THE BENEFITS OF A MARINE FISHERY RESERVE
FOR NASSAU GROUPER *Epinephelus striatus*
IN THE CENTRAL BAHAMAS

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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 diversity of populations, 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 conducted ten 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 in and out of the 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 a top-level predator to coral reef fish species, 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 a commercially valuable top-level predator in coral reef ecosystems (Parrish 1987) and is the most sought after fish in the commercial and artisanal fisheries of the Bahamas. Nassau grouper from the Bahamas were reportedly worth 798,172 lbs worth $1,701,767 US (pers. comm. Bahamas Department of Fisheries). Only 2% of this catch originated from the Exuma Cays. However, this does not include grouper caught for local consumption. Nassau 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 overfishing (Sadovy 1994, in press). Conventional management of coral reef fisheries have largely failed, due to 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).

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 conducted on ten 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 in and out of the 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 a top-level predator to coral reef fish species, 2) habitat was relative unimportant in affecting their distribution, and 3) the ECLSP is exporting Nassau grouper biomass across park boundaries.

The Exuma Cays Land and Sea Park (ECLSP) was 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 of the ECLSP. The ECLSP encompasses a 35-km long section of the northern Exuma Cays, covering an area of 456 km². Initially, limited fishing was allowed, but by the 1980s, fishing pressure had increased dramatically. In 1986, the BNT changed the park by-laws 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 areas outside the reserve, 2) compare the distribution 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^2/n^2)/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 2.46 groupers/ha. Using a desired precision of 0.26. The desired level of precision was 0.20, which represents acceptable variability for ecological studies. The number of transects for a desired level of precision (n), so that for a desired level of precision, the necessary sample size can be calculated: n = (s/p-X)^2. Seven samples were necessary for a precision of 0.20. Based on time constraints, it was decided that the same number of 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 m out and 1 m in. 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 using a visual estimation 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 variance by testing Kolmogorov-Smirnov, 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 the ECLSP were then considered for the ECLSP alone and in each of the treatment effects, allowing valid tests of our
calculated and multiplied by the mean density (no. percentage of individuals in each size category was then calculated for an individual of that size class by the appropriate length-weight relationship (Sadovy and Colin 1995).

The gonadosomatic index of adult, female Nassau grouper was 10% of the weight of ovaries of an individual was taken as 10% of the weight of an individual of ovaries of an individual was taken as 10% of the weight of an individual (Sadovy and Colin 1995).

The number of eggs produced by adult, female Nassau grouper was 1.03 x 10^6, 8.61 x 10^6, and 1.35 x 10^7 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 groupers 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) 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.

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.

<table>
<thead>
<tr>
<th></th>
<th>North</th>
<th>ECLSP</th>
<th>South</th>
</tr>
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<tbody>
<tr>
<td>Biomass</td>
<td>156 (33)</td>
<td>574 (58)</td>
<td>118 (37)</td>
</tr>
<tr>
<td>Size</td>
<td>31 (2)</td>
<td>42 (2)</td>
<td>34 (2)</td>
</tr>
</tbody>
</table>

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 north, inside, and south of ECLSP. The number of transects completed are indicated as n.

<table>
<thead>
<tr>
<th></th>
<th>Patch</th>
<th>Channel</th>
<th>Fringing</th>
<th>Windward</th>
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</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>493 (254)</td>
<td>251 (45)</td>
<td>303 (70)</td>
<td>253 (62)</td>
</tr>
<tr>
<td>Size</td>
<td>30 (3)</td>
<td>36 (1)</td>
<td>41 (2)</td>
<td>40 (2)</td>
</tr>
</tbody>
</table>

The total number of eggs produced by adult, female Nassau grouper was 1.43 x 10^6, 8.61 x 10^6, and 1.35 x 10^7 ha^-1 north, inside, and south of the ECLSP, respectively.
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 (1998) also sampled fished north of the northern Exuma, which likely experiences more intense fishing pressure due to the proximity to more populated areas such as Nassau.

Smith (1998) 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 1990) 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 (Smith 1988). 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 Bennett (1994), 17.8% of tagged Coracinus capensis were recaptured a minimum of 25 km and a maximum of 1,048 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.

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.

**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.

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