Nassau Grouper *Epinephelus striatus* Fish Spawning Aggregations in the US Caribbean

Agregaciones Reproductivas del Mero Cherna *Epinephelus striatus* en el Caribe de Jurisdicción EEUU

Mérou *Epinephelus striatus* Zones de Frai dans les Caraïbes US

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ABSTRACT

The Nassau grouper was an economically and ecologically important species of Caribbean coral reefs but is now listed as Endangered by the IUCN. In Puerto Rico (PR) and the US Virgin Islands (USVI) stocks have declined dramatically and several spawning aggregations were fished to extinction. However, two sites within the US EEZ have recently been found with Nassau grouper aggregating during the main reproductive season, the Grammanik Bank (GB) in the USVI and Bajo de Sico (BDS) off western PR. For the 2012 - 2013 spawning season, a joint study was conducted for both sites to characterize and assess these spawning aggregations simultaneously. Underwater visual census and passive acoustic monitoring techniques were used to estimate spawning population stock, size distributions, and spawning periodicity to compare the characteristics of the Nassau grouper at these spawning aggregations. At BDS data were also collected with ultrasonic acoustic transmitters implanted in 10 Nassau grouper at depth and a grid of passive acoustic recorders was deployed around the aggregation site and the shallow bank areas. Preliminary results documented the maximum number of Nassau grouper observed at BDS was approximately 100 individuals, roughly half of that estimated at GB. Passive acoustic data provided high-resolution data to show slightly different temporal patterns between sites, where BDS had two major monthly peaks in reproductive activity followed by a third minor one, and at GB it was one minor peak followed by two larger ones. Nassau grouper with transmitters at BDS provide confirmation of the presence patterns detected with passive acoustics with remarkable resolution. The variability of reproductive timing of Nassau grouper at these two spawning aggregation sites suggest short seasonal fishing closures may not be enough to recover this endangered species.

KEY WORDS: Passive acoustic, reproductive behavior, acoustic tagging, Puerto Rico, USVI

INTRODUCTION

The Nassau grouper (*Epinephelus striatus*) has been an economically and ecologically important species of Caribbean coral reefs with landing values estimated at US$ 1,592,827 during 2007 in the Bahamas (FAO 2014). Today, it is listed by the IUCN as endangered due to rapid decline of its populations primarily due to aggregation fishing (Albins et al. 2009, IUCN 2010, Sadovy 1999, Sadovy and Eklund 1999). In the US Caribbean, *E. striatus* has been protected since 1996 by a fishery ban and more recently it has been proposed to the Endangered Species List. In order to assist in the recovery of this species, the protection of spawning aggregation sites are considered a high priority. To do this, information to identify spawning aggregation sites is imperative as well as their movement patterns and migration corridors during the precise time periods that they are most vulnerable to human interactions.

Two locations have been identified as Nassau grouper spawning aggregations sites in the US Caribbean, one in the US Virgin Islands (USVI), and the other in Puerto Rico (PR). Research at Grammanik Bank (GB) USVI has shown that Nassau grouper primarily aggregate from February through April (Nemeth et al. 2006, Kadison et al. 2010). Recent tagging studies of two grouper species (Nemeth et al. 2008a) as well as passive acoustic recordings of sounds produced, along with reproductive behaviors at areas near the GB in the USVI, established the timing of the aggregation can extend into May depending upon the lunar cycle of each month (Rowell, unpublished data). At Bajo de Sico (BDS) PR, the timing of spawning was determined to be from February through March (Schärer et al. 2012b, 2013b) based on one year's passive acoustic data. Both of these extend later than the season reported for the historic Nassau spawning aggregation in the USVI at the Red Hind Bank (Olsen and LaPlace 1978) as well as that of other Caribbean locations (Colin 1992, Starr et al. 2007, Whaylen et al. 2008).

The objective of this study was to characterize the temporal dynamics of both Nassau grouper spawning aggregations simultaneously. Three methods were implemented to measure the temporal variability at the GB and BDS spawning aggregations of Nassau grouper: passive acoustic monitoring (PAM) by recording and quantifying grouper sounds, underwater visual census (UVC) to estimate abundances and internal ultrasonic acoustic transmitters implanted at depth with closed circuit diving techniques at BDS.

METHODS

Bajo de Sico (BDS) is an offshore seamount located at 18.22° N, 67.43° W, in the Mona Passage, off the north-western tip of the insular platform of western Puerto Rico approximately 29 km from Mayagüez (Figure 1). Most of the shallow (< 180 m depth) areas of this 11 km^2 seamount are located in the US exclusive economic zone (EEZ). Federal regulations in this area prohibit the fishing of demersal or 'reef' fishes from October to March of each year (CFMC). The benthic habitats are considered mesophotic coral ecosystems (MCE) due to the range of depths and coral/algae development. The areas < 50 m depth include a reef top, vertical reef wall and rock promontories, colonized pavement with sand channels, uncolonized gravel, and substantial areas of rhodolith reef habitat (García-Sais 2007).

Grammanik Bank (GB) is a shelf-edge site located east of the Red Hind Marine Conservation District (MCD) south of St. Thomas (Figure 1). Both of these spawning aggregation sites are located in the US EEZ, and the MCD is a year-round no-take zone that has been shown to significantly protect red hind (*Epinephelus guttatus*) spawning habitat and migration corridors. The GB is closed to all fishing during three months to protect yellowfin grouper, *Mycteroperca venenosa* during spawning (February to April). Various other species have been documented to spawn at GB (Nemeth et al. 2006, Kadison et al. 2006, 2010). The benthic habitats along this reef tract are MCEs that have been characterized by Nemeth et al. (2008b) and Smith et al. (2009).

Surveys were conducted at BDS, Red Hind MCD and GB within the expected time of the Nassau grouper aggregation from January through May of 2013. Technical divers using closed circuit and NITROX diving equipment visited the spawning sites repeatedly to estimate the number of Nassau grouper in UVC. Abundance was estimated by counting the maximum number observed per dive. During surveys the color phase of each individual was also noted as per Archer et al. (2012). Roving dives were used to count target species in areas outside the known spawning area. Unrestricted point counts were used to collect data on fish behavior and abundance at a specific site, usually at the DSG location. Divers conducting unrestricted point counts would remain in a specific location and estimate total abundance of aggregating species within a 360° area defined by the limits of under-water visibility (Samoilys and Carlos 2000).

Passive acoustic monitoring (PAM) was conducted during six months at both sites with long-term remote acoustic recorders (DSG-Ocean; Loggerhead Instruments). In the USVI a DSG-Ocean unit was deployed at GB and another in the Red Hind MCD at the historic site where Olsen and LaPlace (1978) reported a Nassau grouper aggregation with numbers ranging from 1,000 - 2,000. At BDS various DSGs were deployed around the shallow (< 50 m) areas of the bank. Sample rate for all DSGs was 80 kHz and the recording schedule was 20 seconds every five minutes throughout the day and night. These instruments were deployed on the seafloor at a depth of 40m within the area where Nassau grouper aggregate. After six months of continuous scheduled recording, the recording units were recovered, digital files were converted into sound files

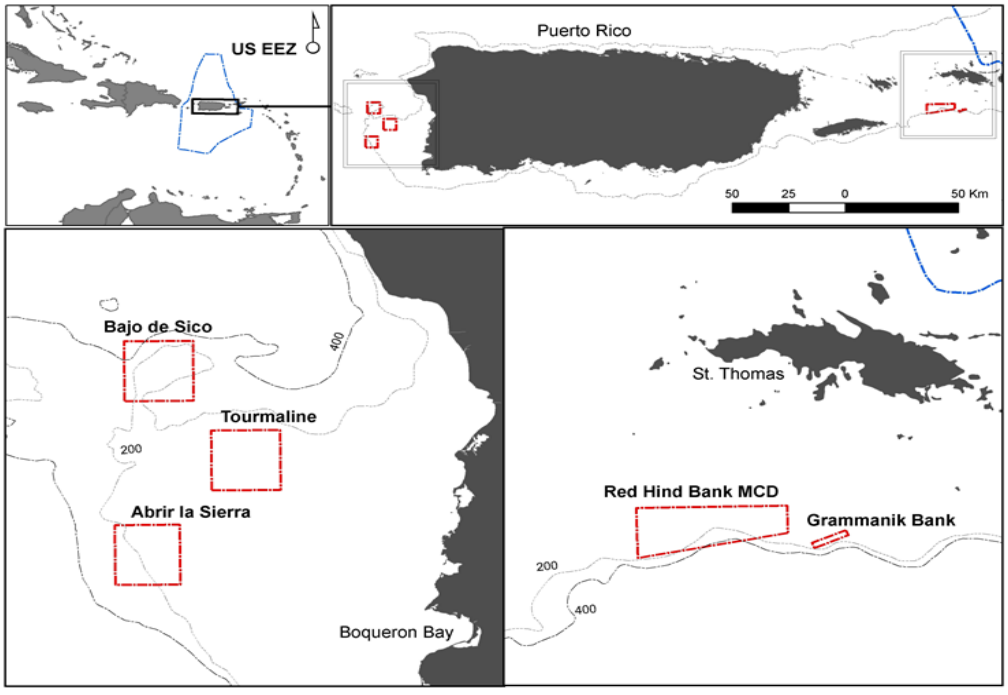

Figure 1. Location of study areas in the US Caribbean.

(.wav) and courtship-associated sounds (CAS) of grouper were quantified per file (as described by Mann et al. 2010, Rowell et al. 2012, Schärer et al. 2012a,b, 2013a). The total number of calls per day was compared between BDS and GB to determine differences in peak days of reproductive sound production associated with spawning aggregation formation. This number was averaged by month and compared between sites. The days of increased sound production were used to determine if the seasonal bans covered reproductive activity of Nassau grouper at each site.

At BDS ten Nassau grouper were tagged with surgically implanted ultrasonic acoustic tags (V16p-4h VEMCO). All surgeries were conducted underwater using closed-circuit rebreather (Inspiration) to avoid barotrauma impacts to Nassau grouper and by-catch of non-target species. Fish were captured using traditional Antillean arrowhead traps, composed of rebar frames with plastic coated 1" wire mesh. Fish traps with dimensions 4'x4'x1.5', were baited and checked periodically throughout the day, with the maximum allowable soak time of 24 hours. Traps had two side doors and slot though which a panel was inserted to guide fish toward the door. Divers coaxed fish inside the trap through one of the doors and into a catch bag, where it was restrained in the upside down position and the fish's eyes were covered to induce a calm state. Scales were removed around the incision site using a scalpel, and an ~2.2 cm incision was made anterior to posterior on the ventral surface of the gastro-vascular cavity just behind the pelvic fin girdle. After the acoustic tag was inserted, the incision was closed with 2 to 3 surgical staples (Reflex one skin stapler with 5.7 mm stainless steel staples). Total estimated handling time was 10 - 12 minutes per fish, after which it was released immediately at the site and depth of capture. Tags are monitored with an array of 19 acoustic receivers (Vemco VR2 and VR2W) placed on the seafloor or attached to subsurface buoys, distributed at depths between 40 and 75 m surrounding the reef promontory area on the shelf.

RESULTS AND DISCUSSION

The results obtained from surveys *in-situ*, PAM, and ultrasonic tags provide an opportunity to examine the temporal patterns at multiple spawning aggregation sites with three methods, as well as to compare among the methods. The first full moon of the Nassau grouper spawning season occurred 28 December 2012, 7 days after the winter solstice (21 December 2012). All three sites were visited from January through May of 2013 on days around the full moon to conduct underwater visual surveys and deploy acoustic recording equipment. At BDS the surveys revealed relatively higher Nassau grouper abundances in February and March whereas at GB fish were more abundant during full moon periods of March and April. At the historic spawning site located in the Red Hind MCD a maximum of eight (8) Nassau grouper were observed in January, and after that only 2 or 4 Nassau were observed each month until May. A maximum abundance of 214 individuals was recorded at GB, during the third lunar cycle after the winter solstice (March). The aggregation at BDS had a maximum of 100 Nassau grouper observed in February. On the days of maximum abundance, multiple courtship behaviors were observed such as fish following and circling as per Colin (1992). During these interactions between Nassau groupers the CAS were heard underwater by rebreather divers, and also recorded *in-situ* with video and acoustic recorders. It was observed that these behaviors often involved bi-color individuals and females with distended abdomens.

Data from PAM provide greater resolution of the temporal trends of Nassau grouper reproductive behaviors at both aggregation sites since dive surveys are spot samples over the spawning period and fish sounds (CAS) are recorded every 5 minutes day and night. At BDS Nassau grouper CAS were detected from January to April, while at GB they were detected from January to July. Nassau grouper appear to have a monthly residence cycle at the aggregation with higher levels of sound production during the period of 7 - 9 days after the full moon (dafm) of January through April at both sites. Three main peaks in CAS, which are associated with reproductive activity, occurred during the first week of February, March, and April since the full moon occurred late in the previous month during 2013. Maximum number of CAS/d at BDS was 38 at 9 dafm in February and 10 dafm in March; while at GB it was 38 CAS/d 8 dafm in March and 7 dafm in April. The two highest peaks in daily CAS/d were observed earlier in the season at BDS (February and March) than at GB (March and April, Figure 2). The months with peak fish abundance determined from visual surveys were also the months with peak CAS/d, suggesting good agreement between these two parameters. Yellowfin grouper (*M. venenosa*) CAS were quantified during the same days as Nassau grouper at GB during March and April.

At BDS the small-scale, hourly presence pattern quantified with acoustic recorders was correlated with the detections by ultrasonic acoustic transmitters implanted in 10 Nassau grouper. After the peak in abundance of aggregating Nassau grouper during March 2013 at BDS, the number of acoustically tagged fish at the aggregation site diminished and the sound rates (CAS/d) dropped sharply on the same day (Figure 3). Following the day with highest CAS/d, an 88 - 100% decrease in Nassau grouper sounds and detections of tagged fish were observed at the main aggregation site. Instead, VR2 receivers at nearby stations within the main bank detected some of the tagged individuals. However, at these outlier sites few CAS were detected by acoustic recorders suggesting that Nassau grouper were not engaging in reproductive behaviors once they left the main aggregation site. This strongly supports the association of sounds with reproductive behaviors during the aggregation (Schärer et al. 2012b).

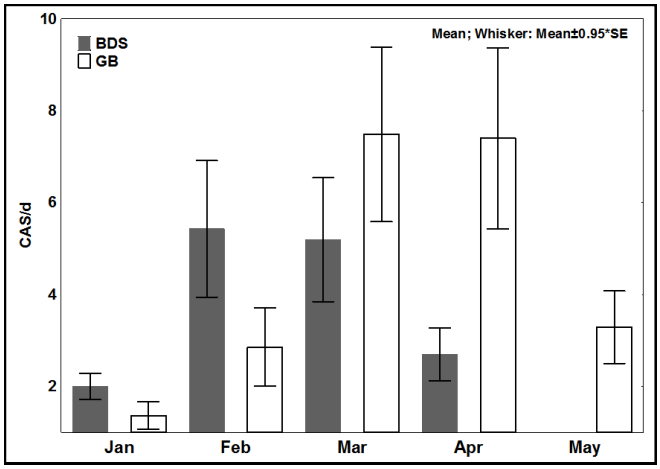

Figure 2. Mean (SE) CAS of Nassau grouper (*E. striatus*) per day at BDS, grey bars (n = 109) and GB, white bars (n = 150) during 2013.

At BDS the seasonal protection that prohibits fishing of reef fish species expires March 31, and at GB the seasonal protection ends on April 30. The presence of Nassau grouper at both spawning aggregation sites extended beyond the duration of the seasonal closure at these sites. Therefore the timing of these seasonal regulations is not covering part of the Nassau grouper reproductive season at these two multi-species spawning aggregation sites. The results obtained in this study suggests that the high-resolution data obtained from PAM is a useful tool to detect the temporal variability in reproductive activity that may limit the effectiveness of seasonal fisheries management measures for protecting multi-species, transient spawning aggregations. Moreover, the difference in the months with peak fish abundances between BDS and GB (February - March *vs*. March - April, respectively) reveals that temporal patterns in spawning aggregations for Nassau grouper differ among sites for as of yet unknown factors. The difference in spawning cycles among sites and inter-year variability in peak spawning months may suggest that spatial management strategies such as permanently closed no-take marine reserves will better protect critical multi-species fish spawning aggregations than short seasonal closures. The use of PAM for documenting the temporal dynamics Nassau grouper spawning aggregations has proven to be an efficient technique to reduce the costs of monitoring multiple sites and may help resolve the limitations of diver-based surveys.

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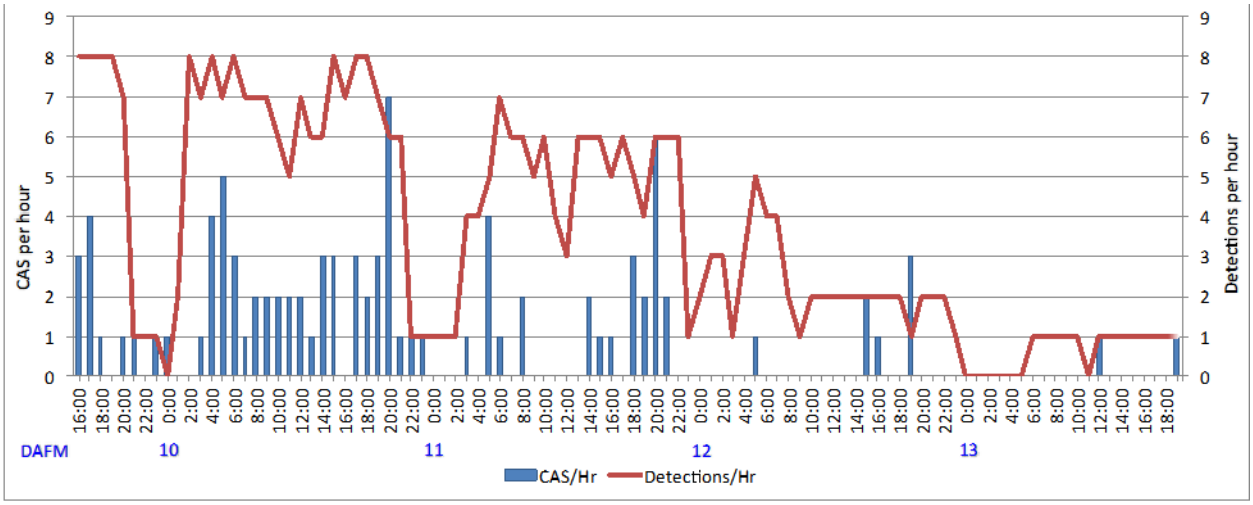

Figure 3. Hourly CAS (blue bars) and detections (red line) of Nassau grouper (*E. striatus*) per hour on days after full moon (dafm).

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