ABSTRACT

Fish spawning aggregation sites should be integrated into the design of marine reserves (MR) that seek to conserve biodiversity and manage local fisheries. Field research conducted since 2005 at Mona Island, Puerto Rico has provided useful data for this purpose. The remote islands of Mona and Monito are enclosed in the largest marine protected area and MR (no-take zone) in Puerto Rico. The MR originally designated around Mona and Monito Islands in 2004 was established using general management principles but not with specific information on fish distribution and abundance. Underwater visual surveys throughout the insular platform were performed using three methods (belt transects, roving and drift dives). At least 22 coral reef species including threatened groupers (*Epinephelus guttatus, Mycteroperca tigris* and *M. venenosa*) were documented spawning or with indirect evidence of spawning at aggregation sites located outside the 2004 MR boundaries. As data on the location of these aggregations became available the MR boundaries were modified in 2007 as an amendment to the local fisheries regulations. The new and expanded boundaries protect other spawning sites as well, since these generally occur on the insular shelf break, and depth (100 fathoms) was utilized to define the new boundary. These results demonstrate the viability of the approach used in this study for locating spawning aggregations to provide information for fisheries management and MR design. The expansion of the no-take zone boundaries at Mona Island provides heavily exploited groupers and other species with the potential for recovery and supports ecosystem-based management.

KEY WORDS: Spawning aggregation, marine reserve, Mona Island
especially true for remote islands, which are more depend-
ent upon local sources of larvae for population stability. 
Once spawning aggregations cease to form at remote 
islands it is less likely their populations will recover, as 
demonstrated by the Nassau grouper.

In Puerto Rico spawning aggregations of grouper have 
documented from Vieques (Sadovy et al. 1994, Matos 
Caraballo et al. 2006), La Parguera (Shapiro et al. 1993) 
and the west coast insular platform (Sadovy et al. 1994). Intensive 
fishing has caused stock declines of some of 
these aggregations (e.g., Marshak 2007), while still others 
are known to have disappeared, most notably several 
Nassau grouper aggregations (Sadovy 1999). On Mona 
Island, Puerto Rico, reports from fishermen indicate that a 
large spawning aggregation of Nassau grouper existed but 
was extirpated in the 1970s (Colin 1982). Recent efforts to 
locate it have been unsuccessful but have provided new 
information on a multi-species aggregation site (Nemeth et al. 2007a), 
which includes various grouper species 
considered threatened on the IUCN Red List (Brulé and 
Garcia-Moliner 2006).

The Mona Channel, located between Puerto Rico and 
the Dominican Republic, is a partial bio-oceanographic 
barrier (Taylor and Hellberg 2003, Baums et al. 2006), 
implying that the Islands of Mona and Monito are possibly 
stepping stones connecting coral reef species of eastern and 
central Caribbean regions. The Mona Island Natural 
Reserve (NR) is currently the largest MPA in Puerto Rico 
(Aguilar-Perera et al. 2006a), with abundant coral reef 
habitats and relatively less impacted fish populations.

**Figure 1.** Mona and Monito Islands Natural Reserve (NR) and no take zone (NTZ) of 2004
Therefore, including critical habitats within this MPA and protecting spawning aggregation sites with no-take regulations is essential for the recovery of threatened grouper species and the conservation of coral reef ecosystems. The decline of grouper populations at this site could have long-term impacts upon genetic connectivity in the region and affect marine eco-regional conservation strategies.

The purpose of this study was to evaluate the abundance of species that form spawning aggregations within the Mona Island NR specifically for coral reef fishes and groupers. Of those species present, could we locate their spawning aggregations? And finally, we wanted to know if these aggregations were within the NTZ boundary, and if not, how could we include them? Our approach consisted of collecting local ecological knowledge (LEK) and surveying the complete insular platform with three distinct underwater visual survey methods in order to determine the location of critical habitats and fish spawning aggregation sites. It was expected that the data resulting from this research could be integrated into the decision-making process following the EBM principle of adaptive management.

METHODS

Mona and Monito Islands (67.89° W, 18.09° N) are located in the Mona Passage between the Dominican Republic (66 km) and Puerto Rico (68 km) (Figure 1). Both islands occur on separate carbonate platforms formed approximately 15 million years ago (Late Miocene to early Pliocene) and uplifted from the seafloor due to tectonic movements (Frank et al. 1998). At Mona Island only the southern half of the insular platform supports shallow (<30 m) coral reefs and seagrass habitats. Vertical cliff walls extending 40 m above and below sea level surround the northern coast of Mona Island and all of Monito Island. Trade winds from the east or northeast generate the predominant waves and surface currents in the Mona Passage. Both islands are uninhabited except for Department of Natural and Environmental Resources (DNER) rangers and biologists on Mona Island. Due to the distance from the main island of Puerto Rico visitors to Mona Island are predominantly fishers and campers, and hunters that visit the island from December to April. All campers require an advanced permit from the DNER to stay overnight; however, boaters that remain on-board their vessels do not require permits. There are two main camping sites, Sardinera on the west coast, staff headquarters with pier, and Pájaros, which lacks permanent infrastructure except for a pier.

The Mona and Monito Islands NR designated in 1986 (Aguilar-Perera et al. 2006a) includes the waters up to 9 nautical miles from shore making it the largest marine protected area (MPA) in Puerto Rico, encompassing 1,576 km². Within the Mona and Monito Islands NR a no-take zone (NTZ), effectively a MR, was designated in 2004...
extending 0.5 nautical miles from shore around all of Monito and most of Mona Island and covering a total marine area of 32 km² (Figure 1). This NTZ designation was included in local fisheries regulations # 6768 (DNER, 2004), which is based on Puerto Rico Law # 278 (DNER, 1998). The NTZ included submerged areas of the insular platform including areas of deep (> 30 m) habitats on the northern coast of Mona Island and around Monito Island as well as shallow (< 30 m) coral reef habitats on the southern portion of the insular platform of Mona Island. The half-mile limit of the NTZ around Mona Island did not include the shelf edge zone of the insular platform along the south and southeast where coral reef development is extensive.

Data on the abundance of fishes and their distribution were investigated through underwater surveys at randomly selected sites around Mona Island. Fish abundance and size (fork length) was collected in stationary belt transects (60 m²) and roving surveys (5 minutes) designed to detect species rarely quantified in belt transects (e.g. large groupers). With this information and a digitized benthic habitat map (100 m² MMU) the important habitats for each species were identified.

Information on spawning aggregations was gathered through a combination of sources including: interviews to fishers with local ecological knowledge (LEK), anecdotal reports, scientific literature, and underwater visual surveys following protocols of the Society for the Conservation of Reef Fish Aggregations, SCRFA (Colin et al. 1982). Fishers from the western coast of Puerto Rico were interviewed to gather information specifically on the fisheries activities of Mona Island that targeted coral reef fishes in spawning aggregations (snappers and groupers).

Based on the LEK, reports and scientific literature on spawning seasonality we targeted underwater visual surveys along drift dives in specific areas of the insular platform of Mona and Monito Islands to locate aggregation sites. Survey dive tracks were recorded with a global positioning system (GPS) unit attached to a buoy in order to quantify the area searched and map the position of observations. Geographic coordinates of the survey tracks were matched with fish observations by recording time of observation on a dive-watch synchronized to GPS satellite time. With this information we created layers of potential spawning aggregation sites. For target species we recorded size (fork length, FL), abundance, and spawning clues such as behavior, coloration and morphological characteristics. Repeated underwater surveys were conducted at sites where aggregations were suspected in order to determine species abundances and record direct or indirect observations of spawning activity (Colin et al. 2003).

### RESULTS

Belt transects were conducted at 613 points between October 2005 to March 2006, and at 283 of these sites roving surveys were also employed (Schärer, 2009). During these surveys evidence of reproductive characteristics was observed for two species: the rock hind (*Epinephelus adscensionis*) and red hind (*E. guttatus*), the former were observed with distended abdomen and the latter in territorial displays and a distinct color phase on the southern coast of Mona Island near the shelf break. Spatial

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthostrocion quadricornis</td>
<td>Scrawled cowfish</td>
<td>Spawning</td>
</tr>
<tr>
<td>Acanthurus coeruleus</td>
<td>Blue Tang</td>
<td>Spawning</td>
</tr>
<tr>
<td>Balistes vetula</td>
<td>Queen Triggerfish</td>
<td>Nesting</td>
</tr>
<tr>
<td>Caranx latus</td>
<td>Horse-eye jack</td>
<td>Group formation</td>
</tr>
<tr>
<td>Clepticus parra</td>
<td>Creole Wrasse</td>
<td>Spawning</td>
</tr>
<tr>
<td>Diodon hystrix</td>
<td>Spot-fin Porcupinefish</td>
<td>Color phase</td>
</tr>
<tr>
<td>Epinephelus adscensionis</td>
<td>Rock Hind</td>
<td>Gravid</td>
</tr>
<tr>
<td>Epinephelus guttatus</td>
<td>Red Hind</td>
<td>Gravid and color phase</td>
</tr>
<tr>
<td>Epinephelus striatus</td>
<td>Nassau Grouper</td>
<td>Color phase</td>
</tr>
<tr>
<td>Halichoeres radiatus</td>
<td>Puddingwife</td>
<td>Spawning</td>
</tr>
<tr>
<td>Lactophrys triqueter</td>
<td>Smooth trunkfish</td>
<td>Color phase</td>
</tr>
<tr>
<td>Lutjanus jocu</td>
<td>Dog Snapper</td>
<td>Color phase</td>
</tr>
<tr>
<td>Mullloidichthys martinicus</td>
<td>Yellowtail Goatfish</td>
<td>Spawning</td>
</tr>
<tr>
<td>Mycteroperca bonaci</td>
<td>Black Grouper</td>
<td>Gravid and color phase</td>
</tr>
<tr>
<td>Mycteroperca interstitialis</td>
<td>Yellowmouth Grouper</td>
<td>Color phase</td>
</tr>
<tr>
<td>Mycteroperca tigris</td>
<td>Tiger Grouper</td>
<td>Gravid and color phase</td>
</tr>
<tr>
<td>Mycteroperca venenosa</td>
<td>Yellowfin Grouper</td>
<td>Spawning</td>
</tr>
<tr>
<td>Pomacanthus paru</td>
<td>French Angelfish</td>
<td>Spawning</td>
</tr>
<tr>
<td>Scorus taeniopterus</td>
<td>Princess Parrotfish</td>
<td>Spawning</td>
</tr>
<tr>
<td>Sparisoma chrysopterum</td>
<td>Redtail Parrotfish</td>
<td>Spawning</td>
</tr>
<tr>
<td>Sparisoma rubripinne</td>
<td>Yellowtail Parrotfish</td>
<td>Spawning</td>
</tr>
<tr>
<td>Sparisoma viride</td>
<td>Stoplight Parrotfish</td>
<td>Spawning</td>
</tr>
</tbody>
</table>
distributions of fish discriminated by size revealed most of the early juvenile settlement habitat for epinephelids occurred in seagrass or rocky habitats in back-reef lagoons near shore (Aguilar-Perera et al. 2006b), most of which were located within the NTZ limits.

During three years (2004 to 2007), 53 GPS track surveys were conducted searching for spawning aggregations, involving approximately 38 hours underwater. Belt transects and 5-minute roving surveys detected groupers in very low frequencies compared to the drifting GPS track surveys (Figure 2). GPS-tracked drift surveys were more successful at sighting groupers and with this method four potential aggregation sites were identified, three of which were located outside the limits of the NTZ. Information from LEK provided information on Nassau grouper aggregations, which were mainly targeted between the 1950s and 1970s at Mona Island. Fishers recalled captures of Nassau grouper with developed gonads during winter months (December to February). Captures of this species ranged between 500 and 1,500 lbs per 5-day trip (~167 lbs/day/vessel). Most fishers no longer target shallow water species as declines in grouper populations made trips to this remote site economically unfeasible.

Overall 22 species including threatened groupers were observed with signs of reproductive behavior, such as color phases, sound production (Mann et al. submitted), and displays associated with courtship, distended abdomens and, or spawning (Table 1). At one site parrotfish, surgeonfish, triggerfish, wrasses, goatfish and at least four grouper species coincided spatially although peak aggregation months differed. Red hind (Epinephelus guttatus) were observed in high densities (relative to other months) during January, February and March, while yellowfin grouper (Mycteroperca venenosa), tiger grouper (M. tigris) and yellowmouth grouper (M. interstitialis) aggregated in higher density between February and May (Nemeth et al. 2007a). In comparison with other grouper species, relatively high densities were observed for yellowfin grouper and red hind at one aggregation site (Figure 3). Furthermore yellowfin grouper were found in densities 9 times higher than tiger grouper. Although tiger grouper presented signs of imminent spawning (e.g. color phase, displays and distended abdomen), they were observed at two of the aggregation sites in low numbers (maximum 12 individuals). No Nassau grouper seemed to be aggregated, only two adults with bi-color phase were observed at Monito Island, suggesting this population has not recovered despite management efforts to reduce their captures.

Most spawning aggregation sites encountered at Mona Island were located outside the NTZ boundaries established in 2004. This information was promptly presented to the management authority in charge of fisheries management regulations at the DNER. The opportunity to incorporate this information in a timely manner was possible through a Fisheries Regulations Board, which was created by the DNER in 2005. This board was composed of multiple stakeholders including fisheries managers of local and federal jurisdictions, scientists, outreach specialists, NGO representatives, fishers and the secretary of DNER. The board agreed with the proposal to modify the
Mona Island NTZ limits to include spawning aggregation sites following the recommendation presented by one of us (MTS). The justification for this recommendation was based on the need to protect threatened groupers (*M. bonaci, M. interstitialis, M. tigris* and *M. venenosa*), recognizing that these species are protected seasonally (February to April) as a special conservation unit (Grouper Unit 4) in U.S. Federal jurisdictions that surround this MPA. In addition it was suggested that for compliance and law enforcement purposes a depth contour boundary of the NTZ was easier to identify in the field with a depth finder than distance from shore, which requires radar or GPS technology. The new boundaries of the Mona and Monito Island NTZ were ratified as amendment # 7326 to the existing fisheries regulations (DNER, 2007). This amendment extended the boundary of the NTZ to include the extent of the insular platform, defined as the 100-fathom (182 m) bathymetric contour around both islands, while a swath on the west coast of Mona remained open to fishing (Figure 4). The expansion of these limits increased the area protected from fishing by 50 km$^2$ for a total marine area of 82 km$^2$. The designation prohibits fishing throughout the year within the NTZ boundary that includes most of the shallow nursery habitats (i.e. seagrass) (Schärer 2009) and critical areas of multi-species fish spawning aggregation sites.

Figure 4. Overlap of the 2004 and 2007 no take zones (NTZ) at Mona and Monito Islands NR upon shallow (< 30 m) benthic habitat map of Mona Island.
DISCUSSION

The collection of data necessary for ecosystem-based management (EBM) is placed-based and requires a variety of approaches. Standard coral reef monitoring efforts will not be sufficient. For example, in Puerto Rico, routine monitoring occurs only on permanent transects located within Natural Reserves containing the most extensive coral reef areas. However, the determination of critical habitats, and hence appropriate MPA and zoning limits requires a broad-scale survey with high spatial resolution, as was done at Mona Island using belt transect and roving diver methods. Even these were not sufficient to locate critical areas such as spawning aggregations. For key grouper species (*E. guttatus*, *E. striatus*, *M. bonaci*, *M. interstitalis*, *M. tigris* and *M. venenosa*) sightings in underwater visual surveys using the belt transect method or roving diver method were rare. Both initial LEK and targeted GPS track drift dives were necessary to identify and confirm aggregations sites. Surveys at aggregation sites during reproductive seasons provide a unique opportunity to measure population abundances of these threatened species, information not obtained from reef fish monitoring efforts. For these, the approach of using GPS tracked drift surveys is clearly advantageous, especially in areas of high current. For example, the sighting frequency of red hind (*E. guttatus*) in GPS track surveys was almost 20 times higher than in belt transects and 3.4 times higher than roving surveys. However, it is important to consider that the migrations these species undergo during reproductive seasons (Nemeth 2007b) can affect our ability to detect them and understand their distributions.

While this approach is promising, to quantify population trends and the effectiveness of management actions further information is essential, such as the temporal variability (daily, lunar and monthly) in abundance and spatial distribution within the aggregation. Measuring these patterns would lead to a better understanding of aggregation dynamics and the development of appropriate strategies for allocating sampling effort in space and time to quantify changes in fish abundances. Protecting the few remaining spawning aggregations is an important first step in achieving this objective and remote MPA areas subject to reduced fishing pressure, such as Mona and Monito Island NR are essential for achieving this goal.

The results of this study established that the half-mile boundary of the NTZ designated in 2004 was insufficient for the protection of key spawning aggregation sites and probable migration corridors for multiple species of coral reef fishes. Spawning aggregations of threatened groupers were located in shelf break zones similar to other locations (Sala *et. al* 2001, Claro and Lindeman 2003, Nemeth *et al.* 2006 and Heyman and Kjerve 2008). Shelf breaks are known to be an important spawning habitat for a variety of species, and at Mona Island the shelf break zone is partly located outside the half-mile limit. In this case EBM was fortuitously applied, as the identification of important habitats was fed-back into the decision-making process to modify the NTZ boundary.

The expansion of this NTZ is an important step for the protection of grouper species considered vulnerable in the Caribbean. However, the protection of multi-species spawning sites could provide greater conservation benefits (‘more bang for your buck’) as various species are protected year round. Nonetheless the implementation and enforcement of the NTZ at this remote MPA is logistically challenging. Increased outreach efforts focused towards managers and local stakeholders as well as timely enforcement efforts during peak spawning seasons may help in the recovery of threatened populations of groupers. These actions may help avoid the disappearance of grouper spawning aggregations as reported elsewhere in the Puerto Rican jurisdiction.

ACKNOWLEDGMENTS

We are indebted with interviewees that shared their knowledge of Mona Island’s fisheries and also with volunteer divers that helped in field surveys as well as the crew of *Orca Too* and *Tourmarine* for transportation to Mona Island. The Department of Marine Sciences of the University of Puerto Rico at Mayaguez (UPRM) provided dive vessel support. The DNER provided research permit (904-IC-004) and logistical support. This publication is a result of funding from the National Oceanic and Atmospheric Administration (NOAA), Center for Sponsored Coastal Ocean Research, under awards NA05NOS4261159 to the UPRM for the Caribbean Coral Reef Institute as well as the NOAA Coral Reef Ecosystems Studies Program (NA17OP2919) awarded to UPRM.

LITERATURE CITED


