Fish and Shellfish

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In a nutshell

- Fish and shellfish in the Florida Keys support commercial and recreational fisheries, help to control the overgrowth of macroalgae on the coral reef, and connect the Florida Keys with other reef ecosystems in the Caribbean region.
- A large part of the Keys economy is supported by people traveling into the region for recreational fishing and for viewing the diversity of marine species through diving and other activities.
- Populations of reef fish have been overfished in the past, and present populations still show signs of the effects of unsustainable overfishing.
- Fish and shellfish populations in the region are vulnerable to changes in critical habitats expected as the result of climate change and the cumulative impact of human activities on coastal marine waters.

Definition of the Resource

The waters surrounding the Florida Keys and Dry Tortugas (FK/DT) coral reef ecosystem contain a diversity of marine life. The goods and services provided by this ecosystem extend beyond fishing to include a range of educational, scientific, aesthetic, and other recreational uses, such as snorkeling, SCUBA diving, and tourism (Ault *et al.,* 2005a). Over 500 species of fish are found here, including more than 389 that are reef associated (Stark, 1968), and thousands of invertebrates, including corals, sponges, shrimp, crabs, and lobsters. A complete list of marine species found in the Florida Keys National Marine Sanctuary can be viewed at http://floridakeys.noaa.gov/scipublications/speciesList.pdf (Levy *et al.,* 1996). This diversity contributes to the designation of Florida as the "fishing capital of the world" by the state legislature (FWC, 2003). The coastal marine ecosystem of the FK/DT supports a vital fisheries and a tourism-based economy that generated an estimated 71,000 jobs and U.S. $6 billion of economic activity in 2001 (Johns *et al.,* 2001).

Fisheries in South Florida are complex. Adult reef fish are caught for food or sport around bridges and on offshore patch and barrier reefs. Commercial and sport fisheries also target Caribbean spiny lobster (*Panulirus argus*), marine aquarium fishes, and invertebrates, both inshore and offshore. The discussion here focuses on a relatively few taxa chosen to represent different roles played by fish and shellfish in the FK/DT ecosystem. The **snapper-grouper complex** is a group of reef-based fish species, comprised of 18 species of groupers, 13 species of snappers, 13 species of grunts, hogfish, and great barracuda (Ault *et al.,* 1998), that are important to the recreational fishery. The **Caribbean spiny lobster** is found throughout the Caribbean and the western Atlantic from Rio de Janeiro, Brazil, in the south to North Carolina, USA, in the north. The **long-spined sea urchin** (*Diadema antillarum*) occurs throughout the western Atlantic and Caribbean. Although not fished, the herbivorous long-spined sea urchin plays an important role in maintaining the health of coral reefs throughout the Caribbean.

Species in the **snapper-grouper complex** utilize a mosaic of cross-shelf habitats and oceanographic features over their life spans (Ault and Luo, 1998, Ault *et al.,* 2005a; Lindeman *et al.,* 2000). Most adults spawn on the barrier reefs and sometimes form large spawning aggregations (Domeier and Colin, 1997). The Dry Tortugas region, in particular, contains numerous known spawning aggregation sites (Schmidt *et al.,* 1999). Pelagic eggs and developing larvae are transported from spawning sites along the barrier reef tract by a combination of seasonal wind-driven currents and unique animal behaviors to eventually settle as early juveniles in a variety of inshore benthic habitats (Lee *et al.,* 1994; Ault *et al.,* 1999b, 2002). Some of the most important nursery habitats are located in the coastal bays and near barrier islands (Lindeman *et al.,* 2000; Ault *et al.,* 2001, 2002). As individuals develop from juveniles to adults, habitat utilization patterns generally shift from coastal bays to offshore reef environments.

Reef fishery that targets the snapper-grouper complex has been intensively exploited over the past 75 years, during which the local human population has grown exponentially and generated concerns over sustainable fishery productivity. Many reef species are extremely sensitive to exploitation (Coleman *et al.,* 2000; Musick *et al.,* 2000; Ault *et al.,* 2008), and coastal development subjects coral reefs to a suite of other stressors that can cumulatively impact reef fish populations by degrading water quality and damaging nursery and adult habitats (Bohnsack and Ault, 1996; Lindeman *et al.,* 2000; Jackson *et al.,* 2001; Porter and Porter, 2001).

Larvae of the **Caribbean spiny lobster** are dispersed widely by ocean currents, and individuals found in the waters of the Florida Keys may have originated from nearly anywhere in the Caribbean and Gulf of Mexico. The coastal marine ecosystem of the FK/DT lies within the West Indian zoogeographic area, a subregion of the Neotropical Province. This area includes the Bahamas, Greater and Lesser Antilles, the northern coast of South America, the eastern coast of Central America, and South Florida. The coral reef fauna of South Florida are remarkably similar to that of the Bahamas and Cuba. The lack of land barriers, connectivity of water masses, and ocean currents facilitate larval transport of progeny among these areas. Post-larvae settle in shallow, protected waters where seagrass beds and mangrove-protected shorelines provide nursery habitat. Between the juvenile and adult stages, individuals migrate from these shallows into deeper waters of the coral reef and hardbottom habitats. Here they seek out refugia within the three-dimensional structure of the coral reef, under sponges, or any other available cover in the hardbottom habitat. The Caribbean spiny lobster preys on snails, crabs, and clams, and it is preyed upon by many high-trophic level fish species.

In Florida, the **long-spined sea urchin** is found in almost all marine habitats, including rock, coral reefs, mangroves, seagrass beds, and sandy flats, in shallow coastal waters from Pensacola through the Florida Keys to Cape Canaveral (Ogden and Carpenter, 1987). A herbivore, adult animals shelter in crevasses and forage at night, often returning to the same crevasse. On Caribbean coral reefs, the long-spined sea urchin feeds preferentially on attached algae. When a healthy population of urchins is present, their grazing is believed to effectively control the biomass of macroalgae on the reefs. This promotes development of the high proportion of cover by live stony corals that indicates a healthy reef ecosystem. The demise of the long-spined sea urchin throughout the Caribbean in the 1980s and again in the Florida Keys in the 1990s corresponded with periods of general decline in the coral reef ecosystems in this region.

Attributes People Care About

People care about sustaining the multispecies coral reef fisheries in the Florida Keys. This is a key conservation concern, given their economic and ecologic importance, the significant dependence of subsistence and artisanal fishers on reef fisheries for their livelihoods, and the considerable and growing threats to coral reef habitats (i.e., coral bleaching and disease, pollution, and climate change). People care about maintaining large expanses of healthy coral in the ecosystem. Overgrowth of the reef by benthic algae signals degraded conditions in the ecosystem, and this is considered undesirable. The presence of herbivorous fish and, especially, the long-spined sea urchin on the reef are important to controlling the growth of algae and promoting a high proportion of cover by live coral.

Attributes We Can Measure

Diverse uses of the FK/DT fisheries requires equally diverse sources of quantitative information to track the condition of the faunal populations that support these uses. The National Marine Fisheries Service and the Florida Fish and Wildlife Commission conduct regular monitoring and assessment of information, such as landings, fishing effort, and biostatistical data, collected in connection with the commercial fisheries. However, other uses of the fisheries in the Keys, which include the bait fishery, the for-hire guide and charter fishery, the aquarium fishery, the sport fishery, spearfishing, diving, and the non-extractive uses of diving and snorkeling for wildlife viewing are equally important economically. In recognition of the need to track the condition and sustainability of fish populations through critical spatial data not included in the fisheries-dependent monitoring and assessment, there is also an ongoing fisheries independent monitoring program in the Florida Keys.

The multiagency fisheries independent monitoring program gathers information that can be used to assess the sustainability of both exploited and non-exploited populations, including those that make up the snapper-grouper complex (Brandt *et al.,* 2009; Smith *et al.,* 2011a, 2011b). Sustainability refers to the ability of an exploited stock to produce goods and services, including yields at suitable levels in the short term, while maintaining sufficient stock reproductive capacity to continue providing these goods and services into the indefinite future (Walters and Martell, 2004). The attributes measured by the fisheries independent monitoring (Table 1) relate directly to parameters in theoretically-based population models that combine the effects of ecosystem dynamics and human impacts via mortality from fishing (Ault *et al.,* 1998, 1999b, 2003, 2005a; Wang *et al.,* 2003). These models explicitly represent the population processes of recruitment, growth, reproduction, mortality from natural causes, and mortality from fishing. The measured attributes provide a metric of abundance, or biomass, and its distribution by age within the population of each species. Relationships in the models allow one to infer from these data the level of fishing mortality for each species and, most importantly, assess whether each population is sustainable under current levels of fishing.

The impact of fishing on populations is normally evaluated as a tradeoff between yield (in biomass) extracted by the fishery relative to the biomass of spawners remaining in the sea that are required to ensure sustained production. This concept is illustrated using two widely used fishery management benchmarks: yield-per-recruit (YPR) and spawning potential ratio (SPR). YPR is the expected lifetime yield of a cohort scaled to annual recruitment of newborns for a given combination of fishing mortality rate and minimum capture age or size. SPR is the expected lifetime spawning biomass of a cohort for a given combination of fishing mortality and age of capture scaled to the unexploited lifetime spawning biomass. In the U.S. South Atlantic, the federal minimum standard is 40 percent SPR for goliath grouper (*Epinephelus itajara*) and 30 percent SPR for other reef fish stocks (U.S. Department of Commerce, 2002). These benchmark values are derived from density-dependent, stock-recruitment theory where the number of recruits to a population is expected to be approximately the same at or above the minimum SPR threshold. The maximum YPR value at which SPR is at or above the 30 percent threshold denotes the level of exploitation expected to produce "maximum sustainable yield" (MSY).

Table 1: Atrributes measured in fisheries-independent and fisheries-dependent monitoring.

- **Population statistics**
  - Size-structured abundance
  - Spawning stock biomass
  - Coral reef habitat quality and distribution
- **Catch/yield**
  - Catch rates
  - Yields
- **Species diversity**
  - Species composition (richness)
  - Habitat occupancy

Sustainability analyses based on fisheries independent monitoring involve comparison of various population metrics at current levels of fishing mortality against standard fishery management sustainability benchmarks. Typically, numerical simulation models are configured to assess several reference points to address several stock sustainability risks, including fishery yields, spawning potential ratio (SPR; Clark, 1991), and precautionary control rules (Restrepo and Powers, 1999). Estimated SPRs are compared to U.S. federal standards which define 30 percent SPR as the threshold below which a stock is no longer sustainable at current exploitation levels (Gabriel *et al.*, 1989; Restrepo *et al.*, 1998). Evaluation of control rules involves determination of Fmsy (F–fishing mortality rate generating maximum sustainable yield, MSY) and Bmsy (population biomass at MSY) typically defined as F = M (natural mortality rate) as a proxy for Fmsy (Quinn and Deriso, 1999; Restrepo and Powers, 1999).

Drivers of Change

Fish and shellfish in the FK/DT coastal marine ecosystem are threatened by (1) fishing, (2) disease, (3) non-native species, (4) alterations to benthic habitats (e.g., loss of mangroves and seagrasses to shoreline development, channel dredging, and ship groundings), and (5) alterations to water quality (e.g., pollution, nutrification, and turbidity), quantity, and timing of freshwater inflows (Figure 1). The effects of fishing include the direct effect of increased mortality, as well as the removal of key prey (e.g., shrimp, baitfish) and predators (e.g., barracuda, sharks). Other environmental issues facing the FK/DT include coral declines from diseases and bleaching, invasion of exotic species, shifts to algal dominance, and damage from contact by anchors, grounded vessels, divers, snorkelers, and fishing gear. In addition, hurricanes have a 16 percent annual probability of striking the Florida Keys (Neumann, 1987) and damaging habitat. Looking at the full spectrum of impacts suggests that achieving sustainable reef fisheries will likely entail substantially more analysis of inter-related factors than simply assessing fishing mortality rates for a few snapper and grouper species (Bohnsack and Ault, 1996; Ault *et al.,*1999b; Lindeman *et al.,* 2000).

Fishing

Snapper-Grouper Complex

Intensive exploitation and overfishing is perhaps the major threat to these fisheries of the Florida Keys ecosystems (Russ, 1991; Haedrich and Barnes, 1997; Ault *et al.,* 1998, 2005a, 2008). Generally, fishing can reduce ecosystem integrity in at least three ways. First, removing targeted species and killing non-target species (as bycatch) may result in cascading ecological effects (Frank *et al.,* 2005). Second, because fishing is size-selective, concerns exist about ecosystem disruption by removal of ecologically-important species such as top-level predators (e.g., groupers, snappers, sharks, jacks) and prey (e.g. shrimp, baitfish) of certain sizes. Third, gear and fishery impacts with critical habitats can reduce the quality and productivity of the environment that supports these valuable fisheries. In coastal bays and near barrier islands, juvenile pink shrimp are commercially targeted as live bait for the recreational fishery. Both food and sport fisheries target pre-spawning subadult pink shrimp as they emigrate from coastal bay nursery grounds to offshore spawning grounds (Ault *et al.,* 1999a).

Inshore, sport fisheries pursue highly prized game fishes, including tarpon, bonefish, spotted seatrout, permit, sheepshead, black and red drum, and snook, while commercial fisheries primarily target sponges and crabs. Offshore of the deep margin of the barrier reef, commercial and sport fisheries capture an assortment of species including amberjack, king and Spanish mackerel, barracuda, sharks, and small bait fishes (e.g., *Exocoetidae, Mullidae, Carangidae, Clupeidae, and Engraulidae*). Farther offshore (seaward of the 40 m isobath), commercial and sport fisheries catch dolphinfish, tunas, and swordfish, and sport fishers target sailfish, wahoo, and white and blue marlin.

Caribbean Spiny Lobster

The Caribbean spiny lobster is perhaps the most important commercial fishery species in the Florida Keys, but it is also intensively fished by the recreational sector. The commercial fishery for Caribbean spiny lobster in the southeast United States began in Florida in the late 1800s as an artisanal and bait fishery for finfish. Transition to a food fishery occurred when construction of the railroad from Miami to Key West and, later, the Overseas Highway, improved transportation links to the mainland. The current heavy exploitation by both the commercial and recreational fisheries removes a large proportion of the adult animals each year. Throughout its range in the Caribbean and Brazil, annual catch peaked between 1987 and 1997 and is currently in decline. The cause of this decline is largely attributed to overfishing, but environmental factors also play a role (Ehrhardt *et al.,* 2009).

In the Florida Keys, damage to benthic habitats from fishing gear impacts and marine debris represent important indirect pressures on the fisheries. For example, regular yet unintended trap loss in the lobster and stone crab trap fisheries results in trap ropes wrapping around coral

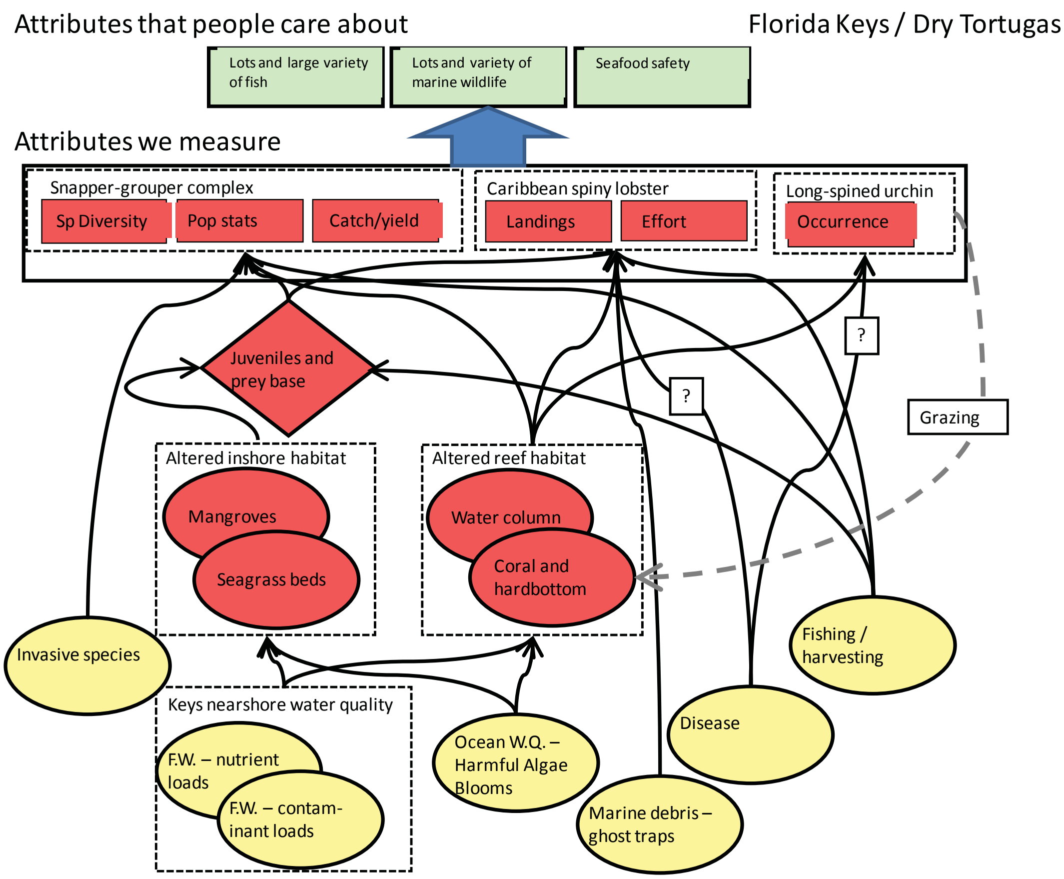

Figure 1. Fish and shellfish submodel diagram for the Florida Keys/Dry Tortugas.

heads and abrading or killing coral colonies. Combined, the two fisheries utilize approximately 815,000 traps per season in addition to an unknown number of recreational stone crab traps (five per person allowable with a Florida saltwater fishing license) that have the same potential for habitat impact. In addition, lobster or stone crab traps can continue "fishing" even after they have been lost, which leads to continued mortality of marine organisms that are too large to escape the traps after capture.

Long-Spined Sea Urchin

There is no fishing of the long-spined sea urchin in the Florida Keys.

Disease

Disease exerts a significant influence on faunal populations in the Caribbean region. Perhaps the best known of this fact is the viral epidemic that struck the long-spined sea urchin between 1983 and 1984. This epidemic decimated urchin populations throughout the Caribbean, and the sudden loss of a major herbivore in the food web contributed to a shift in dominance on many reefs from coral to macroalgae. More recently, a viral disease, PaV1, has taken hold in the Caribbean spiny lobster population. This disease increases mortality primarily in juvenile lobsters, and the consequences of this epidemic are not yet known (Butler *et al.,* 2008).

Non-Native Species

The non-native lionfish threatens the ecosystem by altering the structure of native reef fish communities by out-competing native reef organisms and reducing forage fish biomass (Morris and Whitfield, 2009). Venomous protective spines, combined with their aggressive feeding habits, unique reproduction, and lack of predators contribute to their competitive advantage. Impacts from lionfish include direct competition with groupers for food and predation of reef fish and crustaceans (Ruiz-Carus *et al.,* 2006; Albins and Hixon, 2008; Morris and Atkins, 2009). Observations of sharp increases in lionfish abundance since 2009 throughout the FK/DT also poses a danger to divers and fishermen from their venomous spines and a potential disruption of the ecological balance of the ecosystem (Ruttenberg *et al.,* 2012).

Habitat Degradation

Habitat degradation resulting from other human activities include coastal development, altered freshwater flow, and changes in water quality from pollution, sedimentation, and excess nutrients (CERP, 1999; Cowie-Haskell and Delaney, 2003). Damages related to fishing gear and general boat use also contribute to habitat degradation. Human impacts have grown as a result of Florida's tenfold population growth from 1.5 million people in 1930 to 16 million in 2000. In 2000, over five million residents, nearly a third of Florida's population, lived in the five southern counties adjacent to coral reefs (Palm Beach, Broward, Miami-Dade, Monroe, and Collier). In addition, over three million tourists visit the Florida Keys annually (Leeworthy and Vanasse, 1999).

Pressures

Fishing

Precise data on trends in coral reef fishing effort, combining both commercial and recreational activities, do not exist, but these trends are reflected by state-wide fishing statistics and numbers of registered boats. In 2001, for example, an estimated 6.7 million recreational fishers took 28.9 million marine fishing trips in Florida and caught 171.6 million fish, of which 89.5 million (52 percent) were released or discarded (U.S. Department of Commerce, 2002). From 1964-2002, the number of registered recreational boats in South Florida grew by more than 500 percent, while the number of commercial vessels grew at a much lower rate, about 150 percent. Many of these vessels are used for fishing and for non-extractive activities, such as sailing, sightseeing, transportation, snorkeling, and SCUBA diving.

The increased fishing fleet size has been accompanied by a number of technological advances that have been estimated to have quadrupled average fishing power (Mace, 1997), i.e., the proportion of stock removed per unit of fishing effort (Gulland, 1983). These advances include improvements in fishing tackle, hydroacoustics (depth sounders and fish finders), navigation (charts and global positioning systems), communication, and inexpensive, efficient, and more reliable vessel and propulsion unit designs (Bohnsack and Ault, 1996; Ault *et al.,* 1997, 1998). These fishing trends have thus become an obvious concern to the fishery sustainability and persistence of the coral reef ecosystem.

Although fishing pressure (i.e., number of trips, traps, angler days, etc.) from both the commercial and recreational fisheries declined from 1995 to 2008, it is uncertain if these trends will continue. For example, information from socio-economic surveys in 1995-1996 showed over 572,000 visitors and residents participated in over 2.8 million days of recreational fishing in the Florida Keys (Leeworthy and Wiley, 1996; Leeworthy, 1996; Leeworthy and Wiley, 1997). Similar surveys in 2007 and 2008 showed almost 416,000 visitors and residents participated in almost 2.1 million days of fishing in the Florida Keys and Key West (Leeworthy *et al.,* 2010; Leeworthy and Morris, 2010). This represents a 25 percent decline in recreational fishing effort over the 12-year period. However, this decrease in pressure has an offsetting trend in that the growth in average fishing power (the proportion of stock removed per unit of fishing effort) may have quadrupled in recent decades. The increase results from technological advances in fishing tackle, hydroacoustics (depth finders and fish finders), navigation (charts and global positioning systems), communications, and vessel propulsion (Bohnsack and Ault, 1996; Mace, 1997). Because of this, there remains a significant but largely undocumented effect of tens of thousands of recreational fishers who target hundreds of species using mostly hook-and-line and spear guns (Bohnsack *et al.,* 1994a).

For the 1996 to 2006 period, Murray and Associates, Inc. (2007) summarized various measures of fishing effort for Monroe County relative to "other Florida counties" (Table 2). Over this period, all measures of fishing effort declined more rapidly in Monroe County relative to all other counties in Florida, except for stone crab permits. Trends in recreational and commercial fishing pressure in Monroe County/Florida Keys are in decline due to a number of fishery and extra-fishery factors, including stagnant ex-vessel values (the revenue the fisherman receives for his catch) resulting from low demand, higher landside prices such as cost of living, gear, crew, etc., and less waterfront space availability (Leeworthy and Wiley, 1996; Leeworthy, 1996; Sharp *et al.,* 2005; Leeworthy *et al.,* 2010; Leeworthy and Morris, 2010).

Non-Native Species

Red lionfish, formerly residents of the western Pacific Ocean, Red Sea, and eastern Indian Ocean, were first reported in the 1980s along South Florida and are now well established along the southeast U.S. and Caribbean (Ruiz-Carus *et al.,* 2006; Morris *et al.,* 2009). Reports of lionfish in the sanctuary began in January 2009, and between January 2009 and July 2010 there were approximately 500 reported lionfish sightings in the Florida Keys (250 of those were confirmed and removed from sanctuary waters) (Morris and Whitfield, 2009). Since then, sighting and removal efforts have been continuously increasing. Juvenile lionfish (approximately 30 mm in total length) were observed in spring 2010 at several locations in Florida Bay (C. McHan, FWC, personal observation; M. Butler, Old Dominion University, personal communication; Ruttenberg *et al.,* 2012), suggesting a pervasive invasion is occurring across all the habitats of the Florida Keys ecosystem. The increasing abundance and wider distribution of lionfish in the South Atlantic Bight, Bermuda, Florida, and the Bahamas indicates that lionfish are perhaps the first marine fish species to successfully establish a breeding population in the tropical central western Atlantic.

Status and Trends

Snapper-Grouper Complex

Ault *et al.* (1998, 2005b) assessed the status of reef fish stocks and determined that 13 of 16 groupers, seven of 13 snappers, one wrasse (hogfish), and two of five grunts were overfished according to federal (NOAA's National Marine Fisheries Service) standards. In addition, some stocks appeared to have been chronically overfished since the 1970s, with the largest, most desirable species depleted first, followed by increasingly smaller and less desirable species with time (Ault *et al.,* 1998). The average size of adult black grouper in the upper Keys was about 40 percent of its 1940 value, and the spawning stock for this species was less than 5 percent of its historical, unfished maximum potential (Ault *et al.,* 2001). In subsequent analyses, Ault *et al.* (2005a, 2005b, 2009) determined that 25 of the 34 species within the snapper-grouper complex for which sufficient data were available were experiencing overfishing.

Table 2. Southeast regional stocks that are subject to overfishing or are overfished as defined by NOAA's National Marine Fisheries Service. The list includes species in both the South Atlantic and Gulf of Mexico fishery management council jurisdictions (Source: NMFS, 2010).

Subject to Overfishing	Overfished
Vermillion snapper (South Atlantic only)	Red snapper
Red snapper	Snowy grouper (South Atlantic only)
Snowy grouper (South Atlantic only)	Black sea bass (South Atlantic only)
Red grouper (South Atlantic only)	Red porgy (South Atlantic only)
Black sea bass (South Atlantic only)	Pink shrimp (South Atlantic only)
Gag grouper	Red grouper (South Atlantic only)
Speckled hind (South Atlantic only)	Gag grouper (Gulf of Mexico only)
Warsaw grouper (South Atlantic only)	Gray triggerfish (Gulf of Mexico only)
Tilefish (South Atlantic only)	Greater amberjack (Gulf of Mexico only)
Greater amberjack (Gulf of Mexico only)	
Gray triggerfish (Gulf of Mexico only)	

Generally, there is a very high exploitation rate in the Florida Keys from both recreational and commercial fishing efforts. Trends in reef fish landings from 1981 to 1992 were reported for the Florida Keys by Bohnsack *et al.* (1994a). Depending on the year, recreational landings comprised between 40 percent and 66 percent of total landings. Reef fishes accounted for 58 percent of total fish landings. In its 2010 report to Congress, NOAA's National Marine Fisheries Service classified nine species that are landed in the Florida Keys as overfished (i.e., depleted below minimum standards), and 11 species as subject to overfishing (i.e., being fished at a rate that would lead to being overfished), with some overlap between the two categories (NMFS, 2010; Table 2).

Caribbean Spiny Lobster

Invertebrates (Caribbean spiny lobster, shrimp, and stone crabs) comprise 63 percent of total landings. Commercial fishing catch declined from 21.8 million pounds in 1995-1996 to 9.6 million pounds in 2008, a 56 percent decrease. Fishing trips also declined 56 percent over this period, from 67,422 trips in 1995-1996 to 29,681 trips in 2008. This was a greater decline than what occurred across the entire state of Florida. Florida's total catch declined about 34 percent during the same period, while trips declined about 47 percent. This decline was due in part to changes in fishery management designed to reduce overall fishing effort, as well as decreasing demand for Caribbean spiny lobsters, which is the dominant fishery in the Florida Keys. The FK/DT region historically accounted for 89 percent of commercial Caribbean spiny lobster catch (FWRI, 2010).

Long-Spined Sea Urchin

Historical surveys of the long-spined sea urchin prior to the 1983 and 1984 Caribbean-wide mass mortality event are limited for the Florida Keys. Surveys carried out in the early 1990s suggested that the population was recovering slowly, with densities on shallow spur and groove reefs approaching one tenth (i.e., 0.5-0.6 individuals per 10 square feet) of their pre-1983 level (Forcucci, 1994). Over an 11-year period (1999-2010), researchers examined densities and test sizes of the long-spined sea urchin and other sea urchins at more that 1,100 Florida Keys sites spanning 217 miles (350 kilometers) and encompassing multiple habitat types from inshore to the deeper fore-reef slope. Surveys since 1999 indicate that current densities are still well below one individual per square meter.

Discussion

Consequences of Overfishing

The resulting severe reduction in numbers of large fishes and loss of spawning aggregations deleteriously affects ecosystem integrity and biodiversity. Former spawning aggregation sites in the FK/DT ecosystem are not functioning the way they did historically. Quantitative anecdotes from experienced fishers point towards sharply reduced numbers of spawning aggregations and fewer, much smaller individuals within those that are still present. Researchers from NOAA's National Marine Fisheries Service and Florida's Fish and Wildlife Research Institute have been monitoring one recovering spawning aggregation site for mutton snapper (*Lutjanus analis*) at Riley's Hump in the Tortugas South Ecological Reserve since 2004 (Burton *et al.,* 2005; Feeley *et al.,* 2012). According to diving observers, in 2009-2011 "thousands" of mutton snapper aggregated for spawning at Riley's Hump (Feeley *et al.,* 2012).

Although the no-take marine reserves (NTMR) within the sanctuary were not designed as a fishery management tool *per se*, results from a FWC five-year monitoring project concluded that Sanctuary Preservation Areas were too small to protect Caribbean spiny lobsters from the fishery, but the larger Western Sambo Ecological Reserve (WSER) did function to some degree as a fishery reserve (Cox and Hunt, 2005). There, the mean size of legal lobsters and the frequency of encounters in large lobsters in areas adjacent to the WSER suggested that lobsters were likely emigrating from the WSER to fished areas, thus this zone may have served to enhance fishery landings to some extent. The WSER does not encompass all of the habitats utilized by adult Caribbean spiny lobsters during their life history, and inclusion of the adjacent outlier reef would serve to protect lobsters from fishery exploitation (Cox and Hunt, 2005). On the other hand, a series of synoptic fishery-independent reef fish visual census research cruises spanning two years before and 10 years after NTMR implementation strongly indicated that these NTMRs, in conjunction with traditional fishery management control strategies, were helping to build sustainable fisheries while protecting the fundamental ecological dynamics of the FK/DT coral-reef ecosystem (Ault *et al.,* 2006, 2013).

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