1998; USFWS and NMFS 1999). Shading can impede the growth of SAV that provides shelter and nursery habitat to fish and their prey species (Barnhardt et al. 1992; Griffin 1997; Deegan and Buchsbaum 2005). Seagrasses and other sensitive benthic habitats may also be impacted by the dumping of shells onto the seafloor for use in shellfish aquaculture operations (Simenstad and Fresh 1995). Shell substratum helps to stabilize the benthos and improve growth and survival of the cultured shellfish species. The placement of this material on the bottom not only causes a loss in seagrass and other habitat, but substrate modification also induces a localized change in benthic community composition (Simenstad and Fresh 1995).

Harvesting practices also have the potential to adversely affect seafloor habitat. Perhaps the most detrimental is the mechanical harvesting of shellfish (e.g., the use of dredges). Polychaete worms and crustaceans may be removed or buried during dredging activities (Newell et al. 1998). Mechanical harvesting of shellfish may also adversely affect benthic habitat through direct removal of seagrass and other reef-building organisms (Goldburg and Triplett 1997).

Introductions of exotic invasive species

Aquaculture operations have the potential to be a significant source of nonnative introductions into North American waters (Goldburg and Triplett 1997; USCOP 2004). The cultivation of nonnative species becomes problematic when fish escape or are intentionally released into the marine environment. As discussed in the above section on introduced/nuisance species, introduced species can reduce biodiversity, alter species composition, compete with native species for food and habitat, prey on native species, inhibit reproduction, modify or destroy habitat, and introduce new parasites or diseases into an ecosystem (Goldburg and Triplett 1997; USFWS and

NMFS 1999). Impacts from introduced aquaculture species may result in the displacement or extinction of native species, which is believed to be a contributing factor in the decline of seven endangered or threatened fish species populations listed under the Endangered Species Act (Goldburg and Triplett 1997).

In Maine, escaped aquaculture salmon can disrupt redds (i.e., spawning nests) of wild salmon, transfer disease or parasites, compete for food and habitat, and interbreed with wild salmon (USFWS and NMFS 1999). Escaped aquaculture salmon represent a significant threat to wild salmon in Maine because even at low levels of escapement, aquaculture salmon can represent a large proportion of the salmon returns in some rivers. Escaped Atlantic salmon have been documented in the St. Croix, Penobscot, East Machias, Dennys, and Narraguagus rivers in Maine. Escapees represented 89% and 100% of the documented runs for the Dennys River in 1994 and 1997, respectively, and 22% of the documented run for the Narraguagus River in 1995 (USFWS and NMFS 1999). In 2000, only 22 wild Atlantic salmon in Maine were documented as returning to spawn in their native rivers; however, total adult returning spawners may have numbered approximately 150 fish (Goldburg et al. 2001).

Cultivating a reproductively viable European stock of Atlantic salmon in Maine waters poses a risk to native populations because of escapement and the subsequent interbreeding of genetically divergent populations (USFWS and NMFS 1999). The wild Atlantic salmon population in the Gulf of Maine currently exhibits poor marine survival and low spawning stock size, is particularly vulnerable to genetic modification, and is in danger of becoming extinct. Dilution of the gene pool, when combined with environmental threats such as reduced water levels, parasites and diseases, commercial and recreational fisheries, loss of habitat, poor water quality, and sedimentation could extirpate the wild salmon stock in the Gulf of Maine (USFWS and NMFS 1999). For additional discussions on this topic, refer to the subsection in this chapter on Gene Pool Alterations.

Food web impacts

Aquaculture operations have the potential to impact food webs via localized nutrient loading from organic waste and by large-scale removals of oceanic fish for dry-pellet fish feed (Goldburg and Triplett 1997). As reviewed in previous sections of this chapter, nutrients in discharged organic waste may affect local populations by changing community structure and biodiversity. These localized changes may have broader implications to higher trophic level organisms. For example, biosedimentation at a mussel aquaculture site had a strong effect on benthic community structure both below and adjacent to mussels grown on rafts (Kaspar et al. 1985). Benthic species located beneath and adjacent to mussel rafts included sponges, tunicates, and calcareous polychaete worms, while benthic species at the reference site included bivalve mollusks, brittle stars, crustaceans, and polychaete worms. The shift in benthic community structure at the shellfish aquaculture site may have had implications in higher trophic levels in the ecosystem.

Large-scale removals of anchovy, herring, sardine, jack mackerel, and other pelagic fishes for the production of fish feed has an impact on the food web. Approximately 27% (31 million metric tons) of the world's fish harvest is now used to produce fish feeds, and about 15% of this is used in aquaculture production (Goldburg and Triplett 1997). Feeding fish to other fish on a commercial scale is highly energy-inefficient and may have environmental implications and impacts on other species. Higher trophic levels depend on small pelagic fishes for growth and survival, so the net removal of protein can have significant effects on sea birds, mammals, and commercially important fish species (Goldburg and Triplett 1997).

Gene pool alterations

Escaped aquaculture species can alter the genetic characteristics of wild populations when native species interbreed with escaped nonnative or native aquaculture species or escaped genetically engineered aquaculture species (USFWS and NMFS 1999; Goldburg et al. 2001; USCOP 2004). Interbreeding of the wild population with escaped nonnative species is problematic, as discussed in the Introduced/Nuisance Species section of this chapter. Interbreeding of the wild population with escaped, native species may also be problematic because of the genetic differences between the escaped native and the wild native populations. Aquaculture operations often breed farmed fish for particular traits, such as smaller fins, aggressive feeding behavior, and larger bodies. Therefore, the genetic makeup of escaped native and wild native fish may be different, and interbreeding may decrease the fitness of wild populations through the breakup of gene combinations and the loss of genetic diversity (Goldburg et al. 2001).

Atlantic salmon aquaculture in New England has been established from Cape Cod, MA, north to Canada, although most of this activity is clustered at the Maine-New Brunswick border. In 1994, thousands of Atlantic salmon escaped from an aquaculture facility during a storm event; many of these fish spread into coastal rivers in eastern Maine (Moring 2005). In 2000, a similar storm event in Maine resulted in the escapement of 100,000 salmon from a single farm, which is more than 1,000 times the documented number of native adult Atlantic salmon. Canada is experiencing similar problems with aquaculture escapees and the interbreeding of wild and farmed salmon populations. In 1998, 82% of the young salmon leaving the Magaguadavic River in New Brunswick originated from aquaculture farms (Goldburg et al. 2001). Escapees can and do breed with wild populations of Atlantic salmon, which is a concern because interbreeding can alter the genetic makeup of native stocks (Moring 2005).

Escaped genetically engineered aquaculture species may exacerbate the problem of altering the gene pool of native fish stocks. Genetically engineered (i.e., transgenic) species are being developed by inserting genes from other species into the DNA of fish for the purpose of altering performance, improving flesh quality, and amplifying traits such as faster growth, resistance to diseases, and tolerance to freezing temperatures (Goldburg and Triplett 1997; Goldburg et al. 2001). For example, genetically engineered Atlantic salmon have an added hormone from chinook salmon that promotes faster growth, which may reduce costs for growers (Goldburg et al. 2001, 2003). Although no transgenic fish products are commercially available in the United States, at least one company has applied for permission through the Food and Drug Administration to market a genetically-engineered Atlantic salmon for human consumption (Goldburg et al. 2001, 2003). Transgenic aquaculture escapees could impair wild Atlantic salmon stocks via competition, predation, and expansion into new regions. Interbreeding could weaken the genetic integrity of wild salmon populations and have long-term, irreversible ecological effects (Goldburg et al. 2001).

Impacts to the water column and water quality

Aquaculture may impact the water column via organic and contaminant discharge from land- and water-based aquaculture sites (NEFMC 1998). As discussed in other sections of this chapter, aquaculture discharges include nutrients, toxins, particulate matter, metabolic wastes, hormones, pigments, minerals, vitamins, antibiotics, herbicides, and pesticides. Water quality in the vicinity of finfish aquaculture operations may be impaired by the discharge of these compounds. The water column may become turbid as a result of this discharge, which can degrade overall habitat conditions for fish and shellfish in the area. Discharge may contribute to nutrient loading, which may lead to eutrophic conditions in the water column. Eutrophication often results in oxygen depletion, finfish and shellfish kills, habitat degradation, and harmful algal blooms that may impact human health.

Shellfish aquaculture operations have the potential to improve water quality by filtration of nutrients and suspended particles from the water column (Newell 1988). However, bivalves may contribute to the turbidity of the pelagic environment via their waste products (Kaspar et al. 1985; Grant et al. 1995). These waste products are expelled as feces and pseudofeces, which can be suspended into the water column, thus contributing to nutrient loads near aquaculture sites. Nutrient overenrichment often results in oxygen depletion, toxic gas generation, and harmful algal blooms, thus impairing the water quality near shellfish aquaculture sites. Therefore, both finfish and shellfish aquaculture operations have the potential to adversely affect water quality beneath aquaculture structures and in the surrounding environment. For additional information on discharge of nutrients and its subsequent effects on the water column via eutrophication and algal blooms, see the subsections on the Discharge of Organic Wastes and Discharge of Contaminants in this chapter, as well as the chapters on Agriculture and Silviculture, Coastal Development, and Alteration of Freshwater Systems of this report.

Changes in species diversity

Species diversity and abundance may change in the vicinity of aquaculture farms as a result of effluent discharges or habitat modifications that alter environmental conditions. Changes in species diversity may occur through increased organic waste in pelagic and benthic environments, modification to bottom habitat, and the attraction of predators to the farmed species. Accumulated organic waste beneath aquaculture structures may change benthic community structure. In Maine, salmon netpen aquaculture can alter the benthos by shifting microbial and macrofaunal species to those adapted to enriched organic sediments. At one netpen site, epibenthic organisms were more numerous near the pen than at reference sites, suggesting that benthic community structure can be altered by salmon aquaculture in coastal Maine waters (Findlay et al. 1995).

Cultivated mussels can alter species diversity via biodeposition. Benthic habitat can shift from communities of bivalve mollusks, brittle stars, crustaceans, and polychaete worms to communities of sponges, tunicates, and calcareous polychaete worms beneath mussel aquaculture sites. The difference between the two sites represents a change in species diversity from those that typically reside in highly oxygenated water to those species adaptable to low-oxygen levels that can live in areas with fine-textured, organically rich sediments (Kaspar et al. 1985).

Benthic habitat modification at shellfish aquaculture sites can alter species diversity (Kaiser et al. 1998). Cultivation of shellfish such as hard clams requires the placement of gravel or crushed shell on the substrate. Seed clams are placed on the substrate in bags or directly on substrate covered with protective plastic netting. Benthic structure at shellfish aquaculture sites can therefore shift from polychaete-dominated communities to bivalve and nemertean-dominated communities, which could have repercussions for other trophic levels (Simenstad and Fresh 1995; Kaiser et al. 1998). However, community diversity may be enhanced by the introduction of aquaculture species and the modification of the substrate. For example, the placement of gravel in the intertidal area, the placement of substrates suitable for macroalgal attachment, or predator exclusion nets in some habitats may enhance epibenthos diversity and standing stock (Simenstad and Fresh 1995).

Open water netpens may alter species diversity by attracting wild fish or other predators to the aquaculture site (Vita et al. 2004). Wild benthic and pelagic species are attracted to uneaten pellet feed and other discharged effluent, which can result in impacts to the food web (Vita et al. 2004). Predators such as seals, sea lions, and river otters may also be attracted to aquaculture pens to feed on farmed species, which can alter communities in the vicinity of aquaculture sites (Goldburg et al. 2001).

Sediment deposition

The effects of sediment deposition include eutrophication of the water column; toxic algal blooms; hypoxic or anoxic zones caused by microbial degradation; and the spread of contaminants such as antibiotics, herbicides, pesticides, hormones, pigments, minerals, and vitamins. The impacts of sediment deposition from discharged organic waste and contaminants on the water column and on the seafloor have been discussed in the Discharge of Organic Wastes, Discharge of Contaminants, Seaflood Impacts, Food Web Impacts, Changes in Species Diversity, and Habitat Exclusion and Replacement/Conversion subsections of this chapter.

Introduction of diseases

Parasite and disease introductions into wild fish and shellfish populations are often associated with aquaculture operations and have the potential to lower the fitness level of native species or contribute to the decline of native populations. For example, in the 1940s and 1950s, scientists inadvertently introduced a new disease into eastern US waters when they attempted to restore declining populations of the eastern oyster (*Crassostrea virginica*) via the introduction of the Pacific oyster (*Crassostrea gigas*) (Burreson et al. 2000; Rickards and Ticco 2002). *Haplosporidium nelsoni* is a protistan parasite that causes MSX oyster disease and was present amongst the Pacific oysters introduced in east coast waters. MSX spread from Delaware Bay to the Chesapeake Bay and contributed to the decline in the native oyster population. MSX and another pathogenic disease, Dermo (*Perkinsus marinus*), have collectively decimated the native oyster population remaining along the much of the eastern US coast (Rickards and Ticco 2002).

In eastern Maine and New Brunswick, an outbreak of two diseases in both wild and cultured stocks of Atlantic salmon suggests that cultured stocks are acting as reservoirs of diseases and are now passing them on to wild stocks (Moring 2005). In addition to diseases, sea lice are a flesh-eating parasite that has been passed from farmed salmon to wild salmon when wild salmon migrate through coastal waters. Sea lice also can serve as a host for Infectious Salmon Anemia (ISA), which is a virus that has spread from salmon farms in New Brunswick to salmon farms in Maine (USFWS and NMFS 1999). The ISA virus causes fatalities in salmon at aquaculture facilities, and this virus has been detected in both escaped farmed salmon and wild salmon populations. ISA first appeared in New Brunswick in 1996, was detected in the United States in 2001, and represents a significant threat to wild salmon populations (Goldburg et al. 2001).

Habitat exclusion and replacement/conversion

Aquaculture operations require the use of space, which results in the conversion of natural aquatic habitat that could have been used by native organisms for spawning, feeding, and growth. Approximately 321,000 acres of fresh water habitat and 64,000 acres of salt-water habitat have been converted for use in aquaculture operations in the United States (Goldburg et al. 2001). Aquaculture facilities may exclude aquatic organisms from their native habitat through the placement of physical barriers to entry or through changes in environmental conditions at aquaculture sites. Nets, cages, concrete, and other barriers exclude aquatic organisms from entering the space in which the aquaculture structures are placed. By effectively acting as physical barriers for wild populations, these formerly usable areas are no longer available as habitat for fish and shellfish species to carry out their life cycles. Aquaculture facilities may physically exclude wild stocks of fish, such as Atlantic salmon, from reaching critical spawning habitat upstream of the facilities (Goldburg et al. 2001).

Changes in environmental conditions at the aquaculture site may also exclude aquatic organisms from their native habitat. Discharge of organic waste and contaminants beneath aquaculture netpens and cages may render pelagic and benthic habitat unusable through nutrient loading and the subsequent effects of eutrophication. Low dissolved oxygen caused by eutrophication may force native species out of their habitat, while harmful algal blooms can cause widespread fish kills or exclude fish from areas affected by the outbreak (Goldburg and Triplett 1997). In the case of large shellfish aquaculture operations, filtering bivalves can also decrease the amount and type of nutrients and phytoplankton available to other species. This reduction in nutrients and phytoplankton can stimulate competition between populations of cultured and native species (Dankers and Zuidema 1995). Nutrient and phytoplankton removal could have a cascade effect on the trophic structure of the ecosystem (NEFMC 1998), which may eventually cause mobile species to relocate to other areas. Nonetheless, bivalves grown in open-water mariculture facilities can provide similarily beneficial filtering functions as native bivalves by contributing to the control nutrients, suspended sediments, and water column phytoplankton dynamics.

Aquaculture can result in the replacement or conversion of the natural benthic and pelagic community in the area surrounding the facility. For example, shellfish aquaculture can eliminate seagrass beds when shell material is dumped on the seafloor (Simenstad and Fresh 1995). Seagrass beds in the vicinity of shellfish culture operations may be eliminated during harvesting, which may temporarily reduce levels of biodiversity by reducing habitat for other marine species. Habitat conversion also takes place at netpen sites in which sediment deposition causes underlying habitat to become eutrophic. Sensitive benthic habitats beneath the netpens, such as seagrasses, may be eliminated or degraded by poor water quality conditions, thus converting viable habitat to unusable or less productive seafloor area (Goldburg and Triplett 1997).

Although the effects of replacement and exclusion of habitat by aquaculture facilities are often negative, there may be some positive effects of the structures. For example, cages, anchoring systems, and other devices can increase the structural complexity to the benthic and pelagic environment, which can provide shelter and foraging habitat for some native species. Open-water shellfish mariculture operations can provide some of the same habitat benefits as natural shellfish beds, such as refugia from predation and feeding habitat for juvenile and adult mobile species. Under some conditions, seafloor productivity may increase near aquaculture sites.

Conservation measures and best management practices for aquaculture

1. Assess the aquatic resources in the area when siting new aquaculture facilities, including benthic communities, the proximity to wild stocks, migratory corridors, competing resource uses (e.g., commercial fishing, recreational uses, other aquaculture facilities), hydrographic conditions, and upstream habitat uses.
2. Avoid siting of aquaculture operations in or near sensitive benthic communities, such as submerged aquatic vegetation.
3. Avoid enclosing or impounding tidally influenced wetlands for mariculture purposes.
4. Ensure that aquaculture operations adequately address disease issues to minimize risks to wild stocks.
5. Employ methods to minimize escape from culture facilities to minimize potential genetic impacts and to prevent disruption of natural aquatic communities.
6. Design aquaculture facilities to meet applicable environmental standards for wastewater treatment and sludge control.

7. Locate aquaculture facilities to minimize discharge effects on habitat and locate water intakes to minimize entrainment of native fauna.
8. Evaluate and control the use of antibiotics, pesticides, and herbicides in aquaculture operations. Avoid direct application of carbaryl or other pesticides in water.
9. Consider biological controls to reduce pest populations, such as small, native species that feed on sea lice and fouling organisms.
10. Reduce the metabolic stress of aquaculture species in order to eliminate or reduce the need for using chemicals. Measures to reduce stress include improving water quality, lowering stock densities, and minimizing handling of fish.
11. Use aquaculture gear designed to minimize entanglement of native species attracted to the aquaculture operation (e.g., predators, such as marine mammals and birds).
12. Exclude exotic species from aquaculture operations until a thorough scientific evaluation and risk assessment is performed.
13. Locate aquaculture facilities rearing nonnative species upland and use closed-water circulation systems.
14. Treat effluent from public aquarium displays, laboratories, and educational institutes that are using exotic species prior to discharge for the purpose of preventing the introduction of viable animals, plants, reproductive material, pathogens, or parasites into the environment.
15. Consider growing several cultured species together, such as finfish, shellfish, algae, and hydroponic vegetables to reduce nutrient and sediment loads on the ecosystem.
16. Develop a monitoring program at the site to evaluate habitat and water quality impacts and the need for corrective measures through adaptive management.

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