

Chapter 9

Effects of Climate Change on Fisheries and Aquaculture in the Southeast USA

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In the Southeast (SE), commercial fishing, recreational fishing, and aquaculture sectors are diverse and widespread. They provide a large economic benefit as well as providing sources of food, baitfish, and ornamental organisms for the rest of the nation. Many of the species and infrastructure are likely to be heavily affected by climate change as has already been seen throughout the region.

Key Findings

- ▶ As land loss continues from sea level rise, subsidence, and coastal inundation, vital habitat for juvenile estuarine finfish and crustacean shellfish is lost; fisheries production will also decrease.
- ▶ Most fish species have a fairly narrow range of optimum temperatures. Depending on the species, the area occupied may expand, shrink, or be relocated with changes in ocean temperatures. Extinctions are predicted to occur where dispersal ability is limited or suitable northward habitat is unavailable (e.g., Gulf of Mexico).
- ▶ Chronic exposure to hypoxia and fluctuating oxygen concentrations impairs reproduction, immune responses, and growth. Hypoxic events are predicted to increase from increased run-off, droughts, and increased temperatures.
- ▶ Severe tropical storms negatively affect fishery species through increased pollution run-off, direct storm damage, flooding, saltwater intrusion from storm surge, and habitat loss. In addition, the fishing and aquaculture industries can be devastated by the damage and loss of infrastructure including boats, docks, marinas, equipment, processing plants, and distribution centers.
- ▶ The potential effects of climate changes on molluscan shellfish fishing and aquaculture are significant and complex. Changes in distribution could occur on decadal time periods based on multiple parameters including temperature, ocean pH and local acidification, sea level rise, and saltwater intrusion.
- ▶ Warming water temperatures may lead to an increase in foodborne and waterborne pathogens associated with molluscan shellfish harvest and consumption.
- ▶ Designing adequate mitigation and adaptation strategies for fisheries management will require continued monitoring, research, and predictive modeling. Existing practices such as more efficient gear technology, direct marketing, monitoring, diversified effort, and carbon sequestration options support adaptation or mitigation, but they are not all widely adopted.

9.1 Background

This chapter covers major fishery and aquaculture systems in the Southeast (SE) region beginning with the value and importance of existing systems, the predicted effect from climate change, and adaptations currently underway or that may be taken in the future. Information includes the research needs necessary to increase societal resiliency to climate change. Not all fisheries and sectors in the region are discussed; those highlighted

are known to be vulnerable to climate change. Many of the ecosystem impacts are covered more thoroughly in the natural ecosystem chapter. Some of these gaps in coverage are addressed in the research needs portion, and these topics should be included in future assessments.

Commercial Fishing

Commercial fishing in the SE consists of freshwater fisheries in reservoirs, lakes, and river systems for sport fish (Florida Fish and Wildlife Conservation Commission, personal communication). Commercial fishing for marine species using seines, hook-and-line, cast nets, gill nets, tongs, and other gear types is conducted in state and federally managed waters. Primary commercial marine species include blue crab, stone crab, crawfish, shrimp, scallops, oysters, clams, menhaden, flounder, groupers, mackerels, mullets, red snapper, striped bass, and tunas.

Commercial fishing is a major economic enterprise in the SE and specifically in the Gulf of Mexico. Commercial fishing in the SE has been valued at \$787 million in dock-side sales with more than 800,000 metric tons landed in 2010 (National Marine Fisheries Service 2010). According to the National Ocean Service (NOS 2011), five of the top ten ports by poundage are in Louisiana (three), Virginia (one), and Mississippi (one) for a combined 1,765 million pounds annually. Louisiana and Virginia also each has one of the top ten ports by value. Gulf of Mexico coastal wetlands produce an annual shellfish harvest worth \$474 million (NOS 2011). These areas are expected to be heavily affected by climate change in the SE (NOS 2011).

In the Caribbean, Puerto Rico and the US Virgin Islands landed 2,745 tons of marine finfish, crustaceans, and molluscs in 2010. Most of these fisheries are divided between trap/pots, line, net, hand collection, and spearfishing (FAO 2012). The small nature of the fishery operations and boats makes them susceptible to damage from tropical storms (Norri and Taylor 2011).

Recreational Fishing

Primary marine recreational species in the SE are striped bass, bluefish, black sea bass, spotted seatrout, yellowfin tuna, dolphin fish, red grouper, red snapper, yellow-tail snapper, sheephead, flounder, Spanish mackerel, and Atlantic croaker. The most sought after freshwater recreational species are largemouth bass, sunfishes, trout, and catfish. Recreational fishing occurs in most natural bodies of water and many constructed impoundments. The SE has thousands of kilometers of rivers and streams and thousands of hectares of natural lakes and constructed impoundments.

The combined marine and freshwater recreational fishing industry in the USA was valued at \$42 billion in 2006 (US Fish and Wildlife Service of Interior et al. 2006). Total marine fishing trip and durable equipment expenditures across the Mid-Atlantic, South Atlantic, and Gulf of Mexico regions in 2009 totaled approximately \$19 billion (National Marine Fisheries Service 2010). Florida has the largest freshwater fishing industry of any state. Combined, the saltwater and freshwater sectors contributed more than \$6.1 billion to that state's economy in 2006 (Florida Fish and Wildlife Conservation Commission 2011).

Aquaculture

The most recent estimate of farm-gate sales of freshwater and marine aquaculture in the 11 states of the SE region is approximately \$740 million (Census of USDA 2005). The primary food species farmed in the SE include clams, crawfish, oysters, soft-shell crawfish and crabs, alligators, catfish, striped bass, tilapia, and trout. The production of food organisms is the most common form of aquaculture practiced in the USA. However, all SE states also have bait farms, sometimes known as minnow or crawfish farms. Species of fish and crustaceans produced include golden shiners, fathead minnows, shrimp, goldfish, suckers, and crawfish.

In addition to those species already mentioned, more than 800 species of ornamental fish are cultured for the aquarium trade, primarily in Florida (Hill and Yanong 2010). The ornamental fish, aquatic plant, and snail industry may be divided into two types: tropical and cool-water species. The tropical fish and aquatic plant industry originated in South Florida where annual temperatures are similar to those of the plant or animal's native range. Other varieties of ornamental fish cultured are the goldfish and the koi carp, which are cool-water species. In addition to growing ornamental fish, some farmers grow fish for use as "feeders" for larger aquarium fish. In addition, raising aquaculture products for educational and research biological supply houses covers a broad range of organisms from algae to turtles. Louisiana also has a thriving pet turtle aquaculture industry.

The production of sportfish to stock the farm, city, and county ponds and lakes in the SE is another aquaculture sector. Many combinations of fish are suitable for stocking in ponds and lakes. Some of the more commonly cultured species are largemouth bass, bluegill, redear sunfish, hybrid sunfish, channel catfish, bullhead, trout, crappie, walleye, yellow perch, fathead minnow, bluntnose minnow, and golden shiner. In the Caribbean, Puerto Rico, and the US Virgin Islands aquaculture includes freshwater ornamental fish, tilapia, pacu, prawns, and Pangasius. In 2010, Puerto Rico produced 17 tons of aquaculture species, and the US Virgin Islands produced 10 tons (FAO 2012).

Production methods. When describing aquatic production systems, names of systems refer to the type of water-holding facility in which the organisms are grown. Several kinds of water facilities are used for growing fish in the SE, including ponds, cages, raceways, and recirculating systems (Swann 1992). The most common production system in use is the earthen pond and may include simple small farm ponds in addition to those specifically designed and built for aquaculture. Cage culture of fish uses existing water resources, lakes or ponds, with the fish enclosed in cages or baskets, which allows water to pass freely between the fish and the water body. A raceway production facility requires large quantities of inexpensive high quality water. The water is normally obtained from a spring or stream and is passed through the raceways using gravity. Recirculating raceway facilities reduces water consumption.

9.2 Climate Change Effects

The metabolism of fish, crustaceans, and bivalves is influenced by a variety of water quality parameters including temperature, salinity and pH. Aquatic organisms have

evolved to adapt to daily fluctuations in these parameters (Willmer et al. 2000); however, future climate variation of temperature, for example, may have a significant influence on the metabolism of these organisms. Most freshwater and marine fish, crustaceans, and bivalves are non-thermoregulating ectotherms; they are unable to regulate their body temperature and, therefore, their internal temperatures match the environment. On an acute time scale, the metabolic rate of ectotherms increases approximately exponentially with temperature (Willmer et al. 2000). For example, the metabolic rate of a clam may double with every 7°C to 10°C increase in water temperature. This increase in metabolic rate has important implications for energy use, growth efficiency, and upper lethal limits (Gosling 2003). Temperature, photoperiod, and in the case of marine organisms, salinity also regulate reproduction. Many of these factors are linked, and altering temperature at different times of year (photoperiod) could drastically affect spawning, mating, and growth of many species (Munro et al. 1990).

Observed changes in species distributions begin at the base of the food web: primary producers. Long-term studies begun in 1958 indicate that climate change has altered primary production in the North Atlantic Ocean. Phytoplankton abundance has increased in the cooler regions (north of 55°N) and decreased in warmer regions (south of 50°N) (Richardson and Schoeman 2004, Sarmiento et al. 2005). Although both regions have experienced warming, reductions in primary productivity in the southern region of the North Atlantic Ocean are due to a warming-induced reduction in vertical mixing and the resulting nutrient limitation (Richardson and Schoeman 2004, Sarmiento et al. 2005).

Impacts on phytoplankton have likely influenced other parts of ecosystems through the food web. The planktonic phases of fish life cycles are particularly vulnerable to impacts of unsuitable or insufficient food. Therefore climate-induced changes in productivity may alter the distribution and phenology of fish larvae and, ultimately, recruitment and production of fish stocks through impacts on growth, survival, and reproduction (Beaugrand et al. 2002 and 2003). More data on the effects of climate change on primary productivity in the Mid-Atlantic Ocean and the Gulf of Mexico are necessary to assess these potential impacts on stock distributions.

Finfish and Crustacean Shellfish

Fisheries for finfish and crustacean shellfish (i.e. crabs, shrimp, etc.) face many potential impacts from climate change. Below is a summary of how different threats from climate change may impact these fisheries.

Wetland loss and sea level rise. Sea level rise will be a significant aspect of climate change effects. Currently, the Southeast Atlantic and Florida experience a relative increase of 2.5 mm per year while Louisiana has relative sea level rise rates of 9.5 mm per year. Climate change could increase global mean sea level rise 20 cm to 200 cm over the next 100 years (see Chapter 2, Section 2.3.8). Currently Louisiana's wetland loss represents about 90% of coastal wetland loss nationally, yet Louisiana has still seen a 6.4% per year increase in marine commercial landings since 1930. However, this increase is most likely due to the increasing land-water interface as a result of land loss. As large land masses are splintered, the total interface area increases due to the combined interface area of all the smaller pieces. However, continued erosion, subsidence, and

sea level rise eventually result in the total loss of these splintered islands and reduced length of interface. Fisheries production will likely decrease as land loss continues and the scale tips to shrinking land-water interface, vital habitat for juvenile estuarine finfish and crustacean shellfish such as shrimp (Caffey and Schexnayder 2002, Browder et al. 1985).

While well-documented in Louisiana, all the SE coastal states face these threats. Menhaden, for example, depend on coastal wetlands or estuaries for part of their life cycle because they spawn all along the USA Atlantic coast and Gulf of Mexico in different months at different locations. After two months in the ocean the larvae are carried into the bays and estuaries by ocean currents, and from there they move into the rivers for several months before migrating back to the ocean. Most mature at two to three years and can live to age ten. Changes in ocean currents could disrupt larval transport into bays and estuaries. Additionally, salt water intrusion, coastal inundation, and land loss due to sea level rise in the Gulf of Mexico states may increase nursery habitat while sea level associated with global warming could flood nursery habitats in northern areas of the region, such as the Carolinas and Virginia, where spawning occurs in protected bays rather than on the shelf. Warmer ocean temperatures could also change menhaden adult migration patterns and spawning locations. In addition to being a fishery species, menhaden are an important food fish for many larger fish, and their reduced abundance and distribution would likely affect the populations of fish that prey on them (Aubrey and Emery 1993, Houde and Rutherford 1993, Jones 1994).

Temperature. A number of researchers have hypothesized the effects of climate change on fishes. Effects range from simple extension of native ranges migrating northward in response to the gradual warming of water to total year class failure (i.e., no survival to juveniles) and disappearance of populations due to interruption of reproductive cycles and offset of timing between predator and prey. Most fish species have a fairly narrow range of optimum temperatures related to specific basic metabolism per species, and in addition the food organisms have their own optimum temperature ranges. Depending on the species, the area it occupies may expand, shrink, or be relocated with changes in ocean temperatures. Warmer temperatures in estuaries would be associated with lower dissolved oxygen levels for larvae (Aubrey and Emery 1993, Houde and Rutherford 1993, Jones 1994). Research indicates that within and near oxygen-depleted waters, finfish and mobile macroinvertebrates, such as crustacean shellfish, experience negative effects that range from mortality to altered trophic interactions. Chronic exposure to hypoxia and fluctuating oxygen concentrations impairs reproduction, immune responses, and growth (Breitburg et al. 2009).

Changes in species distributions occur much more rapidly in the marine environment than in terrestrial systems (Rosenzweig et al. 2007), and there are many examples of distribution changes and migration phenology associated with climate change (Ware and Tanasichuk 1989, Sims et al. 2004, Perry et al. 2005, Pörtner and Knust 2007). For example, a number of tropical and subtropical fish species have shifted northwards along the continental slope of England, at rates matching plankton shifts of 50 km per year (Quero et al. 1998, Stebbing et al. 2002). The southern boundary of one North Sea species, the blue whiting (*Micromesistius poutassou*), has moved by as much as 816 km (ICES 2004, Perry et al. 2005). It should be noted that not all species move northward

at the same rate or at all. These disconnected shifts of species in a system may have unpredictable consequences on, for example, trophic interactions of predators and prey (Murawski 1993, Edwards and Richardson 2004). Extinctions are predicted to occur where dispersal ability is limited or suitable northward habitat is unavailable (Thomas et al. 2004). Local extinctions have already occurred at the edges of some current fish ranges (Friedland et al. 2003). These species shifts and extinctions in other parts of the world suggest that similar changes in distribution could be occurring in the SE USA; more research is needed in this area.

Shifts in fish stock distributions are likely having social and economic consequences (Brander 2010). One economic impact of distributional shifts in some fishery species is the displacement of fishing pressure to other species. For example, as cod fisheries have declined due to fishing pressure, landings of shrimp, crab, and lobsters have risen (Parsons and Lear 2001). In fact, northern shrimp (*Pandalus borealis*) and lobster (*Homarus americanus*) populations have actually increased, possibly as a result of increased water temperatures and subsequent improvements in recruitment (Parsons and Colbourne 2000, Mann and Drinkwater 1994).

Storm severity. Recent modeling studies suggest that the frequency of major hurricanes (Categories 3 to 5) likely will increase in the future, while the overall number of tropical cyclones will likely decrease (See Chapter 2.4.6). An increase in tropical storm activity could have large impacts on the fishing and aquaculture industries. Many fished and cultured species are negatively affected by severe tropical storms through increased pollution run-off, direct storm damage, flooding, saltwater intrusion from storm surge, and habitat loss. In addition the fishing and aquaculture industries can be devastated by the damage and loss of infrastructure including boats, docks, marinas, equipment, processing plants, and distribution centers. These types of losses have already been documented throughout the SE after major storms (Figure 9.1).

Molluscan Shellfish

Molluscan shellfish include bivalves such as clams, oysters, scallops, and mussels that are fished or cultured for human consumption. These species are predominately sessile, or immobile, and face different effects from climate change than finfish and crustacean shellfish. Clams and oysters are of particular importance in the SE. For example, shellfish aquaculture products sold in 2005 from SE states were valued at \$42 million—Louisiana and Florida were the largest contributors (USDA 2005). The effects of climate change on molluscan shellfish fisheries and aquaculture are expected to be complex; some potential aspects are considered in the following sections.

Climate change is expected to affect the reproduction, health, and distribution of commercially harvested bivalve species within the Gulf of Mexico, as expected in other coastal marine systems (Harley et al. 2006, Hollowed et al. 2011). The potential effects of increased water temperature on molluscan shellfish fishing and aquaculture, in particular, are significant, potentially complex and highly variable (Allison et al. 2011). Bivalve ranges shift locally on a seasonal basis as freshwater flows ebb and flow. However, larger changes in range could occur on longer time periods based on multiple parameters. Among these are temperature, ocean pH and local acidification, and sea



Figure 9.1 A fishing vessel lies on its side near a wholesale fishing dock in St. Bernard Parish, Louisiana, after Hurricane Katrina. Adjacent infrastructure also suffered massive damage. Photo by Paula Ouder. Courtesy of Louisiana Sea Grant College Program.

level rise that may move coastal estuaries inland. Here the potential aspects of climate change that could influence molluscan shellfish are considered.

Increases in water temperature. Warmer water temperatures are expected to have effects on the physiology of species, leading to possible impacts on metabolism, reproduction, and species distribution in both marine and estuarine environments (Fields et al. 1993, Lubchenco et al. 1993). North Atlantic sea-surface temperatures are expected to show the greatest increases—up to 3°C by the end of the 21st century in the area eastward across the subtropics from South Florida and the Bahamas, and smaller increases across the Caribbean Sea and Gulf of Mexico (see Chapter 2, Section 2.4.7). Increased temperatures may allow tropically distributed species, including nonindigenous species such as the green mussel, *Perna viridis*, (currently established in Florida) to expand their ranges northward. Additionally, warming water temperatures may lead to an increase in foodborne and waterborne pathogens associated with molluscan shellfish harvest and consumption (Rose et al. 2001). Moreover, increased water temperatures

may be associated with an increase in hypoxia events, which pose a significant threat to commercially harvested shellfish in the coastal waters of the Gulf of Mexico (Fogelson et al. 2011, Vaquer-Sunyer and Duarte 2008).

Sea level rise. Sea level rise is expected to have the greatest impacts on fisheries and aquaculture in areas of shallow water, such as Louisiana and much of the Gulf Coast, as estuarine locations could shift significantly. Blum and Roberts (2009) suggest the loss of tens of thousands of square kilometers of delta surface area in Louisiana alone. Rises in sea level may affect the distribution of established oyster reefs as well as the productivity and accessibility of privately leased oyster beds and clam farms.

Freshwater inputs and increased precipitation. Increased precipitation, predicted for parts of the SE is likely to increase freshwater inputs to estuarine and coastal areas, decreasing salinity. On the other hand, diversion of freshwater sources for human and agricultural uses may reduce freshwater inputs and increase salinity. Studies of El Niño-Southern Oscillation (ENSO) events support observations that salinity is a major factor affecting distribution of molluscan shellfish, and any changes in salinity are predicted to have significant consequences (Soniati et al 2006, Kim et al. 1999). Soniat et al. (2006) found that the oyster pathogen, *Perkinsus marinus* or Dermo, was associated with ENSO-driven increases in salinity. Conversely, Kim et al. (1999) suggested that ENSO-driven cycles can lead to increased levels of contaminants, such as pesticides and trace metals, and decreasing salinity with increased freshwater input. Studies of ENSO events can provide a model of what precipitation changes from climate change could mean to the region.

Ocean acidification. The effect of increased CO₂ concentrations in water and the resulting lower pH decreases the saturation state of calcium carbonate and leads to decreased calcification in marine organisms (Raven et al. 2005). Therefore, ocean acidification is expected to have major effects on molluscan shellfish fisheries and aquaculture and has already been linked to failures of shellfish spawning at Pacific coast hatcheries in the USA (Porter 2007, Kraines and Suzuki et al. 1996, Miller et al. 2009). Estuarine waters are less buffered than marine waters and are more susceptible to ocean acidification (Waldbusser et al. 2011). Experimental studies of larval growth and survival have indicated that predicted levels of acidification ($p\text{CO}_2$ up to 560 and 800 μatm) would lead to decreased growth and survival (Miller et al. 2009, Parker et al. 2009, Talmage and Gobler 2010). Miller et al. (2009) studied the Atlantic oyster (*Crassostrea virginica*) and found modest decreases in shell area and calcium content in specimens treated with two expected future CO₂ concentrations (up to approximately three times preindustrial CO₂ levels), compared to controls. However, oysters were able to continue to accrue some new shell, even in situations with limited amounts of aragonite, the most soluble form of calcium carbonate (Miller et al. 2009).

Severity of storms. The potential increase in the severity of tropical storms in the western Atlantic (Emmanuel et al. 2008), should such increase occur, could have devastating effects on both molluscan shellfish fisheries and aquaculture, as evidenced by the catastrophic effects of recent hurricanes within the Gulf of Mexico. Not only are animals

directly affected, but fisheries and aquaculture infrastructure can be completely destroyed. The depression of oyster harvests in the northern Gulf of Mexico by Hurricane Katrina is one well-documented example of the effect of severe storms (NMFS Statistics Office, personal communication). Research is needed to assess the potential impacts of increased storm frequency and severity on molluscan fisheries and aquaculture.

Freshwater Fisheries and Aquaculture

All aquaculture species may face harmful effects from climate change. Increased temperatures may result in hypoxia in outdoor systems (see sea surface temperature, Chapter 2, Section 2.4.7). Outdoor systems near the coast face threats from sea level rise and inundation. All four types of facilities will face challenges due to climate change. Ponds will face threats from extreme temperatures, drought, and flooding and those near the coast will have the additional threats from saltwater intrusion and sea level rise. Drought and increased temperatures, which reduce dissolved oxygen levels, will likely threaten cage production because they increase the need for circulation to compensate. Both raceways and recirculating systems will need to contend with conflicting water uses which may reduce water availability for these facilities. Crawfish and alligators are important fishery and aquaculture species in the SE facing negative impacts by climate change. Sea level rise, reduced rainfall, or seasonal flooding would all have effects.

Although crawfish are fairly tolerant to saltwater, saltwater intrusion will negatively affect production. Tolerance to salinity is directly proportional to crawfish size. Salinity affects crawfish reproduction at much lower concentrations but the effect of continuous exposure to low salinity on crawfish reproduction is not fully known. If salinities higher than 3 ppt occur through most of the crawfish season, production will likely be negatively affected (McClain et al. 2007).

Alligator farmers depend on the collection of eggs from nests found in coastal or inland wetland habitats. Nesting efforts by female alligators are negatively affected by elevated salinity as well as high water levels during the spring prior to egg laying time. Stress levels increase as salinity increases causing female alligators to abort nesting when salinity reaches 8 to 10 ppt. Droughts along the coast and saltwater intrusion also may result in higher salinities. Nesting female alligators respond to high water events prior to nesting by building higher nests or moving to a higher site. High water events following egg laying result in drowning of the embryos should the eggs be submerged (Joanen and McNease 1989). Extreme precipitation events could lead to the submerging of nests (IPCC 2007).

If droughts increase in frequency as expected in parts of the SE, then decreased water levels, increased water temperature, and decreased dissolved oxygen may occur. An extreme drought like that in Texas and western Louisiana in the summer of 2011 resulted in large fish kills as reservoirs dried up and oxygen levels dropped. Nearly 124,000 fish were killed in just one lake, Lake Grapevine, a few miles northwest of Dallas (Texas Parks and Wildlife Department, personal communication). Other SE states could easily witness similar droughts. Additionally, reservoirs, farm ponds, aquaculture ponds and streams are all vulnerable to these climate change conditions.

9.3 Complicating Factors

SE fisheries and aquaculture are not closed systems operating without outside influence. Many factors, some discussed in this section, likely will influence the effects of climate change on these sectors.

The Gulf of Mexico Dead Zone

The Mississippi River captures runoff from 41% of the continental United States. As climate changes throughout the USA, changes in flows of the Mississippi River will affect the Gulf of Mexico. Since the 1970s a large hypoxic zone has been documented off the coast of Louisiana related to the Mississippi River's drainage. The oxygen levels in water there are so low that fish and shellfish often do not survive or must leave the area if possible. As flooding events increase and agricultural practices are adapted to climate change, the extent of the yearly dead zone is expected to increase. In 2010, the Dead Zone size was one of the largest ever recorded at 7,722 square miles (NOAA 2010). However, an increase in severe tropical storms could help offset this hypoxic zone with additional mixing of water (NOS 2011, Rabalais et al. 2009).

Harmful Algal Blooms

Harmful Algal Blooms (HABs) result from a rapid growth of *Karenia brevis* and other "red tide" organisms. An increase in nutrients from human-caused nutrient pollution often increases the prevalence of HABs resulting in fish kills, sea bird mortality, and human illness from contaminated shellfish. In Florida alone, HABs are estimated to cost \$19 million to \$32 million per year in economic damage (NOS 2011). Combinations of increased precipitation, runoff, and nutrient pollution will likely increase the frequency of HAB events, directly killing fish, affecting human and wildlife populations, and impacting the economics of the region.

Restoration Conflicts

In areas where fishers have already relocated to adapt to changes in catch location, such as in the upper reaches of the estuary in response to saltwater intrusion, restoration efforts to return natural tidal flows and salinity regimes can be in direct opposition to these fishers' adaptations. In coastal Louisiana, oyster fishers have moved their leases up the estuaries as saltwater intrusion has changed the oyster zones. Shrimp and crab fishers have started fishing further inland. Restoration such as freshwater diversions are designed to increase freshwater flow and return sediment to the wetlands. However, this freshwater lowers salinity detrimental to oyster leases and results in possible relocation of adult blue crabs and shrimp, forcing fishers and producers to adapt again to changes. Oyster lease relocation programs have, therefore, also been considered as part of the restoration (Caffey and Schexnayder 2002). Florida's clam industry faces these same challenges if there are shifts in salinity regimes due to climate change.

Water Use

Water is an essential resource for communities and for aquaculture. In Louisiana alone, \$326 million is contributed to Louisiana's economy from aquaculture. However, this

economic contribution requires a water investment, usually freshwater. If droughts increase in frequency as expected in parts of the SE, conflicts may arise over water use between communities and aquaculture producers throughout the SE. Best management practices will need to be encouraged for the most efficient use of water resources by all groups involved (Romaine et al. 2011).

9.4 Adaptation and Mitigation

Designing adequate mitigation and adaptation strategies for fisheries management will require continued monitoring, research, and predictive modeling. Existing adaption and mitigation practices exist which may help fisheries and aquaculture adjust to or even offset climate change factors. This section highlights specific concerns for adaptation and mitigation related to aquaculture and fisheries in the SE USA.

Species and systems will be impacted by other concurrent pressures—such as overfishing including age truncation and loss of genetic diversity, increased coastal storm activity, precipitation and runoff, habitat destruction, pollution, invasive species, and pathogens—making populations less resilient to unfavorable conditions related to climate (Knutson et al. 1998, Wolock and McGabe 1999, Brander 2005, 2007, and 2010, Planque et al. 2010). Some projections show that climate change may lead to local extinctions of exploited species, particularly in subpolar and tropical regions (Cheung et al. 2009). Designing adequate mitigation and adaptation strategies for fisheries management will require continued monitoring, research, and predictive modeling. Continued development of aquaculture production may contribute to future food security, although these systems are also likely to experience additional stresses due to climate change (See Chapter 9, Section 9.2.3)

Monitoring

Fishers and farmers adapting to some climate changes could be aided by increased use of weather and water condition monitoring systems in order to fish and harvest at optimal times. Offshore fishers could increase use of satellite weather and water conditions to help them decide if it is cost-effective to stay out on the water or head to port. In Florida, clam farmers currently have a water quality website (http://shellfish.ifas.ufl.edu/water_quality.html) to check wind speed, air and water temperature, and salinity prior to planting or harvest. This results in decreased fuel use and costs and, therefore, lowers emissions (University of Florida 2011).

Gear Efficiency

As fisheries face impacts from climate change, advances in gear technology may support adaptation through improving efficiency and economic resilience. Reducing drag on gear, and thereby fuel consumption, is one option to make the shrimp-trawl fishery more adaptable to a changing future. Reducing fuel expense and extending the intervals for various preventive maintenance activities may enable remaining operators to begin improving economic performance in the shrimp fishery. Efforts to reduce fuel use have also led to the ability to document a reduced carbon footprint. Experimental gear technology such as vented, cambered trawl doors; small-diameter, braided

high-density, polyethylene (HDPE) webbing called Sapphire®; and Kaplan-style propellers could allow the industry to adapt to and mitigate effects of climate change. Results generated by co-operators across the Gulf and South Atlantic suggest that other fishers can expect somewhere between a 20% and 28% reduction in fuel use with the experimental fishing gear (Graham and Haby 2010). Fuel conservation and the reduction in fuel expense is, unequivocally, the largest savings attributable to the new gear, and it is immediate (Graham and Haby 2010).

Shifting Effort

The development of the hard clam aquaculture industry in Florida and other parts of the Gulf Coast is an excellent example of the efforts to shift from fishing to aquaculture. Former gillnet fishers who were no longer allowed to gillnet were trained in shellfish aquaculture, and the industry has become successful (Colson and Sturmer 2000). A shift to a new species or to a new sector (i.e., fishing to aquaculture) may be beneficial, but also involves costs for new resources. In selecting aquaculture species, however, an important consideration must be the degree of dependence on products from fisheries, such as fish meal and fish oil, for food supply. These fish products could also face threats from climate change (Naylor et al. 2000).

Carbon Sequestration

Use of bivalves for carbon sequestration may be plausible (Hall et al. 2011 and 2009, Lee et al. 2011). Mollusk shells sequester carbon, not directly from the atmosphere, but through algae consumption and uptake from the water column. Dehon (2010) studied the issue and concluded that oyster reefs could sequester geologically significant amounts of carbon. Use of artificial reefs for multiple functions has been explored by Hall et al. (2011) and many others. Natural or artificial reefs can become dominated by native oysters and can produce food and habitat, provide protection from erosion, aid in sedimentation, and be useful sustainable tools for estuarine management as well as carbon sequestration (Hall et al. 2011).

Some oyster cultivation in Florida combines commercial harvest and carbon sequestration (Baker 2011). The commercial culture of northern hard clams, *Mercenaria mercenaria*, in Florida is conducted in high-density lease areas, designated by the state in waters that were previously determined to be unproductive for shellfish. Clams grow rapidly in this environment and typically reach commercial size after about one year of growth in the leased areas. Clams are cultured in semi-rigid mesh bags, which provide hard substrata for fouling organisms on an otherwise soft-bottom environment. Market clams, however, accounted for only 70% of the bags. Nonharvested clams, oysters (*Crassostrea virginica* and *Ostrea equestris*), mussels (*Brachidontes* sp.) and barnacles (*Balanus* spp.), among other shell-bearing fauna, were recovered from both on and within the clam bags. With this material added, carbon sequestration estimates rose to 2.2-6.8 Mg ha⁻¹ y⁻¹ (Baker 2011).

Local Markets

Greater use of local markets may increase adaptive capacity for fishers and producers in several ways. By utilizing local markets, fishers and producers can reduce their fuel

costs and emissions. Additionally, they can yield a high price per unit and be better able financially to adapt to lower catch, increased fuel costs, and variable weather from climate change. Some systems to support greater connection to local markets are emerging. For example, Delcambre Direct Seafood, Delcambre, Louisiana, uses the Internet to connect fishers with buyers who want to purchase directly off the boat. By the end of 2010, more than 20 vessels were enrolled and profiled in the Delcambre Direct network and buyer participation had risen to 675 subscribed individuals. Suppliers were reporting a steady and increasing number of requests for product and in many cases fishers reported having most or all of their catch sold prior to leaving port. On average, prices received via Delcambre Direct were 2.5 times greater than average dock-side prices for commodity shrimp. Direct sales netted these fishers a \$6,000 premium over dock prices annually (Hymel and Caffey 2011). In South Carolina, the interactive web-based tool MarketMaker, featuring a searchable database that connects consumers of South Carolina products with suppliers, was redesigned to include seafood and seafood products. The seafood component of MarketMaker serves all elements of the seafood industry (fishers, retail, distributor, and wholesaler) allowing each to create an online business profile highlighting the uniqueness of their products and businesses, and to choose from a nationally compiled list of seafood species and attributes to characterize their products on the sellers' side and specify their needs on the buyers' side (South Carolina Sea Grant Consortium 2012).

9.5 Research Needs

Aquaculture and fisheries are important economic drivers in the SE USA. For these industries to continue to grow and contribute to national food security, strategies must be adopted to mitigate the harmful impacts of climate change, such as sea level rise, coastal storm activity, freshwater inflow events, ocean temperature increase, and ocean circulation alteration (Scavia et al. 2002). However, interactions between climate change processes and anthropogenic factors, such as fishing pressure, are complex and may be unpredictable at our current level of understanding (Harley et al. 2006). Therefore, an active collaboration of ecologists, physiologists, geneticists, engineers, climatologists, oceanographers, economists, resource managers, and members of the fishery and aquaculture industries can be developed. Working together these groups can help prioritize and direct research efforts and policies of relevance to the aquaculture and fishery industries in the SE USA. All climate change predictions need to include ocean currents, sea surface and air temperatures, ocean acidification, land loss, sea level rise, oxygen concentrations, precipitation changes in frequency and intensity, and storm frequency and intensity. Some of the identified research needs are discussed in the following sections.

Impacts of Freshwater Inflow

There is great uncertainty regarding future rainfall and runoff patterns, especially in the Southeast. Additionally, as human populations grow or migrate, water use conflicts are likely to escalate.

Estuaries are particularly important for fisheries and aquaculture production, for example, serving as nursery grounds for larval fish and as the appropriate habitat for

suspension-feeding shellfish. Physical impacts of inflow changes likely will include modified salinity regimes and estuarine stratification; increases in nutrient, sediment, and pollutant load to estuaries; and reduced freshwater availability for inland aquaculture (Kennedy 1990, Najjar et al. 2000). Potential biological impacts include changes in phytoplankton communities and increased eutrophication, resulting in expanded hypoxic or dead zones (Cloern 2001, Rabalais et al. 2002). Both physical and biological impacts of changes in freshwater inflow will interact with fisheries and aquaculture in the SE in complex ways and will require adaptation in the industries. Research examining possible coping strategies is currently lacking. In addition, developing reliable precipitation and inflow models for the SE, including the Gulf of Mexico, will aid future analyses.

Aquaculture Development

As capture fishery production moves northward or species go extinct at the southern edges of their ranges (Ware and Tanasichuk 1989, Friedland et al. 2003, Sims et al. 2004, Perry et al. 2005, Pörtner and Knust 2007), continued development of aquaculture may contribute to future food security. Local extinctions may be a particular problem in the Gulf of Mexico, where northward shifting species have nowhere to go. As a result, place-bound fishers may displace their activities to remaining species, resulting in the decline of these alternative species as well (Parsons and Lear 2001). Under that scenario, aquaculture development may become more important in the SE USA. Research examining methods of culturing new food fish and shellfish species, development of more efficient culture methods, and development of alternative feeds would aid development.

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