Yellowfin Grouper (*Mycteroperca venenosa*): Reproductive Biology, Behavior and Conservation of a Large Caribbean Grouper

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ABSTRACT

The temporal, spatial and behavioral dynamics of a spawning aggregation of yellowfin grouper were examined using underwater visual surveys, histological analysis, and hydro-acoustic tracking. Yellowfin grouper aggregated to spawn on the Grammanik Bank, a shelf-edge coral reef, during two or three consecutive months from February through April each year from 2004 to 2009. Fish arrived at the site on the full moon, and departed 10 to12 days after the full moon (dafm). Highly skewed male dominated sex ratios (> 4:1, M:F) on the full moon dropped to near unity by 4 dafm each month, indicating that males arrived at the spawning site early. Males were on average significantly larger than females. Aggregations of up to 600 fish swam elevated over the reef showing distinct coloration and behaviors. Spawning was observed in March and April 2008 and 2009 from 6 through 10 dafm. During spawning, 7 to 12 putative males followed one female, "rushing" her upward to release gametes. Spawning began near sunset and continued into the night. Histological analysis of ovarian tissue indicated that some females were capable of spawning on two consecutive nights, although the majority spawned every two or three nights. Most hydro-acoustically tagged fish came to the aggregation site two months each year, however left the area for weeks between spawning events. This yellowfin grouper aggregation is the most well studied for the species, and could provide information regarding the effectiveness of seasonal closures, along with the protection of spawning sites, for enhancing regional stocks of Caribbean groupers.

KEY WORDS: Spawning aggregations, Serranidae, marine protected areas, histology, grouper fishery

Guacamayo (*Mycteroperca venenosa*): Biología Reproductiva, Comportamiento y Conservación de un Mero Grande de Caribe

PALABRAS CLAVE: Guacamayo, Serranidae, Áreas Marinas Protegidas, pesquería de mero,

Le Badèche de Roche (*Mycteroperca venenosa*): Biologie de la Reproduction, Analyse Comportementale et Conservation d'un Grand Mérou des Carraïbes

MOTS CLÉS: Badèche de roche, Serranidae, biologie de la reproduction, Aires Marines Protegées

INTRODUCTION

Groupers (Serranidae: subfamily Epinephelinae) have historically been one of the most heavily harvested reef fish in the tropical and sub-tropical oceans of the world. Today stocks of most large grouper species are at record low levels due to over-fishing. The life history trait of forming aggregations at a particular and consistent time and place annually to reproduce makes the group particularly vulnerable to over-exploitation. If spawning populations are fully or partially self-recruiting, fishing aggregation sites can not only quickly remove a significant part of the local species biomass, but also severely jeopardize the sustainability of the population over time. Co-occurring spawning aggregation and local stock declines have been reported in several instances (Sadovy and Ekland 1999, Coleman et al. 1996, Koenig et al. 1996) and it is now accepted by scientists and managers that fishing aggregation sites is an unwise and dangerous fishing practice.

Groupers exhibit a variety of reproductive traits and strategies that may vary between species or within a species across regions (Sadovy 1996). Behaviors that include migration to spawning sites, pre-spawning assembly, spawning frequency, the spawning act itself, and dispersal of adults from the site, are important to understand for effective management and conservation, in light of the fact that the fish are highly exploited during the reproductive period. Combined with sexual development patterns and gamete production systems, these life history traits can provide insight into how reproductive strategies influence reproductive potential over time (Winemiller and Rose 1992).

Yellowfin grouper (*Mycteroperca venenosa*) aggregate to spawn in the Caribbean and western Atlantic annually from January through May (Cushion et al. 2008, Heyman and Kjerfve 2008, Whaylen et al. 2004, Claro and Lindeman 2002, Garcia-Cagide and Garcia 1996, Carter and Perrine 1994, Colin 1992). In the U.S. Virgin Islands, the Grammanik Bank, a deep water reef located 16 km south of St. Thomas, has been identified as a yellowfin grouper aggregation site that is active from February

through April (Nemeth et al. 2004). Although yellowfin grouper spawning aggregations of varying sizes are reported off Belize (Heyman and Kjerfve 2008, Carter and Perrine 1994), the Cayman Islands (Whaylen et al. 2004), the Bahamas (Cushion et al. 2008, Colin 1992), Mexico (Tuz-Salub et al. 2006) and Cuba (Claro and Lindeman 2002, Garcia-Cagide and Garcia), the aggregation on the Grammanik Bank is one of the most well studied and monitored. Protected from fishing since 2005 during the spawning season, reproductive traits exhibited by this spawning population could represent a model to better understand the reproductive strategy of the species. The aim of this work was to examine yellowfin grouper patterns of spawning from 2005 - 2010 on the Grammanik Bank, and specifically to:

i) Document the build-up and reduction of fish density over time along with changes in the sex ratio,
ii) Estimate the number of fish within the core aggregation area at peak aggregation time,
iii) Determine sizes of spawning fish,
iv) Determine the periodicity of reproducing females,
v) Establish the precise timing of spawning, and
vi) Characterize yellowfin grouper spawning behavior.

METHODS

Dive surveys on technical Nitrox or closed circuit re-breathers were conducted around the full moon each year from February through May, 2005 through 2009. Surveys generally were conducted over 2 to 9 days, beginning around the day of the full moon, and were timed to document the arrival and departure of fish. Occasional surveys were made outside of this period to confirm that grouper were not present in large numbers, and that no reproductive behavior or activity was taking place. The number of yellowfin grouper present was estimated using visual surveys along 500 x 30 m transects across the bank during the early and mid-day, and point counts during the late afternoon at the core aggregation site. In 2008 and 2009, in addition to transects and point counts, dives were made around sunset to record and video fish coloration, inter- and intra-specific behavior, and spawning. Groupers were collected daily during the same time period, as well as from February through April, 2010, using standard Antillian fish traps. Captured yellowfin grouper were measured, sexed using an ultrasound or by squeezing the abdomen for milt, and tagged with sequentially numbered external Floy dart tags. A subset of female yellowfin grouper was sacrificed in 2006, 2009 and 2010 (n = 43), to determine gonadosomatic indices (GSIs) and to examine histologically. Ovarian tissue was removed, weighed, and a small section from the middle of the gonad fixed in 10% neutral buffered formalin. Fixed tissue was embedded in paraffin, sectioned at 4 μm, and stained with hematoxylin and eosin following standard procedures. Stained tissue was histologically classified into three development phases: developing, spawning capable (which included the actively spawning sub-phase), or regressing, following Brown-Peterson et al. (2011). Water temperature 1 m from the sea bottom was recorded hourly from February 2005 through October 2010 by a Nortek Acoustic Dopler Current Profiler (ADCP) located within the core aggregation site.

RESULTS AND DISCUSSION

The combined underwater observations, gonosomatic indices, and histological evidence provided a fairly clear picture of spawning for the yellowfin grouper on the Grammanik Bank. Over 90 visual surveys conducted between 2005 and 2009 confirmed that the fish aggregated between February and April each year, with the majority of fish spawning in March and April. Mean hourly water temperature during the spawning season varied between 25.2°C and 27.0°C. This temperature range is greater than that reported for other Caribbean groupers (Kadison et al. 2006, Nemeth et al. 2006, Sadovy and Ekland 1999) indicating that for the yellowfin grouper, moon phase and month of the year may play a greater part in seasonality than temperature. The aggregation was initiated yearly with the early arrival of some males in February. Based on fish collected in traps, all years combined (n = 618), sex ratios ranged from 9.0:1 (M:F) in February to 1.5:1 in April. Although fish collected on the bank in February were spawning capable, spawning behavior or activity was never observed during that month. Similarly, Cushion (2008) collected some spawning capable fish (45%) in February off of the Bahamas, however the majority of spawning there reportedly also takes place in March and April. The arrival, spawning, and departure of fish coincided each month with a consistent moon phase. Over the five year study period, yellowfin grouper arrived on the site beginning the day of the full moon, with abundance increasing steadily from full moon until 5 - 8 days after full moon (dafm), deceasing rapidly over the following 2 - 3 days. It is unclear whether fish returned over consecutive months to the spawning site each year, however tag recaptures suggested that males returned to spawn again, while females did not. The arrival of males to the site each month preceded that of most females. A highly skewed male dominated sex ratio (2.8 - 4.0:1), dropped to near unity 5 - 6 dafm. T his was accompanied by rapid increases in fish density and CPUE indicating females were moving onto the site. Male initiated aggregation formation is not unusual and has also been described for several other species of grouper (Nemeth et al. 2006, Whiteman et al. 2004; Rhodes and Sadovy 2002; Johannes et al. 1999; Samoilys 1997). Maximum spawning population estimates, based on visual surveys, ranged from 600 to 1000 fish annually. Monthly maximum population estimates ranged from 260 fish in February, 2005 to 1000 fish in April, 2007. Average daily abundance was significantly

lower in February than in March or April but was not significantly different between the latter two months, again indicating that these are the primary months of spawning.

Grouper collected in Antillian fish traps ranged in length from 56.4 cm TL to 91.5 cm TL, slightly larger than the previously reported maximum size (Garcia-Cagida et al. 2001). Males were significantly larger than females, which was expected considering that yellowfin grouper are protogenous hermaphodites (Garcia-Cagide and Garcia 1996). All male fish collected on the aggregation site were ripe. Individual female gonadosomatic indices (GSI) of sacrificed fish rose from full moon until 6 dafm, after which higher and lower indices were measured, indicating fish were both preparing to spawn and spent. Asynchonous oocyte development was observed histologically for females collected 6 - 11 dafm, implying that they were capable of spawning multiple times during that five day period. Of 43 female yellowfin grouper examined, all had fully grown vitellogenic oocytes, indicating that spawning would occur in days or weeks. There was some evidence of daily spawning. A minority of females (11.6%) had ovarian tissue with both post-ovulatory follicles (POF) and hydrated oocytes (HO) present, indicating that the fish had spawned less than 24 hours previously and were actively spawning that day. A much higher percentage (41.9%) was undergoing oocyte maturation with no POFs, and 44.2% sampled had POFs ≤ 24 hour old but no HOs. The frequency of these conditions was in close agreement and indicated a spawning frequency for most females of 2 - 3 days. Fish collected late in April (9 - 11 dafm) still had ovaries with vitellogenic oocytes and very little atresia, indicating that they could possibly spawn again that season.

The spawning aggregation initially formed along the 1.5 km linear coral bank in 30 - 40 m of water, with low densities of grouper spread broadly over the entire bank and onto a secondary reef across a 20 m sand channel to the north. During the morning and early afternoon hours fish were observed on or near the bottom with little obvious intra-specific interaction or display behavior, and little or no color changes. This state was also observed late into the afternoon 0 - 4 dafm, with more activity noted each consecutive day after the full moon. Beginning 5 dafm in the early to mid afternoon, fish moved south and west to a core aggregation site, an area approximately 900 m^2, on the shelf edge. Color changes were observed at this time, increasing in frequency as sunset approached. Color phases included the normal blotched and spotted pattern, a dark solid color phase, and a 'whitehead' phase. The whitehead color phase was characterized by a dark body with a very distinct white head and caudal fin, a dark band on the distil end of the caudal fin, and yellow on the pectoral fins and sometimes lips. Both the dark and whitehead phases were rare before 14:30 in the afternoon. Other behaviours observed at this time included mild to vigorous shaking, nuzzling, and slow elevated swimming up to 15 m off the bottom. These actions also increased and intensified as sunset approached. Grouper density at the core aggregation site steadily increased from mid afternoon to sunset, with fish generally assembling at that time into one or two large groups.

Consistent with GSIs, maximum population estimates and histological data, spawning was observed several days in March and April of 2008 and 2009, from 6 through 10 dafm. It occurred from four minutes before sunset to at least 20 minutes after, and probably into the night. Nearly all grouper had the whitehead color phase during spawning. The assembled group swam a slow cyclic pattern, ascending to up to 25 m of water depth and then descending to 60 m or deeper off the southern shelf edge, each cycle lasting 3 - 6 min. From 20 - 40 minutes before sunset, smaller groups within the aggregation began to break off and swim together rapidly upward in 'rushes'. These groups were made up of 5 - 12 fish packed in a tight circle, ventral sides inward. At the top of the rush, which continued ~10 m upward, gametes were released in a cloud, and fish radiated outward and then down in all directions. They returned to the larger aggregation. The frequency of rushes within the aggregation increased as sunset approached and into the night. We were limited by light and left the aggregation with spawning rushes still occurring with high frequency.

Although the yellowfin grouper spawning aggregation appears fairly intact on the Grammanik Bank, with relatively high numbers of fish and frequent observed spawning, little is known of the historic population size or how spawning behaviour may have changed over time due to changes in population parameters. However, yellowfin grouper were not heavily targeted in the northern Virgin Islands before the 1990s due to some, limited ciguatera poisoning. This possibly spared them the fate of commercial extinction suffered in the 1980s by their more historically abundant and popular relative, the Nassau grouper (*Epinephelus striatus*). Although Nassau grouper aggregate to some extent on the Grammanik Bank slightly before and during the spawning season of the yellowfin grouper, their numbers are significantly lower and spawning has never been observed. Targeting yellowfin grouper became popular in the 1990s with an expanding restaurant market, and not until after several years of heavy fishing pressure on the Grammanik Bank did the Caribbean Fisheries Management Council, in 2005, close the area to all fishing activity during the yellowfin grouper and Nassau grouper spawning season, from February through May. The same year, an annual seasonal closure was enacted for yellowfin grouper in all waters of the US Virgin Islands (Federal Register Vol. 70, No 208). The combined effect of the seasonal closure of the Grammanik Bank, the 22 year closure of the Marine Conservation District (MCD), a large marine reserve 4 km to the west, and the seasonal ban on harvest or sale of yellowfin grouper, has undoubtedly played a key role in maintaining the spawning population

that currently exists on the bank. This demonstrates how effective management measures can provide protection and sustainability for aggregation sites. Since few other large spawning aggregations of yellowfin grouper are known to exist in the eastern Caribbean, continued management and protection of the bank is imperative.

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