Gulf and Caribbean Research

Volume 22 | Issue 1

2010

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Recommended Citation

Luckhurst, B. E. 2010. Observations of a Black Grouper (*Mycteroperca bonaci*) Spawning Aggregation in Bermuda. Gulf and Caribbean Research 22 (1): 43-49.
Retrieved from https://aquila.usm.edu/gcr/vol22/iss1/5
DOI: https://doi.org/10.18785/gcr.2201.05

Gulf and Caribbean Research Vol 22, 43-49, 2010 Manuscript received November 16, 2009; accepted February 9, 2010

OBSERVATIONS OF A BLACK GROUPER (*MYCTEROPERCA BONACI*) SPAWNING AGGREGATION IN BERMUDA

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ABSTRACT: Diving observations at a black grouper (*Mycteroperca bonaci*) spawning aggregation site on Bermuda's reef platform revealed many similarities to observations of this species obtained at multi-species spawning aggregation sites in Belize. In addition to similarities in body sizes, color patterns and some behavior, the principal spawning period in the days after the full moon was also similar. Although spawning was not observed in this study, there was ample indirect evidence of spawning at the site, i.e. courtship behavior by males, females with distended abdomens, and color changes. The formation of temporary spawning territories by males and courtship behavior within these territories is described and illustrated. Taken together, these data appear to indicate that the behavior of black grouper at spawning aggregations is consistent across a broad latitudinal range from Belize in the south to the northern limit of the species' range in Bermuda.

INTRODUCTION

Relatively few studies have been published on the biology of black grouper (*Mycteroperca bonaci*), and most of these studies have concentrated on the reproductive biology of this protogynous hermaphroditic species (Crabtree and Bullock 1998, García–Cagide et al. 2001, Brulé et al. 2003, Teixeira et al. 2004). Spawning seasonality of black grouper at spawning aggregation sites in Cuba has been described by Claro and Lindeman (2003). Although the black grouper is recognized as a transient aggregation spawner (Domeier and Colin 1997), only a small number of studies have described the behavior of this species at fish spawning aggregation sites (FSAS) with the majority of the research being conducted in Belize (Heyman and Kjerve 2008, Paz and Sedberry 2008). One study in Florida (Eklund et al. 2000) examined an aggregation site in relation to a Marine Protected Area (MPA) boundary but provided less behavioral information as spawning was not observed. Whaylen et al. (2004) reported seeing small groups of black grouper with distended abdomens during observations at a primary Nassau grouper (*Epinephelus striatus)* spawning aggregation site in Little Cayman but spawning was not observed.

Black grouper have been an important species to the Bermuda fishery for decades but suffered a significant decline in landings from the mid–1970s along with many other grouper species (Luckhurst 1996). Although it was known that black grouper aggregated to spawn, the location of spawning sites was apparently not well known in the local fishing industry. In contrast, red hind (*Epinephelus guttatus*) spawning aggregation sites were well–known and heavily fished, which prompted early management action to seasonally protect these sites (Luckhurst 1998, Luckhurst and Trott 2009). In the summer of 2003, the location of a spawning aggregation site for black grouper was revealed by fishermen and this lead to research to define the dynamics of the aggregation. It was determined that the black grouper site was relatively close to an existing red hind site which was seasonally closed to all fishing. Anecdotal evidence indicated that the black grouper site was being heavily fished and that the bag limit of one fish per boat per day was being routinely exceeded. As enforcement of the bag limit was problematic due to the large number of landing sites, it was decided to incorporate the black grouper site into a redefined and enlarged seasonally protected area (Fisheries Protected Areas Order 2004) which included the original red hind spawning aggregation site (Luckhurst, pers. obs.). Only after the site was seasonally closed to fishing was it possible to conduct an intensive research program to study the aggregation and learn more about its dynamics without interaction with fishermen at the site. The data presented here are the first to be derived from this ongoing study.

MATERIALS AND METHODS

A week before diving observations began, 2 mooring buoys were placed about 40 m apart near the presumed center of the spawning aggregation site at a depth of about 30 m. This was done to avoid anchoring on the site which could have disturbed the aggregated fish and also increased the efficiency of boat operations. There were 2 dive boats on the site for 3 days of the project with a single boat on the remaining 2 days.

Diving observations commenced on the day of the full moon in June 2005 and continued for 6 consecutive days. No diving was possible on the fifth day due to rough sea conditions at the site. Teams of divers from each boat (2–4 divers per team) recorded their observations on waterproof paper on slates and all of the daily observations made during the study were collated and used for the present analysis. Divers surveyed the area widely and made estimate counts of the number of fish within their view and also estimated fish sizes. In addition, divers made notes on behavior and color patterns. After each dive, team members discussed

TABLE 1. *Summary of daily observations at a black grouper spawning aggregation site in Bermuda in June and August 2005. No observations were made in July. See Figure 3 for further details of the behavior noted on June 26 and August 25. Sunset was at 2030 hrs during the June observation period and at 1954 hrs during the August period.*

Date 2005	Time (h)	Moon phase	Fish abundance estimate	Size-FL cm Mean (range)	Observations
June 21	1300	Full	20+	125 (110-150)	Fish hovering mainly over sand holes
	1500		25-30	125 (110-150)	Few color changes but no interactions between fish
	1700		30+	110 (90-150)	Cone-shaped school of 30+ fish hovering above substrate, inactive; pale-body phase fish increasing in number
June 22	1300	Full+1	70-100	No size estimates available	Single layer school moving over substrate, several females with distended abdomens
	1700		200-400	110 (80-150)	Band of fish hovering 7-9 m above reef (10-15 fish high) – 2-4 % of fish in pale-body phase
June 23	1730	Full+2	100-200	110 (100-150)	70-80 % pale-phase fish, band of fish hovering 3-5 m above reef
June 24	1500	Full+3	150-200	100 (90-150)	Band of fish hovering 7-9 m above reef, % of females appears to have increased from June 23
	1815		150+	90 (80-130)	Increased % of females, minimum of 5-6 females with distended abdomens; male courtship observed
June 25		Full+4			No diving – rough sea conditions
June 26	1645	Full+5	150+	90 (80-140)	Males with pale sub-caudal fin margins, females with distended abdomens common, females comprise 90% of fish present, fish becoming more active
	1855		250-300	90 (80-140)	Males (125-140 cm FL) in "sunburst" coloration set up temporary spawning territories, periodically swim 9-12 m. up into water column in courtship behavior, no interaction with females
	1910		250-300	90 (80-150)	Minimum of 12 contiguous spawning territories established, occupied by largest males, all in "sunburst" coloration exhibiting courtship behavior; dark-phase females appear to be sheltering in reef substrate
	1925				Fish were becoming more active at the time that observations ceased
August 24	1300	Full+5	125-150	100 (90-140)	Fish formed cone-shaped school and hovered over reef, 10% pale-phase fish
	1600		150-175	90 (80-140)	Increase in school size, school moving between sand and reef, with associated color changes which were frequent and rapid
August 25	1900	Full+6	125+	(90-150)	Several males observed in "sunburst" coloration in courtship behavior, females largely remain in dark-body phase close to substrate

their estimates of numbers and sizes as well as behavioral observations in an attempt to reach a consensus on what had been observed. A videographer roamed the area and captured footage of behavior and color changes. A portion of this footage was subsequently analyzed to confirm and refine divers' observations.

Due to logistical and safety constraints arising from working offshore, the dive teams were not able to remain on site until sundown. This is reflected in the timing of the observations in relation to sunset (Table 1). Another set of observations was made on the site for 2 days in August 2005, starting 5 days after the full moon. Only 4 divers were involved in these observations.

During observations, males were readily identified due to their larger size (all fish >120 cm fork length (FL)) and were counted as males since earlier research had determined the transition size range from female to male to be 110–120 cm FL (Luckhurst and Trott, unpublished data). Following this

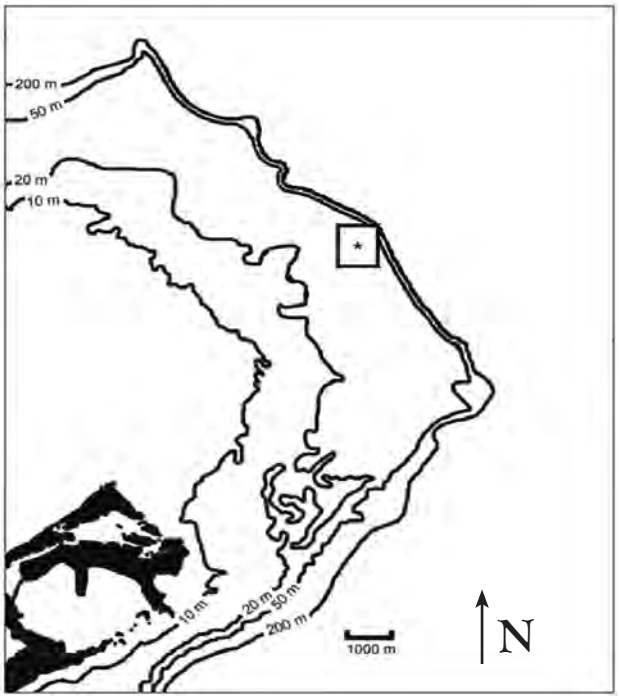

Figure 1. *Location of black grouper spawning aggregation site on the northeast reef platform of Bermuda. The square (1000 m x 1000 m) is the approximate area within which black grouper were observed during diving observations and the star symbol is the site with the highest observed density of black groupers during diving observations.*

protocol, all fishes estimated to be < 120 cm FL were counted as females. Although this species is capable of rapid and dramatic color changes, there was also some consistency in the appearance of the two sexes with smaller females generally being in dark–phase coloration or the normal species color pattern. The interpretation of the pale body coloration is still to be determined but Paz and Sedberry (2008) report that it is seen in both sexes. The width of the sub–marginal black bands of fin pigmentation on the caudal, anal and pectoral fins is also a useful indicator of the sex of the fish (Crabtree and Bullock 1998). In males, these bands are wider and a more intense black. This contrast is accentuated during spawning times, particularly in the caudal fin of males (with a pale caudal margin). Additionally, males in courtship display show a distinctive color pattern on the head. This coloration, termed a "sunburst" pattern by Heyman and Kjerve (2008) is described and illustrated (Figure 3C in their paper). The same coloration pattern is termed a "white-head" phase male by Paz and Sedberry (2008, Figure 3D). I use the term "sunburst" in this paper as the more descriptive term to describe this pattern in courting males as well as to use a term which is already in the published literature.

Results

Site description

The spawning aggregation site was located about 10 km offshore on the northeast reef platform of Bermuda (Figure 1) at a depth of about 30 m. The aggregation area is characterized by an extensive substrate of hard bottom with gorgonians and scleractinian corals. The hard bottom is interspersed with sand holes of variable size, often with ridges between them. The depth in the sand holes is about 33 m while the tops of the ridges range from 24–28 m depth. The bottom gently slopes seaward towards the edge of the reef platform with the shelf break at about 55 m depth. The center of the black grouper site is located about 500 m from the edge of the reef platform (Figure 1).

During the June observations, the surface water temperature was 25°C, however, there was a thermocline present at a depth of about 20 m. Below the thermocline, the temperature was 22°C. There were no water temperature data available from the site for the August observations but divers did not report detecting a thermocline. A comparison of the mean monthly water temperature between Bermuda and Belize (Figure 2) reveals that maximum temperatures occur at about the same time of year (August – September). There is a difference of < 2°C between the maxima (27.9°C in Bermuda in August; 29.5°C in Belize in September). However, the annual temperature range in Bermuda (18.9–27.9°C) is considerably greater than in Belize (26.5–29.5°C).

Behavioral observations

Table 1 briefly summarizes the daily observations by divers at the site. One of the notable constraints during the project was the underwater visibility which varied from 15–25 m, coupled with the fact that black grouper are generally wary and do not allow a close approach by divers on open–circuit SCUBA (Eklund et al. 2000, Paz and Sedberry 2008). As a result, this hindered divers' counts and thus estimates of abundance should be viewed as conservative because it was rarely possible to count all of the fish in the field of view clearly. The abundance estimates are mostly given as a range due to the variability of divers' counts. Because of the spatial extent of the site, it was not always possible to determine if individual divers were counting the same group of fish.

Observations in June 2005 started on the day of the full moon (June 21) when only 30+ fish were counted at the site. The number of fish showed an increasing trend in the following days to about 300 fish on June 26 (moon full + 5), although there was a credible estimate of 400 fish on June 22 (Table 1). The size range of fishes remained reasonably consistent during the 5 days of observations. Although the data are limited, observations confirmed that although males and females were always present on site, females appeared to increase in number during the afternoon and early evening. A small number of females with distended abdomens (a good indirect indicator of spawning readiness) were first observed on June 22 (moon full + 1) and the number of "ripe" females generally increased until observations ceased (Table 1). On June 26th (full moon +5), divers observed the establish-

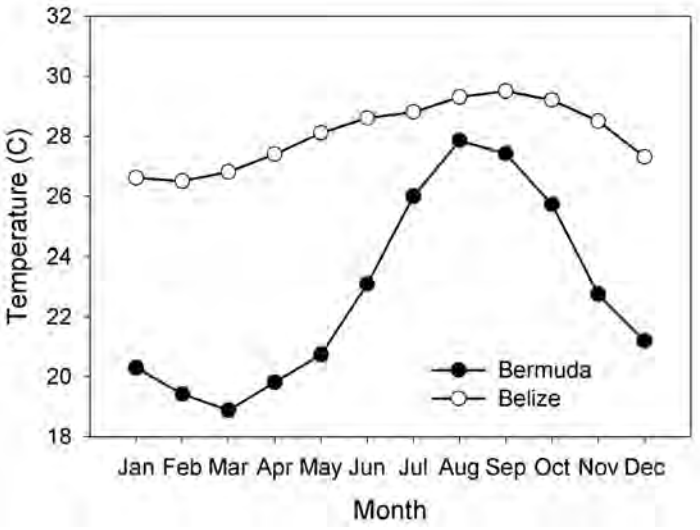

Figure 2. *Mean monthly water temperature (°C) in Bermuda and Belize. Maximum water temperatures occur during the same period (August – September) but there is greater seasonality in Bermuda than in Belize.*

ment of male spawning territories with males in courtship displays showing the distinctive "sunburst" color pattern on the head.

A minimum of 12 male spawning territories were identified by swimming a transect along a ridge line in the late afternoon and counting the large males which were conspicuous swimming above the substrate. These male territories were roughly mapped and appeared to be contiguous. These territories were first observed at 1855 h local time (95 minutes before sunset) but it is not known if they had formed earlier. Divers surveying in the vicinity of these territories during the same time period did not observe any other large males displaying courtship behavior at the site. A diagrammatic representation of male courtship behavior (Figure 3) illustrates the different components of the behavioral sequence. Males began by slowly swimming around the perimeter of their spawning territory about 1–2 m above the substrate. The striking "sunburst" coloration started to become more prominent at this stage. They then turned and swam (in a languid manner) vertically upward in the water column from 9–12 m above the substrate. Upon reaching this height above the substrate, they swam in a circular motion around an imaginary perimeter appearing to delimit their territory as a cylinder (Figure 3). The "sunburst" pattern appeared to become more pronounced when the males were at the top of the cylinder (J. Pitt, pers. comm., Department of Environmental Protection, Bermuda). After a few minutes, they turned and swam slowly downward to the substrate and apparently resumed the sequence again. No pair spawning rushes or gamete release were observed in this study. However, groups of 6–10 smaller fish in dark-phase coloration (considered to be females) were observed sheltering in the reef infrastructure around the male territories (J. Pitt, pers. comm.) although no interactions with males were detected. Due to the falling light level in the water column, it became increasingly difficult to observe clearly what female behavior was occurring at this time. Interestingly, no other transient spawning species were observed at the site during the five days of observations. It appeared that black grouper dominated the area in terms of both number and biomass.

The observations 2 months later (August 2005) were limited to 5 and 6 d after the full moon (Table 1). With only 4 divers, it was not possible to survey the site as thoroughly as in June but similar schooling behavior by black grouper was observed during the day and color changes were common. The estimate of the number of fish (150–175) present on August 24 (full+5) at 1600 h local time compared with the estimate (150+) on the same lunar day in June at 1645 h is similar (Table 1), but no meaningful conclusion can be drawn from this except to confirm that fish were still present in similar numbers 2 months later. The size range of fish between the 2 periods was also similar (Table 1). Again,

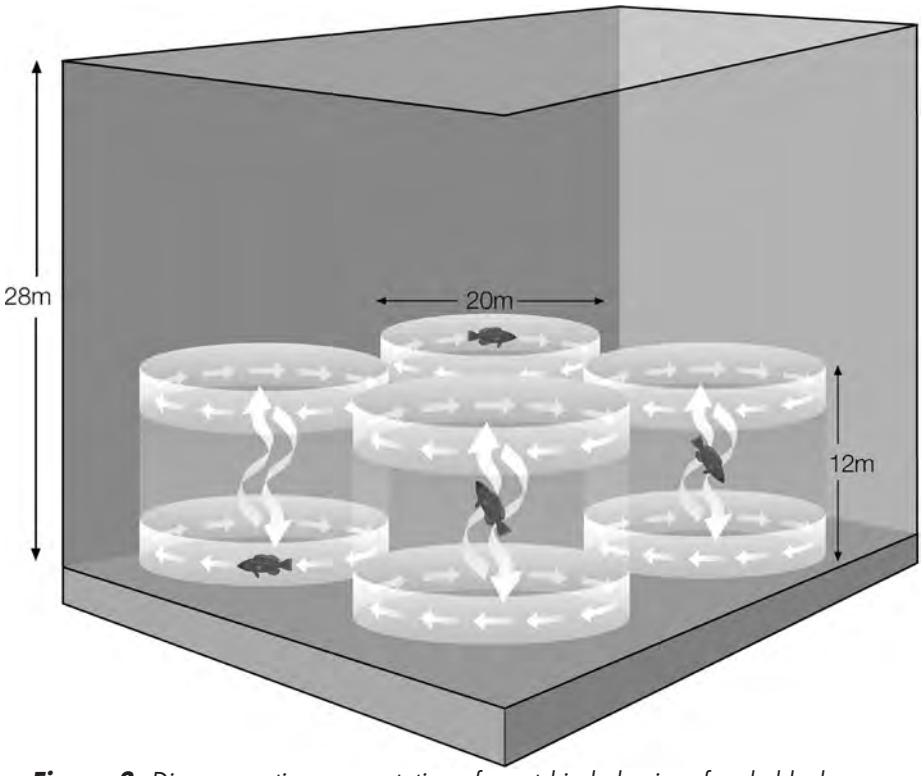

Figure 3. *Diagrammatic representation of courtship behavior of male black grouper in temporary spawning territories. Measurements given are: 28 m – depth of water, 20 m – diameter of cylinder, 12 m – height above substrate. See text for details of behavior and timing.*

there were no observations of other transient spawning species such as groupers or snappers in the area.

Using the limited observational data (Table 1), it is possible to describe a general behavioral pattern of black grouper during the afternoon period at the site. The daily sequence of behavior appears to be the following: 1) Loose schools of fish hover above hard substrate, sometimes forming cone-shaped schools of fish 10–15 layers high, no interactions between fish observed (1300 – 1700 h); 2) The number of females on site increases, fish become more active (1700 – 1800 h); 3) Females with distended abdomens appear more numerous and male courtship behavior is observed (1800 – 1900 h); 4) Males establish temporary spawning territories and commence courtship behavior, females shelter in the substrate in the vicinity of male territories (1900 – 1930 h). These observations were made in the week following the full moon but it is not known for how many days this sequence might continue.

Discussion

The center of the spawning aggregation site, located about 500 m from the edge of the reef platform (55 m depth), appears to be at a greater distance from the shelf edge than other published descriptions of black grouper spawning aggregation sites. Black grouper aggregations have been found near shelf breaks or at reef promontories in Belize (Heyman and Kjerve 2008) and Sala et al (2001) reported that a black grouper spawning aggregation was observed in the vicinity of a series of coral ridges in a spur and groove system close to the shelf break at Glover's Reef, Belize. This site was dominated by Nassau grouper. Whaylen et al. (2004) observed small groups of black grouper at a Nassau grouper spawning aggregation site which is located at a shelf break near a drop–off to deepwater in Little Cayman. Claro and Lindeman (2003) indicated that all of the multi-species spawning aggregation sites which they documented in Cuba were located near the shelf break. However, the black grouper may be more of a generalist as Paz and Sedberry (2008) observed spawning aggregations in a variety of reef formations in Belize. The location of the Bermuda site, at some distance from the shelf break, tends to support this latter observation.

Spawning seasonality in black grouper based on gonad histology has determined that the peak spawning period in populations to the south of Bermuda is from January to March (Florida – Crabtree and Bullock 1998, southern Gulf of Mexico – Brulé et al. 2003). Claro and Lindeman (2003) indicated that the peak of the spawning season for black grouper in Cuba was from February to March around the full moon. Diving observations of spawning seasonality at Gladden Spit, Belize indicate that peak spawning in black grouper occurs during the period January – March from 5–14 d after the full moon (Heyman and Kjerfve 2008). A survey of spawning aggregation sites in Belize revealed that peak spawning occurred in January – February and that black grouper were most abundant at sites from the full to the last quarter moon (Paz and Sedberry 2008). In summary, all of the black grouper populations at latitudes south of Bermuda have a winter spawning pattern. However, the summer spawning period (June – August) for black grouper in Bermuda is consistent with the spawning periods of other local groupers such as red hind (Luckhurst 1998), coney *Cephalopholis fulva* (Trott 2007) and lane snapper *Lutjanus synagris* (Luckhurst et al. 2000).

Thus, it appears that black grouper spawn at the warmest time of year in Bermuda and at a similar temperature, but at the coldest time of year, further south, e.g. Belize (Figure 2). Paz and Sedberry (2008) recorded a bottom temperature range of 24–27°C in Belize at black grouper spawning aggregation sites. This minimum is lower than that recorded at Gladden Spit by Heyman et al. (2005) but this may simply be the result of oceanographic variations. The bottom water temperature (22°C) observed at the aggregation site in the present study in June was recorded below a thermocline but it is not known whether a thermocline is a consistent feature of the oceanography at this site during this time period. A bottom temperature of 25°C was recorded at a shallower red hind spawning aggregation site in June (Luckhurst 1998) in the vicinity of the black grouper site. Although diving observations ceased 5–6 days after the full moon, strong evidence of an increase in fish abundance (in June) and imminent spawning (courtship and color changes, both June and August) was observed. However, it is not known how long the aggregation remained intact for either observation period or how long spawning may have continued. Heyman and Kjerve (2008) indicated that the lunar abundance peak of black grouper occurred 5–14 d after the full moon.

The data presented here are broadly similar to the detailed observations made in Belize and appear to confirm consistent behavioral patterns of black grouper in this spawning aggregation at the northern edge of the species range. The number of black grouper observed in aggregations in Belize over several years ranged from 25 to 375 (Paz and Sedberry 2008), a range similar to that reported here (20+ to 400) for a very limited time period. Heyman and Kjerve (2008) reported a maximum total of about 150 fish at a multi-species aggregation site at Gladden Spit and Sala et al. (2001) reported a similar maximum (140 fish) at Glover's Reef.

Paz and Sedberry (2008) stated that spawning took place at sunset and Heyman and Kjerve (2008) observed spawning 15–20 min before sunset. As the observations in the present study terminated at least one hour before sunset (Table 1), it is perhaps not surprising that the spawning act (i.e. gamete release) was not observed. Both Paz and Sedberry (2008) and Heyman and Kjerve (2008) described pair spawning in black grouper but neither described the full male courtship behavioral sequence documented here. Perhaps this is simply a

variation of the basic spawning behavior already described by these authors. Several elements of the behavioral sequence described for Bermuda are similar to those reported for males in "white-head" coloration (Paz and Sedberry 2008); these authors determined that this color pattern was observed only in mature males in spawning condition. Furthermore, this coloration was only seen in males during spawning months (December–March) in Belize (Paz and Sedberry 2008). By extrapolation, the observation of this male color phase in both June and August suggests that these are active spawning months in Bermuda. Although no observations were made in July, it is reasonable to assume that spawning could have occurred in that month, leading to a conclusion of a minimum spawning period of 3 lunar months in Bermuda. This is consistent with the 3 month peak spawning period at Gladden Spit (January–March) documented by Heyman and Kjerve (2008). Recent acoustic tagging data collected from the Bermuda site indicates that the aggregation may form monthly for a period of 5–6 months (Trott, Luckhurst and Pitt, unpublished data) but additional data is required to confirm this time period. The important issue of whether spawning is occurring in each aggregation month will require continued monitoring of the site. These data are essential to better define the range and variation of the elements of this aggregation which will allow for more responsive and effective management of this commercially valuable species.

Acknowledgements

I want to thank fisherman K. Gregory for taking me to the site when he first became aware of the presence of this spawning aggregation. His long–term support for the management of spawning aggregations and his contributions to fisheries research have been important factors in progressing this work. There were many people involved in this diving project but they are too numerous to list individually by name. I want to acknowledge I. Murdoch and R. Whayman for organizing this project and providing their own vessels to transport divers to the site. Judie Clee, at reef, did much of the organizational work and coordination for the project. Chris Burville generated much valuable video footage which helped to clarify and refine observations and M. Sturmey provided a number of important observations. Tammy Trott provided the Bermuda water temperature data and W. Heyman the Belize data. Joanna Pitt produced Figure 1. Terry Madeiros created Figure 3 based on information provided to him by the author. Ken Lindeman, W. Heyman, T. Trott and J. Pitt provided helpful comments on the manuscript.

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