Should the Critically Endangered Goliath grouper *Epinephelus itajara* be culled in Florida?

SARAH FRIAS-TORRES

Abstract The Goliath grouper *Epinephelus itajara* has been protected in the USA since 1990. In Florida commercial and recreational fishers consider the species a top predator of fish and lobster and advocate culling the grouper population as a solution to recover declining stocks. I examined the scientific evidence for and against culling the Goliath grouper, using commercial landing data from the National Marine Fisheries Service and the Florida Fish and Wildlife Conservation Commission (1950–2010), fisheries-independent diver-based surveys from the REEF Environmental Education Foundation (1993–2007), and published dietary and morphological studies. An analysis of the commercial extinction of the Goliath grouper in Florida indicates that its recovering population is not the cause of declining fish and lobster stocks. The recovering Goliath grouper population could provide ecological and socio-economic benefits: as top-down control on other lobster predators, in ecotourism, and as potential biocontrol of the invasive Indo-Pacific red lionfish *Pterois volitans* on Atlantic reefs.

Keywords Culling, *Epinephelus itajara*, Florida, Goliath grouper, *Lutjanus griseus*, marine megafauna, *Panulirus argus*, *Pterois volitans*

Introduction

The recovery of endangered marine megafauna faces several challenges, including inadequate scientific knowledge. Social perceptions of the impacts of such species on humans, arising from deeply-held attitudes mostly derived from myths, history and greed, often overrule fact-based science (Caro, 1998). For example, Steven Spielberg's 1975 film *Jaws*, based on Peter Benchley's novel, exploited the fear of being eaten alive by sharks. The film's negative effect on shark conservation efforts continues to this day, even after scientific studies show the extreme rarity of humans succumbing to a shark attack (Dudley & Cliff, 2010). Because of overfishing, populations of large predatory sharks are now only c. 10% of pre-industrial levels (Myers & Worm, 2003).

Culling (i.e. selective hunting or fishing) to reduce populations of ocean predators has been proposed as a means to overcome depleted fisheries, with the expectation of increasing fishery yields. This is a recurring argument mostly focused on any species of marine megafauna currently recovering from near extinction, even when there is evidence that fisheries remove far more fish than ocean predators (as seen for whales; Gerber et al., 2009, Cape fur seals *Arctocephalus pusillus*; Punt & Butterworth, 1995 and New Zealand fur seals *Arctocephalus forsteri*; Lalas & Bradshaw, 2001). The consequences of culling are unpredictable (Scheffer et al., 2001) and it has not been demonstrated that the culling of high-order ocean predators improves fishery yields (Yodzis, 2001; Heithaus et al., 2008; Morissette et al., 2012).

Large-bodied grouper fish (genus *Epinephelus, Mycteroperca* and *Plectropomus*) are representatives of the abundant marine megafauna that once inhabited tropical and subtropical seas for thousands of years (Jackson, 2001). Their characteristic breeding behaviour, including the formation of annual predictable spawning aggregations of several hundreds or thousands of individuals, has contributed to the misconception of endless abundance, resulting in chronic overfishing and local extinction (Sadovy et al., 2008). The Goliath grouper *Epinephelus itajara* (Serranidae), the largest grouper in the Atlantic Ocean (2.5 m record total length and 450 kg record weight), is extremely vulnerable to overfishing because of its slow growth, long life (possibly >4 decades), late sexual maturity (up to 8 years), strong site fidelity and formation of spawning aggregations. Juveniles (up to 1.20 m total length) inhabit fringing red mangrove *Rhizophora mangle* shorelines and adults inhabit coral reefs, isolated patch reefs, reef/rock ledges and artificial structures (Sadovy & Eklund, 1999; Frias-Torres, 2006). The IUCN Red List categorizes the Goliath grouper as Critically Endangered throughout its entire range in the tropical and subtropical Atlantic Ocean (Craig, 2011). The species has been protected from fishing in USA waters since 1990, after commercial extinction was documented in the late 1980s (Sadovy & Eklund, 1999). Recent studies suggest a trend towards recovery in the number of juveniles of the Florida Goliath grouper population (Frias-Torres, 2006) and the return of adult Goliath groupers to certain reef locations and spawning aggregation sites (Koenig & Coleman, 2010; Plate 1). However, there is no scientific evidence indicating that the adult population of the Goliath grouper has fully recovered to the levels prior to commercial extinction.

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PLATE 1 Previously extinct Goliath grouper *Epinephelus itajara* spawning aggregation re-forming off Jupiter, Florida, USA, after 22 years of federal and state moratorium on harvest. Photograph by Walt Stearns.

In Florida a powerful lobby of recreational and commercial fishers advocates the culling or 'thinning out' of the Goliath grouper population as a solution to recover fish and lobster stocks and to increase fishery yields. Each encounter with an individual Goliath grouper at sites previously vacant since the commercial extinction occurred is perceived as a population recovery. Hence, fishers perceive the recovery of the Goliath grouper population as of greater magnitude than that shown by scientific studies, and they view such recovery as the main cause for declining catches of other fisheries targets because, due to its size, the species is considered a top predator of Caribbean spiny lobster *Panulirus argus*, grey snapper *Lutjanus griseus* and several other snapper and grouper species. This is an example of the 'shifting baselines syndrome' (Pauly, 1995) whereby fishers accept reduced abundance and size information from recent periods as baselines, resulting in inappropriate reference points for evaluating overfishing and the disappearance of large fish.

Such perceptions, and requests for culling the Goliath grouper, based on the perception that it is the only species responsible for lobster and snapper declines, are repeatedly stated by anglers and spear-fishers (Fleshler, 2011; Kelly, 2011) and at stakeholder meetings of the Florida Fish and Wildlife Conservation Commission (FWC, 2010, 2011). In a study conducted in south Florida (Harrington et al., 2009) of 167 dive and fishing charters, 45% of the businesses considered the increasing Goliath grouper population had a negative impact on the habitats in which their charters operate. Twenty four percent suggested a positive effect, and the remaining 30% either had no opinion or thought the groupers had no effect. When separated by sectors, 46% of fishers thought Goliath groupers were detrimental to the marine ecosystems, 37% of divers considered the groupers had a positive effect, and most spear-fishers had no opinion or thought the groupers had no effect. In 2010 Florida's spiny lobster and grey snapper commercial landings generated an estimated USD 35.5 million and USD 0.5 million in direct revenues, respectively (FWC, 2012). Recreational fishing in Florida regularly supports a multi-billion dollar industry (Johns et al., 2001). Therefore, any potential threats to the lucrative lobster and snapper fishery require detailed investigation.

In population ecology theory the classic Lotka–Volterra predation model predicts oscillations between predator and prey populations in a periodic cycle (Lotka, 1925; Volterra, 1926). Testing hypotheses in predator–prey dynamics often involves the experimental removal of the major predator in the system to measure the response of the prey population. The commercial extinction event of the Goliath grouper in Florida provides a unique opportunity to test predatory effects on spiny lobster and grey snapper. In the food webs proposed by fishers, social perceptions follow a simplification of the Lotka–Volterra predation model (Fig. 1).

Here I examine the scientific evidence for and against culling the Goliath grouper based on the fishers' assertion that fish and lobster stocks in Florida are negatively affected

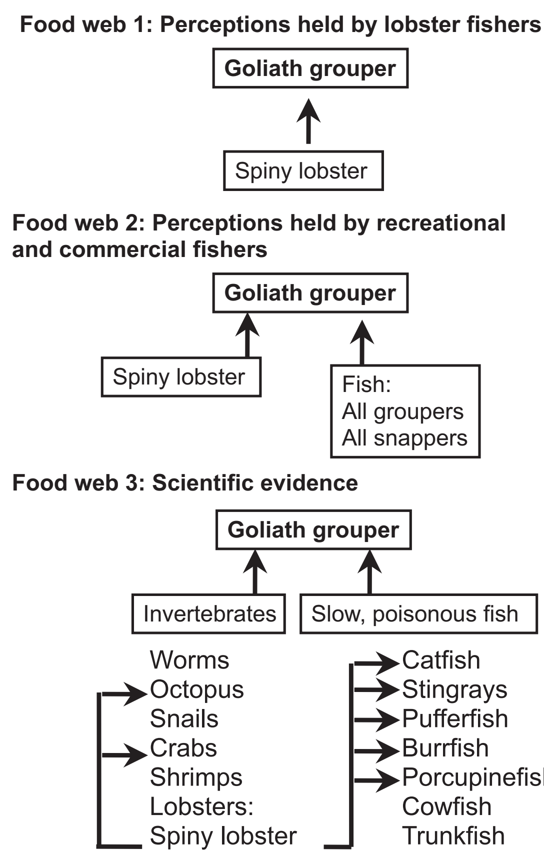

FIG. 1 Goliath grouper *Epinephelus itajara* food webs: (1) from common perceptions held by lobster fishers, (2) from common perceptions held by recreational and commercial fishers, and (3) from scientific evidence based on isotope analysis, dentition and studies of stomach content (see text for references) and the conclusions of this study. Predators of the Caribbean spiny lobster *Panulirus argus*, which are eaten by the Goliath grouper, are also indicated. Arrows flow from prey to predator.

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by the grouper's recovering population. Although a detailed quantitative study of fishers' perceptions is beyond the scope of this article, their general assertions can be used in hypothesis testing. If the fishers' food webs in Fig. 1 are correct, the extinction event of the Goliath grouper should have increased the population and commercial catches of their target prey (lobsters, groupers and snappers), the stomach contents of Goliath groupers should contain predominantly their target prey, and in the case of food web 2, Goliath grouper dentition should include canine teeth typical of a piscivorous fish.

Methods

To examine the relationship between Goliath grouper, spiny lobster and grey snapper abundance I used NOAA's National Marine Fisheries Service (NMFS) database for commercial landings (NMFS, 2012), and Florida Fish and Wildlife Conservation Commission's data on fishing effort (FWC, 2012). Commercial landing data included the period 1950–1990 (the onset of the harvest moratorium) for the Goliath grouper and 1950–2010 (the most recent data available) for spiny lobster and grey snapper. Where necessary data were changed to metric units. The catch per unit effort (CPUE) was obtained by dividing the total annual catch (in kg) by the number of trips reported each year. The number of trips was only available after 1986. However, I used the period 1990–2010 for CPUE analysis, as it coincides with the onset (1990) and duration of the moratorium on harvest of the Goliath grouper.

To examine the relationship between Goliath grouper and grey snapper abundance after the 1990 moratorium in Florida I used 25,995 fisheries-independent diver-based surveys carried out by REEF Environmental Education Foundation trained volunteers (REEF, 2012) between 1993 and 2007 (the most recent data available). The REEF database includes a density index and a percentage sighting frequency. The density index is recorded as a ranked variable with values of 1 (= 1 fish), 2 (= 2–10 fish), 3 (= 11–100 fish) or 4 (> 100 fish). The original fish counts for values 2, 3 and 4 are unknown. Density is considered high at ≥ 3, and low at values < 3. The percentage sighting frequency indicates the percentage of times out of all surveys a species was recorded. At values of $\geq 50\%$ a species is often observed. At values $< 50\%$ a species is rarely observed. A relative measure of species abundance is obtained by multiplying the density index by the percentage sighting frequency. The REEF database does not include invertebrate counts. Parametric correlations, linear regression analysis and non-parametric Spearman's rank correlation coefficients were used as appropriate (Sokal & Rohlf, 1995). Statistical analyses were performed using *Statistica v. 6.0* (StatSoft Inc., Tulsa, USA). Differences were considered statistically significant at $P < 0.05$.

Results

For the Goliath grouper the curve of commercial landing data over time can be used as a proxy for the species-specific extinction curve because declining landings reflect a population shrinking towards commercial extinction. During 1977–1990 correlations for Goliath grouper–spiny lobster landings ($r = 0.006$, $P = 0.98$), and Goliath grouper–grey snapper landings ($r = 0.477$, $P = 0.08$; Fig. 2) were not statistically significant.

During 1950–2010 commercial catches for spiny lobster and grey snapper peaked in 1972 and 1983, respectively. After the peak, linear regressions of catches show a statistically significant decrease for both spiny lobster ($\beta = 0.63$, $r^2 = 0.40$, $F_{1,37} = 24.42$, $P = 0.000$; Fig. 3a) and grey snapper ($\beta = 0.92$, $r^2 = 0.84$, $F_{1,26} = 134.92$, $P = 0.000$; Fig. 4a). Linear regressions of fishing effort, as total number of trips, for 1986–2010 show a statistically significant decrease for both spiny lobster ($\beta = 0.90$, $r^2 = 0.81$, $F_{1,23} = 94.9$, $P = 0.000$; Fig. 3b) and grey snapper ($\beta = 0.96$, $r^2 = 0.93$, $F_{1,23} = 309.6$, $P = 0.000$; Fig. 4b). Linear regressions of CPUE beginning with the onset of the 1990 moratorium on fishing for Goliath groupers show a statistically significant increase for both spiny lobster ($\beta = 0.65$, $r^2 = 0.42$, $F_{1,19} = 13.78$, $P = 0.0015$) and grey snapper ($\beta = 0.93$, $r^2 = 0.86$, $F_{1,19} = 118.45$, $P = 0.000$; Fig. 5).

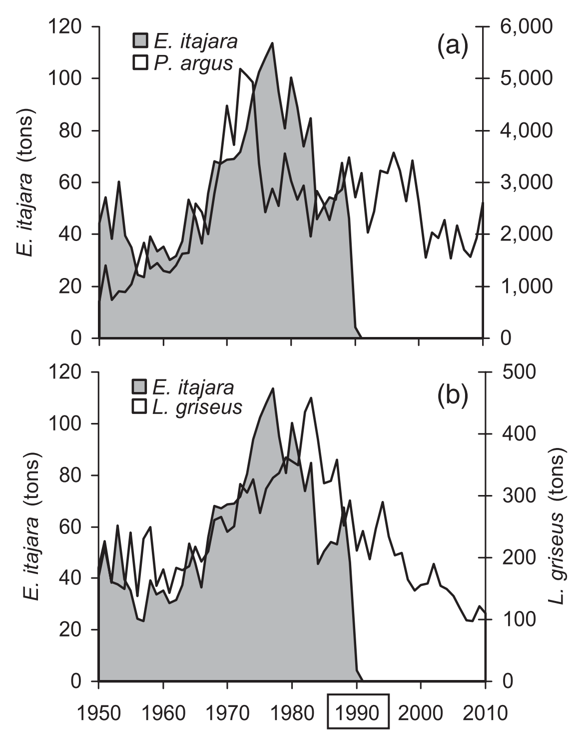

Fig. 2 Time series (1950–2010) of commercial landings in Florida of (a) Caribbean spiny lobster *P. argus*, and (b) grey snapper *L. griseus*, compared to the extinction curve of Goliath grouper *E. itajara*. The moratorium on fishing *E. itajara* began in 1990.

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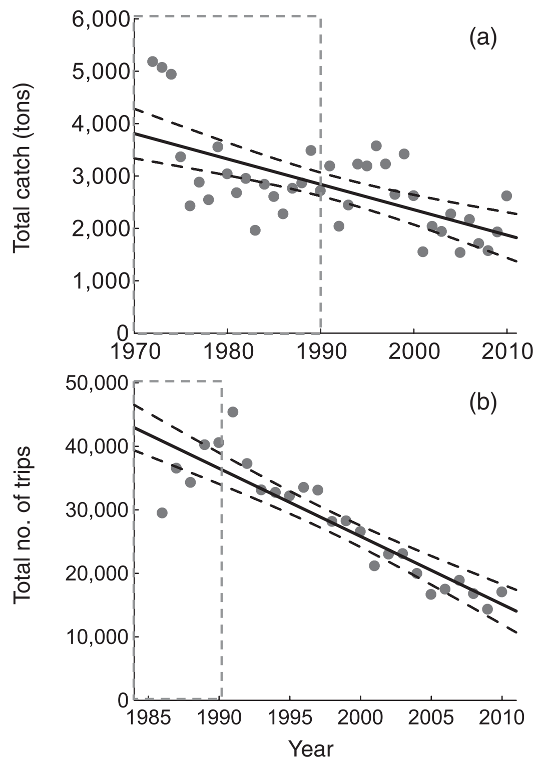

FIG. 3 Trends of commercial fishing effort for Caribbean spiny lobster in Florida since the start of the Goliath grouper extinction event in 1970: (a) total catch during 1972–2010, and (b) total number of trips during 1986–2010. All linear regressions are negative and statistically significant (see text for details). Dotted lines are 95% confidence intervals. The dashed-line rectangles indicate the Goliath grouper extinction period.

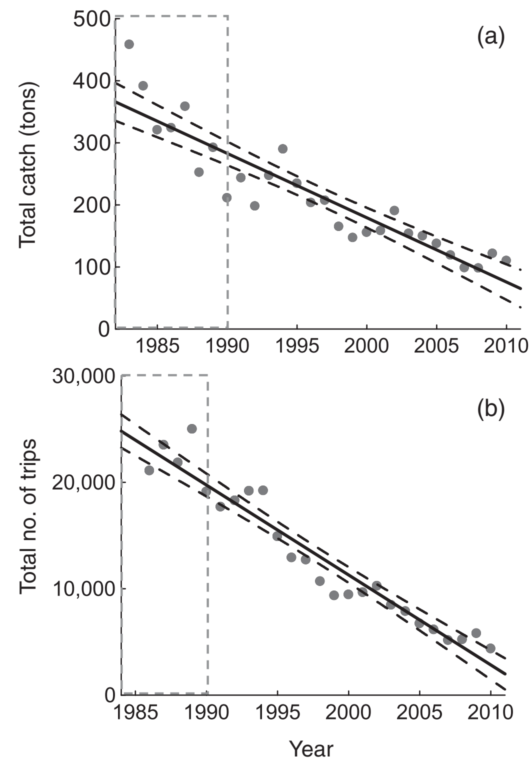

FIG. 4 Trends of commercial fishing effort for grey snapper in Florida since the start of the Goliath grouper extinction event in 1970: (a) total catch during 1983–2010, and (b) total number of trips during 1986–2010. All linear regressions are negative and statistically significant (see text for details). Dotted lines are 95% confidence intervals. The dashed-line rectangles indicate the Goliath grouper extinction period.

For 1993–2007 REEF diver surveys indicate Goliath grouper abundance in the reefs of Florida remained low: the density index increased from 0 in 1993 to 1.4 in 2007 and the percentage sighting frequency remained $< 8\%$. The Goliath grouper is categorized as 'low density–rarely observed' (Fig. 6a). For grey snapper the density index varied between 2.4 and 2.7 and the percentage sighting frequency fluctuated around 50%, from 68% in 1993 to 44.7% in 2007. The grey snapper is categorized as 'low density–often observed' (Fig. 6a). The correlation between Goliath grouper and grey snapper abundance (as density multiplied by percentage sighting frequency) is not statistically significant (Spearman's rank correlation, $r = 0.182$, $P = 0.515$; Fig. 6b).

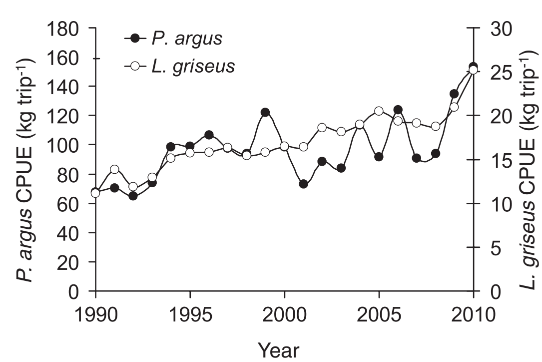

FIG. 5 Time series (1990–2010) of commercial catch per unit effort (CPUE, kg trip^{-1}) in Florida for Caribbean spiny lobster *P. argus* and grey snapper *L. griseus*. The increases are statistically significant in both cases (see text for details).

Discussion

Historical ecology research shows that marine megafauna species such as the Goliath grouper, together with whales, manatees, the sea cow *Trichechus manatus,* dugong *Dugong dugon*, Caribbean monk seal *Monachus tropicalis*, marine turtles, crocodiles, Atlantic codfish *Gadus morhua*, swordfish *Xiphias gladius*, sharks and rays are now functionally or entirely extinct in most coastal ecosystems (Jackson et al., 2001). The earliest European explorers of the Caribbean described the abundance of large-bodied grouper species and native fisheries (Jackson, 2001). In the Florida Keys historical photographs of Goliath groupers as trophy fish and newspaper accounts of landings since 1923 show that inshore depletion of the largest Goliath grouper

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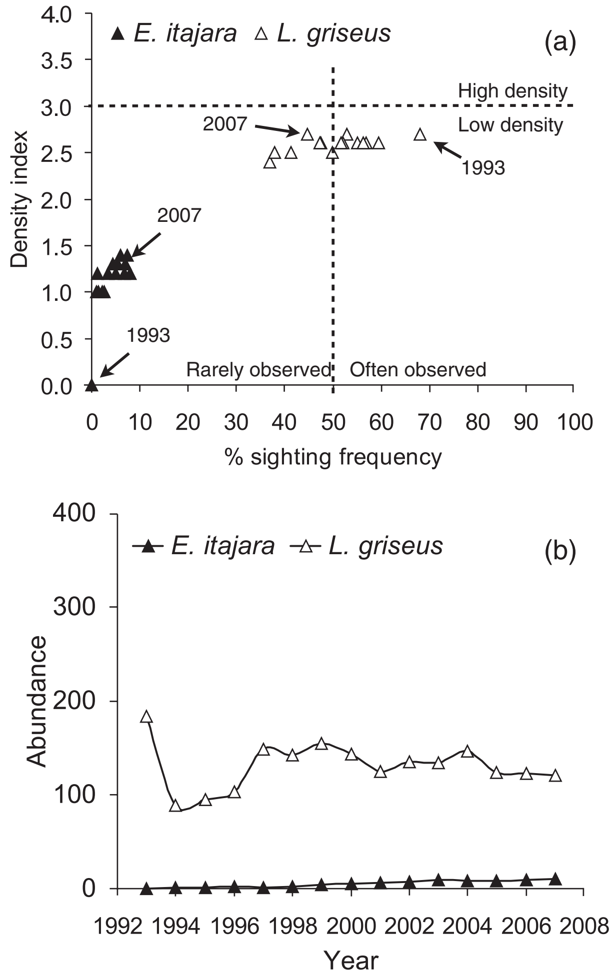

FIG. 6 Trends of Goliath grouper *E. itajara* and grey snapper *L. griseus* abundance in Florida between 1993 and 2007 based on the REEF database: (a) plot of density index versus percentage sighting frequency, indicating the start and end of the time period for each species, and (b) time series of abundance (as density multiplied by percentage sighting frequency).

individuals was occurring by 1950 (McClenachan, 2009). The final decline occurred in the mid 1970s, when fishers began to target the spawning aggregations systematically (DeMaria, 1996) until the fishery, and the population, collapsed in the late 1980s.

The analyses shown here demonstrate that the Goliath grouper commercial extinction event (1970–1990) did not result in an increase of Caribbean spiny lobster or grey snapper commercial landings in Florida (Figs 2–4). When the analyses are extended beyond 1990 (Figs 3–5), the onset of the harvest moratorium for the Goliath grouper, commercial landings of spiny lobster and grey snapper reflect increasing fishing pressure, and REEF fisheries, independent diver-based surveys (Fig. 6) show there is no correlation between Goliath grouper and grey snapper abundance in Florida's reefs. If food webs 1 and 2 proposed in Fig. 1 are correct the correlations in Fig. 2 would be negative and the regressions in Figs 3 and 4 would be positive. Although there are inherent limitations to each analysis they strongly suggest that the Goliath grouper is not a top predator of lobster and snapper. Morphological, diet and isotope studies provide additional support.

The poor development of the canine teeth of the Goliath grouper reflects a generalist (polyphage) diet (Smith, 1971). Studies on stomach contents (Bullock & Smith, 1991; Sadovy & Eklund, 1999) reveal that the diet includes invertebrates, mostly shrimp and crabs, but also octopus, worms, gastropods, lobsters and slow-moving poisonous fish (catfish, Ariidae; stingrays, Dasyatidae; cowfish and trunkfish, Ostraciidae; burrfish and porcupinefish, Diodontidae; pufferfish, Tetraodontidae). In addition to feeding on spiny lobster as part of a diverse diet, the Goliath grouper feeds on species identified as predators of spiny lobster by Randall (1967) and Mintz et al. (1994): octopus, crabs, catfish, stingrays, pufferfish, burrfish and porcupinefish (Fig. 1). Food web dynamics, based on carbon and stable nitrogen isotope analyses of the Goliath grouper confirm the diet preferences (invertebrates and poisonous slow-moving fish) obtained through studies of dentition and stomach content. The isotope analyses indicated a broad prey base with a relatively high trophic status (Evers et al., 2009) but not to the level of a top predatory fish. Thus, all the scientific evidence indicates that the Goliath grouper has a more diverse diet than that proposed by social perceptions (Fig. 1).

Commercial fishing effort in Florida (as total catch and number of trips) declined during and after the Goliath grouper extinction event. After commercial catches peaked for spiny lobster (in 1972) and grey snapper (in 1983), the persistence and increase of CPUE values while catches and fishing effort decreased (Figs 3–5) suggest a condition known as hyperstability, where fish or fishers' behaviour results in stable or increasing CPUE even as fish abundance declines, until the stock starts to collapse (Hilborn & Walters, 1992). Two major regulations, the 1990 ban on gill-nets (Burton, 2001) and the 1992 Trap Reduction Program, which reduced the use of sub-legal sized spiny lobster to bait traps in the commercial fishery (Muller et al., 2000), did not significantly affect the trends observed. The pressure from recreational fisheries must be considered.

Marine recreational fishing activity in Florida has almost doubled over the past 2 decades, from 15–20 million individual trips in the early 1980s to 25–30 million trips in the early 2000s (Ault et al., 2003). Recreational landings estimated for the 2-day sport season lobster fishery in late July and for the period between 6 August and Labor Day (the first Monday in September), indicate that from 1987 to 2000 mean recreational landings were $23.7 \pm$ SE 0.95% of commercial landings in the Florida Keys. This amount should be added to ascertain the total fishing pressure on the spiny lobster (Muller et al., 2000). In the Florida Keys, where grey snapper stocks are overfished, the recreational fishery is the principal fleet targeting grey snapper and other reef-fish species. Here, reef fish populations have declined in recent decades because of a combination of human-related stressors, such as overfishing, and habitat degradation (Ault et al., 2005). Recreational landings in the continental USA, including catch-and-release, seriously affect many of the most valued overfished species, sometimes rivalling or even replacing commercial fisheries (Coleman et al., 2004).

Based on the evidence presented here the recovering trends of the Goliath grouper are not directly responsible for declining commercial landings of spiny lobster and grey snapper. The most likely cause is commercial and recreational overfishing.

Should the Goliath grouper be culled in Florida?

A potential reopening of the Goliath grouper fishery in Florida for culling purposes raises ecological, socio-economic and ethical concerns. For example, non-human predators of spiny lobster are numerous and diverse, consisting of at least 26 different species, including invertebrates, elasmobranchs, teleost fish, reptiles and marine mammals (Mintz et al., 1994; DeLoach, 1999). If preying on spiny lobster is a justification for culling Goliath groupers then we would also need to cull a diverse and significant group of Florida's marine fauna. The rationale for culling the recovering Goliath grouper population as the solution to depleted or decreasing fisheries is questionable because of documented overfishing in Florida, the evidence presented here and the unpredictable consequences of culling a species that has proven extremely vulnerable to overfishing and is slow to recover.

A substantial recovery of the Goliath grouper population could result in three main socio-economic and ecological benefits that require further investigation. Firstly, the Goliath grouper feeds on a number of species identified as predators of the spiny lobster (Fig. 1; Mintz et al., 1994; Randall, 1967). Because of the complexity of trophic cascading effects (Pace et al., 1999) restoring the Goliath grouper population in Florida could result in a top-down control of lobster predators, possibly making more lobsters available to the fisheries. This requires further investigation.

Secondly, the Goliath grouper's enormous size, site attachment (resulting in reliable encounters), formation of spawning aggregations and curiosity towards divers (Sadovy & Eklund, 1999) makes it a major attraction for SCUBA diving ecotourism. Grouper–diver encounter operations have already been initiated in the Florida Keys and in parts of east Florida, where previously extinct spawning aggregations are forming again (Plate 1). Diving ecotourism as an alternative to overfishing provides more value to local economies. For example, global shark-based ecotourism operations provide large economic values, in some cases up to 30% of annual GDP, which benefit from the long lifespan of many shark species (Gallagher & Hammerschlag, 2011). In Belize dive ecotourism targeting spawning aggregations of the snapper–grouper complex can generate 20 times the income produced from fishing the aggregations (Sala et al., 2001). Small groups of properly trained divers seem to have little impact on the normal behaviour of even the most timid aggregating fish (Heyman et al., 2010). The charismatic long-lived Goliath grouper could benefit from dive ecotourism as a sustainable alternative to overfishing and dive ecotourism could become a key strategy to ensure the conservation of the species. Socio-economic valuations of how such ecotourism could benefit local communities, and studies to quantify what levels of diver ecotourism pressure alter normal spawning aggregation behaviour in the Goliath grouper require further investigation.

Thirdly, the Goliath grouper could provide biocontrol of invasive Indo-Pacific red lionfish (*Pterois volitans/Pterois miles*, Scorpaenidae). The venom-spined piscivorous lionfish, introduced to Florida waters in the early 1990s, has invaded the USA eastern seaboard, Florida, the Gulf of Mexico and the Caribbean. A voracious predator of native juvenile reef fishes and invertebrates, the lionfish population has the potential to act synergistically with other existing stressors, such as climate change, overfishing and pollution, making this invasion of particular concern for the future of Atlantic coral reefs (Albins & Hixon, 2008). The Goliath grouper exploits a unique niche, feeding on invertebrates and venomous fish. Venom is common in the fish fraction of the Goliath grouper's diet: skin-secreted toxins of Ostraciidae (cowfish, trunkfish), Diodontidae (porcupinefish, burrfish) and Tetraodontidae (pufferfish; Malpezzi et al., 1997), and venom-charged spines of Dasyatidae (stingrays) and Ariidae (catfish; Haddad & Martins, 2006; Sivan, 2009). Thus, the Goliath grouper's adaptation to feeding on poisonous and venom-spined fish could potentially serve as a natural biocontrol for invasive lionfish. However, predation by the Goliath grouper on *P. volitans/P. miles* has not yet been documented, and non-lethal studies of the stomach contents of the Goliath grouper in the current *P. volitans/P. miles* invasion are still underway. The potential of other large-bodied groupers (Nassau *Epinephelus striatus*; tiger *Mycteroperca tigris*; black *Mycteroperca bonaci*; yellowfin *Mycteroperca venenosa* and yellowmouth *Mycteroperca interstiticialis*) as natural biocontrol of invasive lionfish has been demonstrated: when comparing lionfish abundance in marine reserves (where large-bodied groupers eating lionfish are present) vs unprotected sites (where large-bodied groupers are overfished or extinct) in the Caribbean, lionfish biomass exhibited a 7-fold and non-linear reduction in relation to the biomass of groupers (Mumby et al., 2011).

In conclusion, the recovering population of the Goliath grouper in Florida is not the cause of declining lobster and

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fish stocks in the region. Instead, overfishing is the main cause. The Goliath grouper could provide ecological and socio-economic benefits as top-down control on lobster predators, in ecotourism, and as a potential biocontrol agent for invasive lionfishes. Culling the Goliath grouper is not supported by the scientific evidence and continued protection of the species is required.

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