Timing, Size, and Duration of a Dog (*Lutjanus jocu*) and Cubera Snapper (*Lutjanus cyanopterus*) Spawning Aggregation in the U.S. Virgin Islands

El Tiempo, Tamaño y la Duración de un Perro (*Lutjanus jocu*) y Cubera Mordedores (*Lutjanus cyanopterus*) Agregación de Desove en las Islas Vírgenes de los EE.UU.

Moment, Taille et la Durée d'un Chien (*Lutjanus jocu*) et l'Agrégation de Frai Cubera Snapper (*Lutjanus cyanopterus*) dans les Îles Vierges Américaines

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ABSTRACT
Spawning aggregations are a common reproductive strategy for large, reef fish. Although they are predictable in time and space, they remain difficult to quantify. The majority of studies on spawning aggregations have not gone beyond describing behavior or reporting the time of visual observation. Acoustic telemetry provides the opportunity to expand the extent and detail of information collected regarding the timing and movement of fish at an aggregation site. This study describes the size, duration and monthly variation of an aggregation of dog snapper (*Lutjanus jocu*) and Cubera snapper (*Lutjanus cyanopterus*) at the Grammanik Bank, U.S. Virgin Islands using acoustic telemetry and 12 years of visual surveys. Twenty-two Cubera and 29 dog snapper were implanted with acoustic tags and tracked between June and September 2014. Residence events were calculated when two or more detections were recorded at one receiver within 0.5 hour. Abundance data was collected opportunistically with visual surveys from 2002 - 2014 and lengths were measured with laser calipers mounted on a video camera in 2014. Dog and Cubera snapper begin aggregating in February, with peaks in March and May, respectively. Cubera were resident in pulses during the first two weeks after the full moon June-September, but were not resident the third week after the full moon in several months. Individual Cubera were resident for just over a week on average. The most residence events for dog snapper were recorded in the first two weeks after the full moon. Fish tended to remain within the receiver array throughout the following weeks, but individuals were resident for an average of only five days. These results provide information that is critical to the effective design and implementation of protected or closure areas around spawning sites. This study also illustrates a method for collecting spawning timing data that is much less labor intensive than visual surveys, which has been used in the past.

KEY WORDS: Acoustic telemetry, movement patterns, reproduction

INTRODUCTION

Spawning aggregations represent a reproductive strategy utilized by many large, reef fish species (Domeier and Colin 1997, Claydon 2004). Although a well-accepted occurrence, spawning aggregations remain difficult to characterize due to the mobile nature of fish and the limited amount of time that we are able to observe them underwater. However, resident and transient variations of spawning aggregations have been identified (Domeier and Colin 1997). Resident aggregations occur throughout the year, are drawn from a relatively small area and fish generally travel less than a day to reach the spawning grounds (Nemeth 2009). Transient aggregations do not occur year-round and draw from a relatively large area (Domeier and Colin 1997). Whether transient or resident, fish tend to aggregate at nearly the same site annually (Domeier and Colin 1997, Claydon 2004, Heyman et al. 2005) and often for decades (Colin 1996). This site fidelity puts spawning aggregations at great risk from fishing pressure. In fact, fishermen have often targeted these aggregations, which have led to the decline of many populations (Beets and Friedlander 1992, Coleman et al. 1996, Claro and Lindeman 2003). Therefore, the description, classification and understanding of spawning aggregations are critical to the success of fishery management.

Cubera snapper (*Lutjanus cyanopterus*) and dog snapper (*Lutjanus jocu*) are important food fish throughout the Caribbean (Gobert et al. 2005, Claro and Lindeman 2003) and Cubera are listed as vulnerable on the IUCN Red List (2014). Dog and Cubera are two of the largest snapper species. For Cubera, 90 cm total length (TL) is common (Smith 1997) and 160 cm is the maximum recorded TL (Allen 1985). Dog snapper are smaller, with an average TL of 60 cm and maximum TL of 74 cm. (Allen 1985). Sexual maturity is achieved at ~65 cm in Cubera, 30 - 40 cm in dog snapper (Allen 1985, Martinez-Andrade 2003) and there is little to no sexual dimorphism (Domeier et al. 1996, Martinez-Andrade 2003). Snapper are dioecious and remain the same sex throughout their life. Sex ratio of dog and Cubera snapper is not known, but a 1:1 ratio is typical for yellowtail snapper (*Ocyurus chrysurus*) (Trejo-Martinez et al. 2011), black spot snapper (*Lutjanus fulviflamma)*(Kamukuru and Mgaya 2004), and mutton snapper (*Lutjanus analis)*(Kojis and Quinn 2011).

The earliest report of dog snapper spawning comes from Carter and Perrine (1994). They observed dog snapper aggregating in Belize at a depth of 25 - 30 m approximately one week after the full moon (WAFM) with courtship beginning around sunset and spawning was observed on the seaward side of the shelf edge. Whaylen et al. (2004) observed a similar event of dog snapper aggregating at a multi-species aggregation site in the Cayman Islands. Lindeman et al. (2000) identified Cubera spawning sites in Florida and Claro and Lindeman (2003) identified multiple spawning sites around Cuba. It should be noted that the identification of aggregations in Florida and Cuba were based primarily on catch information provided by fishers. Heyman et al. (2005) described spawning behavior of Cubera in Belize, which consisted of twitching and rubbing followed by rapid spiral rises in the water column along the shelf edge. The largest numbers were observed in March - July. In the Virgin Islands, Kadison et al. (2006) observed the largest aggregations May - August, which coincided with rising water temperature each year. In all instances the aggregations formed along a promontory or shelf edge. There are no studies that describe the residency or have tracked the movement of either dog or Cubera snapper at an aggregation.

Movement patterns to and within aggregation sites have not been well documented but have been continually suggested for study (Domeier and Colin 1997, Colin et al. 2003, Whiteman et al. 2005). Acoustic telemetry provides an opportunity to increase both the temporal and spatial extent of information gathered at spawning sites while at the same time providing fine scale movements (Colin et al. 2003, Huepel et al. 2004, Starr et al. 2007, Hitt et al. 2011). Determining the range and frequency of movement of fish in the area of a spawning site can provide important information that can be used in the management of snappers and other commercially important species, especially as protected areas are becoming more common around aggregation sites. Specifically, if an aggregation site is to be closed to fishing, the timing must coincide with the presence of the target species and the boundaries must be placed to encompass an effective portion of movement and migration around the site. This study uses acoustic telemetry and visual surveys to describe the size, timing, and duration of spawning aggregations for dog and Cubera snapper at the Grammanik Bank, St. Thomas U.S. Virgin Islands.

METHODS

Study Site

The Grammanik Bank is a seasonal closure area located on the south shelf edge of St. Thomas USVI (Figure 1). The bank is located on the Puerto Rican shelf, 14 km south of St. Thomas, USVI. It runs east/west for 1.5 km and is 500 m wide. The benthic habitat is primarily composed of a mesophotic reef at depths between 30-60 meters, which includes a combination of *Montastrea/ Orbicella* coral and hard bottom interspersed with gorgonians and sponges (Smith et al. 2008).

Telemetry

Acoustic data were collected with VEMCO receivers (VR2W, 69 kHz) and transmitters (V13, 147-153 db, 13 x 36 mm). Eight receivers were placed along the West end of the Grammanik Bank approximately 250 meters apart (Figure 1). The receivers are anchored on the bottom to a cement block with polypropylene line in bottom depths between 30 - 45 meters. The receivers are suspended ~ 15 meters above the bottom, supported from above by two styrofoam floats. The detection range varied from 149 - 286 meters and was determined by drifting or slowly motoring across the array while dragging a test tag suspended at a depth of 15 meters. Each time a tagged fish is within range of a receiver, a detection is stored that includes the identification code, date, and time of arrival and departure from the receiver range and residency time. To implant acoustic transmitters, fish were caught with hook and line between 7:30 p.m. and 10:00 p.m., 0 - 10 days after the full moon in June, July, August, and September. The fish were placed in a seawater tank on

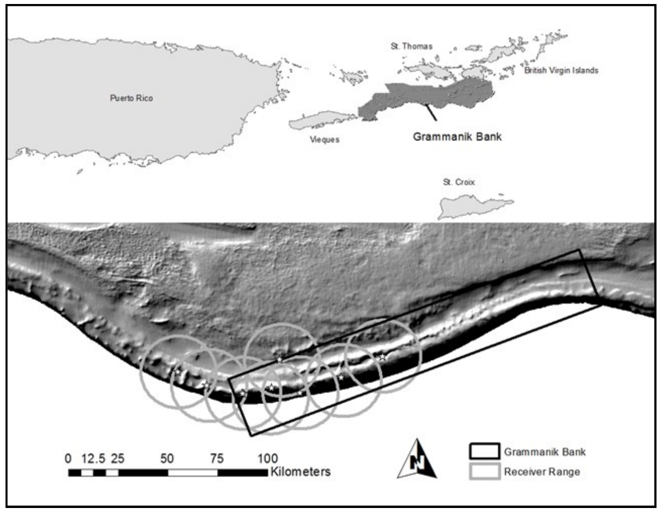

Figure 1. The Grammanik Bank, USVI. A seasonal closure area and a spawning aggregation site for dog and Cubera snapper. White stars represent the location of the acoustic receivers and gray circles mark the range of detection.

board the boat. Fork length (FL), weight and gender were recorded for each fish. Gender was determined by either cannulation (Felip et al. 2009) or abdominal massage and squeezing (Nemeth 2006). The air bladder was deflated with a hypodermic needle and a 2 - 3 cm incision was made along the ventral side of the body cavity and the acoustic tag was inserted. The opening was closed with sutures and covered with antibiotic gel. The fish was then placed back in the water and lowered to the bottom with the assistance of a weighted line.

Visual Surveys

Scuba divers collected abundance data opportunistically at the aggregation site and along the bank with underwater, visual surveys. A combination of roving diver surveys, belt transects, scooter surveys and unrestricted point counts were used. Dives generally took place during the first WAFM (7 - 10 days), January through August between 2002 and 2014. Only two surveys were completed in October 2014 and 12 in December 2002 and 2003. During surveys in April and May of 2014, sizes of fish were measured with laser calipers mounted on an underwater camera (Heppell et al. 2012).

Data Analysis

The detections were downloaded from each receiver and analyzed using the VTrack package (Campbell et al. 2012) created for the R environment (R core 2008). A residency event was created when one receiver had at least two detections within 0.5 hours, which is longer than it would take a fish to swim through the detection range at 0.2 m/sec. The duration of the residency event was recorded along with the start time, end time and date. Laser FL were calculated using imageJ software (Schneider et al. 2012), which calculates the distance between points on the screen. The lasers were 15 cm apart, so the FL was calculated as (15*Screen fork length)/screen laser length. A fisher's exact test was used to test for a 1:1 sex ratio for each species.

RESULTS

Twenty-two Cubera were tagged between June (14 fish), July (5 fish) and August (3 fish) 2014. Eight were female, seven were male and sex was indeterminate for seven individuals. Sex ratio was not significantly different from a 1:1 ratio for Cubera ($p = 0.49$) as analyzed with a fisher's exact test. FL of tagged Cubera averaged 92.8 +/- 2.2 cm and the laser lengths of Cubera at the aggregation site averaged 75.6 +/- 7.0 cm.

Cubera were resident at the Grammanik Bank during each WAFM in June (12 fish) and for the first, second, and fourth WAFM in July (14 fish) (Figure 2). Thirteen Cubera were resident for the first, second and fourth WAFM in August. In September, 11 Cubera were resident for the first two WAFM, which is when the receivers were downloaded. More than six times as many residence events occurred during the first WAFM than the second WAFM except in June, when the most events were in the second WAFM. A total of twelve Cubera returned to the spawning site in multiple months. The average number of days an individual was resident each month was 7.8 d for males, 7.2 d for females, 8.3 d for unsexed fish and 7.7 d overall.

A total of 29 dog snapper were tagged between June (20 fish), July (5 fish), August (3 fish) and September (1 fish). Seven fish were female, 11 male and sex was indeterminate for 11 individuals. The fisher's exact test showed that the sex ratio was not significantly different from a 1:1 ratio ($p = 0.45$). The FL of tagged dog snapper averaged 65.0 +/-1.2 cm and the laser lengths of dog snapper at the aggregation averaged 52.5 +/- 1.3 cm.

Nineteen of the tagged Dog snapper were resident at the Grammanik Bank in June and 16 fish were resident in July. Residence events in August and September were recorded for 12 and 6 fish, respectively. Dog snapper were resident during each WAFM June-Sept, with the most number of events occurring during the first WAFM in July and September (Figure 2). In June and August, the most residence events occurred in the second WAFM. The number of residence events generally declined between the second and fourth WAFM. Twelve of the dog snapper had residence events in multiple months. The average days resident per month for an individual dog snapper was 3.9 days for males, 5.0 days for females, 6.9 days for unsexed fish and 5.2 days overall.

The most visual surveys were conducted in March (388 surveys), followed by April (244 surveys) and February (136 surveys) (Figure 3). Fewer than 58 surveys were conducted in each of the remaining months. Dog snapper were observed every month with the largest group, 2000 fish, present in March. Groups of 40 or more dog snapper were observed February through June. Cubera snapper were most abundant in May and groups of 130 fish or more were observed March through August.

DISCUSSION

Dog and Cubera snapper are resident at the Grammanik Bank predominantly in the first or second week after the full moon (WAFM) during the spawning season. This is the same time period reported from visual surveys in Belize (Carter and Perrine 1994) including accounts where actual spawning was observed (Heyman et al. 2008). Cubera show pulses where they are resident within the array just before the full moon until two weeks after, but are absent during the third WAFM. It is uncertain where the Cubera go during that time or how far they travel, but it suggests that they are indeed transient and not resident spawners. They could be staying within the spawning area while continually moving between receivers and thus, not recording any residence events or they may return to their home territory. Most likely there is some combination of behavior, and it may be related to the individuals that return for multiple months and those that do not. The pattern may be similar for dog snapper, but there is some evidence that they move less in the period in between full moons. They are resident throughout each month, but with a decreasing number of events each consecutive week after the full moon. However, no one individual fish remains within the array for the entire month. In fact, individual dog snapper are resident for less than a week on average. It is possible that the fish remain on the bank, but utilize an area larger than the current array of receivers, so residence events are less frequent. These results also suggest that there may be a combination of resident and transient spawning behavior for the dog snapper. Increasing the number of receivers and area covered will help to fill in the gaps about where the fish are during the 3 and 4 WAFM.

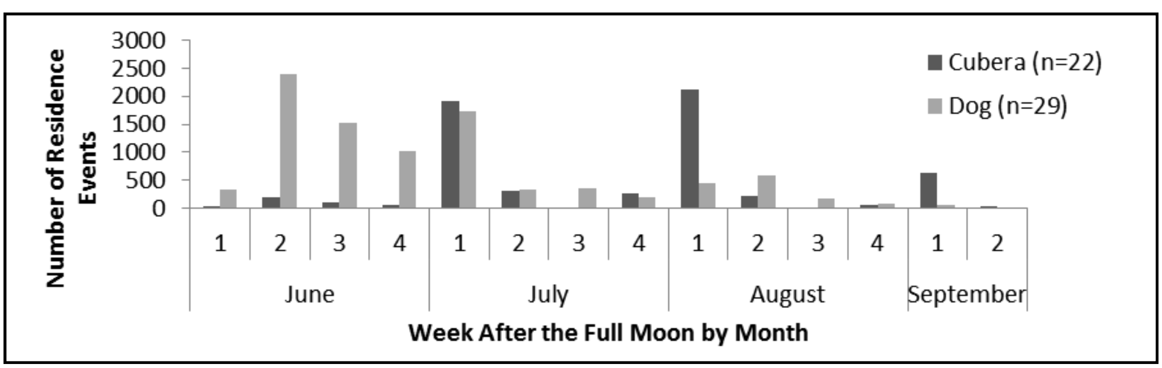

Figure 2. Total number of residency events for tagged Cubera (n = 22) and dog snapper (n = 29) at the Grammanik Bank by week after the full moon from June 11 - September 16, 2014. A residence event is created when two or more detections are recorded at that same receiver within 0.5 hours.

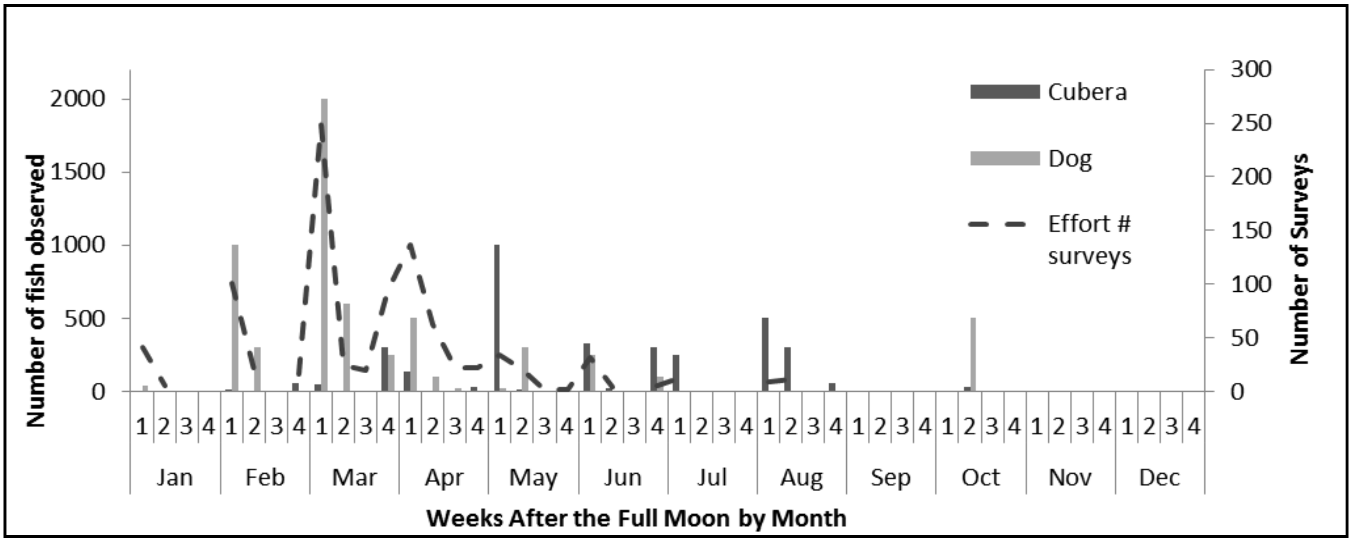

Figure 3. Number of individuals in the largest group of Cubera and dog snapper observed at the Grammanik Bank each month by week after the full moon, from 2002-2014. The dashed line represents effort as the total number of surveys conducted each month.

Cubera snapper begin to aggregate at the Grammanik Bank in February and continue through August, with the largest group being observed in May. Given that survey effort was high at the beginning of that time period, it is likely that February is in fact the first month of the spawning season in the U.S. Virgin Islands. This is the earliest month that Cubera have been observed aggregating in the Caribbean. In Belize, Cubera began spawning in March (Heyman et al. 2005) and Claro and Lindeman (2003) reported the spawning season in Cuba to be June-September. However, the study in Belize included surveys in February during only one year and the dates provided by Claro and Lindeman (2003) were based on peaks in fishing catch data. Therefore, it is possible that aggregations occur in February in those areas as well, but just have not been observed. Our study includes few or no surveys conducted in September, October, and November, so the spawning season may extend into those months, but further study is needed to confirm an accurate end date.

Dog snapper begin aggregating in groups larger than 40 individuals in February and peak in March. The group sizes decrease after March, but remain greater than 250 fish through June. The absence of aggregating groups in July and August may be attributable to the low survey effort in those months. The group of 500 dog snapper observed in October indicates that the spawning season extends throughout the summer and into the fall. Carter and Perrine (1994) observed aggregations in Belize in January, and it is likely that dog snapper at the Grammanik Bank spawn throughout the year as reported in Cuba (Claro and Lindeman 2003).

The average FL of dog (52.5 +/- 1.3 cm) and Cubera (75.6 +/- 7.0) observed during visual surveys is comparable to the average total lengths, 55 cm and 80 cm respectively, observed by Kadison et al. (2006) at the Grammanik Bank. A decrease in size of fish at an aggregation is indicative of a declining population from over-fishing or other causes (Coleman et al. 1996, Shin 2005). Since the average size of dog and Cubera within the aggregation has not changed much in the last eight years, it suggests that the aggregating population is stable (Ault et al. 2008). The average length of tagged fish was larger than the average length of fish within the aggregation for each species as measured with laser calipers. The difference in sizes between tagged fish and fish within the aggregation may be attributable to the hook size, which has been shown to affect the mean size of fish caught (Alos et al. 2008). It could also be due to larger fish being more aggressive and more likely to take bait as with male grouper. Male grouper are generally larger than females and are caught more often than females when using hook and line (Beets and Friedlander 1998, McGovern et al. 1998). Future efforts should utilize different hook sizes to ensure a representative sample of sizes are caught and tagged.

The sex ratio of the tagged fish was skewed in favor of males for dog snapper and almost even for Cubera, with only one more female than male caught and tagged. Neither was significantly different than a 1:1 ratio, but the small sample size is a factor to be considered. This represents the first report of sex ratio for dog or Cubera at an aggregation site. A 1:1 ratio was expected based on information for other snapper species. If the dog snapper population does contain more males, it could be due to effects of fishing removing more females. In contrast to grouper, Lutjanids are gonochoristic, and females may live longer and be more abundant at larger sizes (Grimes and Huntsman 1980). This scenario has been observed in mutton snapper in St. Croix. Kojis and Quinn (2011) found that an unfished population had a 1:1 sex ratio, while a heavily fished population was skewed in favor of males. Dog snapper are not targeted by fishers in St. Thomas, so a biased sex ratio would be surprising. However, dog snapper are actively fished in Puerto Rico (Ault et al. 2008), and the preponderance of males may indicate connectivity and spawning migrations from that area.

Analysis of the data collected using acoustic telemetry and visual surveys results in very similar conclusions. Both methods indicate the month and WAFM that fish are present at the spawning site. However, the acoustic tags collect more data than visual surveys with regards to the length of time fish spend at the site and the extent of movement. Also, the use of acoustic tags is less labor intensive than visual surveys. One drawback of the acoustic tags is that the actual spawning event cannot be verified. However, if the goal in understanding the spawning aggregation is to provide information that improves protected and closure areas, observing the actual spawning event may not be necessary. Marine Protected Areas (MPA) have been successful in protecting spawning aggregations from fishing and preserving the viability of the fishery (Alcala 1988, Roberts et al. 2001, Grüss et al. 2014), but the efficacy is dependent on several factors including the placement of the MPA boundaries and the extent of movement of the fish. The data collected here is a first step in resolving these issues and providing the most effective management. Increasing the number and range of receivers in the array is the next step in understanding the extent of movement during and in between periods of spawning. This information is necessary to manage and protect the dog and Cubera fisheries, but may also be applicable to other snapper species throughout the Caribbean.

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