CHAPTER 14

Climate Change Impacts on Florida's Fisheries and Aquaculture Sectors and Options for Adaptation

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Florida supports diverse marine and freshwater fisheries and a significant aquaculture industry with a combined economic impact of approximately 15 billion US$. We begin by describing the characteristics of the different fisheries and aquaculture sectors. This is followed by a description of the relevant climate change and confounding drivers. We then present an integrated social-ecological systems framework for analyzing climate change impacts and apply this framework to the different fisheries and aquaculture sectors. We highlight how the characteristics of each sector gives rise to distinct expected climate change impacts and potential adaptation measures. We conclude with general considerations for monitoring and adaptation.

Key Messages

- Sea level rise, more frequent severe storms, coastal habitat loss associated with both factors, changes in nutrient dynamics, and ocean acidification are likely to impact the productivity of Florida's marine fisheries. Some of these factors will also affect fisheries access.
- Florida's freshwater fisheries will be impacted by increased hydrological variability, increased temperatures, and more frequent severe storms. Shallow lakes may respond by switching from a clear to a turbid, phytoplankton-dominated state that provides poor sport fishing. Greater hydrological variability will also exacerbate fishing access issues.
- Among the aquaculture sectors, shellfish aquaculture is particularly sensitive to multiple drivers including sea level rise, coastal habitat loss, increased frequency of harmful algal blooms and ocean acidification. Ornamental fish culture and other forms of intensive aquaculture under controlled conditions will be relatively insensitive to climate change.
- Key adaptation options for marine fisheries include switching of species, locations and fishing methods, while adapting catch limits to changes in productivity. In freshwater fisheries, on the other hand, water and habitat management will be key to adaptation. Change in farming methods will be important in aquaculture, along with species and location changes, particularly in the shellfish industry. Aquaculture for fisheries enhancement and ecological restoration can aid adaptation in both marine and freshwater fisheries. Adaptation will benefit from awareness of drivers and impact pathways, monitoring of a broad suite of impact indicators, and adaptive decision-making.

Keywords

Fisheries; Aquaculture; Sea level rise; Coastal habitat; Social-ecological system; Fisheries enhancement; Restoration aquaculture

Introduction

Florida's fisheries and aquaculture sectors are of major economic, social, and cultural importance to the state, generating some $15 billion in economic activity, supporting over 150,000 jobs, and attracting more than 2.4 million visiting anglers to the 'fishing capital of the world' (Table 14.1). Both fisheries and aquaculture use aquatic biological resources for human ends, but they do so in very different ways (FAO 1990; Anderson 2002). Fisheries involve the harvesting of wild aquatic organisms held in some form of common ownership. Aquaculture, on the other hand, entails the active husbandry of aquatic organisms that are privately-owned (Bostock et al. 2010). Fisheries and aquaculture, therefore, differ in both the technology used and the way in which resources are owned and regulated. Not all fisheries and aquaculture enterprises fall neatly into these two categories. For example, in some fisheries, catch shares confer private use rights to wild aquatic organisms (Fujita & Brozon 2005). Also, some fisheries are enhanced by using technologies akin to active husbandry, such as the deployment of artificial reefs or the release of hatchery-reared fish (Bortone et al. 2011; Lorenzen et al. 2013).

Fishing may be for commercial purposes (income), for recreation, or for subsistence (meeting nutritional needs). All three types of fishing exist in Florida, but recreational and commercial fisheries predominate. Commercial and subsistence fishers are motivated by a desire to harvest fish; they get satisfaction primarily from income earned or nutrition gained. Recreational fishers, on the other hand, are motivated by a variety of factors, including enjoyment of the outdoors, relaxation, escape, and self-actualization, as well as or instead of a desire to harvest fish (Fedler & Ditton 1994; Cooke et al. 2017; Garlock & Lorenzen 2017). Little is known about subsistence-oriented fishing in Florida, which exists in both the marine and freshwater realms. It is often carried out from shore and involves a broad range of fish species, including many that are not targeted in the commercial or recreational fisheries.

Being reliant on sensitive ecosystems and support infrastructure (e.g., docks, boat ramps), fisheries and aquaculture are likely to be among the sectors of Florida's economy most vulnerable to climate change. Here, we briefly discuss the importance and diversity of Florida's fisheries and aquaculture sectors before outlining key considerations for understanding potential climate change impacts and adaptation options. We then apply these considerations to select fisheries and aquaculture sectors, and point out similarities and differences in vulnerabilities and adaptation options.

Overview of Florida's Fisheries and Aquaculture Sectors

Florida's fisheries and aquaculture sectors are exceptionally diverse and of great economic, social, and cultural importance to the state (Table 14.1). Marine fisheries—which consists of recreational, commercial, and commercial marine life fishing—is the largest subsector overall, with an economic impact of over $13 billion annually. Marine recreational fishing is responsible for more than $12 of that $13 billion, producing 70,000 jobs and attracting 6.5 million participants each year (Southwick Associates 2012; NMFS 2016). In fact, Florida has the largest and most valuable marine recreational fisheries of any state in the U.S., with its economic impact generated through expenditures by recreational anglers and by jobs in the fishing equipment, hospitality, guide services, and other support areas. Out-of-state visitors are responsible for about 18% of Florida recreational fisheries' economic impact (USFWS & USCB 2013), and Florida is a net gainer in the movement of recreational fishers; in other words, more fishing trips are 'imported' to the state than are 'exported' from it (Ditton et al. 2002). Much of Florida's marine recreational fishing takes place on private boats or from shore, but about 15% of fishing trips involve charter vessels ranging from smaller personalized guide services to large 'head boats.' Charter operators are not allowed to sell fish caught during charter trips (i.e., they are not commercial fishermen); they exist to provide a service to anglers. Marine commercial fishing adds another $1 billion to the state's marine fisheries and produces some 12,000 jobs (NMFS 2016). The economic impact of commercial fishing in Florida is generated through sales of harvested seafood. Seafood is a widely-traded commodity, and a substantial share of the seafood produced in Florida is exported out of state and out of the country. On the other hand, much of the seafood consumed in Florida is imported, with locally-produced seafood accounting for only about 15% of consumption. As a result of such trade patterns, seafood production and consumption in the state are only weakly linked. In addition to the commercial fishery for seafood, a smaller and very specialized 'marine life' fishery provides live organisms for the aquarium trade and for research (Larkin et al. 2001).

Freshwater fishing in Florida is also predominantly recreational, but it does have subsistence-oriented and commercial components. The state's freshwater recreational fishing generates about $1.7 billion annually and is responsible for some 14,000 jobs, the highest impact of freshwater recreational fishing in any state in the U.S. (Southwick Associates 2012). And while the freshwater commercial fishing industry in Florida is of less economic importance than recreational, it still contributes several million dollars to the state's bottom line each year (FWC 2011).

Finally, Florida's aquaculture industries (also known as aquafarming) generate about $69 million in sales volume annually and has an economic impact that is double, possibly triple that generated by 686 aquaculture operators across the state and supporting an estimated 2000 jobs (USDA 2013). The largest aquaculture subsector in terms of economic impact is the ornamental fish industry, which produces a variety of tropical species for the aquarium trade. Second in economic importance is the shellfish industry, which harvests mainly clams and oysters. In addition, there are several smaller but profitable industries, including sturgeon farming for caviar and culture of baitfish for recreational anglers. Emerging aquaculture subsectors include open ocean aquaculture, which is being considered for the Gulf of Mexico. Restoration and fisheries enhancement aquaculture (i.e., producing organisms for release into natural ecosystems) is currently carried out only at the research-level but it may expand into a more significant industry over the long term. In its totality, Florida's aquaculture industry presents a diversity of production systems, ranging from the extensive and environmentally-open systems used in shellfish farming to the intensive and highly controlled indoor systems used in sturgeon farming or in the marine ornamental industry.

Table 14.1. Economic impact, employment, and participation in Florida's fisheries and aquaculture sectors and subsectors.

Sector	Economic Impact or Value ($ Million)	Employment	Participation (Thousands)	Harvest
Marine fishing				
Recreational	12,249(1)	70,109(1)	6500(1)	
Commercial	1,060(1)	12,241(1)	12(1)	99 million lbs(1)
Commercial (marine life)	7(2)			12 million individuals
Freshwater fishing				
Recreational	1,689(3)	14,040(3)	3100(3)	
Commercial	5(4)			10 million lbs(4)
Aquaculture	69(5)	2000(5)	2(5)	
Ornamental	27(5)	400(5)	< 1(5)	
Shellfish	12(5)	400(5)	< 1(5)	
Other	30(5)	1000(5)	1(5)	

Sources: (1) NMFS 2016; (2) Larkin et al. 2001; FWC 2017 (3) Southwick Associates 2012; (4) FWC 2011; (5) USDA 2013.

Key Considerations for Understanding Climate Change Impacts on Fisheries and Aquaculture

Climate change will impact fisheries and aquaculture through multiple drivers and pathways in ways that will be strongly dependent on specific characteristics of the different systems. It is, therefore, important to adopt an integrated, social-ecological systems approach to assessing potential impacts and adaptation measures. (Hollowed et al. 2013; Bush et al. 2016; Hunt et al. 2016). Here, we conceptualize climate change impacts on these systems by applying the considerations outlined in Table 14.2.

Table 14.2. Key considerations for understanding climate change impacts and adaptation options relating to Florida's fisheries and aquaculture sectors.

Climate Change and Confounding Drivers	Fishery or Aquaculture System Attributes	Impact Pathways	Outcomes	Adaptation Options
Climate Change Temperature Rainfall Altered circulation Altered hydrology Storm frequency and severity Sea level rise Geomorphic changes Acidification Habitat Mitigation and adaptation policies **Confounding Factors** Demography Land use change Water demand	**Environment** **Resource** **Technology** **Users/producers** **Governance**	**Resource pathway** **Resource user/producer pathway**	**Resource conservation** **Resource use/production** **Economic** **Social** **Governance**	**Technical change** **Behavioral change** **Governance change**

Climate change and confounding drivers outside the control of fisheries/aquaculture stakeholders or governance systems constitute external drivers. These drivers include changes in temperature, rainfall, circulation, hydrology, frequency and severity of storms, sea level, geomorphology, ocean acidity, habitats and infrastructure, and even mitigation policies. However, the impact of climate change-related drivers may be confounded by other anthropogenic drivers (e.g., changes in human population demography, land use, and markets for inputs and outputs of fisheries and aquaculture). Attributes of a fishery or aquaculture system influence its exposure to climate change drivers and, ultimately, the likely outcomes and potential adaptation options available to it. These attributes include characteristics of the environment where the fishery or aquaculture system is situated; the resource/cultured species (e.g. temperature preferences, life history, and habitat use); the degree of technical control over the environment and biological production (typically low in fisheries but high in certain aquaculture systems); motivations, socio-economic status, and adaptive capacity of resource users/producers; and governance arrangements (e.g., rules and regulations in place, compliance and effectiveness, adaptive capacity). The pathways through which impacts of climate change and confounding drivers on the fisheries/aquaculture system occur fall into one of two broad categories: (1) A resource pathway that includes all impacts on the exploited/cultured resources (and thus eventually, on users). For example, this could include a temperature-induced range or productivity shift in a fish stock. (2) A resource user/producer pathway that includes all impacts that act directly on the resource users/producers and on the governance system. Examples would include changes in resource access due to the destruction of boats or landing facilities by a storm, or an increase in operating costs due to a carbon tax on fuel.

Climate change impacts can be characterized and measured in multiple ways: effects on resource conservation status, effects on resource productivity, economic impacts (e.g. overall economic activity, viability of businesses), social impacts (e.g. exclusion of poorer sections of the population from fishing), and performance or sustainability of governance systems. Adaptation to climate change, those actions generally aimed at reducing negative impacts, comes in different forms as well, including technical changes (e.g., modifications made to fishing gear), behavioral changes by resource users/producers, or changes in the governance system.

Drivers of Climate Change Impacts and Confounding Factors in Florida

Key drivers of climate change impacts on Florida's fisheries and aquaculture sectors include (Carter et al. 2014):

- Temperature increases (Carter et al. 2014)
- Moderate increases in average rainfall and increases in variability (Carter et al. 2014; Moser et al. 2014)
- Altered hydrology with an increase in average and variability of river flows, lake water levels, groundwater recharge, and freshwater outflow into coastal systems (Georgakakos et al. 2014; Obeysekera et al. 2015)
- Changes in large- and meso-scale circulation features in the Gulf of Mexico (Liu et al. 2012)
- Changes in ocean stratification (Doney et al. 2014)
- Changes in the frequency and intensity of harmful algal blooms (Moore et al. 2008)
- Greater frequency and severity of storms (Carter 2014)
- Sea level rise; Florida is highly vulnerable and this is perhaps the single most important driver of climate change impacts in the state (Carter et al. 2014)
- Salt water intrusion (FWC 2009; Barlow & Reichard 2010)
- Ocean acidification , although higher latitudes tend to face a greater challenge (Ekstrom et al. 2015)
- Changes in coastal and riparian geomorphology (Glick 2006; FWC 2008; Moser et al. 2014)
- Changes in infrastructure (e.g. boat ramps, docks, roads; Moser et al. 2014)
- Mitigation policies (e.g., a carbon tax on fuel or carbon credits for sequestration in shellfish farming)

In addition, several confounding factors have the potential to affect Florida's fisheries and aquaculture sectors, including:

- Human population growth (FWC 2008 predicted a doubling of over the next 50 years) and increased resource utilization
- Conversion of natural and agricultural land to urban land use, leading to an overall reduction in freshwater and coastal wetland area and more intensive use and modification of remaining areas (FWC 2008)
- Increased demand for fresh water (FWC 2008), including surface and groundwater.
- Increased introduction of nutrients from land-based sources
- Invasive species (e.g. lionfish)
- Economic factors (e.g., changing operating costs for fisheries, changing demand)

Impacts on Marine Fisheries and Adaptation Options

Marine fisheries operate in large natural ecosystems where human influence and control over environmental conditions is comparatively limited. Fishing itself has been the predominant human influence on many marine fish stocks. Florida's marine fisheries are characterized by a high diversity of resources and fishers (Lowther 2011). Key fisheries include offshore commercial shrimp fisheries, offshore reef (mostly snapper/grouper) and pelagic (mackerels, mahi mahi, tunas and billfishes) fisheries that are shared by commercial and recreational fishers, predominantly nearshore lobster and crab fisheries that are likewise shared between sectors, and inshore finfish fisheries (red drum, snook, spotted seatrout, and others) that are almost exclusively recreational. Many marine recreational fisheries in Florida are harvest-oriented (fishers tend to harvest fish they can legally keep), but in some fisheries such as those offshore for billfishes or inshore for snook, voluntary release of legally harvestable fish has become common. Voluntary release can help maintain the fishing quality (e.g., catch rates and size structure) under high recreational fishing pressure (Arlinghaus et al. 2007).

Florida's marine fisheries are managed by the Florida Fish and Wildlife Conservation (FWC) Commission in coastal waters (nine miles from the coast in the Gulf of Mexico and three miles in the Atlantic). In federal waters outside the state limits, fisheries are managed by the Gulf of Mexico and South Atlantic Fisheries Management Councils (GMFMC and SAFMC), respectively, with administrative oversight from the National Marine Fisheries Service (NMFS) and the U.S. Department of Commerce. Coordination routinely occurs between these entities with respect to stocks and issues that straddle management boundaries. Management of tuna and billfish is complicated by the wide-ranging migratory habits of these fish that take them through the exclusive economic zones of various eastern and western Atlantic countries. The International Commission for the Conservation of Atlantic Tunas sets catch limits for about 15 pelagic species landed in Florida waters. The mainstay of marine fisheries management is to regulate harvest, often to a level that will allow the stock to produce the greatest average catch in the long term ('Maximum Sustainable Yield'). Harvest regulations are informed by regular, scientific stock assessments for the major fisheries (Cooper 2004; Methot 2009). Stock assessments use data collected from the fisheries and from fisheries-independent monitoring programs to track the abundance of stocks and their responses to fishing and environmental variation. Hence, fisheries management systems have many features that make them well suited to track and respond to change. Most fisheries have experienced major natural and/or fishing-induced variation in stock abundance and historically, many have been overfished. Today, effective management has largely rectified this situation, with most major marine fish stocks around Florida exploited near their sustainable limit, while some remain overfished and a few are underexploited (NOAA 2017a). Demand for marine fisheries products and recreational fishing remains such that any relaxation of management efforts or failure to account for changes in stock productivity could easily lead to overfishing in many stocks.

In addition to harvest regulations, deployment of artificial reefs that aggregate fish (and fishers) at known locations is a common fisheries management measure in Florida, often conducted by coastal counties with the aim of enhancing local recreational fisheries and associated economic activity (Bortone et al. 2011; Lindberg & Seaman 2011). Stocking of hatchery fish is another way of enhancing fisheries, conducted experimentally by the FWC and Mote Marine Laboratory (Tringali et al., 2008; Camp et al. 2014).

Although Florida's offshore habitats (with the exception of coral reefs) have been relatively removed from human impacts other than fishing, inshore habitats have been heavily impacted by coastal development, with substantial losses of saltmarsh, mangrove, and seagrass habitats over the past century. Such inshore habitat changes potentially affect not only inshore fish and fisheries but also many offshore stocks, which rely on inshore habitats as juveniles. Nonetheless, even though the importance of habitat in maintaining fisheries has been widely acknowledged, relationships between habitat and fish stock dynamics are complex and clear quantitative links have proved elusive (Rose 2000). Efforts have been made by fisheries management agencies to identify essential fish habitat and, to a lesser extent, to conserve and restore such habitat (Rosenberg et al. 2000). However, these efforts have remained limited in scope and they are somewhat separate from the fisheries management process. Marine fisheries management systems are set up primarily to regulate fishing rather than manage environmental conditions or habitats. Marine protected areas may include zones in which harvest is largely or entirely restricted, and these zones may be associated with enhanced stock and community resilience.

Climate Change Impacts on Marine Fisheries Resources

The physical environment of the ocean has a major influence on the productivity and distribution of organisms at all trophic levels (Karnauskas et al. 2015). Climate change alters the amount of salt and heat in different parts of the ocean, leading to changes in the major currents of the ocean (the thermohaline circulation, Schlesinger et al. 2006). Wind and rainfall patterns are being changed as well (Mann and Emanuel 2006). These changes affect species abundance, biodiversity, and fisheries catch composition in the Gulf of Mexico and the Atlantic Ocean coasts of Florida. The scope and nature of the impact on the ecosystem and on fisheries are difficult to predict (Brander 2010). Some effects may be harmful and others may be beneficial to exploited and functionally important marine species.

Changes in Oceanic Flows and Winds

The Gulf Stream and the Loop Current are the dominant circulation features on the east and west coasts of Florida, respectively (Schmitz et al. 2005). On the Atlantic continental shelf, upwelling of the Gulf Stream caused by tides and winds provides nutrients and stimulates production (Mann and Lazier 2013). Additional nutrients are delivered to the ocean by rivers and coastal wetlands, including the Everglades. In the Gulf of Mexico, anticyclonic (warm-core) and cyclonic (cold-core) eddies pinched off from the Loop Current can show some upwelling of nutrients around their periphery and in their centers, respectively (Mann and Lazier 2013, Chérubin et al. 2006). Although the Loop Current does not impinge on the West Florida Shelf (WFS) directly, it can establish a cross-shelf pressure gradient that intensifies upwelling onto the shelf (Hetland et al 1999). Upwelling is further strengthened by seasonal southeasterly winds that act via Ekman transport of surface water offshore, and bottom water toward the inshore (Weisberg at al 2005). A change in strength, location, or variability of oceanic flows and winds implies a change in overall productivity of the shelf. Some have suggested a mechanism by which ocean warming globally could intensify alongshore wind stress and accelerate upwelling (Bakun 1990), potentially leading to increased rates of primary production. The WFS is upwelling-favorable on long-term average (Weisberg et al., 2009), particularly around the spring transition (Liu and Weisberg 2012). This is a critical period in larval feeding for many exploited species (e.g., the shallow-water grouper complex, Farmer et al. 2017). However, any change in seasonal forcing would change the phenology of species and favor a different set of species and fisheries. For example, a 1–2 month delay in peak upwelling on the WFS could favor summer spawners, such as red snapper. So too, temporal changes in stratification or water mass convergence will benefit species that can take advantage of concentrated food during critical life stage periods. Besides providing nutrients for photosynthesis, cross-shelf movement of water plays a role in larval dispersal and retention on both the east and west coasts of Florida (Weisberg et al. 2014, Werner et al. 1997). Gag grouper spawning aggregation sites are well positioned to take advantage of seasonal cross-shore currents (Todd 2013). Thus, the adaptability of populations will depend on the plasticity of animal behavior and stock demographics. Ubiquitous and year-round spawners may be better able to mitigate the effects of more variable productivity and current flows.

Changes in Marine Productivity, the Food Web, and Habitats

Marine primary productivity forms the basis of the food web on which all other productivity depends. Substantial uncertainty surrounds likely changes in marine primary productivity. Globally, different modeling approaches have yielded predictions ranging from a 20% decline to an 8% increase (Sumaila et al. 2011).

A large, seasonal anoxic zone in the northern Gulf of Mexico has well-documented temporary effects on the distribution of fisheries resources. This affects some of the fisheries assisted by Florida-based boats. The future spatial extent and severity of this anoxic zone will depend on river flow and agricultural practices in the Mississippi River Basin, and the degree to which this and other anoxic zones cause an overall reduction in fisheries yields is subject to ongoing scientific debate (Rabalais et al. 2002; Diaz and Rosenberg 2008; Breitburg et al. 2009).

Ocean acidification is predicted to proceed at a relatively moderate pace around Florida, but has the potential to greatly affect coral reefs, the resources directly associated with live corals, exploited epibenthic invertebrates (shrimp, crabs, bivalves), and indirectly, benthic fish preying upon macrobenthos. These impacts will be felt most strongly in the nearshore fisheries. Another issue connected with ocean acidification is the potential change in plankton community structure and secondary production rates; this indirectly affects predatory fish species. A detailed ecosystem and fisheries modeling study on the effects of ocean acidification has recently been completed for the California Current, where acidification is projected to proceed more rapidly than in Florida (Marshall et al. 2017). Impacts around Florida can be expected to follow similar patterns.

Many of Florida's marine fish stocks rely on coastal habitats for at least part of their lifecycle. That is true even for the snapper and grouper species harvested in deeper offshore waters, many of which rely on saltmarsh or mangrove areas as juveniles. Juvenile stages are critical to the population dynamics of fish, and availability of juvenile habitat often limits the overall abundance of stocks. Therefore, changes in costal wetland habitats due to sea level rise and changes in rainfall and freshwater flow patterns may well be among the most important drivers of climate change impact on Florida's marine fisheries (Glick 2006). At a statewide level, it is predicted that sea level rise will cause the area of saltmarsh habitat and tidal flats to decline substantially, whereas the area of mangroves is set to increase (Saintilan et al. 2014), as is the area of brackish marsh. These habitats may not be functionally redundant as nursery areas for many coastal fish and shellfish species, leading to altered faunal assemblages. Additionally, most habitat considered important for juvenile fish are produced by organisms such as sea grasses, salt marsh grasses, mangroves, and oysters, all of which have their own population dynamics that may be affected differently by sea level rise or climate change. While some (oysters, mangroves) may, under some conditions, rapidly respond to colonize newly inundated areas (Saintilan et al. 2014; Rodriguez et al. 2014), it is not clear if others (seagrasses, marsh grasses) can do so (Morris et al. 2002; Orth et al. 2006). Changes in these critical juvenile habitats can reasonably be expected to have impacts on fish stocks and fisheries yields, but such impacts are likely to be complex and sometimes counterintuitive (Zimmerman et al. 2002). For example, research on saltmarsh loss in Louisiana showed that local shrimp production actually increased as the area of the marsh declined, most likely because the remaining saltmarsh area became more accessible to the shrimp. In concert, it is reasonable to expect habitat-mediated changes in fish populations and communities, but the intensity and even the directionality of such changes will depend on the speed at which habitat forming organisms and fish populations respond to altered environmental conditions, and this is not yet well described.

Climatic warming is expected to result in poleward distributional shifts of species and assemblages. Such shifts are well-documented for marine fish stocks, particularly in temperate latitudes (Perry et al. 2005; Pinsky et al. 2013, Doney et al. 2014). So far, studies in the Gulf provide some evidence of such shifts occurring (Tolan & Fisher 2009; Fodrie et al. 2010). For Atlantic marine waters, temperature increases are expected to be less pronounced around Florida than along the U.S. mid- and North Atlantic coasts, which will warm rapidly due to a northerly shift in the Gulf Stream (Saba et al. 2016). Distributions in the South Atlantic appear to be responsive to short-term climate fluctuations but, so far, have not shown long-term directional changes (Morley et al. 2016). Even if the magnitude and speed of distribution shifts around Florida are uncertain, it is useful to consider how such shifts might affect the stocks currently fished. Florida's marine fisheries target a range of south-temperate and tropical stocks, the majority of which have distributions that extend somewhat south of Florida or are centered in the tropics (Robertson & Van Tassell 2015; Froese & Pauly 2017). This is true for the crustacean stocks (shrimps, spiny lobster, stone and blue crab), for offshore reef fish (groupers, snappers, and others), offshore pelagics (mackerels, tuna, billfishes) and for inshore fish (red drum, snook, spotted seatrout). Therefore, these stocks can be expected to maintain their distributions or expand further into Florida. Red drum has its southern limit around South Florida, so the species may become increasingly rare in the southern parts of the state. It is not, however, the mainstay of the fishery in those areas even at present. A detailed analysis of potential changes in habitat suitability for a range of juvenile fish and lobster in Florida Bay concluded that changes varied between scenarios but were on average small (Kearney et al. 2015).

Impacts of distributional shifts on stock abundance and fisheries yields have been explored on a global level using dynamic bioclimate envelope models, which suggests that average abundance and yield potential will decline in the tropics, increase in polar oceans, and remain largely unchanged in the temperate zone (Cheung et al. 2010). However, species interactions may have a moderate dampening effect on distribution and yield changes (Fernandes et al. 2013). No specific assessments have been conducted for the stocks around Florida.

Climate Change Impacts on Marine Fisheries Users

Changes in the abundance and distribution of fisheries resources will affect the benefits that fishers attain from their activities and the costs incurred. Climate change and confounding factors may also impact fishing activities through, for example, changes in boating access or costs of fishing inputs such as fuel. Sea level rise, associated habitat alterations, and coastal defense responses may affect boating access to marinas and boat ramps, as well as the spatial extent of habitats normally sought out by fishers (FWC 2009). As discussed in more detail below, fishers can adapt to such changes in a variety of ways including switching target species, changing fishing locations, modifying the overall effort they expend on fishing, and changing fishing methods and/or motivations (Colburn et al. 2017). Overall reductions in individual and collective fishing efforts may occur where neither species switching nor location change are viable adaptation strategies.

Given their proximity to the coast, fishers, support industries and related infrastructure are highly vulnerable to direct impacts of storms, weather, and sea level rise (Colburn et al. 2017). A vulnerability assessment of commercial fishing communities identified those in South Florida, including the Florida Keys, as particularly vulnerable in this respect (Colburn et al. 2017). The dramatic impacts of hurricanes on the marine fisheries sector are well-documented, and it is clear that an increase in frequency and severity of such events will have major economic and social consequences (Tilmant et al. 1994; Buck 2005; Solis et al. 2013).Recreational fishing effort in Florida is substantially influenced by migration to the state and by tourism, both of which may decline somewhat with climatic warming due to increasing attractiveness of currently temperate regions. Impacts of sea level rise and extreme weather on Florida’s tourism infrastructure may further reduce recreational fishing in the state (Weatherdon et al. 2016). Climate in and of itself is likely to affect the level of recreational fishing effort (Carter & Letson 2009; Whitehad & Willard 2016).

Adaptation Options

Marine fisheries may adapt to climate change through changes in fishers’ targeting and spatial behavior, changes in governance, and use of certain fisheries enhancement and restoration measures. Switching of target species is a common feature of fisheries sub-sectors in which a number of different species can be caught with broadly similar means and at similar locations (for example, within the recreational inshore or recreational and commercial reef fisheries). Marine recreational fishers in Florida tend to target multiple species and switch between them in response to changes in abundance, even in the inshore fisheries that rely on only 2-3 major species (Camp et al. 2016). Such behaviors may, however, be constrained by species-specific regulations. Switching between fisheries sub-sectors (e.g. from inshore to reef fisheries) is less common and more costly since it typically requires investment in new gear and a steep learning curve with respect to fishing practices, locations, etc. Changes in fishing locations can be an alternative to switching species, i.e., fishers may choose to follow changing spatial abundance patterns of their traditional targets. Both strategies are found in fisheries but for reasons of cost, switching species within the sub-sector is likely more common unless the market or recreational value of alternative species differs greatly. In Florida, many fishers are familiar with and value both tropical and temperate species within their sub-sectors. This, combined with the fact that a majority of recreational fishers appear to conduct the majority of trips within a limited 'home range' of less than 50 miles (Camp et al. 2017), suggests that switching species will be the predominant adaptation strategy among Florida's fishers.

Overall reductions in individual and collective fishing effort may occur where neither species switching nor location change are viable adaptation strategies. This may be the case in response to changes in overall resource availability, access, or costs and prices of inputs and outputs. Effort changes in response to such factors are well-documented, for example, in the Gulf of Mexico shrimp fisheries (Nance et al. 2008).

Since catching fish is one of a wide range of motivations behind recreational fishing, and since anglers can attain satisfaction even if no or few fish are being caught, there is scope for new and different fishing approaches to compensate for certain negative impacts on traditional fisheries (Radomski et al. 2001; Hunt et al. 2016). Thus, recreational fishers are likely to show the greatest adaptive capacity. This is illustrated, for example, in the switch to predominantly catch-and-release fishing in the snook fishery, which has allowed for improvements in fishing quality despite increasing fishing effort and habitat changes that would otherwise have resulted in declines in fish abundance and fishing quality. Commercial fishers are often more specialized, more constrained by economic factors, and less inclined and able to switch to other ways of making a living than are charter boat captains (Seara et al. 2016).

No major changes in geographical boundaries of governance structures (FWC, GMFMC, and SAFMC) will be required for climate adaptation of Florida's marine fisheries, since distribution shifts are likely to be small on average and the northward boundary of tropical stocks occurs within current governance boundaries.

The focus of climate adaptation in Florida's marine fisheries management will be on adapting catch limits and fishing regulations to changes in stock distributions and productivity. Failure to adapt catch limits would result in overfishing of stocks that are declining within the management area and forego the potential for higher sustainable catches from stocks that are expanding in range and productivity. As discussed above, fisheries management systems are well set up to track and respond to changes in stock abundance and fishing pressure (Melnychuk et al. 2014). However, stock assessments that inform the setting of catch limits typically are based on the assumption that stock productivity will not undergo long-term changes. Explicitly incorporating long-term changes in stock productivity into stock assessment is, therefore, an important priority for adapting assessment and management systems, even though it may not be easy to discern such changes from available data (Punt et al. 2014). Several approaches can increase the ability anticipate climate-related changes and help inform monitoring and management strategies. A methodology for assessing the climate change vulnerability of individual fish stocks, which is based on combining existing information on the exposure of a stock to climate stressors and its sensitivity to the stressors, has been devised by NOAA and completed for the northeast U.S.

Continental Shelf (Hare et al. 2016). Application of this vulnerability assessment method to the Gulf and South Atlantic is planned under NOAA's Climate Change Strategy and Regional Action Plans (Bush et al. 2016; Lovett 2016). More quantitative assessments of changes in stock productivity are likely to remain elusive until quantitative relationships can be established between key climate change drivers and stock dynamics. In the meantime, it may be most appropriate to consider the implications of broad, plausible forecasts related to how biological parameters may change in the future as a way to assess the robustness of management strategies rather than attempting specific predictions per se (Punt et al. 2014).

Climate change effects acting on habitats and different species may combine in synergistic ways and lead to unintuitive consequences (Ainsworth et al. 2011). Likewise, human responses to ecological changes at all levels will be important drivers of fisheries outcomes (Haynie & Pfeiffer 2012). It is, therefore, important to complement analysis of changes in stock dynamics with ecosystem-scale and socio-economic assessments. This will involve identifying and monitoring relevant ecological or socio-economic indicators to establish trends and provide early warning of climate change impacts. Moreover, thresholds could be set to demark a qualitative change in fishery performance and trigger adaptation actions (Bush et al. 2016). Advancing place-based and cooperative management of fisheries by promoting more locally-adapted and stakeholder-involved management strategies may enhance adaptation to changing environmental conditions and stakeholder needs (Lorenzen et al. 2010; Camp et al. 2017).

Marine fisheries, both recreational and commercial, are highly dependent on coastal access infrastructure (boat ramps, docks) and on support industries (marinas, fish houses). It is, therefore, crucial to maintain such infrastructure in the face of sea level rise, impacts from storms and coastal erosion, and confounding factors such as increasing coastal population density and property values.

Fisheries enhancements, technical interventions aimed at enhancing or restoring fisheries such as the provision of artificial habitat and the release of hatchery-reared fish, may have some scope to aid climate change adaptation (Sale et al. 2014). Artificial reefs are already widely deployed in Florida and have the effect of creating reef fish habitat in areas where it is naturally scarce. Artificial reefs attract reef fish (e.g. snappers and groupers) and fishers to known locations. Their benefits, from a fisheries management perspective, are primarily the result of the aggregation of fish at known and often easily accessible locations; but artificial reefs may also support overall increases in fish production (Bortone et al. 2011). Hatchery programs raise early life stages and juveniles of fish under controlled conditions and can help sustain fisheries under conditions where natural habitats for these sensitive life stages are reduced in extent or quality (Camp et al. 2014). In practice, the effectiveness of such approaches has been found to be variable but often low. Moreover, such approaches are expensive to develop and maintain; they will, therefore, be an option only for certain high-value species (Lorenzen et al. 2010, 2013). In addition to resource enhancements, there may be way to improve fisheries through infrastructure, for example by enhancing boating access (FWC 2009).

The expected increase in the frequency and severity of storms, combined with the extreme vulnerability of the fisheries sector to such events, may call for greater attention to disaster response as an explicit function of the fisheries governance system. Previous experience has indicated the value of systematic attention to recovery planning for the fisheries sector (Dyer & McGoodwin 1999; Land 2015).

Impacts on Freshwater Fisheries and Adaptation Options

Freshwater fisheries operate in a large number of water bodies that are ecologically separated and confined to various degrees, and often are strongly influenced by human water and land use (Arlinghaus et al. 2016). Compared to marine fisheries, freshwater fisheries in Florida are also characterized by a lower diversity of exploited species and of fishers. Largemouth bass is the single most important resource, primarily targeted by some 40% of freshwater anglers, followed by sunfishes (23%), crappie (16%), catfish (12%), and striped bass (4%) (Morales 2016). Freshwater fishing is almost exclusively recreational, and strongly catch-and-release-oriented in the bass fishery, but much less so for the other species. Freshwater fisheries operate in ecosystems that are heavily influenced by multiple anthropogenic pressures. In various combinations, eutrophication due to accelerated nutrient loading from agricultural and domestic sources, hydrological alterations for water supply and flood control, and spread of invasive aquatic plants have affected a majority of Florida's lakes and rivers (Williams 1985). Despite a broad suite of pollution control and water management measures, these stressors remain relevant and continue to have adverse impacts on fish stocks and fisheries (Dotson et al. 2015). In addition, inter-annual variation in rainfall causes substantial variation in water levels, which affects both fish stocks and fisheries access and use. Fishing has a relatively minor impact on freshwater fish stocks in Florida. Owing to the widespread use of voluntary catch and release, largemouth bass fisheries are lightly exploited and harvest regulations have only a small impact on fisheries outcomes (Myers at al. 2008; Kerns et al. 2015). Fisheries for the other freshwater species are more harvest-oriented, but overall less intensive than the marine sector.

Florida's freshwater fisheries are managed by the FWC. Freshwater fisheries management in Florida, as elsewhere, involves habitat management for fish and fisheries enhancement measures, such as placement of fish attractors and stocking of hatchery fish, in addition to harvest regulations (Arlinghaus et al. 2016). Stock assessments and other scientific approaches used to inform freshwater fisheries management need to account for the large number of freshwater systems, limited resources for sampling, and the wide range of anthropogenic factors affecting freshwater fisheries (Lorenzen et al. 2016). Harvest regulations are widely used, but due to the generally low rates of exploitation of largemouth bass stocks, the scope for improving stock abundance using such regulations is limited (Myers et al. 2008). Nonetheless, restrictive harvest regulations have the potential to improve trophy bass opportunities (Dotson et al. 2013). Recent initiatives aim to conserve very large 'trophy-sized' fish while simultaneously engaging anglers in scientific data collection through a program called TrophyCatch that encourages non-lethal documentation and release of trophy fish (Dutterer et al. 2014). Overfishing of crappie stocks is of some concern (Dotson et al. 2009) and harvest regulations can be used to improve stock abundance (Allen et al. 2013).

Freshwater habitats and their environmental quality are managed by multiple organizations, including the U.S. Army Corps of Engineers, the Florida Water Management Districts, the Florida Department of Environmental Protection, local counties, and the FWC. Of these, the FWC is the only agency focused primarily on fisheries and wildlife management. In response to the fish habitat issues outlined above, the FWC has initiated more than 50 major restoration projects in the past 40 years (Dotson et al. 2015). These include measures such as extreme drawdown, muck removal, tussock removal, control of nuisance plants, and planting of native plants. However, due to their high costs, such projects have become increasingly rare. In addition, the FWC conducts stocking to restore fish populations after natural or intentional drawdowns and to supplement weak largemouth bass year-classes in systems with limited recruitment owing to poor habitat quality (Porak et al. 2002; Mesing et al. 2008).

Climate Change Impacts on Freshwater Fisheries Resources

Overall freshwater availability is predicted to increase moderately in most of Florida, but to decline in the Panhandle and the southwest (Carter et al. 2014). However, variability in rainfall is predicted to increase along with the frequency and severity of storms, which means that hydrological variability is likely to be an equally or more important driver of fish habitat quality and population dynamics under climate change. Since most of Florida's lakes are shallow and well-mixed, no major changes in dissolved oxygen are expected as a result of rising temperatures. However, increased temperature and severity of storms could exacerbate eutrophication, degrading habitat availability and quality, thereby creating an alternate stable state that is less desirable for sport fisheries (Scheffer 1990; Ficke et al. 2007). Wind-driven wave action and high water levels from hurricanes can uproot plants, suspend nutrients, and increase turbidity, which can have deleterious effects on shallow lakes with aquatic macrophyte communities dominated by submersed aquatic vegetation. Clear lakes with expansive submersed aquatic vegetation and premier sport fisheries can quickly transition to a turbid, phytoplankton-dominated system with poor sport fisheries. These effects in Florida lakes are well-documented (Bachmann et al. 1999; Havens et al. 2001; Havens 2005; Rogers and Allen 2008; Johnson et al. 2014). Increased frequency of storms, along with increased temperature and other confounding anthropogenic influences, will make it exceedingly difficult to slow or reverse eutrophication. Some freshwater habitats near the coast may suffer saltwater intrusion as a consequence of sea level rise, and this may severely impact local freshwater fisheries if it results in substantial increases in salinity (FWC 2009; Barlow & Reichard 2010; Herbert et al. 2015). Freshwater mussels are of particular concern, as there are currently 15 federally-protected endangered and threatened mussels that are found in major Gulf Coast basins in Florida between the Escambia and Hillsborough rivers; and all but one have designated critical habitats in state coastal rivers and streams (Williams et al. 2014).

Climate-related distributional shifts are expected for freshwater fish, but may occur at a slower rate compared to marine fish due to lower connectivity between freshwater systems and in particular watersheds. Of the commonly fished species, most are relatively flexible and have distribution ranges that extend throughout Florida and to the north of the state (Hocutt & Wiley 1986). Striped bass (Atlantic and Gulf strain) and American shad, as well as many non-game imperiled fishes (e.g., gulf sturgeon, Atlantic sturgeon, alligator gar, Alabama shad, crystal darter, harlequin darter, tessellated darter, saltmarsh topminnow, blackmouth shiner, bluenose shiner, blackbanded sunfish, spotted bullhead, snail bullhead) that are limited to temperate Florida, are more sensitive to environmental fluctuation and may reduce their range in the state or disappear entirely. At least 34 exotic freshwater fishes are already naturally reproducing in Florida waters, a phenomena occurring more in Florida than any other state (Fuller et al. 1999; Shafland et al. 2007). Most of these species are currently restricted to South Florida (south of State Road 70), but rising temperatures may allow for range expansions northwards and establishment of additional exotic fishes currently thermally restricted. The potential ecological impacts of exotic species on Florida's freshwater ecosystems is not well understood, but displacement or suppression of native fish populations is of serious concern.

Several interrelated confounding factors are likely to have major impacts on inland fisheries habitats and resources: population growth, conversion of natural and agricultural land to urban land use, and increase in demand for fresh water (FWC 2008). Although the precise magnitude of these changes is uncertain, they could be substantial (FWC 2008 predicted a doubling of all three over a period of 50 years). Consequences will include an overall reduction in freshwater habitat area and more intensive use and modification of remaining areas.

Climate Change Impacts on Freshwater Fisheries Users

In addition to impacts mediated through the resources, climate change and confounding factors can affect anglers directly. Most importantly in the case of freshwater fisheries, changes in the spatial distribution and hydrology of freshwater systems will impact accessibility, both in terms of travel distances and boating access. Low water levels severely restrict boat and shore access to freshwater fisheries. The occurrence and magnitude of extremely low water levels preventing access and use to freshwater lakes in Florida has substantially increased over the last two decades.

Overall, it is likely that climate change and confounding factors will increase costs for many freshwater anglers and result in an overall reduction in fishing satisfaction and fishing-related economic activity. This reduction is likely to disproportionally affect the poorer sections of the angling public, who face greater challenges in adapting.

Adaptation Options

Freshwater recreational anglers can adapt to the expected changes in habitats, abundance and distribution of species, and access by changing fishing locations or switching target species. Both short-term (inter-annual) variation and long-term changes are likely to be regionally differentiated, and changes in fishing location are therefore likely to be a major adaptation option (see Ward et al. 2016). However, anglers are likely to vary greatly in their propensity for location change, which typically involves increased costs, time, and inconvenience. The majority of freshwater anglers conduct most of their fishing within 50 miles of their residence, which is a good indication of the limits to costs and time that they are willing to invest (Morales 2016). Such anglers, many of whom are poor, are likely to reduce their fishing activities. A much smaller portion of freshwater anglers, mostly those who fish tournaments at least occasionally, are highly mobile and likely to adapt easily to changing opportunities. There is potential for recreational anglers to shift their focus from freshwater to marine, and vice versa, as fisheries respond to climate change. The hydrological, habitat, and population impacts expected from climate change and confounding factors are likely to affect all exploited resources in a broadly similar manner so that in freshwater systems, switching species is unlikely to be a major adaptation option. In Florida, the establishment and possible expansion of exotic freshwater fish present the greatest opportunity for expanding traditional freshwater fisheries. Popular sport fisheries for peacock bass, mayan cichlids, oscars, among others, already exist in the Miami area.

Due to the widespread adoption of voluntary catch-and-release, the bass fisheries are lightly exploited and harvest regulations have only a small impact on fisheries outcomes (Myers at al. 2008). This implies that adapting fishing regulations to climate-driven changes in stock productivity is not a major concern. Substantial increases in fishing intensity due to population growth, shifting effort from marine to freshwater fisheries, or a reduction in available freshwater habitat could affect this conclusion, but increasing catch-and-release orientation and stable or declining per capita participation in freshwater fishing make this unlikely.

The most important fisheries management responses are likely to be active habitat restoration and stock enhancement measures such as those already in use. The difference is that such measures may be more widely and frequently required. Protection of freshwater habitats is a key issue that largely extends beyond the fisheries management real, but to which the importance of fisheries and the expertise and engagement of anglers and fisheries professionals can make vital contributions (Lynch et al. 2017). Maintenance and enhancement of access facilities, such as boat ramps, will also be important in order to maintain fishery access under conditions of great hydrological variability.

Since freshwater fishing is a recreational activity, there are many ways in which participation, satisfaction, and economic impact can be enhanced (Radomski et al. 2001). This includes the provision of fishing opportunities in urban and other modified habitats, or development of programs that incentivize participation through organized competitions and rewards. Such approaches are, perhaps, most developed in the largemouth bass fisheries, which are already the mainstay of Florida's fisheries.

Impacts on Marine Shellfish Aquaculture and Adaptation Options

Shellfish aquaculture in Florida involves growing hard clams in mesh bags on the bottom or oysters either on planted shell or in suspended cages (UF 2011). These activities take place on state-owned submerged land leases. With the exception of spawning and rearing of early life stages, which are carried out under more controlled conditions, shellfish aquaculture is reliant on suitable natural conditions and primary productivity for production, and is, therefore, vulnerable to environmental stressors and public health threats. Moreover, although the cultured shellfish are privately-owned, they are grown in public waters that are subject to a wide range of other uses. For effective production, shellfish require suitable environmental conditions (substrate, depth, tidal range, salinity, primary productivity) at the culture site. To protect the health of consumers, shellfish culture is permitted only in designated areas with low levels of waterborne human pathogens. Harvesting is temporarily suspended in response to heavy rainfall in the watershed, which increases the risk of illness, or in response to high cell counts of "red tide" organisms that could expose consumers to neurotoxins. Added to these constraints is a policy to limit environmental impacts by not permitting shellfish culture in sensitive habitats such as seagrass beds or in areas of potential use conflicts. As a result, the extent of suitable lease areas for shellfish farming in Florida is very limited (FDACS 2013).

Climate Change Impacts on Production and Producers

Clearly, many of the general conditions required for shellfish cultivation are sensitive to climate change drivers, from temperature and rainfall patterns to sea level rise. It is, therefore, likely that the quality of current shellfish growing areas will change and the distributions of optimal areas shift (Allison et al. 2011; Anderson et al. 2013). In addition to these general changes, ocean acidification poses a fundamental threat to shellfish culture because it affects the ability of mollusks, particularly their larval stages, to build shells (Ekstrom et al. 2015). Recognized as a major threat to shellfish culture at the national and international level, ocean acidification is, however, expected to progress comparatively slowly in the southeastern U.S., including the marine waters around Florida (Ekstrom et al. 2015). Furthermore, ocean acidification is affected by local conditions, including freshwater inflow (reduces acidification) and eutrophication (enhances acidification), and is therefore likely to vary spatially (Clements & Chopin 2016; Ekstrom et al. 2015). Rising water temperatures may increase the prevalence of human pathogens and the frequency of harmful algal blooms (Rose et al. 2001; Moore et al. 2008), particularly in North Florida where both are currently less of a problem than in the south and where the state's major shellfish industry is located.

Adaptation Options

The principal adaptation options for the shellfish aquaculture industry include technology changes and relocation of farms, which may be facilitated by some changes in governance. Production systems can be adapted to adverse environmental conditions by raising the most vulnerable juvenile stages in closed systems with controlled water temperature and chemistry. Development of water treatment systems, principally buffering, is a key aspect of adapting shellfish hatcheries to the threat of ocean acidification (Barton et al. 2015). In the longer term, selective breeding of shellfish for greater tolerance to higher temperatures or acidic conditions may further strengthen adaptive capacity (Barton et al. 2015). Relocation of operations in response to environmental changes will be a key aspect of adaption. This is likely to be a gradual process except when distinct events, such as hurricanes, cause major changes in geomorphology. Growers may also adapt by shifting to other species or developing new strains.

The existing management system by which leases are granted based on site surveys and various criteria lends itself, in principle, to adaptation when conditions change and culture operations may seek to relocate. Regular monitoring of conditions in existing and potential lease areas may support adaptation planning. With respect to ocean acidification, monitoring of acidification in the environment and in culture facilities is an important step toward identifying impacts and developing management responses (Barton et al. 2015). In addition to the adaptation measures outlines above, which can be taken by individual producers, curtailing eutrophication will be a key management priority for shellfish growing areas, as it can reduce both ocean acidification and the risk of harmful algal blooms (Ekstrom et al. 2015).

Overall, adaptive capacity in the shellfish industry is likely to be limited due its strong reliance on environmental conditions (Ekstrom et al. 2015). Moreover, shellfish culture tends to be concentrated in regions of the state that are characterized by low adaptive capacity (Colburn et al. 2017).

Impacts on Freshwater Ornamental Aquaculture and Adaptation Options

Freshwater aquaculture is predominantly carried out in earthen ponds, combined with indoor/tank-based hatcheries for reproduction and rearing of early life stages. Florida's ornamental aquaculture industry (production for the aquarium trade) produces over 30 species of tropical freshwater fish (Hill & Yanong 2010). While pond systems are more environmentally open than indoor tanks, producers can exercise a high degree of control over environmental conditions by means of water management, aeration, provision of cover, treatment of pond water, feeding, etc. (Watson & Shireman 1996). The species currently produced differ widely in their environmental requirements and tolerances, and ornamental aquaculture producers are therefore well-positioned to manage these conditions. Ornamental aquaculture in Florida is regulated by the Florida Department of Agriculture and Consumer Services (FDACS), in particular with respect to containment of non-native species and effluent control (Tuckett et al. 2016).

Since ornamental production is focused on tropical species, a change in climate towards more tropical conditions is not, in general, problematic for the industry. Indeed, the length of the growing season for certain sensitive species may well increase in the industry's focal area around Tampa. However, production may become more challenging due to greater variability in rainfall and higher temperatures that would influence oxygen saturation and other water quality parameters. Producers have the technical means to address these issues, but production costs could increase moderately as a consequence.

No major management/regulatory changes are likely required to help producers adapt. However, changing climate may alter the survivability of escapees from ornamental farms. This may necessitate additional policy measures to guard against the inadvertent introduction of potentially invasive species.

Aquaculture in Support of Restoration and Fisheries Enhancement

Aquaculture can be used to maintain or restore populations of aquatic organisms or to enhance fisheries. Demand for restoration aquaculture and fisheries enhancements is likely to increase since these adaptation approaches can make climate change impacts more manageable (Lorenzen et al. 2013; Barton et al. 2017). Restoration and enhancement aquaculture uses some of the same technologies that are used in commercial aquaculture, but it often requires different husbandry and genetic management approaches in order to produce organisms that maintain wild-like characteristics and survive well upon release (Lorenzen et al. 2012). Furthermore, aquaculture-based enhancement or restoration initiatives need to be integrated into overarching fisheries management or restoration programs using a planning framework such as the 'responsible approach' (Lorenzen et al. 2010). Overall, use of aquaculture offers some potential for climate change adaptation, but this is likely to be effective and economically viable only in certain cases.

Conclusion

Complex interactions among climate change and confounding drivers and the characteristics of Florida's diverse fisheries and aquaculture industries make it difficult to predict the magnitude and sometimes even the directionality of climate change impacts. Nonetheless, even a qualitative, conceptual assessment such as presented here is valuable because it helps identify impact pathways and adaptation options that are likely to be most relevant under the specific conditions found in Florida.

While colloquial debate about climate change impacts often focuses on increases in temperature and associated impacts such as species range changes, the assessment presented here points to the likely importance of additional and more complex drivers. For example, sea level rise and increased frequency and intensity of storm events can be expected to exert major impacts on coastal habitats and fishing-related infrastructure, which in turn will impact on the productivity and accessibility of marine fisheries. Likewise, in fresh waters, increased variability in rainfall is likely to be a major driver, possibly combined with impacts of frequent storm events. Anticipating such impacts helps in designing indicators and monitoring programs to track climate impacts, and in identifying possible adaptation options.

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