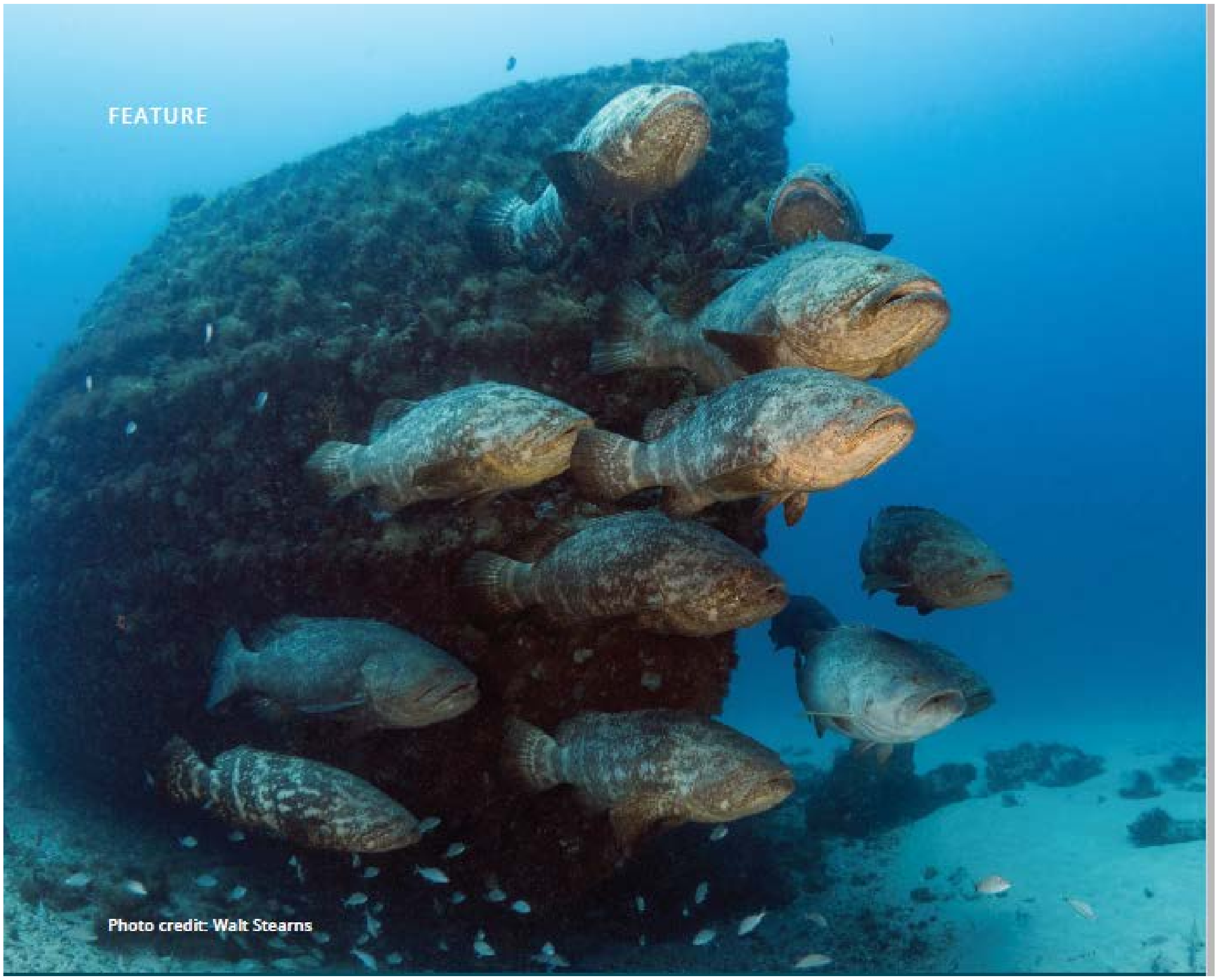

ATLANTIC GOLIATH GROUPER OF FLORIDA:

TO FISH OR NOT TO FISH

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ABSTRACT

The Atlantic Goliath Grouper *Epinephelus itajara,* a large indigenous tropical reef fish, approached local extinction in U. S. waters by the 1980s as a result of intense fishing pressure. In 1990, federal and state laws intervened to protect this species. The resulting fishery closure, over the intervening years, allowed limited, slow population recovery in Florida waters while populations outside of the U. S. remained vulnerable (IUCN: Bertoncini et al. 2018). The closure led to the blossoming of a dive ecotourism industry catering to local and international divers seeking opportunities to see and photograph these enormous fish. This fundamentally changes the paradigm for Goliath Grouper from a fishery resource to a non-extractive resource with a commercial value vastly greater than that gained through fishing. While federal and state agencies attempted to re-establish the fishery, all three stock assessments were rejected after peer review. Here, we discuss Goliath Grouper's biology, the controversy surrounding its protection, and the drawbacks of re-establishing a fishery, including: the loss of nursery habitat, increasingly destructive episodic events like red tide and cold snaps, and the effects of mercury contamination on survival. Add to this the human health risk of consuming mercury-contaminated fishes, and the argument supporting re-opening the fishery evaporates.

INTRODUCTION

General

Groupers (163 species in the family Epinephelidae) form an important component of reef fish fisheries around the world. According to the Food and Agricultural Organization of the United Nations (www.FAO.org), groupers contributed more than 462,000 MT to global fisheries production in 2017 with an approximate linear increase in catch since 1960 of 61,000 MT per decade. The International Union for the Conservation of Nature (IUCN) red list assessments show that about 20 of these grouper species (12% of total) are under threat of extinction if current trends continue (Sadovy de Mitcheson et al. 2012).

Grouper species that are particularly vulnerable to overfishing tend to share similar life history traits: great longevity, late sexual maturity, and protogyny (sex change from female to male). Many species also aggregate at temporally and spatially predictable spawning sites, resulting in fishers targeting these sites to increase their catch per effort, a practice that may disrupt the mating system and the sex-change process. It also depletes large old breeders that have the highest reproductive potential, and often results in the eventual collapse of the aggregations (Sadovy and Domeier 2005; Russell et al. 2014; Hixon et al. 2014). Such has been the fate of spawning aggregations of Nassau Grouper *Epinephelus striatus* and Red Hind *E. guttatus* (Sadovy and Domeier 2005 and many others). In addition, juvenile groupers of many species have obligatory sojourns in coastal habitats (e.g., mangroves, seagrass meadows, and near-shore algal and hard-bottom habitats) that are often exposed to extreme anthropogenic perturbations, including direct destruction, increases in nutrient loads (eutrophication) that cause hypoxia and harmful algal blooms such as red-tide, and inputs of toxicants such as pesticides, heavy metals, and other pollutants.

The Atlantic Goliath Grouper *Epinephelus itajara* (hereafter referred to as "Goliath Grouper"), a species that possesses all these life history characteristics, is vulnerable throughout its range (Bertoncini et al. 2018). It has all but disappeared from the eastern Atlantic (from Senegal to Congo) and is relatively rare in the Caribbean and southwestern Atlantic off Brazil. One region within its range where this is not the case is off the Florida coast in the southeastern United States. Here, the Goliath Grouper population shows signs of recovery because of complete protection from extractive exploitation since 1990 afforded by state and federal fishery management agencies. However, there are factors that cast doubt on whether full recovery has occurred that would support reopening a fishery (SEDAR 2011; SEDAR 2016).

Here, we discuss Goliath Grouper's biology, the controversy surrounding its protection, and the drawbacks of re-establishing a fishery. The latter includes the loss of fishery potential resulting from loss of nursery habitat, increasingly destructive episodic events like red tide and intense cold, and the sublethal and lethal effects of mercury contamination on Goliath Grouper survival. Add to this the human health risk of consuming mercury-contaminated fish, and the argument supporting re-opening the fishery evaporates.

Current Status and Biology Overview

Goliath Grouper occurs in tropical and subtropical waters on both sides of the Atlantic Ocean, ranging from North Carolina (USA) to southeastern Brazil in the western Atlantic – including Bermuda, the Gulf of Mexico and Caribbean, and from Senegal to the Congo in the eastern Atlantic. Note that the eastern Pacific population, formerly included with *E. itajara*, is now known to be a genetically distinct species, the Pacific Goliath Grouper, *E. quinquefasciatus* (Craig et al. 2009). The specific status of the eastern Atlantic population is unknown because genetic samples have not been available.) It is the largest grouper in the Atlantic, reaching lengths of 2.4 m and weights of 310 kg (Robins and Ray 1986). The species is long-lived (at least to 37 years), slow to mature (Bullock et al. 1992, Koenig and Coleman 2016), and seemingly unafraid of divers.

Goliath Grouper form spawning aggregations at predictable times of the year (late July through October) on predictable sites (Koenig et al 2011; Ellis et al. 2014) (Figure 1). Dozens of spawning sites occur off southeast and southwest Florida, and Malinowski et al. (2019) describe a recently discovered spawning site in the northeastern Gulf of Mexico which suggests an increase (or recovery) of the population's range.

Goliath Grouper are nocturnal group spawners, favoring new-moon nights and early morning hours for greatest spawning activity (Koenig et al. 2016). Long-range spawning migrations are common, extending up to 500 km (Ellis et al. 2014). After spawning, they return to home sites where they display strong site fidelity. Spawning sites (and most home sites) are natural high-relief rocky reefs or artificial reefs and shipwrecks in southeast and southwest Florida (Koenig et al. 2011, Collins et al. 2015).

Timing of the spawning season and larval planktonic duration (30 – 80 d) corresponds to the most favorable times for larval settlement in mangrove leaf litter in South Florida – that is, during the dry season (December – May) when salinity is high and prey resources abundant (Lara et al. 2009, Koenig et al. 2016). As they grow, juveniles move from leaf litter to red mangrove prop-root systems and undercuts along mangrove shorelines (Koenig et al. 2007) where they reach total lengths of about 1.0 m over their 5- to 6-year sojourn in that habitat (Koenig et al. 2007; Brusher and Schull 2008.)

Goliath Grouper have undergone population declines throughout their range since at least the 1950s (McClenachan 2009a; 2009b) due in part to overfishing and in part to destruction and/or pollution of essential red mangrove *Rhizophora mangle* nursery habitat. Their recovery – both in the number of spawning aggregations and the number of spawners per aggregation – started to become apparent in offshore waters of southwest Florida in 1998. It expanded over the following two decades to include the southeast coast of Florida by 2004, continuing for the next few years (Koenig et al. 2011, Koenig and Coleman 2016). However, recurring cold events (2008 and 2010) and red tide events (2005 and 2018) compounded by restricted recruitment have caused or added to a decline in both juvenile and adult stocks (SEDAR 2016, Figure 2).

Scientists at the NOAA Fisheries Southeast Science Center (SESC) and the Florida Fish and Wildlife Research Institute (FWRI) of the Florida Fish and Wildlife Conservation Commission (FWC) have conducted several Goliath Grouper stock assessments for the SouthEast Data, Assessment, and Review (SEDAR, http://sedarweb.org) process. Goliath Grouper assessments (SEDAR 2004, 2011, 2016), while focused on determining the state of stock recovery, suffered from poor catch records both before and following closure of the fishery in 1990. As a result, all three stock assessments were rejected by SEDAR following peer review.

SEDAR 6 (SEDAR 2004) concluded that "the goliath grouper stock in south Florida waters was recovering, but that full recovery to the Magnuson-Stevens Fisheries Conservation and Management Act management target might not occur until 2020 or later." Similarly, SEDAR 23 (SEDAR 2011) could not define the degree of recovery. The FWRI developed SEDAR 47 (SEDAR 2016) without direct involvement of NOAA Fisheries. This assessment recognized a significant decline in the stock in the mid to late 2000s based on indices of abundance (Figure 2), and attributed it to cold events (2008 and 2010) and a severe red tide (2005). Another severe red tide occurred in 2018, the impacts of which will almost certainly add to stock decline. Nevertheless, they concluded that spawning stock biomass likely exceeded the management reference target of $SSB_{50\%SPR}$ (Spawning Stock Biomass at 50% Spawning Potential Ratio) and that the stock was likely no longer in the overfished condition. Although the assessment was subsequently rejected by peer review, the state considered the possibility of re-opening a limited fishery in Florida waters only. Thus, a controversy arose between those who wanted to open a fishery and those who wanted to keep it closed.

CONTROVERSY

The controversy of whether to re-establish a fishery or to continue protection for Goliath Grouper is restricted to Florida, where recovery of the population has been greatest (Cass-Calay and Schmidt 2009, Koenig et al. 2011, SEDAR 2016). Data pointing to a population in recovery mode engendered a broad spectrum of opinions from the public. Those with a sufficiently long history of fishing south Florida reefs to have witnessed declines in water quality and habitat considered recovery of Goliath Grouper a plus for the entire ecosystem. Many newcomers, on the other hand, unaccustomed to seeing such large fish on reefs, considered Goliath Grouper an invasive species, both novel and at once intolerable because of the moratorium on fishing them. Their differing perspectives reflect a shifting baseline (Pauly 1995), wherein people accept as normal their first experiences (the baseline), against which all subsequent changes are measured. Hence, those with the longer history and viewpoint considered the recovery positive while those with only limited knowledge of the region viewed the (re)appearance of Goliath Grouper as an aberration that needed to be reversed or controlled.

The community of fishers in favor of re-opening a fishery for Goliath Grouper have made a series of claims about Goliath Grouper having negative ecological and economic effects in Florida. Missing most often from their argument is the available scientific information that suggests otherwise. What must be clearly acknowledged is that Goliath Grouper is a native species recovering from near extinction in Florida waters, and that it is vulnerable with a declining population trend (Bertoncini et al. 2018) throughout its range. Here we juxtapose the most persistent claims with the scientific evidence.

Example 1. The primary claim is that Goliath Grouper substantially reduce populations of groupers and snappers on the reefs of Florida, putting the reefs out of balance. Those promulgating this view point see the solution as being the removal of Goliath Grouper. Fishers apparently see Goliath Grouper populations increasing while the abundance of the species they target are decreasing, and they interpret the pattern as cause and effect – increase in the Goliath Grouper population is causing the decline in the economically important populations of groupers and snappers.

The science clearly contradicts this view through two lines of evidence – one provided by studies of Goliath Grouper diet and another provided by video surveys of the distribution and abundance of reef fish on Florida reefs. Goliath Grouper diets were evaluated in two ways: via stomach-content analysis and using stable-isotope analysis (Koenig and Coleman 2016, Malinowski unpublished data). Stomach contents represent prey eaten just prior to capture – a direct indication of the dominant prey species. Stable isotope analysis provides information over the long-term, revealing the organism's position (*i.e.*, trophic level) in the food web. Juveniles and adults have very similar diets dominated by crabs and some slow-moving bottom-associated fishes. Both the percent occurrence and percent weight of economically important species was very low in the stomachs of juveniles and adults. Stable isotope analyses demonstrate that Goliath Grouper are mid-trophic level predators (Koenig and Coleman 2009 and 2016). Goliath Grouper, often referred to as an "apex predator," actually feeds on lower trophic-level species, not on those species occupying higher trophic levels, such as groupers and snappers.

The reality overall is that we humans tend to remove ourselves from an observed system, when we are, in fact, an integral part of all ecosystems on earth, especially considering our contribution to climate change (Vitousek et al. 1997). In this case, fishers have regionally overfished the most sought-after species – snapper and grouper – but point to recovering Goliath Grouper as the cause of their decline. The fact is that fishery species will not recover by reducing the abundance of Goliath Grouper. Rather, they recover by invoking ecosystem-based fisheries management (e.g., Ruckelshaus et al. 2008) while attempting to reduce a variety of other human-induced impacts.

Some fishers claim that Goliath Grouper deplete the economically important spiny lobster (*Panulirus argus*) populations of South Florida. The assumption that lobster form an important component of the Goliath Grouper diet follows from a report about the diet of reef species sampled from the West Indies in the 1960s (Randall 1967). In this report, Randall indicated that spiny lobsters were a significant component of the diet of Goliath Grouper. At that time (1959 – 1961) and place (St. John, VI), lobsters were very abundant (Randall, personal communication), so the observation of Goliath Grouper feeding on them is not surprising. In South Florida, where the spiny lobster fishery is intense, it is doubtful that Goliath Grouper can affect the fishery catch significantly – Goliath Grouper diet data and lobster catch data support this view. Spiny lobster make up <1% of the juvenile diet and <3% of the adult diet (Koenig and Coleman 2016, Malinowski unpublished data). The number of lobsters this represents is minute compared to the total commercial and recreational catch. In addition, total Florida commercial lobster landings and catch per trip in Florida (https://public.myfwc.com/FWRI/PFDM/ReportCreator.aspx) have actually increased from 2000 to 2018 (Figure 3), a period of increase of the Goliath Grouper population (Koenig et al. 2011, Figure 2). That is, Goliath Grouper abundance and lobster catch and catch per trip in Florida are positively correlated, the opposite expected if Goliath Grouper had a major impact on the lobster fishery.

Despite the perception that Goliath Grouper recovery is having a negative effect on the populations of reef fishes, the data indicate that this is not the case. For instance, Koenig et al. (2011), using two independent surveys (one from the Reef Environmental Education Foundation (REEF) and the other from Florida State University researchers) found a positive relationship between the abundance of Goliath Grouper on a reef site and the abundance of other fish species as well as a positive relationship with fish species richness. That is, the higher the number of Goliath Grouper occupying a reef, the higher the number of reef fish and the greater the fish species richness (Figures 4 and 5).

Although correlation does not equal causation, it is possible that the positive relationships between Goliath Grouper abundance and fish species richness, reef fish abundance, and lobster catch are due, at least in part, to the excavating behavior of Goliath Grouper. Koenig et al. (2011) described this behavior as the removal of sediment from spaces in and around the reefs they occupy and exposing more spaces and rocky substrate, thereby enhancing the structural complexity of the habitat and making more refuges available to more species and more individuals.

Organisms that enhance the structural complexity of habitat – known as ecosystem engineers – enhance local biological diversity (Coleman and Williams 2002, Wright and Jones 2006, Coleman et al. 2010). Red Grouper *Epinephelus morio* for instance – a congener of Goliath Grouper – is known for its excavating behavior that occurs with both juveniles in inshore habitats and adults over large areas of the shelf edge. This behavior enhances both structural complexity and local species richness (Coleman et al. 2010, Ellis et al. 2015). While the evidence suggests that excavations of Goliath Grouper may also result in increased species richness and abundance (Koenig et al. 2011, Collins et al. 2015), this has not been determined experimentally. It is known, however, that behaviors that have a positive influence on abundance and species diversity are likely to contribute positively to both ecosystem function and overall productivity (e.g., Sala and Knowlton 2006, Duffy et al. 2016).

Example 2 – Another widely repeated claim is that Goliath Grouper are dangerous to divers. This is largely a concern of spearfishers. It is far more likely that Goliath Grouper are targeting the stringer of fish clipped to a diver's belt rather than the diver. Goliath Grouper have a very weak bite because they feed primarily by suction rather than biting. Also, their teeth, although sharp, are very small, so an accidental nip would result in a wound resembling an abrasion rather than a piercing bite, very unlike a shark would inflict. Dive ecotourism guides have interacted with thousands of adult Goliath Grouper underwater and researchers have tagged 2100 with spearguns (see Koenig et al. 2011). Not a single aggressive interaction has been reported.

Example 3. – A third claim is that Goliath Grouper are a nuisance and interfere with fishing by taking baited hooks or hooked or speared fish. Whether Goliath Grouper are taking hooked fish or simply going after baited hooks is immaterial. The fact is that fishhooks and leaders often occur in the mouths, gills and throats of Goliath Grouper (Figure 6). However, it is worth noting that many predators with large gapes – including sharks and bottlenose dolphin – will take bait or an injured or struggling fish at the end of a fishing line. This may be an inconvenience to fishers, but it does not rise to the need to thin out the population. Indeed, culling predator populations has the potential to precipitate serious problems within an ecosystem, including those associated with trophic cascades (e.g., Estes et al. 2011).

Overall, there is much misinformation disseminated throughout the public that drives the controversy and puts pressure on resource managers to open a limited fishery for Goliath Grouper. Issues we discuss below cast considerable doubt on the wisdom of this course of action.

MERCURY CONTAMINATION IN GOLIATH GROUPER POSES HUMAN HEALTH CONCERN

Goliath Grouper from the Gulf of Mexico and western Atlantic Ocean off the coasts of Florida have the highest known concentrations of liver and muscle mercury of any commercially important shallow-water grouper species in Florida (Table 1) and among the highest recorded for any commercial fish species currently listed by the Food and Drug Administration (FDA) (Table 2). Muscle tissue total mercury concentrations in Goliath Grouper are generally higher in the Atlantic than in the Gulf of Mexico, and in regions closest in proximity to urban runoff and other sources of pollution (Malinowski 2019). In muscle tissue – the filet portion that is most often consumed – a majority (> 90%) of this mercury is in the more toxic methylated form (*i.e.,* methylmercury) (Adams and Sonne 2013, Malinowski 2019). For adult Goliath Grouper, approximately 96% exceed EPA's risk level for human consumption of 0.3 µg/g ww (µg/g ww = micrograms per gram wet weight) total mercury, in some cases reaching as high as 25 times this amount. About 50% exceed the FDA action level of 1.0 µg/g ww total mercury, the signal concentration for the FDA to remove the contaminated fish from the market. The EPA and FDA jointly advise that no one should eat fish containing above 0.46 ug/g ww total mercury, , a level that occurs in 93% of the adult Goliath Grouper (Malinowski 2019).

Methylmercury is a highly potent developmental neurotoxicant that poses a serious threat to human health at all life stages (Bakir et al. 1973), but with particularly damaging effects on the central nervous system of developing fetuses, infants, and young children. Uptake from the human digestive tract is around 90 to 95% (Carocci et al. 2014). In infants, symptoms of congenital methylmercury poisoning are mental retardation, movement problems, seizures and speech difficulty (Bose-O'Reilly et al. 2010, Grandjean and Herz 2011).

Methylmercury has also been implicated in cardiovascular disease and Alzheimer's disease (Guallar et al. 2002, Mergler et al. 2007; Carocci et al. 2014). As with most toxicants, severe intoxication by methylmercury is dose dependent — methylmercury exposure depends on the concentration in the flesh of the consumed species, the frequency of intake, and the size of each meal. A damaging dose is not always apparent because response to a toxic dose is delayed and toxic effects on pregnant women and their fetuses may differ. Relatively low doses in the diet of mothers may produce brain damage in the fetus, while the mother may be asymptomatic (Grandjean and Herz 2011, Karagas et al. 2012). Implication of methylmercury as the cause of possible impairments to a newborn child can be determined using chronic biomarkers, such as hair-growth segments, which provide a recent history of relative dose levels to the mother (Mergier et al. 2007).

Clearly, it is highly risky to eat adult Goliath Grouper and state and federal agencies with the responsibility of protecting the public from toxic food products strongly advise not to eat fish with mercury levels as high as occur in Goliath Grouper. But the question remains as to what advantage it is to the State of Florida to allow recreational fishers to catch and eat these fish, knowing that they are putting human health, especially the health of innocent children, at great risk.

BOTTLENECKS TO RECOVERY

Habitat decline

Juvenile habitat for Goliath Grouper must have two main components: (1) structurally complex habitat in the form of red mangroves — important because of their complex prop-root systems that provide extensive cover and ready access to prey for juveniles (ages 0 to 6); and (2) consistently high water quality, with salinities > 5 PSU and dissolved oxygen content >3 mg L^{-1} (Koenig et al. 2007, Shideler et al. 2015) as Goliath Grouper are intolerant of conditions below these levels. Koenig et al. (2007)

conducted studies in the mangroves of the Ten Thousand Islands and Florida Bay in southwest Florida and found that Goliath Grouper juveniles were more abundant and grew more quickly around mangrove islands where conditions were similar to those indicated above. They were less abundant and grew slower in mangrove-lined rivers, which experienced more variable environmental conditions. Some rivers had periodic bouts of hypoxia that rendered the mangrove habitat unacceptable to juveniles (Koenig et al. 2007). Koenig et al. (2007) also demonstrated that red mangrove habitat was essential (*sensu* Beck et al., 2001) to the production of Goliath Grouper. Thus, declines in the availability of quality red mangrove habitat results in a decline in recruitment and presents a significant impediment to their full recovery.

Most of the mangrove forests in south Florida declined over time due to intense population and agricultural growth accompanied by dramatic changes in land use, water use, and nutrient regimes. The result is eutrophication – the over-enrichment of water by nutrients such as phosphorus and nitrogen (Howarth et al. 2008) – the primary acute symptoms of which are hypoxia and harmful algal blooms, which, in addition to direct toxic effects, destroy the suitability of nursery habitat for a suite of species, including Goliath Grouper. This is a ubiquitous problem in the coastal environment of south Florida's major estuarine systems (Figure 7) and of considerable concern given the global losses of some 30 to 50% of all mangrove habitat (Valiela et al. 2001; Lovelock et al. 2009; Giri 2011).

The following is a brief summary of the condition of major south Florida estuaries in terms of mangrove cover and degree of eutrophication as represented in Figure 7.

On the east coast of Florida, the Indian River Lagoon, Lake Worth, and Biscayne Bay have experienced similar losses in mangrove habitat cover (86%, 87%, and 80%, respectively) and eutrophication. The losses in the huge Indian River Lagoon are largely due to impoundment (mangrove marshes diked off from the marine environment for mosquito control) while the loss of nursery habitat for Goliath Grouper is much greater because of serious eutrophication (LaPointe et al. 2015; Barile 2018). In this poorly flushed system, eutrophication comes primarily from leaching septic tank effluents and agricultural nutrients from Lake Okeechobee overflow through the St. Lucie Canal (Figure 7). Virtually the entire Indian River Lagoon is unsuitable as nursery habitat for Goliath Grouper and probably many other fishes as well.

By comparison, losses of mangrove cover in Florida Bay are relatively small (15%; Strong and Bancroft 1994). That may say more about the poor records related to habitat loss than about lack of damaging effects. In fact, during the intense population growth of the early 20th century from Miami to the Florida Keys, many tidal passes were blocked by construction of roads. Excessive nutrient loading, water diversions, hurricanes (e.g., Katrina, Rita and Wilma) and groundwater seepage contaminated with septic effluents (LaPointe and Clark 1992; Corbett et al. 1999) led to extensive eutrophication and other water quality problems (Glibert et al. 2009). This resulted in recurring algal blooms, especially blooms of the cyanobacterium, *Synechococcus* spp., which in some cases led to significant die-offs of sponges and seagrasses in the 1980s and 1990s and more recently from 2005 through 2008 (Millette et al. 2018).

The Caloosahatchee and Port Charlotte estuaries are somewhat continuous and exhibit eutrophication patterns similar to those of other south Florida estuaries. These estuaries have undergone a general decline over the last several decades due in part to agricultural runoff and the release of overflow water from Lake Okeechobee that is routed to the Caloosahatchee Estuary via the Caloosahatchee River. In fact, Port Charlotte estuary has a significant hypoxic zone (i.e., < 2 mg L^{-1}) that approaches 90 km^2 in area in September (Turner et al. 2006). When the Lake Okeechobee water release occurs in a pulse, the salinity declines rapidly and the high nutrient loads stimulate phytoplankton blooms and periodic low dissolved oxygen — conditions that render the entire mangrove system unsuitable for juvenile Goliath Grouper.

In Sarasota Bay, much of the nitrogen input is derived from sewage (Dillon and Chanton 2008), 27% of which is in submarine groundwater entering the bay (Mwashote et al. 2013). Conditions in Sarasota Bay are unlikely to support nursery function for Goliath Grouper.

Unlike other areas in Florida, the mangrove coverage in the Ten Thousand Islands increased by 35% between 1927 and 2005 (Krauss et al. 2011) due largely to mangrove encroachment into marsh habitat as a consequence of sea-level rise and reduced freshwater input to the system. Here, relatively high densities of juvenile Goliath Grouper occur around mangrove islands, but essentially none in the eutrophic waters of some mangrove-lined rivers of that region (Koenig et al. 2007).

Over the past 100 years, Tampa Bay lost at least 44 percent of its coastal wetlands, including mangroves, salt marshes, and seagrasses. Symptoms of eutrophication became pronounced during the 1970s and early 1980s coincident with a rapid increase in human population (from about 0.5 M to 1.5 M). Eutrophication impacts were severe in Hillsborough Bay, the portion of Tampa Bay receiving the largest inputs of municipal sewage effluent (Santos and Simon 1980). However, regional management action, initiated in the 1980s, brought about a reversal in the deteriorating conditions of the bay, particularly related to seagrasses (Greening et al. 2014).

What is clear from this brief survey of the major estuarine systems of south Florida is that most of them are unsuitable as juvenile habitat for Goliath Grouper. Thus, only a small area — mostly in the Ten Thousand Islands — is available to accommodate their long estuarine phase and to support population recovery. Clearly, recruitment is severely bottlenecked by this lack of essential habitat. The most recent stock assessment (SEDAR 2016) corroborates this conclusion showing very low juvenile abundance coincident with declining adult abundance over the last 8 years (Figure 2).

A disturbing discovery by Lovelock et al (2009) provides evidence for impacts of eutrophication on the mangrove trees themselves. Although nutrient enrichment has been shown to stimulate enhanced growth in mangroves, under heavily eutrophic conditions mangroves reallocate energy from their roots to their above-ground biomass. Experimental studies conducted in a global network of sites by Lovelock et al. (2009) demonstrated that this change in investment increased mortality of mangroves during drought periods causing low humidity and high salinity in the ground water. The reduction of root biomass leads to reduced transport of water to the canopy resulting in mangrove mortality. Thus, eutrophication puts intense stress on not only the aquatic species, but on the entire estuarine community, including the emergent trees, and poses one of the more serious threats to coastal ecosystems. The reduction and control of nutrient input, thus, is one of the leading challenges to coastal communities.

Can we control nutrients in eutrophic systems? The Tampa Bay community demonstrates emphatically that we can. Indeed, they made nutrient control in a severely eutrophic system a priority, recovering water quality and seagrass habitat to historical levels recorded in the 1950s (Greening et al. 2014). This illustrates what can be accomplished with a combination of sound science, a clear plan of action with quantifiable goals, and the thorough engagement of the community and its political leaders. The same result is possible for other heavily eutrophic estuaries of south Florida and is essential to the production of the many economically and ecologically important species that are so important to Florida's economy (Whitfield 2017).

Destructive episodic events in Florida

Red Tide: 'Red tide', a dense bloom of the dinoflagellate *Karenia brevis,* produces a suite of compounds called brevetoxins that are toxic to a wide variety of marine animals within which these toxins bioaccumulate (Brand and Compton 2007). *K. brevis* occurs naturally in the Gulf of Mexico at concentrations up to around 10^3 cells L^{-1} (Tester and Steidinger 1997). Under certain conditions, dense blooms form with >10^5 cells L^{-1} — abundances that are deadly to fish and other aquatic animals. Blooms of *K. brevis* are a recurrent problem in the Gulf of Mexico, with nearly annual occurrences on the southwest Florida coast within 5 km of shore, and fewer occurrences off northwest Florida and elsewhere in the Gulf (Stumpf et al. 2003). In addition, they are much more abundant over longer periods of time now than they were in the 1950s when populations were low and occurred only in the fall. Since 1994 (and to the present), they have occurred from fall through spring. Although the factors that initiate a bloom are not clear, abundant nutrient loading in submarine ground water and in surface water runoff supports blooms of *K. brevis* and promotes their occurrence both temporally and spatially (Smith and Swarzenski 2012).

Red tide continues to be a problem in southwest Florida, taking its toll on Goliath Grouper (both juveniles and adults) and other species occupying shallow shelf habitat. The effects can be severe, as indicated by marked declines in their abundance indices (Figure 2). This past year (2018) was another very bad red tide year for southwest Florida (http://myfwc.com/REDTIDESTATUS) and although no comprehensive estimate of mortality could be made, many adult Goliath Grouper were found dead on the beaches. Indeed, then Florida Governor Rick Scott called a state of emergency for all coastal counties in southwest Florida and massive clean-up of Florida beaches occurred in its wake.

Cold temperature events: Goliath Grouper is a tropical-subtropical species and as such is intolerant of temperatures much colder than about 15° C (Sadovy and Eklund 1999). One would think that this would not be a problem in south Florida. Yet, cold-temperature events do occur, the most recent in January 2010. During that event, juvenile Goliath Grouper mortality in the Everglades National Park apparently reached over 90% (SEDAR 2016), with no recovery, even after 8 years (Figure 2). The trajectory of cold temperature events between 1930 and 2012 (Figure 8) illustrates how often temperatures were sufficiently low to have been lethal to some part of the juvenile Goliath Grouper population of south Florida. The frequency in recent decades is high enough — nearly once per decade — to severely curtail recruitment to the adult population. Cold-event kills in 2008 and 2010, combined with a major red tide event in 2005, discussed above, precipitated sharp declines in the adult population of Goliath Grouper and limited recruitment success (SEDAR 2016; Figure 2). Thus, although the Goliath Grouper population was in recovery mode starting in 1990, limited juvenile habitat and severe setbacks by red tide and cold events make full recovery uncertain.

Mercury contamination

In addition to the human health concerns associated with eating mercury-contaminated fish, there are also concerns for the fish itself. High concentrations of mercury can lead to a variety of sublethal health effects in Goliath Grouper, including lesions, altered immune system function, reduced liver function, anemia, and osmoregulatory problems (Adams and Sonne 2013; Morcillo et al. 2017, Malinowski unpublished data) – all of which likely reduce survival potential and therefore recovery for this species. Perhaps of greatest concern is the potential for adverse effects on reproductive endpoints (Crump and Trudeau 2009). For instance, when the mercury burden in female fish is transferred to their eggs, it can severely reduce survival in embryos and larvae (Jezierska et al. 2008). In Goliath Grouper, the mercury level in eggs exceeds levels producing abnormalities in other species (Munn and Short 1997, Cizdziel et al. 2003, Drevnick et al. 2008) and are among the highest recorded in wild fishes (average concentrations > 0.3 ug/g ww) (Malinowski unpublished data).

ECOTOURISM - CHANGING THE ECONOMIC PARADIGM

At the same time pressure to open the fishery grew, non-consumptive enterprises – notably the dive ecotourism industry and the catch-and-release charter fishery – took note of the growing presence of Goliath Grouper and the potential business opportunities it afforded. There are also other opportunities for scientists and educators to dispel the misinformation about Goliath Grouper and to educate the public on biodiversity and conservation of our marine and estuarine resources.

Capture-release fishery

Goliath Grouper supports an active catch-and-release charter fishing industry which brings in revenue from both coasts of Florida. The FWC permits this capture of Goliath Grouper, but the fish must be released as soon as possible unharmed without removing them from the water. There are numerous advertisements for catch and release charters on the web, for example: http://www.fishverobeachfortpierceflorida.com/goliath_grouper.php; and http://www.fisheyesportfishing.com/goliath-grouper-charters.html. Although capture-release appears to be relatively harmless to Goliath Grouper in shallow water, as the depth of capture increases so does the intensity of barotrauma (expansion of gas in the swim bladder) and the probability of mortality resulting from hemorrhage. Reduction of such injuries may be accomplished by the use of circle hooks—J-hooks should *not* be permitted for catch–release fishing. If catch–release charter fishing for Goliath Grouper is to continue in Florida, mortality estimates should be made on participating charter boats to ensure minimal impact on the population.

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Diving Ecotourism

Goliath Grouper present a unique dive experience that has captured the attention of millions of divers from around the world leading to increases in the dive-ecotourism industry in Florida (Jerald Caroll, owner Jupiter Dive Center, personal communication). Indeed, Shideler and Pierce's (2016) survey of 1537 divers found Florida divers willing to spend $100 to $200 to see and photograph a school of Goliath Grouper, whereas out-of-state divers are willing to pay around $300 for that experience. Especially lucrative for the dive industry is diving on spawning sites because the fish are abundant at that time. Although some have criticized the dive ecotourism industry for disturbing the spawning behavior of Goliath Grouper during their reproductive period, such a disturbance is unlikely because the fish spawn on dark new-moon nights from about 0100 through 0500 EST, a period when divers are unlikely to be in the water (Koenig et al. 2016).

Reports from other countries show that sustainable (non-consumptive) ecotourism can be extremely lucrative in terms of both direct and indirect revenues. For example, the revenue benefits to the Bahamas of conservation efforts begun 25 years earlier to protect sharks and rays contributed $114 million to the Bahamian economy in 2014 and attracted 19,000 divers (43% of the of all dive tourists) specifically intent on diving with sharks (Haas et al. 2017). Similarly, dive ecotourism to view sharks enriched the economy of Palau by $18 million per year (Vianna et al. 2012). The global scale of ecotourism related to elasmobranchs is quite high. The shark ecotourism industry generates around $314 million per year to the economies of some 20 countries, attracting 590,000 divers, and supporting 10,000 jobs (Cisneros-Montemayor et al. 2013). Similarly, the Manta Ray dive ecotourism industry across 23 countries brings more than $73 million annually as a direct economic impact, as well as another $140 million annually in indirect tourism expenditures (O'Malley et al. 2013). Ten countries account for almost 93% of the global revenue estimate. All of these operations advertise their ecotourism opportunities globally (e.g., whale shark dive tourism https://www.mexicowhaleshark.com/).

The ecotourism dive opportunities cited above are shared by many countries. The same opportunity could be further developed for Goliath Grouper, but *only* in Florida, as they are relatively rare elsewhere. There are between 2.7 to 3.5 million active scuba divers in the U.S. with as many as 6 million active scuba divers worldwide (Diving Equipment and Marketing Association (DEMA) estimate: https://cdn.ymaws.com/www.dema.org/resource/.../Diving%20Fast%20Facts-2013.pdf). Florida natural resource managers could pursue this enormous market by posing the question to the Florida legislature, "What are the potential revenues – direct and indirect – that would accrue to Florida's economy by continued protection of Goliath Grouper and development of an associated ecotourism industry?" The Florida Economic Development Council should connect Florida stakeholders and advocates for development of these dive ecotourism opportunities. Political leaders and resource managers must ignore the misinformation espoused by those who wish to open the fishery. As discussed above, their claims are without merit.

SUMMARY AND CONCLUSION

The Goliath Grouper population in the southeastern United States declined to near-extinction during the 1970s and 1980s. The indigenous population, fully protected since 1990, underwent a slow steady recovery to the mid-late 2000s when a severe red tide event (2005) and two cold events (2008 and 2010) in south Florida, the center of their abundance in the southeastern U.S., caused dramatic declines in the population (Figure 2). Another intense red tide event that occurred in 2018 will undoubtedly be shown to have caused further decline.

Juvenile Goliath Grouper production depends on red mangrove habitat that has continuously high water-quality to accommodate their long (5 to 6 year) estuarine sojourn before joining the adult population. Mangrove forests of south Florida have changed significantly from what they were 100 years ago when the Goliath Grouper population flourished. Now, mangrove habitat and water quality are seriously compromised, ultimately because of the dramatic increase in the human population of south Florida and attendant problems with eutrophication and direct destruction of mangroves (Figure 7). Add to this the lethal effects of episodic cold and red tide events that not only stopped, but reversed recovery (Figure 2), making the possibility of a fishery even more remote.

Another serious issue that effectively takes Goliath Grouper off the list of possible fishery species is the very high levels of methylmercury in the edible parts of the fish. If a recreational fishery were allowed, it would put at risk those who consumed the flesh. This is an unacceptable risk for everyone, but especially to developing young people because of the potential for irreversible damage to their brains.

All over the world, fishery resources are being depleted at an alarming rate (Pauly 2008, Pinnegar et al. 2008, Pauly and Zeller 2016). Even though there are efforts to recover these overfished populations (Worm et al. 2009) the prognosis remains gloomy. Floridians have a truly unique situation – Goliath Grouper are present in Florida waters after having undergone partial and erratic recovery, but are rare throughout the rest of their range. The only location where divers can reliably and consistently dive with schools of Goliath Grouper year-round is in Florida while opportunities in other countries, say for whale sharks, are seasonal. Developing a diving ecotourism industry with a targeted international advertising campaign related to Goliath Grouper could attract millions of divers and considerable direct and indirect revenues to Florida from all over the world.

We propose that resource managers, who typically assess fish populations for extractive purposes, simply change the paradigm for Goliath Grouper from a fishery resource to a non-extractive resource with a commercial value vastly greater than that gained through fishing. This species, which is essentially inedible because of high methylmercury levels, is a potential boon to Florida's economy and should join the ranks of marine turtles and marine mammals in being fully protected in perpetuity. Goliath Grouper is like a valuable diamond in the hands of Florida politicians and resource managers — it would be exceedingly foolish on many levels to treat this diamond as just another lump of coal.

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Table 1. Body muscle burdens of total mercury (Hg) in the protected Atlantic Goliath Grouper*Epinephelus itajara* and in commercially important groupers of the southeastern United States. GOM = Gulf of Mexico, ATL = Atlantic.

Species	Location	Mean total length (cm)	Mean Hg(µg/g)	Min Hg (µg/g)	Max Hg (µg/g)
Atl. Goliath Grouper	ATL/GOM	172.0	1.11	0.21	7.60
Black Grouper	GOM	84.0	0.91	0.26	1.60
Gag Grouper	GOM	67.6	0.4	0.13	1.06
Scamp	GOM	53.3	0.24	0.07	0.59
Red Grouper	GOM	42.9	0.17	0.03	0.79
Snowy Grouper	GOM	88.9	0.20	0.04	0.57

Data sources: Adams et al. 2003, Tremain & Adams 2012, Malinowski 2019.

Table 2. Body muscle burdens of total mercury in the protected Atlantic Goliath Grouper, *Epinephelus itajara,* populations along the Atlantic and Gulf of Mexico coasts of Florida, and fish species rated as having the "highest mercury" by the U. S. Food and Drug Administration, the Environmental Protection Agency, the Natural Resources Defense Council, and Florida Department of Health. GOM = Gulf of Mexico, ATL = Atlantic.

Species	Location	Mean Hg (µg/g)	Min Hg (µg/g)	Max Hg (µg/g)	N	Federal and State advisory
Atl. Goliath Grouper	ATL	1.28	0.25	7.60	117	none
Atl. Goliath Grouper	GOM	0.94	0.21	2.10	30	none
Tilefish	GOM	1.12	0.65	3.73	60	Do not eat
Swordfish	ATL	0.99	NA	3.22	636	Do not eat
Shark	ATL+GOM	0.98	NA	4.54	356	Do not eat
King Mackerel	ATL+GOM	0.73	0.23	1.67	213	Do not eat
Bigeye Tuna	ATL+GOM	0.69	0.13	1.82	21	Do not eat

Data sources: Malinowski 2019; FDA website: https://www.fda.gov/Food/FoodborneIllnessContaminants/Metals/ucm115644.htm

FIGURE CAPTIONS

Figure 1. Spawning aggregation of Atlantic Goliath Grouper, *Epinephelus itajara*, on a shipwreck off Palm Beach County, Florida, USA. Photo credit: Walt Stearns (www.waltstearns.com).

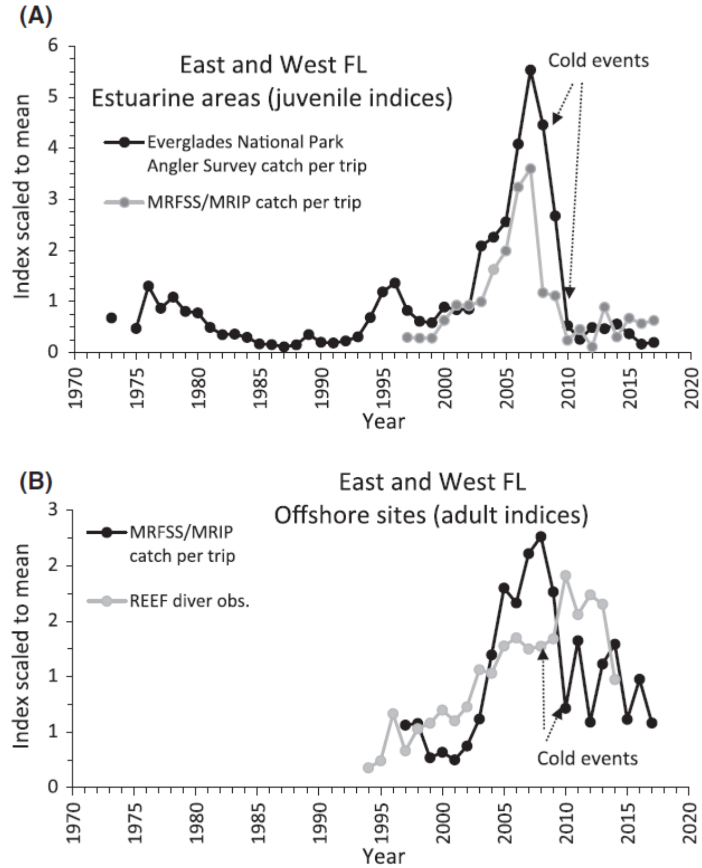

Figure 2. Standardized relative indices of abundance of (A) juvenile and (B) adult Atlantic Goliath Grouper, *Epinephelus itajara,* in estuaries of southeast and southwest Florida, USA. Source: SEDAR 2016; update through 2017 from Joe O'Hop, senior author of SEDAR 2016, Fish and Wildlife Research Institute (FWRI), St. Petersburg, FL. REEF = Reef Environmental Education Foundation (https://www.reef.org/) and MRFSS/MRIP = Marine Recreational Fisheries Statistics Survey/Marine Recreational Information Program (https://www.fisheries.noaa.gov).

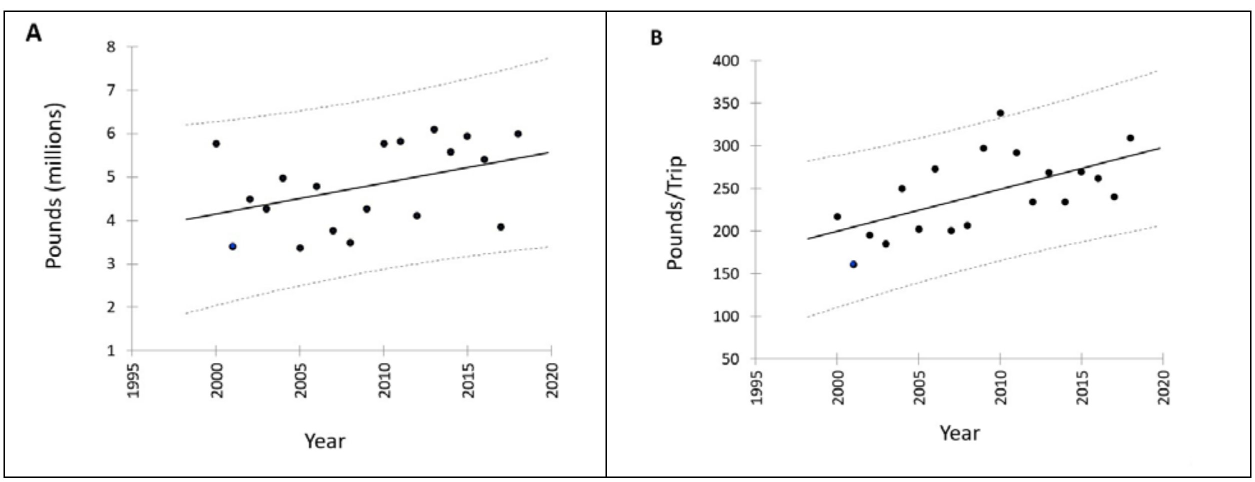

Figure 3. Regression of Spiny Lobster *Panulirus argus* catch in Florida per year from 2000 – 2018, a period of Atlantic Goliath Grouper *Epinephelus itajara* population increase in Florida. (A) Millions of pounds caught per year, Pounds = -137,401,032.1+70778.1*Year (R^2 = 0.17, P = 0.09). (B) Pounds caught per trip = -9683.8+4.9*Year (R2 = 0.354, P < 0.007). Dashed lines, 95% confidence limits. Source: https://public.myfwc.com/FWRI/PFDM/ReportCreator.aspx.

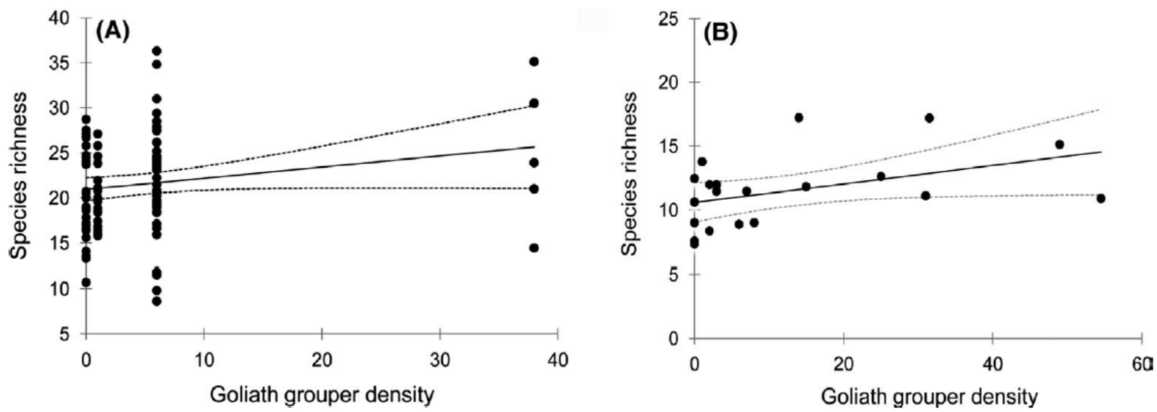

Figure 4. Regression of fish species richness vs. site density of the Atlantic Goliath Grouper, *Epinephelus itajara*, on high-relief reefs surveyed in 2006 – 2008 in Florida. (A) Survey data from the Reef Environmental Education Foundation (REEF), $Y = 20.9 + 0.12*X$ ($R^2 = 0.04$, P = 0.07). (B) Survey data from Florida State University, $Y = 10.57 + 0.007*X$ ($R^2 = 0.19$, P = 0.06). Dashed lines, 95% confidence limits. Source: Koenig et al. (2011).

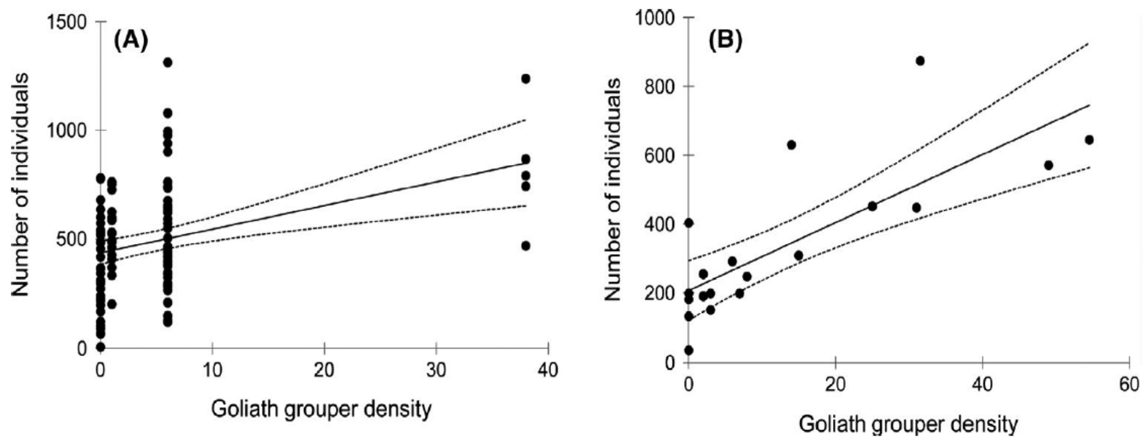

Figure 5. Regression of fish abundance vs. Atlantic Goliath Grouper, *Epinephelus itajara*, density on high-relief reefs surveyed in 2006 – 2008 in Florida. (A) Survey data from the Reef Environmental Education Foundation (REEF), $Y = 436.2 + 10.87*X$ ($R^2 = 0.12$, $P < 0.001$). (B) Survey data from Florida State University, $Y = 206.8 + 9.88*X$ ($R^2 = 0.60$, $P < 0.0001$). Dashed lines, 95% confidence limits. Source: Koenig et al. (2011).

Figure 6. An example of a mass of fishing tackle lodged in the throat of a captured Atlantic Goliath Grouper, *Epinephelus itajara*. Image on right shows Chris Malinowski holding the removed mass of tackle. Occurrences of fishing tackle were about 12% indicating targeting of bait or hooked fish by Goliath Grouper. Source: Koenig and Coleman (2016). Photo credit: Jess Cusick

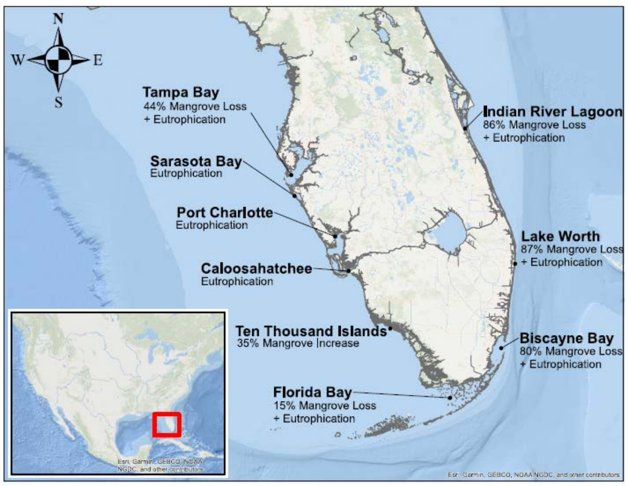

Figure 7. Map of mangrove habitat condition and water quality in major estuarine areas of south Florida.

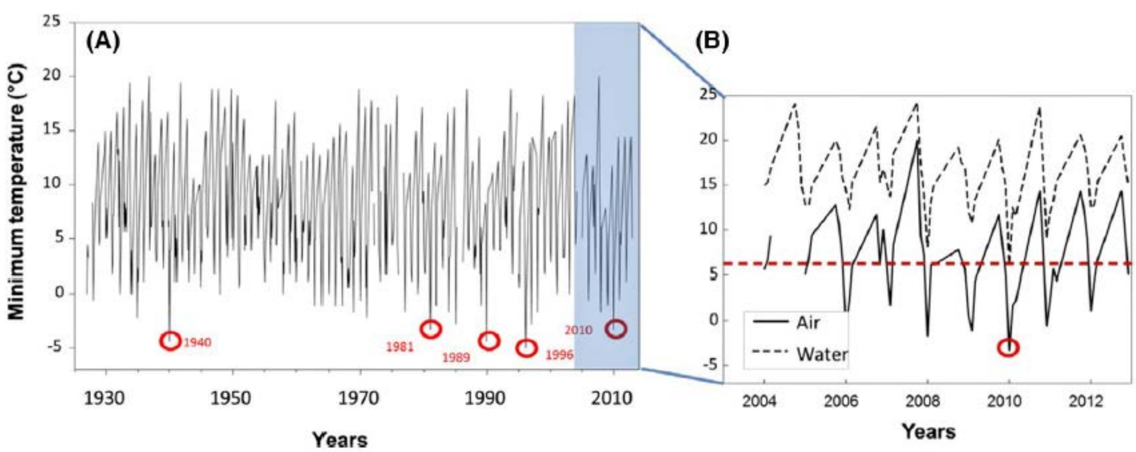

Figure 8. (A) Frequency of historical cold events in south Florida (circled bottom peaks). (B) An expanded view from 2004 to 2012 shows the most recent cold events of 2008 and 2010. The dashed line represents 6 °C water temperature. Source: Comprehensive Everglades Restoration Plan (CERP). http://141.232.10.32/pm/ssr_2014/ssr_cold_event_2014.aspx.