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Contribution to the Theme Section 'Range-wide status and conservation of the goliath grouper'

Monitoring changes in the catch rates and abundance of juvenile goliath grouper using the ENP creel survey, 1973–2006

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ABSTRACT: In early 2006, NOAA National Marine Fisheries Service removed goliath grouper from its list of species of concern. It cited a recent status report that showed a significant increase in the abundance of the USA population and suggested that goliath grouper are re-establishing themselves throughout their historic range. However, under the Magnuson-Stevens Conservation Act, the goliath grouper remains 'overfished,' and harvest is still illegal. The historical center of abundance of goliath grouper is the Ten Thousand Islands area of southwest Florida. Detailed catch and effort data are available from this region for 1973 to 2006. The data were collected by Everglades National Park (ENP) officials during voluntary dockside interviews of sport fishermen. Using this data, a standardized index of abundance was created for juvenile goliath grouper. The index shows a substantial decline in abundance during the late 1970s and early 1980s. Since that time, the abundance of juveniles within ENP has increased considerably, suggesting that strong year classes have recently occurred in ENP. This information is useful for managers and stock assessment biologists tasked to evaluate the stock status of goliath grouper, and to determine acceptable harvest levels for scientific research and/or fishing.

KEY WORDS: Goliath grouper · Jewfish · *Epinephelus itajara* · Delta-lognormal abundance index

INTRODUCTION

Goliath grouper *Epinephelus itajara* (formerly referred to as jewfish) occur in tropical areas of the western Atlantic Ocean, from Florida south to Brazil, including the Gulf of Mexico and the Caribbean Sea (Heemstra & Randall 1993). They are the largest of the western north Atlantic groupers, reaching a size of 2.0 to 2.5 m total length (TL) (Heemstra & Randall 1993) and 320 kg (Smith 1971). Adults are typically found in shallow, inshore waters at depths less than 40 m (Sadovy & Eklund 1999). They generally occupy limited home ranges near areas of refuge such as caves, shipwrecks, and rocky ledges (Nagelkerken 1981). Goliath grouper are slow to mature and long-lived. Their reproductive ecology is poorly known, but they appear to mature at 5 to 7 yr of age and 1.15 to 1.35 m in length (Bullock et al. 1992). The maximum recorded age from an exploited population of goliath grouper is 37 yr (Bullock et al. 1992).

Goliath grouper may be unusually susceptible to overfishing due to their unwary behavior, conspicuous size, apparent site specificity and relatively long life span. Inshore populations began to decline in the 1950s, likely due to fishing pressure (Sadovy & Eklund 1999). During the late 1970s and 1980s, fishing effort on goliath grouper increased rapidly, while subsequent catches decreased. By 1989, substantial reductions in the number and size of spawning aggregations were noted (Sadovy & Eklund 1999, D. DeMaria pers. comm.). These observations led to strict regulatory measures. In 1990, the Gulf of Mexico Fisheries Man-

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agement Council (GMFMC) prohibited the landing of goliath grouper in US federal waters of the Gulf of Mexico (GMFMC 1990). Identical moratoria were enacted in 1990 by the South Atlantic Fisheries Management Council (SAFMC) and the State of Florida. In 1993, the Caribbean Fisheries Management Council (CFMC) and the territorial government of the US Virgin Islands expanded the moratorium to federal and territorial waters of the US Caribbean.

In addition to the regulatory measures, the National Marine Fisheries Service (NMFS) identified goliath grouper as a candidate species under the USA's Endangered Species Act (ESA) in June 1991 (56 FR 26797). In 1996, the International Union for Conservation of Nature (IUCN) recognized the species as 'critically endangered' throughout its range and distribution, implying an extreme risk of extinction in the wild in the immediate future. In April 2004, NMFS established a list of 'Species of Concern,' defined as those species about which NMFS has some concerns regarding status and threats, but for which insufficient information is available to indicate a need to list the species under the ESA. At that time, citing a lack of sufficient information, NMFS transferred 25 species, including goliath grouper, from ESA candidate status to 'Species of Concern.'

In February 2006, NMFS produced a status report that provided a summary of information pertaining to the USA distinct population segment of goliath grouper (NMFS 2006). The purpose of this report was to examine the status of goliath grouper relative to inclusion criteria for the NMFS list of 'Species of Concern.' The report concluded that the USA population of goliath grouper had undergone significant increases in abundance since 1991 and had re-established itself throughout its historical range. The authors did express concern regarding the rate of mangrove habitat loss, but they did not believe current habitat loss was affecting the species status. Therefore, they concluded that the inclusion of goliath grouper on the NMFS list of 'Species of Concern' was no longer warranted (NMFS 2006).

The most recent NMFS stock assessment of goliath grouper off Southern Florida was completed in January 2004, and reviewed by a panel of independent experts from January 27 to 30, 2004 (Kingsley 2004). The assessment indicated that the 1990 harvest ban had reduced fishing pressure by about 83% (Porch et al. 2006). Regardless, due to illegal harvest and release mortality, the fishing mortality rate remained above the overfishing threshold ($F_{SPR50\%} \approx 0.05$) and the stock biomass remained overfished ($S/S_{SPR50\%} < 1$). If the population continued to undergo fishing mortality at the current rates, the authors estimated the probability of recovery within the next 10 yr at less than 40%.

In the absence of a reliable catch history during the moratorium, the stock assessment relied on indicators of abundance including 2 visual surveys: the personal observations of a professional spearfisher (D. DeMaria pers. comm.) and a volunteer fish-monitoring program administered by the Reef Education and Environmental Foundation (www.reef.org) (Porch & Eklund 2004). In addition, the assessment used an earlier version of the Everglades National Park (ENP) creel survey index that had been standardized using data collected during 1972 to 1999 (Cass-Calay & Schmidt 2003). This index showed a decline in juvenile abundance from 1973 to 1987, followed by a strong recovery from 1993 to 1996. However, abundance during 1997 to 1999 was somewhat reduced from the time series maximum in 1995. Sensitivity runs of the most recent stock assessment model (Porch et al. 2006) demonstrated that the results were sensitive to the inclusion of the ENP creel survey index.

This study describes an updated index of abundance constructed using ENP data collected from 1973 to 2006. It was developed to monitor and quantify the abundance of juvenile goliath grouper within ENP. This information will be useful for managers and stock assessment biologists tasked to evaluate the status of the US population of goliath grouper.

MATERIALS AND METHODS

Data collection. The current center of abundance for USA populations of goliath grouper is the Ten Thousand Islands area of southwestern Florida (Sadovy & Eklund 1999). Here, extensive estuarine and swamp mangrove habitats exist, ideal for juvenile goliath grouper (Bullock & Smith 1991, Koenig et al. 2007). The Ten Thousand Islands region is located near Chokoloskee and Everglades City, Florida, and is predominantly contained within the borders of ENP (Fig. 1).

ENP was established in 1947 and systematic collection of fisheries data began in 1958. Monitoring procedures are described in detail by Davis & Thue (1979) and Schmidt et al. (2002). For the first 10 yr (1958 to 1969) monitoring was conducted by the University of Miami's Institute of Marine Science and evaluated only the sport fishery. Estimates of catch and catch per unit effort (CPUE) were recorded only for specific species (not including goliath grouper) landed by sport fishermen operating out of Flamingo. In 1972, the National Park Service expanded the monitoring program to include daily trip ticket reports from commercial permit holders and park-wide monitoring of sport fishing and commercial catch and effort. At this time, the species list was expanded to include all species typically

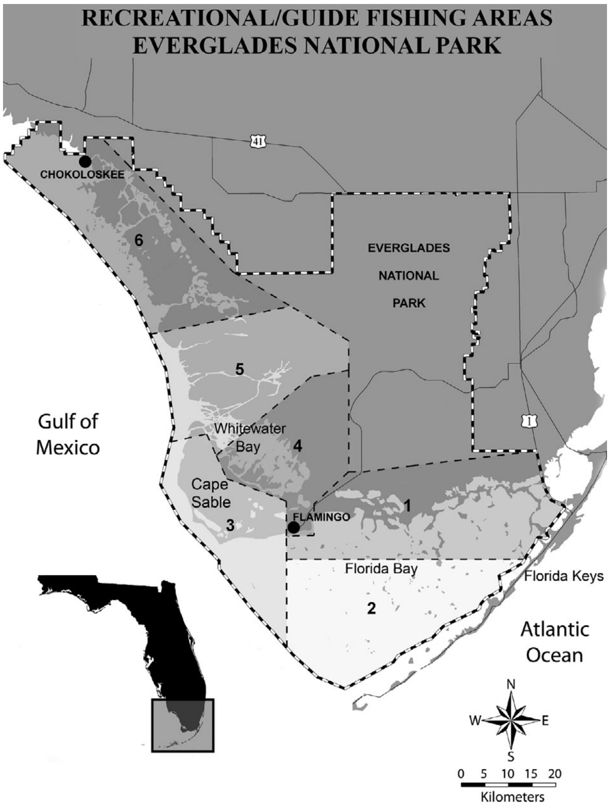

Fig. 1. Everglades National Park and defined fishing areas (Schmidt et al. 2002). The Chokoloskee and Flamingo boat ramps are indicated (●). The Ten Thousand Islands area is located to the north and west of Chokoloskee, partially within Area 6

landed within ENP. Fish length measurements were collected as of 1974 and, in 1980, routine monitoring of the Chokoloskee-Everglades City boat ramps began. For goliath grouper, CPUE data is currently available from 1973 to 2006.

ENP data were provided by the National Park Service's South Florida Ecosystem Office. Detailed descriptions of ENP data collection and recording formats include Higman (1967), Davis & Thue (1979) and Tilmant et al. (1986). To summarize, sport fishermen are interviewed by ENP personnel at the Flamingo and Chokoloskee-Everglades City boat ramps (Fig. 1) upon completion of their trip. Data routinely recorded include trip origin, area fished (Fig. 1), number of fish kept and released by species, number of anglers, hours fished, species preference, angler residence, and type of fisherman (skilled, family, novice, sustenance). According to ENP documentation (Davis & Thue 1979) the type of fishermen is defined as follows:

(1) Skilled anglers show their experience by their knowledge of park waters, fishing experience, fishing rods rigged with appropriate lures or fishing in a specialized manner for a particular species.

(2) The family designation is applied to groups of children and adults, or to groups of adults whose primary interest is other than fishing.

(3) The novice fisherman has little experience fishing or little experience in the park.

(4) The sustenance fisherman is primarily fishing for food and usually keeps everything caught.

When possible, fish length measurements are also obtained. These measurements are recorded in separate data files. Goliath grouper length measurements are available from 1974 to 2005 (n = 419).

It is important to emphasize that landings of goliath grouper have been prohibited in all USA federal and State of Florida waters since 1990. Yet goliath grouper continue to be captured and released by sport fishermen. Since ENP records include fish kept and released, they can be used to develop a standardized abundance index. For each trip, we calculated CPUE using:

$$\text{CPUE} = \frac{(\text{no. kept} + \text{no. released})}{1000\ \text{angler-hours}} \quad (1)$$

Index development. In order to develop a sufficiently balanced sample design, it was necessary to construct the following categorical variables (Table 1). The factor Skill refers to the skill level of the fishing party. Two levels were considered, fishers identified as 'skilled' by ENP and 'other' (fishers identified as family, novice or sustenance by ENP). This classification is supported by the following. Skilled fishers caught or released 6.0 goliath grouper per 1000 angler-hours, while sustenance, family and novice fishers caught or released 2.1, 1.8 and 1.4 goliath per 1000 angler-hours, respectively. In addition, skilled fishers caught or released a goliath (positive trip) on 3.9% of trips, while sustenance, family and novice fishers caught or released a goliath on 1.2%, 1.7% and 1.1% of trips, respectively. The factor Season was constructed from Month to create 4 periods generally reflective of water temperatures and rainfall in the shallow waters of ENP. Those periods were December through February,

Table 1. Description of factors used in the standardized abundance index

Factor	Levels	Description
Year	33	1973, 1975–2006
Skill	2	Skilled = Skilled
		Other = Novice + Sustenance + Family
Area	6	See Fig. 1
Season	4	Winter = December–February
		Spring = March–May
		Summer = June–August
		Autumn = September–November

March through May, June through August and September through November. The factor Area used the ENP definitions intended to delimit different habitats (Fig. 1).

We used the delta-lognormal model approach (Lo et al. 1992) to develop the standardized index of abundance. This method combines separate generalized linear modeling (GLM) analyses of the proportion of positive trips (PPT; trips that kept or released a goliath grouper ÷ total trips) and the catch rates on positive trips to construct a single standardized CPUE index. Parameterization of each model was accomplished using a GLM procedure (GENMOD; Version 8.02 of the SAS System for Windows 2000, SAS Institute).

A forward stepwise regression procedure was used to determine the set of fixed factors and interaction terms that explained a significant portion of the observed variability. For both the binomial and lognormal components of the delta-lognormal model, deviance tables were constructed to determine the percentage of total reduction in deviance ($\%rd_t$) explained by the addition of each factor or interaction term, i.e.

$$\%rd_t = 100\,(rd_f)/(rd_{nm} - rd_{fpm}) \qquad (2)$$

where rd_f = residual deviance due to addition of factor or interaction term, rd_{nm} = residual deviance of null model, and rd_{pm} = residual deviance of fully populated model. Factors and interaction terms were selected for final analysis if the percent of deviance explained by adding the factor exceeded 5% and the χ^2 test was significant ($p \leq 0.05$). Fixed factors and interaction terms appear in the final models from highest to lowest explanatory power (highest to lowest % total deviance).

Once the set of fixed factors and interaction terms was identified, the influence of the Year × Factor interactions were examined. Year × Factor interaction terms were added to the mixed model as random effects if they explained at least 5% of the total deviance and the χ^2 and likelihood ratio tests (Littell et al. 1996) were significant ($p \leq 0.05$). The final delta-lognormal model was fit using the SAS macro GLIMMIX.

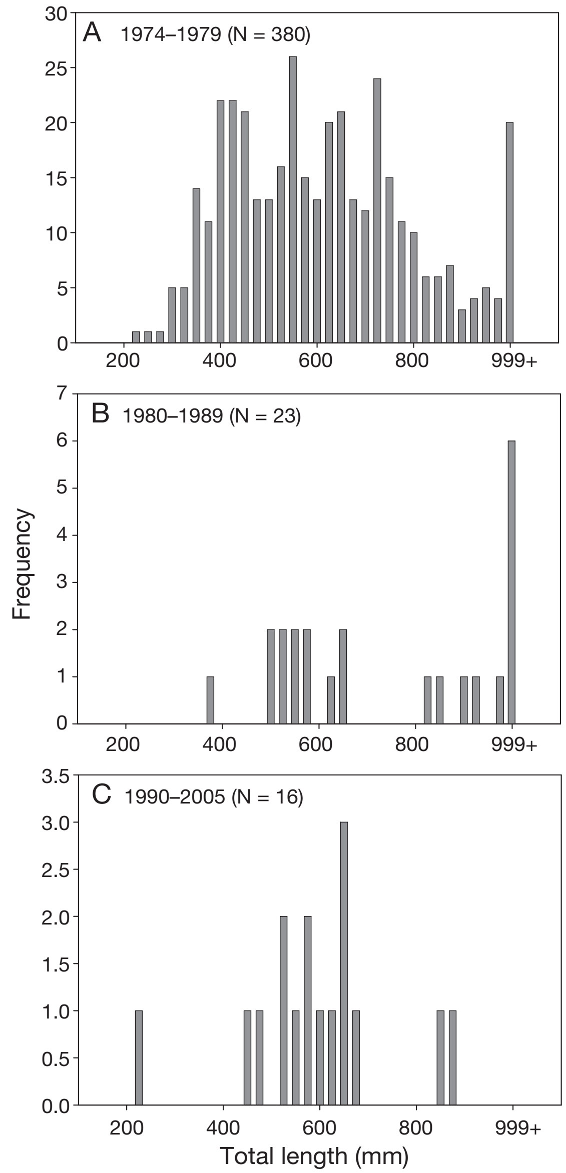

Fig. 2. *Epinephelus itajara.* Length frequency of goliath groupers captured in Everglades National Park from (A) 1974–1979, (B) 1980–1989 and (C) 1990–2005

RESULTS

ENP records include more than 180 000 sport fishing trips within the park. A total of 9682 goliath grouper were caught during 5157 of these trips. 'Catch' refers to animals retained and those subsequently released. Prior to the 1990 harvest moratorium, 13.7% of goliath grouper were released. Since 1990, 99.6% of goliath grouper were released. Length measurements are available for 419 goliath grouper landed within the park from 1974 to 2005 (Fig. 2). An unexpected peak occurs at 999 mm (n = 24) because ENP technicians record length only to 999 mm, therefore this represents a plus-group. The mean total length, excluding the plus-group, was 583 ± 168 mm (mean ± SD).

The length composition was examined for 3 time intervals: 1975 to 1979, 1980 to 1989 and 1990 to 2005. Unfortunately, measurements are too sparse after 1979 (n = 39) to permit strong statistical inference regarding changes in mean size over time. However, the available data does not support obvious changes in the size range of goliath grouper observed during the 3 time intervals.

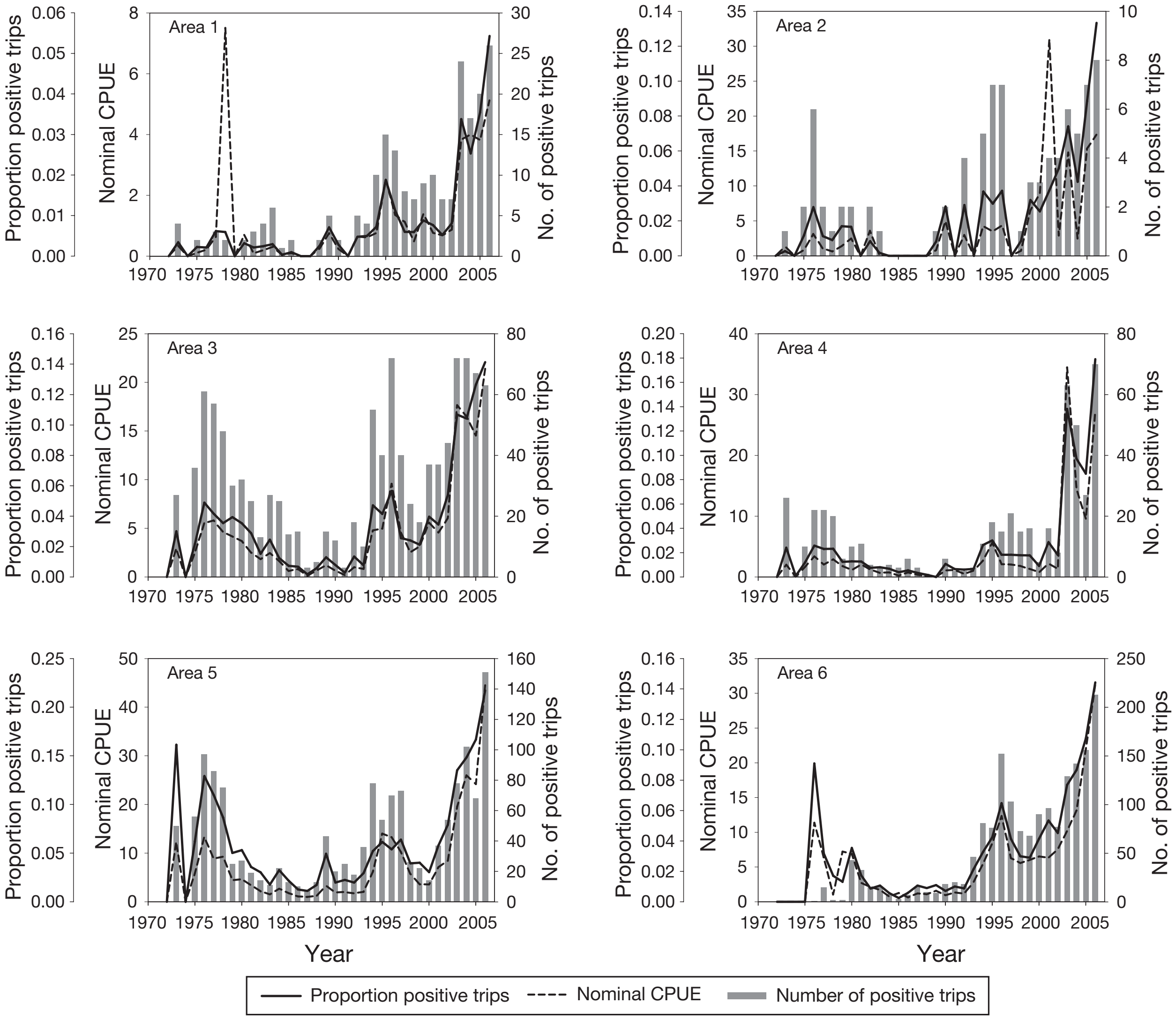

Fig. 3. *Epinephelus itajara.* Annual trends in the number of positive trips, proportion of positive trips and nominal catch per unit effort (CPUE) by fishing area (numbers per 1000 angler-hours). Nominal CPUE is the average annual CPUE before standardization

Index 1973 to 2006

In all areas of ENP, the proportion of positive trips declined from 1975 to 1990 (Fig. 3). In Areas 3, 5 and 6, the decline was particularly severe. The nominal CPUE also declined in Areas 3, 5 and 6 from 1975 to 1990 (Fig. 3). In other areas, nominal CPUE was generally low. The extreme value in 1978 in Area 1 is based on only 2 trips during which goliath were caught. The proportion of positive trips and the nominal CPUE on positive trips began to increase throughout the park after 1990. In 2006, the proportion of positive trips and nominal CPUE were the highest ever recorded. Throughout the park, a goliath grouper was caught during 15% of trips in 2006 and the nominal catch rate was 28.6 goliath per 1000 angler-hours.

The stepwise construction of the binomial model on proportion of positive trips is summarized in Table 2 and the construction of the lognormal model on catch rates of positive trips is described in Table 3. The mixed models, including Year × Factor interaction terms are shown in Table 4.

Factors that influenced the proportion of positive trips included Year, Area and Season. The proportion of positive trips was higher in Areas 5 (5.8%) and 6 (3.6%) than in Areas 3 (2.8%) and 4 (2.2%), and lowest in Areas 2 (1.5%) and 1 (0.6%). Goliath grouper were more likely to be caught in summer (4.0%) than in autumn (3.3%) or spring (2.6%), and they were least likely to be caught in winter (1.9%).

Factors that influenced catch rates (goliath landed or released per 1000 angler-hours) on positive trips

Table 2. Deviance table for the binomial model (1973–2006). Factors were added to the model if they accounted for at least 5% of the total reduction in deviance and were significant according to a χ^2 test ($p \leq 0.05$). Terms added to the model are indicated in bold

Binomial model factors — proportion positive trips (PPT)	df	Deviance Residual	Deviance Reduction	Deviance % total	Log-likelihood	Chi square	p
Null	174084	46212.1	—	—	–23106.1	—	—
Year	174052	42391.8	3820.4	**59.7**	–21195.9	3820.4	**<0.001**
Year + **Area**	174047	40999.0	1392.8	**21.8**	–20499.5	1392.8	**<0.001**
Year + Area + **Season**	174044	40590.7	408.3	**6.4**	–20295.4	408.3	**<0.001**
Year + Area + Season + Skill	174043	40331.9	258.8	4.0	–20165.9	258.8	<0.001
Year + Area + Season + Skill + Area × Skill	174038	40266.5	65.4	1.0	–20133.3	65.4	<0.001
Year + Area + Season + Skill + Area × Skill + Season × Area	174023	40223.2	43.3	0.7	–20111.6	43.3	<0.001
Year + Area + Season + Skill + Area × Skill + Season × Area + Season × Skill	174020	40215.2	8.1	0.1	–20107.6	8.1	0.040
Year + Area + Season + Skill + Area × Skill + Season × Area + Season × Skill + **Year × Season**	173924	39853.7	361.4	**5.6**	–19926.9	361.4	**<0.001**
Year + Area + Season + Skill + Area × Skill + Season × Area + Season × Skill + Year × Season + Year × Skill	173892	39808.7	45.0	0.7	–19904.4	45.0	0.060

Final model: PPT = Year + Area + Season + Year × Season

Table 3. Deviance table for the lognormal model (1973–2006). Factors were added to the model if they accounted for at least 5% of the total reduction in deviance and were significant according to a χ^2 test ($p \leq 0.05$). Terms added to the model are indicated in bold

Lognormal model factors — catch per unit effort (CPUE)	df	Deviance Residual	Deviance Reduction	Deviance % total	Log-likelihood	Chi square	p
Null	5121	2988	—	—	–5887.6	—	—
Year	5089	2873.9	114.1	**40.9**	–5787.9	199.4	**<0.001**
Year + **Skill**	5088	2848.9	25.0	**9.0**	–5765.5	44.8	**<0.001**
Year + Skill + **Area**	5083	2823.2	25.7	**9.2**	–5742.3	46.4	**<0.001**
Year + Skill + Area + **Season**	5080	2806.9	16.3	**5.9**	–5727.4	29.7	**<0.001**
Year + Skill + Area + Season + Area × Skill	5075	2793.2	13.7	4.9	–5714.9	25.0	0.001
Year + Skill + Area + Season + Area × Skill + Season × Skill	5072	2787.9	5.3	1.9	–5710.1	9.7	0.021
Year + Skill + Area + Season + Area × Skill + Season × Skill + Season × Area	5057	2779.5	8.4	3.0	–5702.3	15.5	0.414
Year + Skill + Area + Season + Area × Skill + Season × Skill + Season × Area + Year × Season	4962	2720.3	59.2	21.2	–5647.2	110.2	0.137
Year + Skill + Area + Season + Area × Skill + Season × Skill + Season × Area + Year × Season + Year × Skill	4930	2709.2	11.1	4.0	–5636.8	20.9	0.934

Final model: log(CPUE) = Year + Skill + Area + Season

Table 4. Analysis of mixed model formulations for the binomial model on the proportion of positive trips (1973–2006). The likelihood ratio test was used to test the difference in restricted log-likelihood between 2 nested models. The final model is indicated with bold

	Restricted log-likelihood	Akaike's information criterion	Schwartz's Bayesian criterion	Likelihood ratio test
Year + Area + Season	2068.9	2070.9	2075.5	—
Year + Area + Season + Year × Season	2036.7	2040.7	2046.5	32.2

included Year, Skill, Area and Season. On average, catch rates on skilled fishing trips were 3.6 times as high as on other trips (6.0 versus 1.6). With regard to area, catch rates were higher in Areas 5 (7.6) and 6 (6.1) than in Areas 3 (3.6) and 4 (3.0). The lowest catch rates were observed in Areas 2 (2.6) and 1 (0.8).

Various diagnostics were examined to evaluate the fit of each component of the delta-lognormal model, including distributions of residuals by factor, frequency histograms of the proportion of positive trips by model strata and Q-Q plots of the deviation from the expected lognormal distribution. All diagnostic plots met our expectations, and supported an acceptable fit to the selected models.

The delta-lognormal index shows a decline in the abundance of juvenile goliath grouper from 1976 to 1990. No index estimate was possible for the year 1974 because only 1 positive trip was reported. After the harvest moratorium in 1990, there was a significant increase in the abundance of juvenile goliath grouper (Fig. 4). The uncertainty of the abundance index was

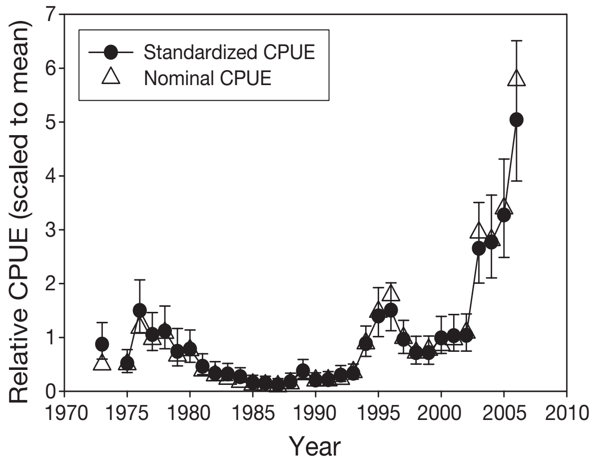

Fig. 4. *Epinephelus itajara.* Nominal and standardized catch per unit effort (CPUE) from 1973–2006. Nominal CPUE is the average annual CPUE before standardization. Both series have been scaled to their respective means. Error bars: upper and lower 95% confidence intervals for the standardized CPUE estimates

Table 5. *Epinephelus itajara.* Abundance index statistics (1973–2006) including nominal catch per unit effort (CPUE, goliath per 1000 angler-hours), number of trips for which interviews were conducted, proportion positive trips (PPT), standardized CPUE, upper and lower 95% confidence intervals (UCI and LCI, respectively) and coefficients of variation (CV)

Year	Nominal CPUE	Trips	PPT	Standardized CPUE	LCI	UCI	CV
1973	2.46	3861	0.028	0.873	0.597	1.275	0.191
1975	2.49	4466	0.024	0.519	0.348	0.776	0.203
1976	5.83	3551	0.053	1.500	1.087	2.070	0.162
1977	4.80	4237	0.044	1.053	0.760	1.460	0.164
1978	5.37	3624	0.041	1.120	0.791	1.584	0.175
1979	3.28	2289	0.028	0.740	0.470	1.164	0.230
1980	3.78	4152	0.028	0.784	0.539	1.140	0.189
1981	1.91	5784	0.016	0.464	0.308	0.697	0.206
1982	1.47	5424	0.010	0.333	0.201	0.549	0.255
1983	1.15	6205	0.010	0.322	0.201	0.516	0.240
1984	0.86	7781	0.008	0.270	0.166	0.438	0.245
1985	0.62	6748	0.005	0.160	0.086	0.298	0.317
1986	0.54	7765	0.005	0.153	0.083	0.279	0.309
1987	0.46	6615	0.005	0.120	0.061	0.236	0.349
1988	0.73	4120	0.008	0.177	0.093	0.337	0.330
1989	1.57	3942	0.019	0.378	0.242	0.590	0.226
1990	1.00	6421	0.009	0.209	0.127	0.343	0.252
1991	1.01	5374	0.009	0.215	0.126	0.364	0.269
1992	1.13	5798	0.011	0.297	0.184	0.479	0.243
1993	1.75	6087	0.016	0.335	0.222	0.504	0.207
1994	4.40	7044	0.034	0.885	0.647	1.211	0.158
1995	7.31	5250	0.040	1.398	1.016	1.924	0.161
1996	8.82	7084	0.046	1.505	1.124	2.013	0.146
1997	4.90	7844	0.031	0.963	0.704	1.318	0.158
1998	3.56	6204	0.024	0.718	0.504	1.021	0.178
1999	3.82	5758	0.024	0.718	0.501	1.027	0.181
2000	4.24	5533	0.029	0.988	0.702	1.391	0.172
2001	4.78	5498	0.036	1.032	0.747	1.424	0.162
2002	5.39	4530	0.042	1.037	0.748	1.438	0.164
2003	14.58	4046	0.090	2.653	2.009	3.505	0.140
2004	13.89	4248	0.089	2.770	2.106	3.643	0.138
2005	16.81	3297	0.103	3.273	2.484	4.312	0.139
2006	28.58	3505	0.150	5.042	3.905	6.509	0.128

quantified using 95% CI (Fig. 4) and coefficients of variation, which ranged from 13 to 35%, and averaged 21% (Table 5). All index statistics, including the proportion of positive trips, nominal (average annual) CPUE, standardized CPUE and uncertainty estimates are summarized in Table 5.

Index 1990 to 2006

We also constructed an index covering the period between 1990 (when the harvest moratorium began) and 2006. This shorter time period is intended to restrict the dataset to trips whose intended catch was not the goliath grouper. The deviance table used during the stepwise construction of the binomial model on proportion of positive trips is summarized in Table 6. The construction of the lognormal model on catch rates of positive trips is described in Table 7. No Year × Factor interaction terms met the inclusion criteria.

Like the previous index, factors that influenced the proportion of positive trips included Year, Area and Season. Goliath grouper were more likely to be caught in Area 5 (6.4%) and Areas 2, 3, 4 and 6 (3 to 4.5%) than in Area 1 (1.1%). Goliath grouper were more likely to be caught on sport fishing trips in summer and autumn (~5%) than in spring (3.5%), and they were least likely to be caught in winter (2.8%).

Factors that influenced catch rates (goliath landed or released per 1000 angler-hours) on positive trips

Table 6. Deviance table for the binomial model (1990–2006). Factors were added to the model if they accounted for at least 5% of the total reduction in deviance and were significant according to a χ^2 test ($p < 0.05$). Terms added to the model are indicated in bold

Binomial model factors — proportion positive trips	df	Deviance			Log-likelihood	Chi square	p
		Residual	Reduction	% total			
Null	93520	31362.8	—	—	−15681.4	—	—
Year	93504	29202.3	2160.5	**63.0**	−14601.2	2160.5	**<0.001**
Year + **Area**	93499	28518.4	683.9	**20.0**	−14259.2	683.9	**<0.001**
Year + Area + **Season**	93496	28276.3	242.1	**7.1**	−14138.2	242.1	**<0.001**
Year + Area + Season + Skill	93495	28132.9	143.5	4.2	−14066.4	143.5	<0.001
Year + Area + Season + Skill + Season × Area	93480	28091.6	41.3	1.2	−14045.8	41.3	0.003
Year + Area + Season + Skill + Season × Area + Area × Skill	93475	28060.4	31.2	0.9	−14030.2	31.2	<0.001
Year + Area + Season + Skill + Season × Area + Area × Skill + Season × Skill	93472	28058.7	1.7	0.0	−14029.3	1.7	0.634
Year + Area + Season + Skill + Season × Area + Area × Skill + Season × Skill + Year × Season	93424	27958.0	100.7	2.9	−13979.0	100.7	<0.001
Year + Area + Season + Skill + Season × Area + Area × Skill + Season × Skill + Year × Season + Year × Skill	93408	27935.6	22.4	0.7	−13967.8	22.4	0.13
Final Model: PPT = Year + Area + Season							

Table 7. Deviance table for the lognormal model (1990–2006). Factors were added to the model if they accounted for at least 5% of the total reduction in deviance and were significant according to a χ^2 test ($p < 0.05$). Terms added to the model are indicated in bold

Lognormal model factors — catch per unit effort (CPUE)	df	Deviance			Log-likelihood	Chi square	p
		Residual	Reduction	% total			
Null	3732	2316.1	—	—	−4406.0	—	—
Year	3716	2263.0	53.2	**34.6**	−4362.7	86.7	**<0.001**
Year + **Season**	3713	2246.2	16.8	**10.9**	−4348.7	27.9	**<0.001**
Year + Season + **Area**	3708	2231.4	14.8	**9.6**	−4336.4	24.6	**<0.001**
Year + Season + Area + **Skill**	3707	2220.2	11.1	**7.2**	−4327.1	18.7	**<0.001**
Year + Season + Area + Skill + Season × Area	3692	2206.6	13.6	8.9	−4315.6	23.0	0.085
Year + Season + Area + Skill + Season × Area + Season × Skill	3689	2201.5	5.1	3.3	−4311.2	8.7	0.034
Year + Season + Area + Skill + Season × Area + Season × Skill + Area × Skill	3684	2197.8	3.7	2.4	−4308.1	6.2	0.284
Year + Season + Area + Skill + Season × Area + Season × Skill + Area × Skill + Year × Season	3636	2168.7	29.2	18.9	−4283.2	49.8	0.4
Year + Season + Area + Skill + Season × Area + Season × Skill + Area × Skill + Year × Season + Year × Skill	3620	2162.3	6.4	4.1	−4277.7	10.9	0.814
Final model: log(CPUE) = Year + Season + Area + Skill							

included Year, Season, Area and Skill. Catch and release rates were higher on fishing trips in summer (8.8) and autumn (8.3) than in spring (5.0). The lowest catch and release rates were in winter (3.8). With regard to area, catch rates were higher in Areas 5 (10.1) and 6 (7.8) than in Areas 2, 3 and 4 (~5.5). The lowest catch rates were observed in Area 1 (1.4). Skill also had an effect on catch rates. Skilled anglers caught and released about 3 times as many goliath grouper as others (7.8 vs. 2.6).

Various diagnostics were examined to evaluate the fit of each component of the delta-lognormal model. All met our expectations and supported an acceptable fit to the selected models. The resulting delta-lognormal index shows a significant increase in the abundance of juvenile goliath grouper since the 1990 harvest moratorium (Fig. 5). The uncertainty of the abundance index was quantified using 95% CI and coefficients of variation. The coefficients of variation ranged from 7% to 24%, and averaged 13% (Table 8). All index statistics including the proportion of positive trips, nominal CPUE, standardized CPUE and uncertainty estimates are summarized in Table 8.

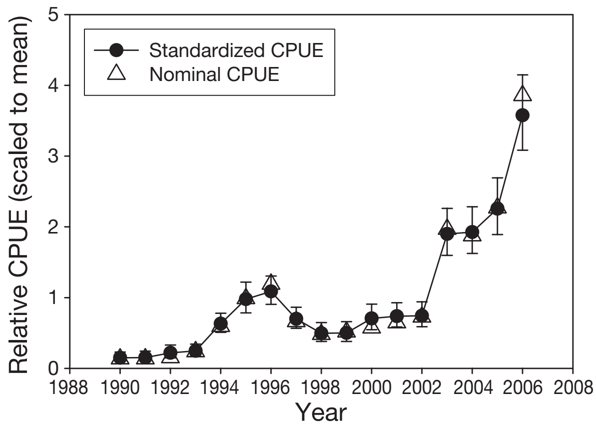

Fig. 5. *Epinephelus itajara.* Nominal and standardized catch per unit effort (CPUE) from 1990–2006. Nominal CPUE is the average annual CPUE before standardization. Both series have been scaled to their respective means. Error bars: upper and lower 95% confidence intervals for the standardized CPUE estimates

DISCUSSION

Ninety-four percent of goliath grouper measured by ENP biologists were smaller than 1 m TL. According to Bullock et al. (1992), most goliath grouper reach sexual maturity at 1.15 to 1.35 m TL. These results indicate that most goliath grouper kept or released by fishermen in ENP are juveniles, and that ENP data are appropriate for the construction of an index of abundance for juvenile goliath grouper. This conclusion is further supported by Bullock & Smith (1991) who report that juvenile goliath grouper are predominately found in the estuarine and swamp mangrove habitats common in ENP.

Anglers in Areas 5, 6 and 3 (Fig. 1) were more likely to encounter goliath grouper and had higher catch rates on positive trips. This result is not unexpected, as these areas contain extensive estuarine and swamp mangrove habitats ideal for juvenile goliath grouper (Bullock & Smith 1991, Koenig et al. 2007). Anglers in

Table 8. *Epinephelus itajara.* Abundance index statistics (1990–2006) including nominal catch per unit effort (CPUE, goliath per 1000 angler-hours), number of trips for which interviews were conducted, proportion positive trips (PPT), standardized CPUE, upper and lower 95% confidence intervals (UCI and LCI, respectively) and coefficients of variation (CV)

Year	Nominal CPUE	Trips	PPT	Standardized CPUE	LCI	UCI	CV
1990	1.00	6421	0.009	0.149	0.097	0.230	0.220
1991	1.01	5374	0.009	0.152	0.095	0.244	0.240
1992	1.13	5798	0.011	0.220	0.146	0.330	0.206
1993	1.75	6087	0.016	0.246	0.177	0.343	0.167
1994	4.40	7044	0.034	0.630	0.510	0.779	0.106
1995	7.31	5250	0.040	0.978	0.784	1.220	0.111
1996	8.82	7084	0.046	1.087	0.905	1.305	0.092
1997	4.90	7844	0.031	0.700	0.567	0.864	0.106
1998	3.56	6204	0.024	0.495	0.379	0.647	0.134
1999	3.82	5758	0.024	0.501	0.380	0.660	0.138
2000	4.24	5533	0.029	0.705	0.547	0.908	0.127
2001	4.78	5498	0.036	0.737	0.586	0.928	0.115
2002	5.39	4530	0.042	0.743	0.588	0.940	0.118
2003	14.58	4046	0.090	1.900	1.597	2.261	0.087
2004	13.89	4248	0.089	1.925	1.624	2.283	0.085
2005	16.81	3297	0.103	2.256	1.890	2.693	0.089
2006	28.58	3505	0.150	3.576	3.083	4.148	0.074

Area 4 were less likely to encounter goliath grouper and had lower catch rates on positive trips. These trips were likely to occur in Whitewater Bay, a habitat less ideal for juvenile goliath grouper. The lowest proportion of positive trips and catch rates on positive trips occurred in Florida Bay and its immediate surroundings (Area 2), suggesting that this may be a poor habitat for juvenile goliath grouper, which are known to prefer undercut banks and mangrove swamps.

The delta-lognormal index is quite similar to the nominal CPUE series and the annual trend in the proportion of positive trips. Each time series indicates a substantial decline in abundance during the late 1970s and 1980s. During that time, rising demand for goliath grouper inflated selling prices, which led to a corresponding increase in landings and directed effort, particularly in the USA Gulf of Mexico (Sadovy & Eklund 1999). Commercial landings of goliath grouper off the Florida Gulf Coast increased from 15 400 kg in 1978 to 61 400 kg in 1988, then dramatically declined (Sadovy & Eklund 1999). Index abundance estimates were uniformly low during the 1980s, consistent with reports of diminished populations at aggregation sites (D. DeMaria pers. comm.).

Since the 1990 moratorium, which prohibited landing goliath grouper in USA federal and State of Florida waters, abundance estimates suggest that populations of juvenile goliath grouper have increased appreciably within ENP. Particularly large numbers of juveniles are noted during 1995, 1996 and 2004 to 2007, suggesting that one or more strong year classes were present during those years. These results are consistent with additional indices described by Porch & Eklund (2004). They constructed indices for goliath grouper using visual survey data and reported similar increases after 1990, with the highest abundances occurring after 1997. These indices have not been updated since publication. Since these surveys monitored the reef and wreck habitats typically occupied by adults, it is not inconsistent that maximal abundances occurred after 1997. A short delay is anticipated as juvenile fish mature and migrate to adult territory.

It is possible that fishermen are less likely to target goliath grouper since the 1990 harvest moratorium, although catch and release has always been permitted. Therefore, we constructed a second index restricted to the period of the moratorium. This index shares the same trend as the longer time series.

The results of this study suggest that the abundance of juvenile goliath grouper within ENP has increased considerably since the 1990 harvest moratorium. This conclusion is further supported by the research of Koenig et al. (2007), who determined the density of juvenile goliath grouper at selected sampling sites within ENP and the Ten Thousand Islands region, then estimated the total abundance of juveniles in the region by extrapolating their density across the total area of suitable habitat. They estimated that 71 000 juveniles were present within the analysis region. This number may underestimate the total abundance of juvenile goliath grouper if the range of appropriate habitat extends beyond ENP and the Ten Thousand Islands area. However, the number may be an overestimate if the habitat within the region is, on average, less suitable than the selected sampling sites.

These results support the conclusion of NOAA/NMFS that the USA population of goliath grouper is no longer in danger of extinction in the immediate future. However, the species cannot be considered fully recovered from a management standpoint until spawning stock biomass and age structure have recovered to a sustainable level (i.e. maximum sustainable yield). More conservative measures of recovery would dictate that the species repopulate its former geographic range at historic densities (i.e. 'virgin' or unfished stock size). It should also be noted that while these results suggest greatly increased abundance of juveniles in the primary habitat (ENP), it is unclear what proportion of these animals survive to sexual maturity, or whether similar increases in abundance are occurring in the adult habitat. This may become evident as visual surveys of adult habitat are reanalyzed (Porch & Eklund 2004) prior to the next stock assessment.

It is unlikely that the ENP indices solely reflect trends in abundance. Goliath grouper appear to be hardy animals with low release mortality. Tagging studies in ENP have recaptured juvenile goliath grouper up to 8 times without mortal injury (J. Schul pers. comm.). As goliath grouper increase in abundance within ENP, fisherman might be more likely to target certain sites known to be inhabited by a resident goliath grouper. If certain individuals are repeatedly targeted by fishermen, estimates of abundance would be inflated. It is not known how often this fishing behavior occurs or whether the likelihood of this type of fishing has varied through time. Indices of abundance would only be affected if the likelihood has varied substantially and systematically over time. This could be an important topic for future research.

In addition to fisheries-dependent CPUE data, environmental variables are also routinely monitored within ENP, including rainfall, water level, salinity, temperature, turbidity and nutrients. These factors may also influence the abundance of juvenile goliath grouper in part by altering the quality and quantity of the habitat available within the park. We are currently investigating the construction of an improved index of abundance that incorporates environmental covariates. This technique would enhance our understanding of the factors that influence the abundance of goliath grouper and could be used to examine trends in the abundance of other species commonly observed within ENP.

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