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REPORT

Historical and contemporary evidence of a mutton snapper (*Lutjanus analis* Cuvier, 1828) spawning aggregation fishery in decline

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Abstract Scientific information on reef fish spawning aggregation fisheries is sparse in light of numerous regional declines and extirpations from overexploitation. Fisher interviews of the small-scale commercial mutton snapper (*Lutjanus analis*) spawning aggregation fishery at Gladden Spit, Belize, suggests a historic decadal decline. The reported trend is supported by analysis of inter-seasonal catch and effort and yield (2000–2002) that reveals a 59% decline in catch per unit effort (CPUE) and a 22% decrease in mean landings per boat. Declining population-level trends are also supported by a significant decrease in inter-annual median lengths of mutton snappers (2000–2006). These findings demonstrate the need for additional life history information that includes length-associated age and details on growth to provide clearer support of the effects on, and responses by, populations following fishing. In view of the historical changes to mutton snapper CPUE and landings at Gladden Spit and the fishery-associated declines in fish spawning aggregations observed globally, a precautionary approach to spawning aggregation management is warranted that provides full protection from fishing to enhance population persistence. The findings also highlight the need for substantially greater enforcement and long-term fisheries monitoring under a comprehensive regional management strategy.

Keywords Lutjanidae · Overfishing · Spawning aggregation · Belize · Marine protected area

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Introduction

Fish that aggregate to reproduce at predictable times and sites are particularly vulnerable to capture (Sadovy and Domeier 2005). Indeed, historical and documented evidence from several tropical locales points to a local, regional and global pattern of over-exploitation, including the extirpation of reef fish spawning aggregations (FSA) (e.g., Sadovy and Eklund 1999; Sadovy et al. 2003). Responses by FSA to fishing include changes to the reproductive population structure, such as decreases in mean fish size (e.g., Sadovy 1994), abundance (e.g., Claro et al. 2001), genetic diversity (Chapman et al. 1999) and alterations in aggregation sex ratio (Koenig et al. 1996). Within the fishery, increasing effort and declines in catch are often noted following intense fishing of FSA (Beets and Friedlander 1998; Matos-Caraballo et al. 2006). Consequently, interest is turning towards FSA conservation, with several countries enacting protective measures such as seasonal closures (e.g., Rhodes and Sadovy 2002), harvest bans (e.g., Sala et al. 2001), gear bans and area closures (e.g., Beets and Friedlander 1998) in an attempt to stem declines in fish stocks. At least one mutton snapper (*Lutjanus analis*) FSA heavily impacted from commercial and recreational fishing over approximately two decades in (Riley's Hump) Florida has been reported to increase in abundance following area protection (Burton et al. 2005) and some serranid FSA in the western Pacific are showing improvements following their near commercial extirpation (Colin et al. 2003).

Among snappers (Lutjanidae), several studies report declines or extirpations from both small- and large-scale commercial FSA fishing. Examples include the near-extirpation of lane snappers (*Lutjanus synagris*) and the serial exploitation and depletion of other snapper species in Cuba (Claro 1991) and loss of a mutton snapper FSA at Long Caye, Belize. The latter FSA was reportedly depleted by targeting fish along a reproductive migratory pathway (Craig 1966), highlighting the importance of placing these pathways under protection along with the respective spawning aggregation. Increasingly, characterizations of FSA declines are relying on historical fisher accounts (Johannes 1998; Sadovy and Cheung 2003), often in combination with empirical data, including several in the wider Caribbean (Olsen and La Place 1979) and Belize (Sala et al. 2001). Particularly in the developing tropics, historical accounts are necessary for measuring and subsequently managing the health of a fishery in the absence of detailed documentation of catch statistics (Johannes 1998; Zeller et al. 2006). Similarly, the promotion of precautionary management is expanding as scientific evaluation and contemporary management of fisheries-affected populations (and FSA) becomes increasingly difficult in the face of expanding resource use and the immediacy of management needs.

The mutton snapper fishery at Gladden Spit in Belize is one of four actively fished FSA in Belize (Fig. 1). Two other sites, Maugre Caye (Turneffe Atoll) and Northern Two Cayes (Lighthouse Reef Atoll) are permitted for a total of four local fishers only, whereas Gladden Spit and the Sapodilla Cayes Marine Reserve remain accessible to all Belizean fishers and consequently sustain greater fishing effort. As of June 2006, Gladden Spit's FSA fishery was to be fished only by traditional fishers but the number and identity of traditional fishers to be allowed in the fishery has not yet been established. Thus, fishing remains relatively intense at the site. All other documented FSA fisheries were closed by the Government of Belize in 2003 (Government of Belize 2003), although effective enforcement is still lacking across all sites and there are indications of continued declines and possible extirpation for some FSA within these protected areas.

Mutton snappers are a reef-associated species with a high commercial value throughout the Caribbean (Bortone and Williams 1986; Claro 1991). Mutton snappers are gonochoristic transient group-spawners whose spawning aggregation behavior is entrained by a lunar rhythm (Munro et al. 1973; Claro 1981). The species matures at ~5 years and 50 cm total length (TL), with sex-specific growth rates and females typically larger than males. The maximum estimated age for mutton snappers is 29 years (Burton 2002). Like several other species of spawning reef fish, mutton snappers migrate from inshore reef areas to fore reef sites, using promontories or other areas of high relief to spawn (Claro 1981; García-Cagide et al. 2001). Midday spawning occurs in sub-groups of 8–12 individuals breaking away from a larger school follows a spawning rush from depth to the surface (R. Graham, personal observation).

In Belize, mutton snapper peak reproductive abundances are from March through June, based on previous anecdotal reports and informal observations of landings. Fishers using handlines concentrate efforts during these peak lunar months over 10–16 days that encompass the days just before and following the full moon periods. Periodicity of the mutton snapper fishery varies annually. Fishers will traditionally fish for snapper in April, May and June if the full moon falls before mid-month. Alternatively, if the full moon falls after mid-month, fishers will fish the FSA from March through May. Consequently, the Gladden Spit mutton snapper FSA is rarely fished throughout the entire season. Though handlines are one of the least destructive of gear types used, they can exert strong pressures on fish stocks when aggregating to spawn (Craig 1969; Olsen and La Place 1979), with a rapid depletion of the reproductive population possible (Rhodes and Sadovy 2002; Matos-Caraballo et al. 2006).

The aim of this study was to characterize the status of the largest known mutton snapper FSA fishery on the Mesoamerican Barrier Reef and derive morphological and fisheries information for its management and conservation, using both contemporary and historical information. Specifically, the fishing effort and yield of the mutton snapper fishery at Gladden Spit, Belize, are assessed, as are changes in size frequency in catch from 2000 to 2006, exclusive of 2005. Results are discussed in the context of historical fishing effort at Gladden Spit gleaned from published reports and traditional fishers that have fished the site from years to decades. Improvements to management and enforcement are also discussed, with comments on the current spawning aggregation conservation strategies employed in Belize and elsewhere.

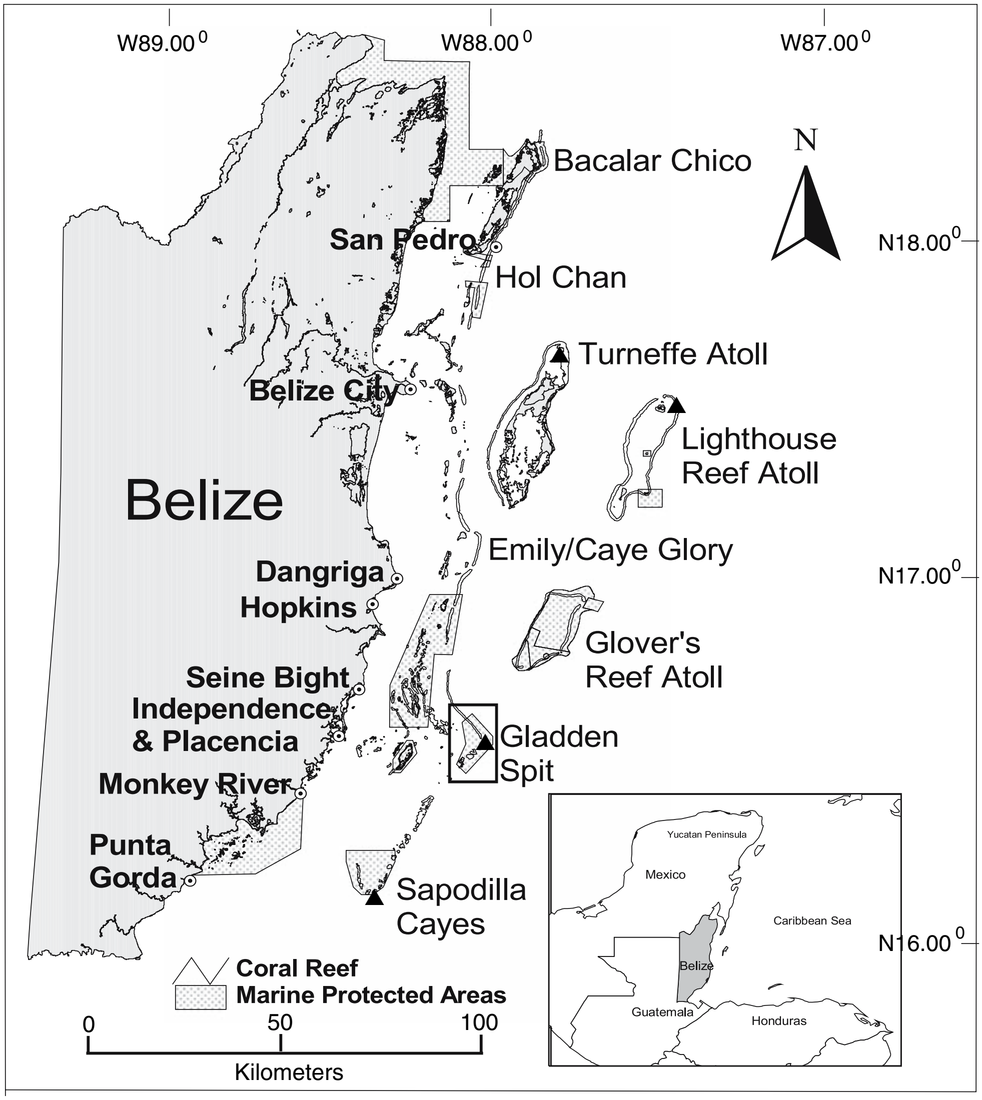

Fig. 1 Map of Belize and its marine protected areas. A black square encompasses the Gladden Spit Marine Reserve and the symbols (*filled triangle*) identify the location of currently fished FSA (Base map kindly provided by Belize's Coastal Zone Management Authority (CZMA))

Materials and methods

Site description

The study focused on Gladden Spit (16°35′N 88°00′W), a promontory forming a near 90° bend in the Belize Barrier Reef located ~46 km from the mainland, and ~42 km due east of the coastal town of Placencia (Fig. 1). A channel located immediately south of the bend in the reef bisects Gladden Spit. The northern half of the point slopes away gently from the reef crest for 2.5 km and reaches 45 m depth before steeply dropping off to over 2,000 m into the southern finger of the Cayman Trench. On the southern end of the point beyond the channel, the narrow shelf drops off rapidly reaching over 1,000 m within 3 km of the reef crest. The spawning site is located on the northern edge and tip of the reef promontory. More detailed descriptions of Gladden Spit can be found in Graham and Castellanos (2005); Heyman et al. (2005). Although the Government of Belize declared Gladden Spit a marine reserve on 18 May 2000 (Government of Belize 2000), there are currently no restrictions to the snapper fishery for licensed Belizean fishers.

Survey of landings and catch per unit effort

Landings and catch-per-unit-effort (CPUE) data were collected by a 4-person team at Buttonwood Caye, the primary landing site for mutton snapper taken from Gladden Spit. Landings were recorded within 2 or 3 months of the March-June peak mutton snapper fishing season between 2000 and 2006, excluding 2005, when no landings were taken. The 2000–2002 data were collected by the senior author and the

Belize Fisheries Department (BFD), while 2003, 2004 and 2006 data were collected by BFD and The Nature Conservancy. CPUE estimates were based on 2000–2002 data only, as was the subsequent fisheries valuation. Otherwise, landings methods were standardized, with analyses incorporating all sample years. The fishery, and thus landings data collection, typically took place from 7 to 14 days monthly between March and June and 2–3 days prior to and 1–14 days after, full moon periods.

CPUE estimates were based on kg boat^{-1} and man-hours fished^{-1}, with boats identified by captain along with the number of fishers per boat and soak time. For CPUE, time fishing included soak time, the short travel to and from the fishing site, and anchor and baiting time, yet was exclusive of bait search and preparation. Travel times and bait and anchor times were not considered sufficiently different among boats to affect CPUE comparisons among fishing periods (e.g., months or years). Fishing times were reported to researchers at the landings site and verified by twice-daily on-site visits to the fishing grounds during two weeks of each full moon period of the fishing season. Although every attempt was made to record all mutton snappers landed at Buttonwood Caye, occasionally several boats arrived on Buttonwood Caye simultaneously and/or catches exceeded ~100 fish. During those periods, logistical constraints required a sub-sampling of the total number of boats landing fish. Overall daily catch from all boats fishing at the site was estimated by recording the number of boats fishing and number of fishers and then extrapolating the catch based on the recorded mean catch per fisher during daily landings assessments. Similarly, the mean daily catch was used to determine seasonal catch for all fishers and boats during 2000–2002.

Morphometrics and gonad analysis

All fish examined were weighed whole (nearest 0.25 kg) and measured (nearest 0.5 cm fork length, FL). Gonads were weighed to the nearest 20 g and reproductive development was determined macroscopically and classified to stages using the following criteria: (1) Stage I, Immature: small transparent, undeveloped gonads with no vascularization; (2) Stage II, Mature: vascularization of the ovaries and visible eggs; (3) Stage III, Running ripe: highly vascularized with mostly hydrated eggs visible; (4) Stage IV, Spent: most or all hydrated eggs released, ovary sac flaccid. Males were sexed based on the presence of milt, but were not staged. With the exception of gonad development Stage I (Immature), some individuals could not be classified to sex, based on the above criteria and were listed as "undetermined". Owing to the uncertainty between juveniles (immature) and resting or non-reproductive adults, undetermined individuals were excluded from inter-seasonal and inter-annual mean size comparisons, but were included in calculations of CPUE and total annual and seasonal catch volume and incomes. Morphometric data used for comparisons were first tested for normality using the Kolmogorov–Smirnov test, with non-normal distributions analyzed non-parametrically using Kruskal–Wallis or Mann–Whitney *U* methods.

Fleet and fisher surveys

The percentage of fishers and boats fishing the Gladden Spit Marine Reserve was estimated through daily counts of boats sighted at the fishing grounds during the course of the mutton snapper FSA fishery. Daily data collection ceased when over 75% of fishers had left the area.

Short semi-structured interviews consisting of eight questions were conducted with 13 traditional fisher boat captains provided historical information on the fishery. The captains represented an additional 39 fishers (up to three additional fishers per boat) that utilized the snapper spawning aggregation fishery. Interviews were administered to the captains during off-work periods at the landing sites or in the captain's community. Questions were asked in the same sequence beginning with name and age, residence and number of years fished, the number of people employed in the boat, their fishing technique, followed by questions eliciting their perceptions of the current status of the mutton snapper aggregation fishery versus when they started fishing the aggregation and their perception of mean size of fish landed (smaller, larger or the same as when the fisher started fishing). Placencia and Mango Creek/Northern Fishermen's Cooperatives provided total fisher numbers in the stakeholder communities.

Results

Catch composition

A total of 7,639 individual fish were included in the catch between 2000 and 2006, exclusive of 2005, when landings data were not collected (2000: $n = 770$; 2001: $n = 2{,}042$; 2002: $n = 2{,}064$; 2003: $n = 898$; 2004: $n = 1{,}045$; 2006: $n = 820$). Individuals of undetermined sex ($n = 220$) ranged in size from 25 to 70 cm FL (mean = 50.3 ± 0.4 SE) and were significantly different in mean size than sexed individuals (Mann–Whitney *U*, $Z = -6.05$, $P < 0.001$). The percentage of undetermined catch within landings estimates ranged from 0.0 to 5.6% of the total (mean = 2.5 ± 1.1% year^{-1}). The male: female sex ratio within examined catch was 1:1.2. Males represented both the maximum (96 cm FL) and minimum (18 cm FL) sizes of mutton snapper recorded. The maximum fork length recorded for females

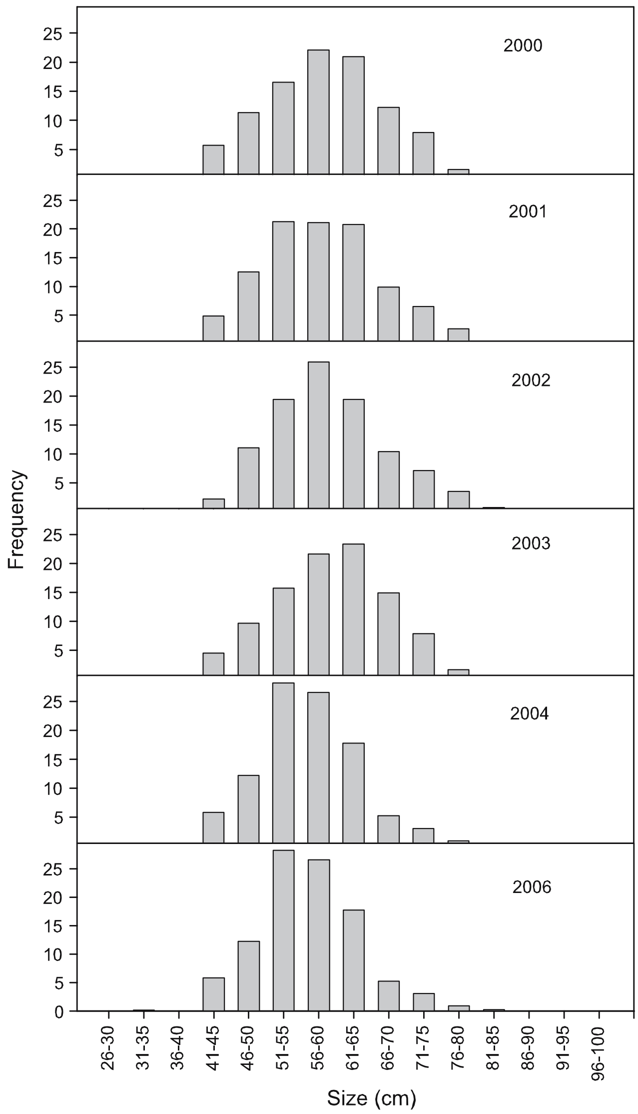

Fig. 2 The length-frequency distributions of *Lutjanus analis* per fork length category from the seasonal fishery at Gladden Spit in 2000–2004 and 2006

of 91 cm, while the smallest mature female was 34 cm. Over 80% of macroscopically examined ovaries were in the late stages of maturation (Stage II) or running ripe (Stage III). The majority of fish recruited into the spawning population at lengths >40 cm FL (Fig. 2). Although sex-specific size distributions overlapped, females were significantly larger than males (Females: mean = 55.4 ± 1.0 cm (SE) FL, $n = 3{,}323$, range = 30–91 cm FL; Males: mean = 52.3 ± 0.8 cm (SE) FL, $n = 4{,}096$, range = 18–96 cm; Mann–Whitney *U*; $n = 7{,}419$; $P < 0.001$) (Fig. 3). Median length showed a slight, but significant sex-specific decline among sample years (Kruskal–Wallis: $X^2_{\text{Males}} = 83.6$; $df = 5$; $P < 0.001$; $X^2_{\text{Females}} = 71.3$; $df = 5$; $P < 0.001$) (Fig. 4). No clear trends in inter-annual differences in sex-specific mean size were apparent.

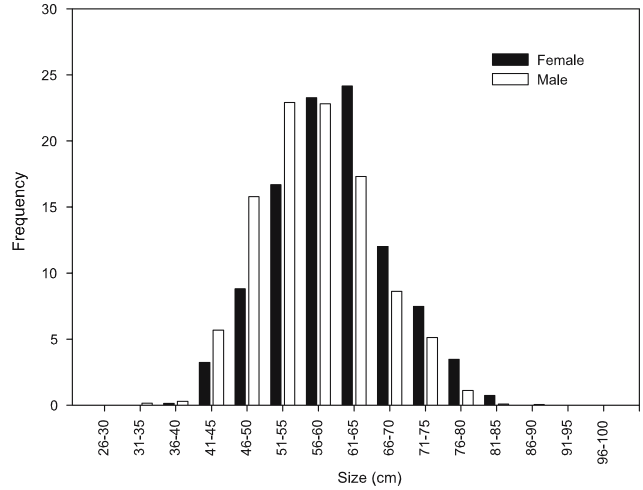

Fig. 3 The length frequency distributions of *Lutjanus analis* females and males ($n = 7{,}419$) from the seasonal fishery at Gladden Spit between 2000 and 2006 excluding 2005

Catch, income and effort

Between 2000 and 2002, 18,552 kg of mutton snapper were sampled through landings at Buttonwood Caye (Table 1). This volume represented 44.8% of the total estimated mutton snapper caught at Gladden Spit (41,429 kg), based on extrapolated data from all boats and fishers fishing at the site during that period (Table 1). Based on 2000–2002 whole fish prices (US$2.75 kg^{-1}), mutton snapper fetched US$113,930 within that period, averaging US$37,977 per season (Table 1). Based on fishing cooperative records in 2000, the Belize Central Statistical Office recorded 50,000 kg of gutted reef finfish landed (equivalent to 62,500 kg of whole fish) (CSO 2001). The Department of Fisheries recorded an additional 12,820 kg of fillet (equivalent to 21,409 kg whole fish) for a total combined weight in 2000 of 83,909 kg of landed whole finfish landed. Thus, mutton snapper from Gladden Spit represented approximately 16.4% of 2000 national finfish, excluding direct sales to individuals or restaurants.

Despite a historical decrease in boats and fishers at Gladden Spit from the early 1990s, CPUE declined from 4.1 to 1.7 kg man-hour fished between 2000 and 2002 (Kruskal–Wallis test: $n = 244$; $df = 2$; $X^2 = 25.23$; $P < 0.001$) (Table 2; Fig. 5). Similarly, the catch boat^{-1} day^{-1} also fell significantly from 82.1 kg in 2000 to 64.0 kg in 2002 (Kruskal–Wallis test: $n = 244$; $df = 2$; $X^2 = 7.67$; $P < 0.05$) (Table 2). During the same period, fishing effort increased significantly from 12.6 to 16.9 hours-boat^{-1} day^{-1} (Kruskal–Wallis test: $n = 244$; $df = 2$; $X^2 = 14.07$; $P < 0.001$) (Fig. 5).

All 13 local boat captains interviewed indicated that prior to 1992, 60–80 boats fished the site daily, representing over 200 fishers. Despite the substantial decrease in fishing effort since 1992, interviewed fishers perceived a continued

Fig. 4 Difference in median fork length size of female (*F*) and male (*M*) *Lutjanus analis* from the seasonal fishery at Gladden Spit from 2000 to 2004 and 2006 ($n = 7{,}419$) ± SE. The boxplots display the median, interquartiles range, non outliers and outliers of each data set

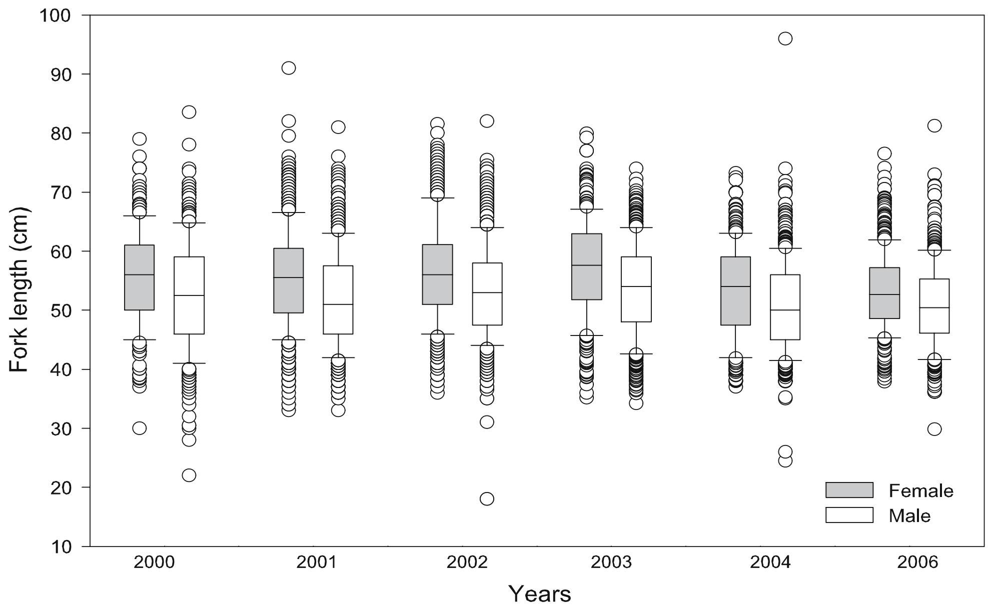

Table 1 Summary of estimated catch and value of mutton snapper aggregation fishery for all boats and fishers sampled on Buttonwood Caye and recorded at Gladden Spit

Year	Total no. of boats sampled	Total no. of boat-days recorded at Gladden	No. of days sampled	Total no. of fisher-days	Total no. of estimated fisher-days	Total landings recorded whole fish (kg)	Total estimated landings whole fish (kg)	Total estimated value in US$ of landings (US$2.75/kg)	Mean landings whole fish per fisher per day (kg)
2000	62	163	18	131	354	5,093	13,764	37,851	38.9
2001	84	135	16	200	321	7,184	11,530	31,708	35.9
2002	98	247	24	247	635	6,275	16,135	44,371	25.4
Total	244	545	58	578	1,310	18,552	41,429	113,930	33.4[a]

The total number of fishers recorded fishing the Gladden Spit from 2000 to 2002 is based on daily boat and fisher counts during the peak mutton snapper fishing period. Estimated total landings in kg are based on mean landings recorded at Buttonwood Caye for a proportion of the fishers fishing Gladden Spit mutton snapper spawning aggregation

[a] Mean values used

Table 2 Summary of catch and effort for the hook and line mutton snapper fishery at Gladden Spit during the full moon periods (8 months) from 2000 to 2002

Month	CPUE kg h fished ± SE	Hours fished/boat ± SE	Catch/boat (kg) ± SE	No. fishers/boat ± SE
April 2000	1.7 ± 0.4	13.0 ± 1.6	30.5 ± 6.1	2.2 ± 0.2
May 2000	5.2 ± 0.8	12.4 ± 1.0	105.0 ± 13.3	2.2 ± 0.1
Mean	4.1 ± 0.6	12.6 ± 0.8	82.1 ± 10.3	2.2 ± 0.1
April 2001	2.5 ± 0.5	16.3 ± 2.5	39.2 ± 6.8	2.8 ± 0.3
May 2001	2.5 ± 0.3	15.6 ± 0.9	80.5 ± 7.0	2.4 ± 0.1
June 2001	4.0 ± 0.6	15.8 ± 1.6	111.7 ± 14.5	2.2 ± 0.2
Mean	3.0 ± 0.3	15.8 ± 0.8	85.5 ± 6.4	2.4 ± 0.1
March 2002	1.0 ± 0.9	13.9 ± 2.4	7.6 ± 4.0	2.8 ± 0.2
April 2002	1.8 ± 0.3	16.7 ± 1.1	70.1 ± 10.1	2.4 ± 0.1
May 2002	2.4 ± 0.3	17.8 ± 1.2	83.4 ± 7.7	2.5 ± 0.1
Mean	1.7 ± 0.2	16.9 ± 0.8	64.0 ± 5.9	2.5 ± 0.1
Mean 2000–2002	2.8 ± 0.2	15.4 ± 0.5	76.0 ± 4.2	2.4 ± 0.0

CPUE = catch per unit effort

decline in catch size and volume (Table 3). CPUE increased significantly between and among months in 2000 and 2002, respectively, but not in 2001 (Kruskal–Wallis: $n = 84$; $df = 2$; $X^2 = 4.60$; $P = 0.101$) (Mann–Whitney U_{2000}; $n = 62$; $P < 0.001$; Kruskal–Wallis$_{2002}$: $n = 98$; $df = 2$; $X^2 = 30.85$; $P < 0.001$) (Table 2).

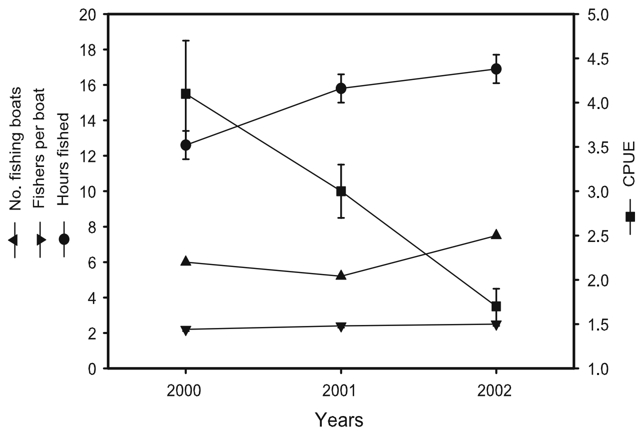

Fig. 5 Mean numbers of fishers per boat, hours fished per boat, fishing boats and catch per unit effort in kg per man-hour fished for the mutton snapper fishery at Gladden Spit for 2000–2002. Error bars show ± SE

Discussion

Historically, reef fish spawning aggregations have been targeted by fisheries for their spatial and temporal predictability and high yields (Johannes 1981; Sadovy 1994). In Belize, spawning aggregations and migrations have contributed substantially to the national annual reef fish landings over the past 60 years (Sala et al. 2001; CSO 2001). For example, between 1937 and 1944, 1.36–1.82 million kg of fish was caught annually by 350–400 local fishers, with at least some taken during "runs", an apparent reference to spawning migrations (Thompson 1945). Deeming Belizean fisheries under-exploited, Thompson (1945) suggested increasing fishing effort and promoted recreational fishing to generate additional income. Since that time, the serial depletion of several FSA or spawning migrations has occurred, including multi-species FSA at Rocky Point, Glover's Atoll and Rise and Fall Banks. The only recorded Belizean FSA of endangered Goliath grouper (*Epinephelus itajara*) has been extirpated (Sadovy and Eklund 1999). Although no specific reference was made to Nassau grouper, Thompson (1945) reported grouper congregating at Caye Glory "in almost countless numbers" and "so closely packed as to hide the white sand bottom". In the 1960s, fishers were reportedly removing up to 32,000 kg in just two months from the FSA (Craig 1969). Today the site is virtually void of Nassau grouper (Sala et al. 2001). In response to these depletions, the Belize Government banned fishing at 11 of 13 known multi-species FSA sites in 2003 (Government of Belize 2003), although with insufficient enforcement to stem their extirpation, which for some is predicted in as few as 6 years.

For the Gladden Spit FSA, fisher interviews suggest similar declines are affecting mutton snapper, supported both by reductions in CPUE under increasing effort and an historical decrease in fishers targeting the site. For many fishers, the costs of fishing now outweigh the benefits of fishing mutton snapper at Gladden, a clear sign of commercial extinction. Concomitantly, access to and catch from other FSA is declining nationwide.

Population-level declines in mutton snapper are also indicated by historical records of individual fish weight. In 1945, 10–12 pound mutton snappers were not uncommon (Thompson 1945), yet landings from 2000 to 2006 showed 10–12 pound individuals (minimum size ≥ 67 cm FL) to be quite rare. A 'gold rush' on the Gladden Spit aggregation followed rumors of a total mutton snapper FSA closure that may have contributed to the recent demise in larger sized

Table 3 Summary information from semi-structured interviews with 13 boat captains that fished the Gladden Spit snapper spawning aggregation

Boat captain	Total no. of fishers represented	Estimated no. of years fishing (captains)	Residence	Decline in catch compared to 10 years ago? Yes/No	Decline in fish size compared to 10 years ago? Yes/No
1	3	30	Placencia	Y	Y
2	2	45	Placencia	Y	Y
3	2	30	Monkey River	Y	Y
4	2	25	Independence	Y	–
5	1	30	Placencia	Y	Y
6	3	50	Placencia	Y	Y
7	3	47	Monkey River	Y	Y
8	2	12	Placencia	Y	Y
9	2	30	Mango Creek	Y	Y
10	3	30	Mango Creek	Y	–
11	1	50	Placencia	Y	Y
12	3	35	Placencia	Y	Y
13	3	20	Placencia	Y	–
	Σ 30	X 33.2 ± SD11.5			

– Indicates that the respondent did not know individuals (D. Neil, formerly Belize Fisheries Department, personal communication). While there is no long-term record of declines in mean size, the data presented here shows a significant decrease over the survey period that, while perhaps not biologically meaningful over the survey period, may be representative of larger, more long-term changes that have occurred. Long-term monitoring efforts of size and age will be necessary to determine the true biological significance of these changes.

Life history information that could support the hypothesis of fishery-induced population-level changes, such as age and growth and cohort structure is currently lacking. Nonetheless, all available indications suggest that the mutton snapper FSA fishery is having a negative impact on Gladden Spit reproductive populations and will likely continue to do so in lieu of strict management and enforcement that protects FSA, associated reproductive migratory pathways and other life history phases.

Implications for management

The Gladden Spit and Silk Cayes Marine Reserve encompasses the mutton snapper FSA site, which is managed by the local NGO Friends of Nature (FoN) through a co-management agreement with the Belize Fisheries Department. Fishing closures enacted in 2003 at 11 spawning aggregation sites throughout Belize and a seasonal ban on Nassau grouper fishing from December to March (Government of Belize 2003) as recommended by the country's multisectoral spawning aggregation working group have strengthened efforts to manage overexploited spawning aggregations, although the lack of enforcement and monitoring clearly hinders its effectiveness. For two other FSA sites, including Gladden Spit, fishing remains open during daylight hours only. (In the absence of effective enforcement at Gladden, poaching occurs at night on FSA of the congeneric cubera snapper, *Lutjanus cyanopterus.*) In light of the numerous FSA extirpations documented globally and the apparent slow recovery potential, precautionary management, backed by strong enforcement, that includes a complete ban on fishing at Gladden Spit is both justified and warranted. In Belize, a combined approach to management that includes a reproductive seasonal catch closure and large-scale, actively enforced no-take MPAs incorporating reproductive migratory pathways is a viable precautionary management tool. For a seasonal ban to be effective, the Belize Fisheries Department should not only monitor and enforce MPA sites, but also require a "skin-on" policy that allows buyers and enforcement officials to identify the species being captured and sold. Additional management improvements can come from bans on spearfishing, gill nets and long lines that are known to increase adult mortality and catalyze overfishing of these and other species. While protection of mutton snapper FSA is an obvious management need, conservation of this and other commercially fished species in Belize will only be effective when a fully comprehensive management scheme is enacted that includes a strong, effective enforcement component.

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References

Beets J, Friedlander A (1998) Evaluation of a conservation strategy: a spawning aggregation closure for red hind, *Epinephelus guttatus*, in the US Virgin Islands. Environ Biol Fish 55:91–98

Bortone SA, Williams JL (1986) Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Florida)—gray, lane, mutton and yellowtail snappers. US Fish Wildl Serv Biol Rep 82(11.52), US Army Corps of Engineers, TR EL-82–4

Burton ML (2002) Age, growth and mortality of mutton snapper, *Lutjanus analis*, from the east coast of Florida, with a brief discussion of management implications. Fish Res 59:31–41

Burton ML, Brennan KJ, Muñoz RC, Parker RO Jr (2005) Preliminary evidence of increased spawning aggregations of mutton snapper (*Lutjanus analis*) at Riley's Hump two years after establishment of the Tortugas South Ecological Reserve. Fish Bull 103:404–410

Chapman RW, Sedberry GR, Koenig CC, Eleby BE (1999) Stock identification of gag, *Mycteroperca microlepis*, along the southeast coast of the United States. Mar Biotechnol 1:137–146

Claro R (1981) Ecología y ciclo de vida del pargo criollo, *Lutjanus analis* (Cuvier), en la plataforma cubana. Información Científica Técnica, Academia de Ciencias de Cuba 186:1–83

Claro R (1991) Changes in fish assemblage structure by the effects of intense fisheries activities. Trop Ecol 32:36–46

Claro R, Baisre JA, Lindeman KC, García-Arteaga JP (2001) Cuban fisheries: historical trends and current status. In: Claro R, Lindeman KC, Parenti LR (eds) Ecology of the marine fishes of Cuba. Smithsonian Institution, Washington DC, pp 194–219

Colin PL, Sadovy YJ, Domeier ML (2003) Manual for the study and conservation of reef fish spawning aggregations. Society for the Conservation of Reef Fish Aggregations Special Publication No. 1, Hong Kong

Craig AK (1966) Geography of fishing in British Honduras and adjacent coastal waters. Coastal Studies Laboratory Louisiana State University, Baton Rouge

Craig AK (1969) The grouper fishery of Cay Glory, British Honduras. Ann Assoc Am Geogr 59:252–263

CSO (2001) Abstract of statistics: 2000. Central Statistical Office, Belmopan, Belize

García-Cagide A, Claro R, Koshelev BV (2001) Reproductive patterns of fishes of the Cuban shelf. In: Claro R, Lindeman KC, Parenti LR (eds) Ecology of the marine fishes of Cuba. Smithsonian Institution, Washington DC, pp 73–114

Government of Belize (2000) Statutory Instrument No. 68 of 2000. Fisheries (Establishment of Gladden Spit and Silk Cayes Marine Reserve) Order, 2000

Government of Belize (2003) Statutory Instrument No. 161 of 2003. Fisheries (Spawning Aggregation Site Reserves) Order, 2003

Graham RT, Castellanos DW (2005) Courtship and spawning behaviors of carangid species in Belize. Fish Bull 103:426–432

Heyman WD, Kjerfve B, Graham RT, Rhodes KL, Garbutt L (2005) Characterizing spawning aggregations of cubera snappers, *Lutjanus cyanopterus* (Pisces: Lutjanidae) on the Belize Barrier Reef over a 6 year period. J Fish Biol 67:83–101

Johannes RE (1981) Words of the lagoon: fishing and marine lore in the Palau District of Micronesia. University of California, Berkeley

Johannes RE (1998) The case for data-less management: examples from tropical nearshore fisheries. Trends Ecol Evol 13:243–246

Koenig CC, Coleman FC, Collins LA Sadovy, Y, Colin PL (1996) Reproduction in gag (*Mycteroperca microlepis*) (Pisces: Serranidae) in the eastern Gulf of Mexico and the consequences of fishing spawning aggregations. In: Arreguin-Sanchez F, Munro JL, Balgos MC, Pauly D (eds) Biology, fisheries and culture of tropical groupers and snappers. Proceedings of an EPOMEX/ICLARM international workshop on tropical groupers and snappers. ICLARM conference proceedings, vol. 48, ICLARM, Manila, pp 307–323

Matos-Caraballo D, Posada JM, Luckhurst BE (2006) Fishery-dependent evaluation of a spawning aggregation of tiger grouper (*Mycteroperca tigris*) at Vieques Island, Puerto Rico. Bull Mar Sci 79:1–16

Munro JL, Guat VC, Thompson R, Reeson PH (1973) The spawning seasons of the Caribbean reef fishes. J Fish Biol 5:69–84

Olsen DA, La Place JA (1979) A study of a Virgin Islands grouper fishery based on a breeding aggregation. Current Caribbean Fisheries Research 31:130–144

Rhodes KL, Sadovy Y (2002) Temporal and spatial trends in spawning aggregations of camouflage grouper *Epinephelus polyphekadion*, in Pohnpei, Micronesia. Environ Biol Fish 63:27–39

Sadovy Y (1994) Grouper stocks of the Western Central Atlantic: the need for management and management needs. Proc Gulf Caribb Fish Inst 43:42–64

Sadovy YJ, Donaldson TJ, Graham TR, McGilvray F, Muldoon GJ, Phillips MJ, Rimmer MA, Smith A, Yeeting B (2003) While stocks last: the live reef food fish trade. Asian Development Bank, Manila

Sadovy Y, Cheung WL (2003) Near extinction of a highly fecund fish: the one that nearly got away. Fish Fish 4:86–99

Sadovy Y, Domeier M (2005) Are aggregation-fisheries sustainable? Reef fish fisheries as a case study. Coral Reefs 24:254–262

Sadovy Y, Eklund AM (1999) Synopsis of biological data on the Nassau grouper *Epinephelus striatus* (Bloch, 1792), and the jewfish, *E. itajara* (Lichtenstein, 1822) NOAA Technical Report NMFS 146, FAO Fisheries Synopsis 157

Sala E, Ballesteros E, Starr RM (2001) Rapid decline of Nassau grouper spawning aggregations in Belize: Fishery management and conservation needs. Fisheries 26:23–30

Thompson EF (1945) The fisheries of British Honduras. Development and Welfare Bulletin, West Indies 21:1–32

Zeller D, Booth S, Craig P, Pauly D (2006) Reconstruction of coral reef fisheries catches in American Samoa. Coral Reefs 25:144–152