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R. SLUKA,
M. CHIAPPONE,
K. M. SULLIVAN,
and
R. WRIGHT

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THE BENEFITS OF A MARINE FISHERY RESERVE FOR NASSAU GROUPER *EPINEPHELUS STRIATUS* IN THE CENTRAL BAHAMAS

R. Sluka[1], M. Chiappone, K.M. Sullivan, and R. Wright

The Nature Conservancy, Florida and Caribbean Marine Conservation Science Center and University of Miami, Department of Biology, P.O. Box 249118, Coral Gables, Florida 33124, U.S.A.
[1]Current address: Oceanographic Society of Maldives, P.O. Box 2075, Malé, Republic of Maldives

ABSTRACT

Nassau grouper (*Epinephelus striatus*) are an important coral reef fish, both economically and ecologically. Intense fishing pressure has been shown to decrease the abundance and average size of this species. Marine reserves have been suggested as areas which can ameliorate the effects of intense fishing pressure and protect the size, abundance, and reproductive output of targeted species; as well as provide benefits to fisheries outside of the reserve. This benefit will be through export of biomass by larval transport and/or adult emigration. The benefits of a marine fishery reserve in the central Bahamas, Exuma Cays Land and Sea Park (ECLSP), were evaluated with regard to these factors. Seventy-four sites among four coral reef and hard-bottom habitat types were sampled along the northern Exuma Cays from Sail Rocks to Staniel Cay, a distance of approximately 90 km. Habitats were selected within, north and south of the park. Groupers are known to be associated with coral reef and hard-bottom habitats, thus it was hypothesized that habitat type might influence grouper distribution in addition to fishing pressure. Underwater visual censuses were completed using ten 20-m x 5-m transects at each site. Statistical analyses were performed to evaluate differences in density and biomass relative to protection and habitat type. The average biomass and size of Nassau grouper was statistically greater inside the ECLSP than outside. There was no significant difference in the average biomass among habitat types. The average biomass of Nassau grouper at sites within 5 km of park boundaries was more similar to sites inside the park than sites greater than 5 km. It is suggested that this is due to the movement of individuals across park boundaries. Reproductive output (no. eggs ha^{-1}) was over six times higher inside the ECLSP than outside. We conclude that: 1) the ECLSP is adequately protecting Nassau grouper resources, 2) habitat was relative unimportant in affecting their distribution, and 3) the ECLSP is exporting Nassau grouper biomass across park boundaries.

INTRODUCTION

Historically, Nassau grouper (*Epinephelus striatus*) was one of the most important coral reef fisheries resources in the tropical western Atlantic (Sadovy in press). This species is ecologically important as a top-level predator in coral reef ecosystems (Parrish 1987) and is the most sought after finfish in the commercial and artisanal fisheries of the Bahamas. Nassau grouper landings in the Bahamas for 1992 were 798,172 lbs worth $1,701,767 US (pers. comm. Bahamas Department of Fisheries). Only 2% of this catch originated in the Exuma Cays. However, this does not include grouper caught for local consumption. Grouper abundance in the Exuma Cays is high relative to intensively fished areas such as the Florida Keys (Sluka et al. 1994).

Intense fishing pressure tends to decrease the abundance and average size of fish species (Roberts and Polunin 1991). Moreover, Nassau grouper exhibits the characteristics of slow growth to a large size, delayed reproduction, possible sex reversal, and aggregation spawning (Manooch 1987; Shapiro 1987). These characteristics make this species especially susceptible to intense fishing (Sadovy 1994, in press). Conventional management of coral reef fisheries have largely failed, due to either inadequate enforcement or lack of biological information on targeted species. However, recent evidence shows that protection of groupers in a marine fishery reserve (MFR) results in a reversal of the effects of fishing (PDT 1990). Groupers inside MFRs tend to be more abundant and larger than those occurring outside (Russ 1985).

Grouper species tend to differ in their relative abundance among types of coral reefs and can have specific habitat preferences (Nagelkerken 1979; Shpigel and Fishelson 1989; Sluka and Sullivan 1996b). Thus, it may be critical to consider the habitat preferences of commercially targeted species when designing marine fishery reserves. Nassau grouper can be found in high-relief coral reef habitats and over rocky bottom (Starck 1968; Bannerot et al. 1987). Post-settlement (25-35 mm TL (total length)) Nassau grouper in the Bahamas occupied algal-covered coral clumps, early juveniles (60-150 mm TL) were found outside of and adjacent to algal-covered coral clumps, and larger juveniles (>150 mm TL) were found associated with patch reefs (Eggleston 1995). Sluka and Sullivan (1996a) and Sluka et al. (in press) showed that the movement and activity patterns of Nassau grouper were significantly influenced by the position and presence of cleaning stations.

The Exuma Cays Land and Sea Park (ECLSP) is located in the central Bahamas and was established by the Bahamas Government in 1958. The following year, the Bahamas National Trust (BNT), a non-governmental organization, was created by an Act of Parliament and mandated with the responsibilities and powers to manage the ECLSP and any future national parks. The ECLSP encompasses a 35-km long section of the northern Exuma Cays, covering an area of 456 km^2. Initially, limited fishing was allowed, but by the 1980s, fishing pressure in the park had increased dramatically and the BNT changed the park by-laws in 1986 to make the entire area a no-take zone.

The goals of this study were to: 1) determine if protection within the ECLSP has resulted in grouper assemblages with greater size, biomass, and reproductive output than assemblages outside the reserve, 2) determine the role of habitat in influencing the distribution of Nassau grouper, and 3) determine whether or not the ECLSP is exporting Nassau grouper biomass to areas north and south of the park boundaries.

MATERIALS AND METHODS

Data were collected at seventy-four sites in four types of hard-bottom habitats: patch reef, channel reef, fringing reef, and windward hard-bottom (Fig. 1). At each site ten 20-m x 5-m haphazardly placed transects were surveyed for the number and size of Nassau grouper. Density values were converted to biomass using a known length-weight relationship (Sadovy and Colin 1995). The width of the transect was visually estimated. The number of transects surveyed reflects a balance between cost in time and precision of estimates (McCormick and Choat 1987). Precision is defined by $p = (s/n^{0.5})/X$, where p = precision, s = standard deviation, n = sample size, and X = mean. The precision of our sampling design was evaluated prior to commencing field work using data from Sluka et al. (1994). The mean density of groupers in the ECLSP during the study of Sluka et al. (1994) was 2.45 (no. 100 m^{-2}) with a standard deviation of 1.26. The desired level of precision was 0.20, which represents acceptable variability for ecological studies. The equation for precision can be solved for sample size (n), so that for a desired level of precision, the necessary sample size can be calculated: $n = (s/(p \cdot X))^2$. Seven samples were necessary for a precision of 0.20. Based on time constraints, it was decided that all transects at a site should be completed in one dive. Thus, ten transects were determined to be an appropriate sample size at each site, being greater than the calculated value for the desired precision and easily completed in one SCUBA dive at the range of depths that would be encountered.

Observers were trained to accurately estimate the width of transects by swimming the length of a transect and placing construction flags at the estimated distance of 2.5 m out on each side of the line. The average estimated distance was compared to the desired estimate and biases were made known to the observers. Observers were also trained to estimate the length of fish to the nearest cm by swimming past a series of fish models and visually estimating their sizes. Results were compared to known lengths for each model and the individual biases were made known to each observer.

Data, using transects as replicates, were tested for normality and homogeneity of variances using the Wilke-Shapiro and Cochran's Q test, respectively (Sokal and Rohlf 1981). It was determined that the data were non-normal and variances heterogeneous after transformation. Mean values for sites were then considered as the replicates within each of the treatment effects, allowing valid tests of our

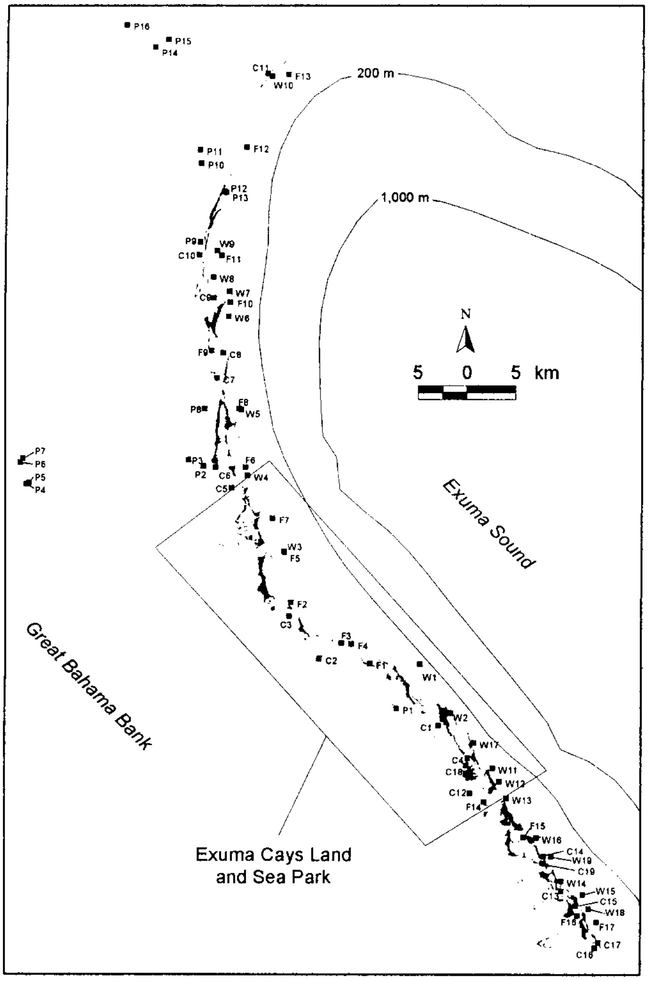

Fig. 1: Map of study sites showing location along the northern Exuma Cays island chain. Site codes indicate which habitat type was sampled: C = channel reef, F = fringing reef, P = patch reef, and W = windward hard-bottom.

hypotheses, but avoiding 'sacrificial pseudo-replication', the combining of data from several sites for statistical analyses (Hurlbert 1984). Using the sites as replicates, biomass data were normal and variances homogeneous after transformation. Thus, differences due to protection from fishing and varying habitat were determined by two-way analysis of variance (ANOVA). Tukey tests were used to determine which categories were significantly different from each other. Size data were not normally distributed even after transformation. Sites were again used as replicates, but Kruskal-Wallis ANOVA was used to test each factor separately. Patch reefs were not included in statistical analyses due to the unequal distribution of sites among location categories (Fig. 1).

The total number of eggs produced by adult, female Nassau grouper per ha was estimated from the length distributions and density calculations. For data collected north, inside, and south of the ECLSP, the length frequency distributions were calculated separately using 5-cm intervals. The percentage of individuals in each size category was calculated and multiplied by the mean density (no. ha^{-1}) (density (1 SE) = 0.20 (0.03), 0.35 (0.04), 0.16 (0.3) north, inside, and south of ECLSP, respectively). Observations of immature Nassau grouper (<50 cm TL) were disregarded (Sadovy and Colin 1995). The number of individuals in each size category ha^{-1} was then multiplied by 0.67 to account for a 2:1 F:M sex ratio (Sadovy and Colin 1995). The weight of a grouper in a particular size category was estimated by multiplying the midpoint of the size category by the appropriate length-weight relationship (Sadovy and Colin 1995). The gonadosomatic index of adult, female Nassau grouper is 0.10 (Sadovy and Colin 1995). The weight of ovaries of an individual was taken as 10% of the weight calculated for an individual of that size class. This value was then multiplied by the total number of individuals ha^{-1} in that size class. This gave the total weight of ovaries ha^{-1} for each of the three protection categories. Taking the average number of eggs per mg of ovary tissue for Nassau grouper as 4.5 (Sadovy and Colin 1995), the total number of eggs produced ha^{-1} was then calculated by multiplying the total ovary weight ha^{-1} for each size class by 4.5 and summing.

RESULTS

There was a significant difference in Nassau grouper size among sites with differing protection from fishing ($p < 0.01$, Table 1). Mean Nassau grouper size inside the ECLSP was significantly greater than outside. There was no significant influence of habitat type ($p > 0.05$, Table 2). However, patch reefs contained smaller individuals than the other three habitat types (Table 2).

Table 1: Mean (SE) biomass (g 100 m^{-2}) and size (cm) of Nassau grouper north, inside, and south of ECLSP. The number of transects completed in each area are indicated as n. Patch reefs are not included in this summary due to their unequal distribution among locations.

	North	ECLSP	South
n	248	200	150
Biomass	156 (33)	574 (98)	118 (37)
Size	31 (2)	42 (2)	34 (2)

Biomass differed significantly among protection levels ($p < 0.001$), but not habitat types ($p > 0.05$). However, patch reefs had a higher biomass per unit area than did the other three reef types (Table 2). The interaction factor was not significant ($p > 0.05$). The mean biomass was significantly higher inside ECLSP than outside (Table 1). Precision of biomass estimates for sites ranged from 0.21 inside to 0.27 south of the ECLSP.

Table 2: Mean (standard error) biomass (g 100 m^{-2}) and size (cm) of Nassau grouper among habitat types. The number of transects completed are indicated as n.

	Patch	Channel	Fringing	Windward
n	49	190	170	190
Biomass	493 (254)	251 (45)	303 (70)	253 (62)
Size	30 (3)	36 (1)	41 (2)	40 (2)

The total number of eggs produced by adult, female Nassau grouper was 1.43×10^6, 8.61×10^6, and 1.35×10^6 ha^{-1} north, inside, and south of the ECLSP, respectively. The number of eggs produced inside the park was 6.02 and 6.38 times greater than north and south of the ECLSP, respectively (Fig. 2). Thirty-five percent of the individuals inside the ECLSP were greater than 50 cm TL and thus likely to be sexually mature. Only 14% and 8% of the groupers observed north and south of the park were estimated to be sexually mature, respectively.

DISCUSSION

This study showed that the ECLSP is protecting the size, abundance, and reproductive output of Nassau grouper in the central Bahamas. There were more and larger Nassau grouper inside the ECLSP than outside and habitats inside the park produced on the average six times as many eggs per unit area as did similar habitats outside of the park. Biomass data reported here are much higher than previously estimated for these habitats. Smith (1988) estimated that the mean biomass of Nassau grouper in coral reef (defined similarly to our patch, channel and fringing habitat types) and rock (defined similarly to our windward hard-bottom habitat type) habitats in the northern Great Bahama Bank was 150 and 80 g 100 m^{-2}, respectively. Our estimate for the combined patch reef, channel reef, and fringing reef habitats was 349 g 100 m^{-2} and for the windward hard-bottom 253 g 100 m^{-2}. Our estimates were higher probably due to 1) sampling design and 2) location of samples. Smith (1988) surveyed groupers using 150 x 10 m transects, and noted that some transects crossed into other types of habitats, including soft-sediment and sand habitats which were shown

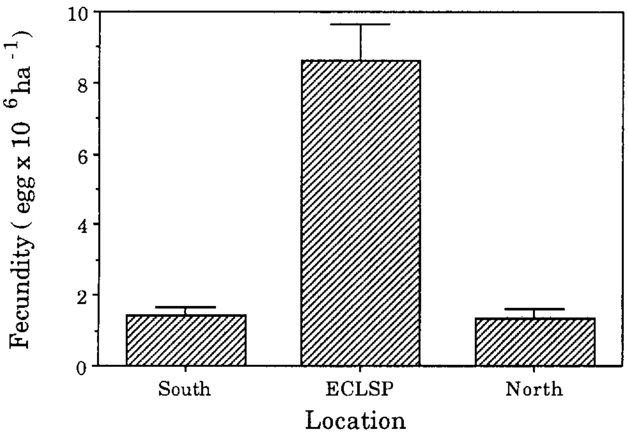

Fig. 2: Reproductive output (no. eggs ha^{-1}) of Nassau grouper north, inside, and south of the Exuma Cays Land and Sea Park (ECLSP). Error bars indicate 1 standard error.

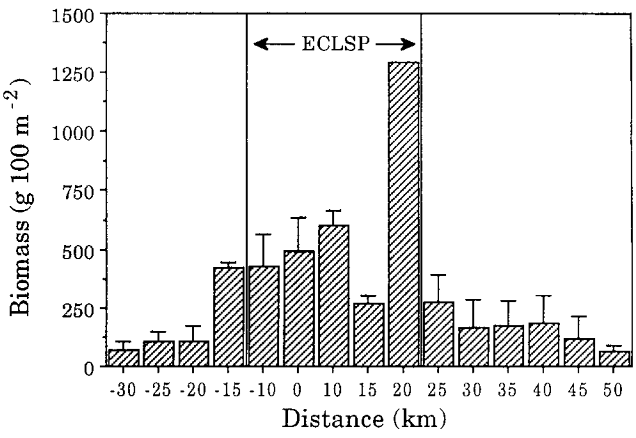

Fig. 3: Relationship between distance north (positive number) and south (negative number) of the ranger station and Nassau grouper biomass (g 100 m^{-2}). Error bars indicate 1 standard error. The boundaries of the Exuma Cays Land and Sea Park (ECLSP) are indicated by vertical lines.

to have very low Nassau grouper biomass. The habitat type of a transect was designated as the habitat constituting the majority of the transect. Smith (1988) also sampled farther north of the northern Exumas, which likely experiences more intense fishing pressure due to the proximity to more populated areas such as Nassau.

Smith (1988) showed that Nassau grouper occur almost exclusively in hard-bottom habitats with structural relief. The lack of a significant relationship between habitat and the abundance of Nassau grouper in the present study implies that it is unimportant which hard-bottom habitats are protected, but mainly that some preferred habitat of Nassau grouper is protected. This result only applies to the range of coral reef habitats studied. For example, we can make no statement about the importance of mangrove habitats to Nassau grouper abundance. It appears that Nassau grouper do not preferentially occupy either channel, fringing, or windward hard-bottom habitats, and can be abundant equally among these habitat types. Thus, it is more important to protect reefs from fishing than to protect the 'correct' type of reef. However, it should be clear that a wide range of habitats is still necessary to protect all life history stages. Algal covered clumps and patch reefs are important in the early life history of this species (<150 mm total length) (Eggleston 1995) and should be included in any reserve design. Patch reefs in the Exuma Cays had a greater abundance of smaller individuals, indicating ontogenetic movements offshore with increasing size (Ross and Moser 1995). The relationship between grouper abundance and habitat is a function of the scale and detail at which it is studied (Sluka 1995).

Direct evidence of biomass export through the spillover of adults was not collected in the study. However, by examining patterns in the spatial distribution of grouper biomass, this process can be inferred. Based upon theoretical evidence and tagging studies, it is hypothesized that the abundance of targeted species should increase directly outside of marine fishery reserve boundaries due to movement of adults (Russ et al. 1992; Attwood and Bennett 1994). For example, in a study by Attwood and Bennet (1994), 17.8% of tagged *Coracinus capensis* were recaptured a minimum of 25 km and a maximum of 1,044 km from the tagging site. Trap catches decreased gradually from the center of a marine reserve in Barbados (Rakitin and Kramer 1996). However, this pattern was not established for visual census or individual species data and sites sampled were located at a maximum distance of 4 km from the center of the reserve. The data from the present study support the hypothesis that Nassau grouper biomass was more similar to levels inside ECLSP immediately outside of park boundaries than in areas further away (Fig. 3).

In conclusion, the ECLSP is protecting the size, biomass, and reproductive output of Nassau grouper in the northern Exuma Cays. There was no evidence that habitat was an important consideration in the design of marine fishery reserves for adult Nassau grouper, within the range of coral reef habitats studied. However, there was evidence of ontogenetic migrations by this species. Analysis of spatial patterns of Nassau grouper biomass indicated that the ECLSP was exporting Nassau grouper biomass to the surrounding area through adult emigration.

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