Nassau grouper (*Epinephelus striatus*) Tagging Report, Sandbore, Northern Lighthouse Reef, Belize

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Executive Summary

Between 5 and 9 January 2006, a total of 34 individual Nassau grouper were captured by fish trap, tagged with Vemco acoustic transmitters and released at the Sandbore (Lighthouse Reef) Belize, Nassau grouper (fish) spawning aggregation (FSA) site. Tagged individuals included 20 females and 14 males. Of the 34 fish tagged, 13 females and 10 males were detected by the Vemco receiver centrally placed within the FSA. The fate of the 11 undetected individuals is unknown, since three of the four Vemco receivers placed at the site flooded with seawater or were lost. Thus, these individuals may have been within the FSA, but out of range of the central receiver. Among those individuals that were detected by the receivers, residency was shown from a few days to more than one month. Repeat visits to the site occurred frequently among tagged grouper and ranged from one to four months, with an average of 2.1 months for both sexes. Both the time of arrival and departure varied monthly relative to the full moon. Reliance on one centrally placed receiver (owing to floods and loss) did not allow direction of movement to be determined. However, data suggests that aggregations may form at slightly different locales within the FSA site, i.e., the aggregation location is not static. Therefore, monitoring protocols using fixed transects or areas are liable to be ineffective. Data also suggest that individuals may move substantial distances for feeding within an aggregation month, possibly carrying them outside of the MPA. Monitoring at different times of the day would, therefore, provide variable estimates. Although these results are considered preliminary, these and other acoustic data suggest that a seasonal catch ban may be more effective than MPAs, since Nassau grouper are now known to move considerable distances away from FSA sites during the reproductive season, and along reproductive migratory pathways, where they are vulnerable to fishing. To detect patterns of movement away from the FSA and gain additional information about movement during spawning periods, additional receiver placement within and way from the FSA site is warranted.

Introduction

The Nassau grouper, *Epinephelus striatus* (Bloch, 1822), is a long-lived, slow growing and regionally important serranid (Serranidae: Epinephelinae) that forms temporally and spatially predictable spawning aggregations (Sadovy and Eklund, 1999). Other aspects of its life history include a functionally gonochoristic reproductive life history and possible long distance migratory movement from its home range to reach spawning sites (Sadovy and Colin, 1995; Bolden 2000). These combined traits make Nassau grouper particularly vulnerable to overfishing, similar to many of its confamilials.

Within its range, the Nassau grouper has been targeted historically by both local and commercial fisheries and once formed the basis for large-scale fisheries, including in Belize (Sala et al. 2000). The species is vulnerable to a wide range of gears and has proven to be less than resilient to anything other than light levels of fishing, as shown by widespread declines in landings, mean size, (fish) spawning aggregations (FSA) and catch-per-unit-effort. Indeed, recent reports estimate as much as 1/3 of known Nassau FSA has been decimated, including one well known site in Belize—Emily (Caye Glory) (Sadovy 1993). While management in many parts of its range is increasing (e.g. Whaylen et al. 2004), monitoring and enforcement efforts are lacking in most locales. As such, it remains uncertain what effect management is having regionally.

In Belize, nine Nassau grouper FSA sites were known and fished historically. During its heyday, the Caye Glory Nassau fishery—initiated in the 1920s— took between 1,200 and 1,800 Nassau grouper daily throughout the fishing season, which was concentrated in December and January (Craig, 1969). By 2001, only 21 fish were observed and 9 were taken by fishers. Similarly, at North Point Glover's, spawning populations appear to have declined from 15,000 to approximately 570 or less in recent years, with continued legal fishing at the site until 2003 (Starr et al. 2007). By 2001, only 2 of 9 formerly recognized Nassau grouper FSA were reported to be active. In 2003, partly in response to observed declines in these and other species, the Government of Belize closed 11 of 13 known multi-species spawning aggregation sites around the country, however, enforcement is

lacking and few details of the efficacy of the existing MPAs in protecting Nassau grouper are available (GoB, 2003).

Sandbore (Lighthouse Reef Atoll) is one of the few known spawning aggregations sites in Belize. The site has been historically fished and recently has been heavily fished by trap fishers since at least 1975. The abundance of the aggregation at the time fishing began was unknown, although recent estimates have shown at least 1,500 fish at the site during peak spawning periods in March. The site is currently under MPA protection, with limited fishing known to occur by patriarch fishers. To gauge the potential effectiveness of the MPA in protecting Nassau grouper, the current research program is employing an acoustic array to identify sex-specific residency times and patterns of movement at the site by acoustically tagged fish. The anticipated outcome of the program is to roughly map the direction of movement of tagged individuals to and from the site during reproduction and determine whether current MPA boundaries are sufficient in protecting reproductively active fish during spawning periods. The program is also seeking to determine whether sex-specific differences in vulnerability may exist as a result of variations in movement pattern or residency at the spawning site during reproductive periods.

Methods

To determine residency times, fishing vulnerability and patterns of fish movement, an acoustic tagging program was launched at Sandbore, Lighthouse Reef, Belize, in January 2007. To capture fish for tagging, fishers used a baited 1.5 m^2 chevron trap with wire mesh placed on the reef between 25-30 m depth. Traps were relocated by surface floats and hauled daily or semi-daily depending on the number of fish needed for tagging daily. Following retrieval, all fish were transported to Northern Two Cayes by boat prior to tagging and placed in a circular chickenwire cage (~3 m^2) submerged in ~1 m of seawater at high tide. Prior to tagging, the air bladder was deflated using a 20-gauge sterile needle and the fish were allowed to recovery for approximately 1 hr.

Following initial recovery, each individual was transferred into a MS-222 anesthetic solution (0.75 g l^{-1}) for a period of 3-5 min, with the total immersion time depending on fish size. Fish were subsequently removed from the anesthetic solution following loss of equilibrium and placed on a wet padded platform for weighing (nearest 0.1 kg body weight) using a spring-loaded balance. Individuals were then measured (nearest 0.5 cm Total Length) and cannulated to determine sex and maturity stage using a 1-mm bore cannula. All measures were recorded for subsequent analysis. During all procedures, fish were covered with a wet cloth to reduce stress. To introduce the acoustic transmitter (Vemco V16®), a 3-cm incision was made just prior to the vent using a surgical scalpel. A beeswax-coated transmitter was then introduced into the gut cavity. Incisions were then closed using ConMed Wide® surgical staples and a topical antibiotic (triple antibiotic ointment) was applied to prevent infection. Following surgery, fish were placed back into the circular cage for an 8-12 hr recovery period that also allowed investigators to assess potential mortality. Recovered fish were either transported back to the capture site or released in the lagoon proximate to the FSA site. Released fish were monitored briefly on snorkel or SCUBA to check for normal activity, such as swimming or re-joining the aggregation.

To monitor direction of movement and residency times, four VR1® receivers were deployed at the spawning aggregation site, including one centrally located receiver and two receivers placed 1 km north and south of the central location. A fourth receiver was placed just west of the spur-and-groove reef formation to monitor movement close to the spur-and-groove habitat and in an attempt to detect whether fish may be entering the lagoon by moving across the reef crest. All receivers were positioned to determine residency times and patterns of movement to and from FSA sites. At least one additional receiver was to be placed at one or both ends of the Sandbore MPA boundary in February 2007 during routine monitoring in that month. Receivers were checked in May 2007 and replaced by VR2W®. During replacement, all receivers were fitted greater floatation and with more mooring line to increase the distance from the bottom (thereby allowing greater range of detection). The positions of the receivers are listed in Table 1.

Table 1: WGS 84 coordinates, locations and depths for the Sandbore VR2W® receivers.

Location	Latitude	Longitude	Depth (ft)
North	E 0452260	N 1929458	80
South	E 0452401	N 1927383	96
Central	E 0452520	N 1928574	90
West	E 0452131	N 1928608	40

Results

Between 5 and 9 January 2007, a total of 34 Nassau grouper were tagged using Vemco V16® acoustic pingers that included 21 females and 13 males (Table 2). Of those, signals were received from 13 females and 10 males. The fate of the 11 undetected individuals is unknown, since 3 of 4 Vemco VR1® receivers flooded with seawater or were lost. Thus, the results presented here represent signals from the centrally placed receiver only. In addition, the loss of all but one receiver precludes analysis of direction of movement and spatial habitat use within the aggregation site.

For the 33 individuals with detections at the FSA site, temporal variations were observed among individuals daily, monthly and seasonally. Both males and females averaged 2.1 months at the site overall, with tagged females detected at the site from 1-8 months males from 1-3 months. Most females detected at the site returned for 2 months of the study, while males returned in relatively equal numbers in each month of the spawning season. Seven females and size males were detected over a sufficient number of days to allow visualization of temporal patterns. Temporal patterns for select females are shown in Figure 1. These include all individuals present during at least several days in one or more months of the survey. One female appears to be resident at the site and was present during all survey months (Figure 2). The temporal patterns for males are presented in Figure 3. As shown by the figures, a number of individuals were present at the site outside what is considered the 'normal' spawning season (January-March).

Differences were also observed for both sexes in the times that individuals arrived and departed the spawning site (Table 3). In general, males spent more time at the FSA

*Table 2: Details of the January 2007 tagging, including individual fish length, weight and sex. Tagging dates are provided. M=male, F=female. *All fish were present at the site for a minimum of 1 month, although some were not detected after release. ***=not taken.*

Date	Tag	Sex	Weight (kg)	Length (TL)	Signal	No. months*
5/1/07	2545	F	4.8	59.5	Y	1
5/1/07	2540	F	> 6	69.0	N	0
5/1/07	2542	F	> 6	66.0	N	0
5/1/07	2538	F	3.5	56.5	Y	2
5/1/07	2536	F	4.8	60.0	Y	1
5/1/07	2537	F	5.7	61.0	Y	2
5/1/07	2543	M	6.5	62.5	N	0
5/1/07	2541	F	4.4	59.0	N	0
5/1/07	2544	M	6.0	58.5	N	0
5/1/07	2539	M	***	65.0	Y	3
6/1/07	2527	M	***	52.0	Y	1
6/1/07	2528	M	***	57.5	N	0
6/1/07	2546	M	***	54.5	N	0
6/1/07	2529	F	***	61.5	N	0
6/1/07	2530	F	***	58.0	N	0
6/1/07	2548	F	***	74.0	Y	4
6/1/07	2547	F	***	61.0	Y	2
6/1/07	2525	F	***	64.5	N	0
6/1/07	2524	M	***	55.0	Y	3
6/1/07	2519	F	***	55.5	N	0
7/1/07	2521	F	4.0	55.0	Y	1
7/1/07	2522	M	3.4	53.0	Y	2
7/1/07	2523	F	4.1	56.5	Y	2
7/1/07	2520	F	> 6	77.0	Y	1
7/1/07	2516	F	5.8	63.5	Y	2
7/1/07	2518	F	4.7	61.5	Y	2
7/1/07	2549	F	4.9	60.0	Y	8
8/1/07	2555	F	4.8	60.5	Y	2
8/1/07	2553	M	4.2	54.5	Y	1
8/1/07	2552	M	4.0	57.0	Y	2
8/1/07	2550	M	4.5	58.5	Y	1
8/1/07	2517	M	4.9	57.5	Y	2
8/1/07	2551	M	5.8	60.5	Y	3
8/1/07	2554	M	5.5	60.0	Y	3

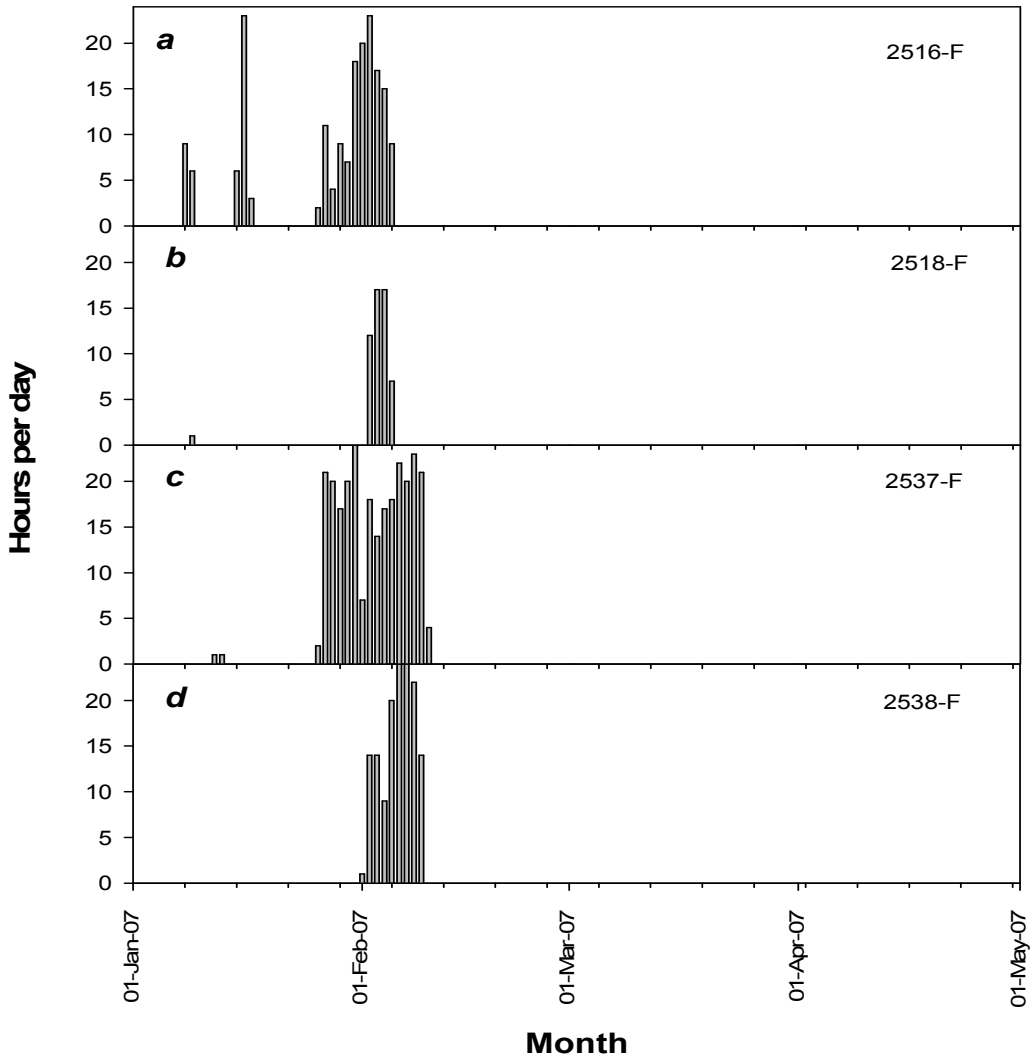

Figure 1 a-d: Seasonal activity profiles for females detected by the centrally located Vemco receiver at Sandbore January-August 2007. No detections were observed after 1 May 2007 for any of the females shown, such that X-axis values are limited to five months. All females were tagged in January 2007 and were, therefore, at the spawning site, although detections may not have been recorded by the receiver at that time. Note: Variations in the arrival and departure times among individuals may represent movement away from the range of the receiver and not actual arrival or departure times.

site, according to central receiver data, than females, particularly during the first three months (although no data is available on arrival times in January). Interestingly, in March (both sexes) and April (females only), arrival times at the site were dramatically later

than in previous months, assuming central receiver data accurately reflects arrival times. Alternatively, times were not substantially different and the FSA formed outside the receiver range and subsequently moved to within detection range.

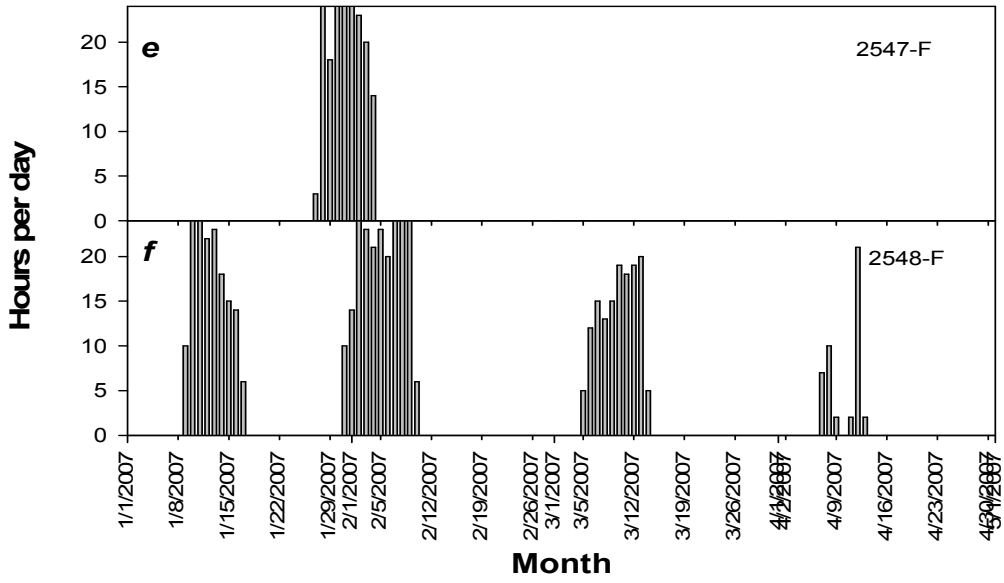

Fig 1 e-f: Seasonal activity profiles for females detected by the centrally located Vemco receiver at Sandbore January-August 2007. No detections were observed after 1 May 2007 for any of the females shown, such that X-axis values are limited to five months. All females were tagged in January 2007 and were, therefore, at the spawning site, although detections may not have been recorded by the receiver at that time. Fish 2548-F represents the only female present at the site (or detected) over 4 months of the 8-month study period. Note: Variations in the arrival and departure times among individuals may represent movement away from the range of the receiver and not actual arrival or departure times.

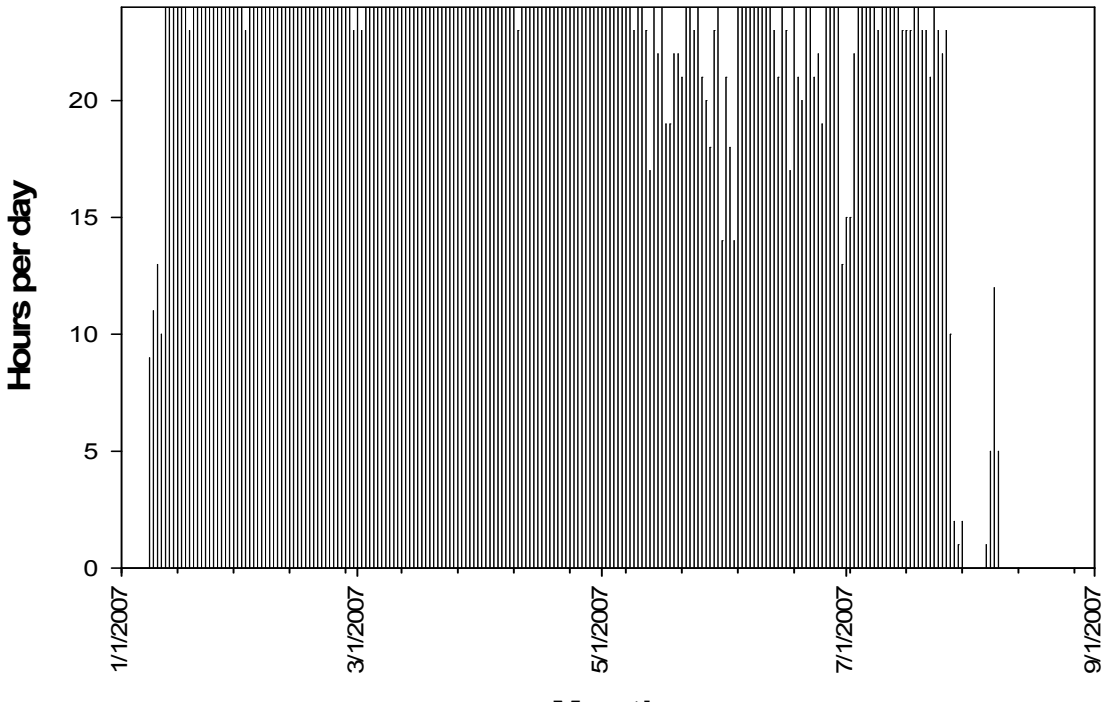

Fig 2: Detection pattern of a resident female at the Sandbore spawning aggregation site. The female was present in all months of the survey and appears to rarely leave the area of the receiver. The individual was the only tagged fish detected at the site in all survey months.

Table 3: The number and percentage of males and females that returned to the aggregation during the first 8 months of the survey (January-August). One female (2549) was present in all months and is considered resident.

No. months	No. males	% Males	No. Females	% Females
1	3	40.0	4	30.8
2	2	20.0	7	53.8
3	4	40.0	0	0.0
4	0	0.0	1	7.7
5+	0	0.0	1	7.7
Total	**10**	**100**	**13**	**100**

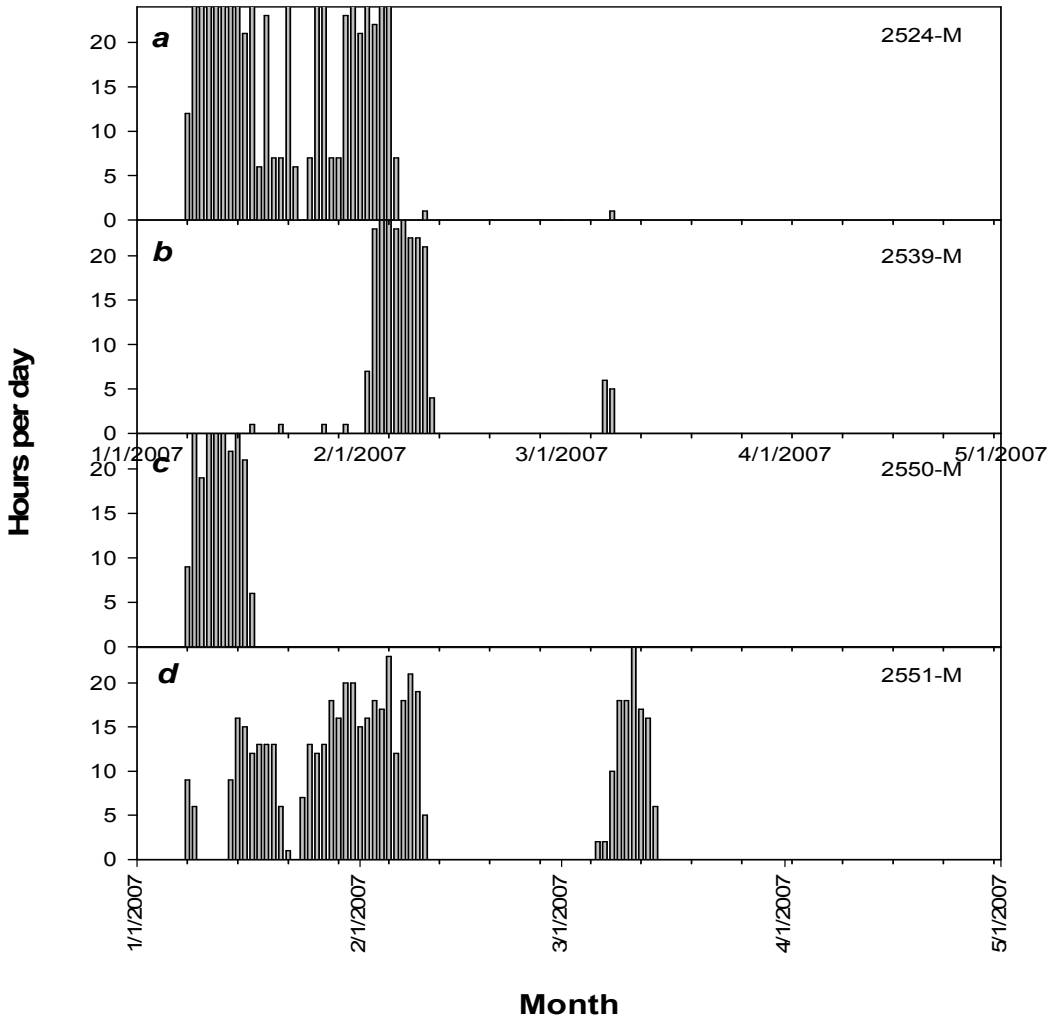

Figure 3 a-d: Seasonal activity profiles, as both the number of days and hours per day, for males detected by the centrally located Vemco receiver at Sandbore January-August 2007. No detections were observed after 1 May 2007 for any of the males shown, such that X-axis values are limited to five months. All males were tagged in January 2007 and were, therefore, at the spawning site, although detections may not have been recorded by the receiver at that time. Limited detections for some individuals in March likely indicate ineffective receiver coverage for the site. Note: Variations in the arrival and departure times among individuals may represent movement away from the range of the receiver and not actual arrival or departure times.

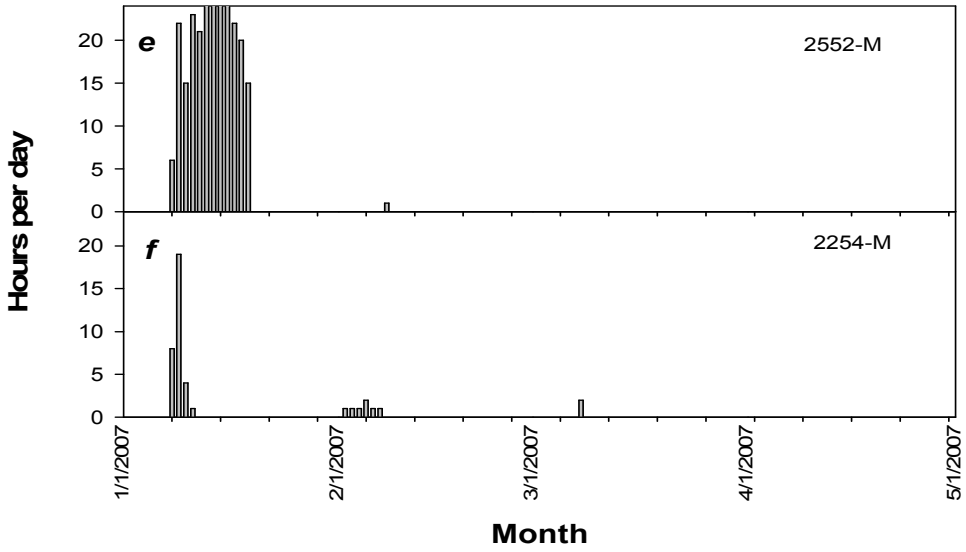

Figure 3 e-f: Seasonal activity profiles, as both the number of days and hours per day, for males detected by the centrally located Vemco receiver at Sandbore January-August 2007. No detections were observed after 1 May 2007 for any of the males shown, such that X-axis values are limited to five months. All males were tagged in January 2007 and were, therefore, at the spawning site, although detections may not have been recorded by the receiver at that time. Limited detections for some individuals (e.g., March) likely indicate ineffective receiver coverage for the site. Note: Variations in the arrival and departure times among individuals may represent movement away from the range of the receiver and not actual arrival or departure times.

Temporal variations were widely observed among tagged individuals. These variations include the number of months that tagged individuals frequented the site, the length of time at the site within an individual month and in the number of hours that they remained proximate to the receiver within the month or even within a day. Figures X-Y provide both seasonal and monthly information on fish residency and movement relative to the spawning site. Some individuals that were present in a single month for a few days only or individuals that were present in more than one month, but only for a or a few days for each month, were excluded from analyses, since they provide no additional information on residency times, seasonal visitation or behavior. Figure 4 provides indications of daily patterns of movement within the aggregation site by one male and one female, as examples. The movement, although speculative, appears to be feeding forays into areas

away from the receiver. Patterns of movement during feeding (or other behaviors) and migration to and away from sites monthly will require additional receiver coverage.

*Table 4: Variations arrival and departure times at the aggregation site, based on central receiver detections, for tagged Nassau grouper at Sandbore, Lighthouse Reef. Sample sizes are given in parentheses. Standard errors are shown for combined sexes, but not for males and females separately. *** represent no data. DBFM=days before full moon; DAFM=days after full moon. "+" values represent days after full moon periods.*

	Females		Males		Combined	
Month	**DBFM**	**DAFM**	**DBFM**	**DAFM**	**DBFM**	**DAFM**
Jan	***	11.2 (4)	***	11.8 (6)	***	11.5±4.6 (11)
Feb	4.3 (6)	5.2 (6)	7.5 (4)	6.8 (6)	5.4±5.4 (11)	6.4±3.2 (14)
Mar	(+2) (1)	11(1)	(+4) (3)	7.0 (3)	(+3.5±1.3) (4)	8.0±3.4 (4)
Apr	(+5) (1)	11 (1)	***	***	(+5.0±0.0) (1)	11.0±0.0 (1)
May	***	***	***	***	***	***

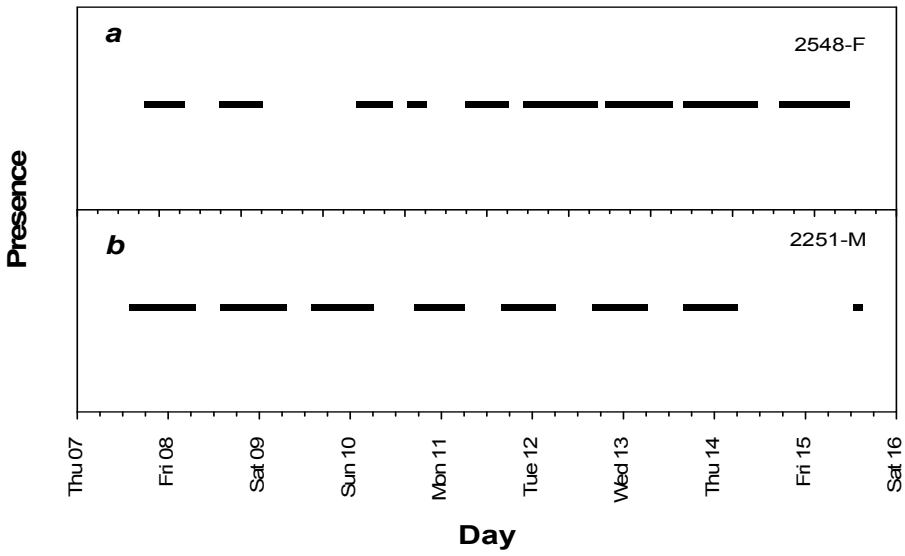

Fig 4: Daily activity patterns for a (a) tagged female and (b) a tagged male. The graph shows only a portion of the month (10-d period) to highlight movement around (black lines) and outside (intermittent areas of clear) the receiver range. The patterns may suggest movement in relation to feeding or changes in depth. Monitoring protocols that do not consider these types of variations risk inaccurate abundance estimates. Note that males and females may not always overlap in time daily at the site.

Discussion

The findings presented here show that substantial variations in residency and visitation times occur, which is consistent with findings from other Nassau FSA investigated in Belize (Starr et al. 2007). These temporal variations undoubtedly affect the vulnerability of individuals to fishing. For example, when FSA fishing is allowed, individuals that spend longer times at the aggregation would be more vulnerable than those spending less time there. Although the average time spent at the FSA varied both seasonally and within months, individuals would be vulnerable to fishing, on average, for around 13 - 23 d over a period of two months, based on the available data.

Findings from this report showed no evidence of significant sex-specific differences in the average site visitation frequency (~2 months), although some differences were shown in the number of days spent at the FSA monthly both by sex and among individuals. While both males and females frequented the site around two months per spawning season, males appeared at the site (or in range of the receiver) during more days than females within individual spawning months. From this evidence, it may appear that males may be more vulnerable to fishing than females at the FSA. Curiously, females outnumbered males in (trap) catches during the project. These findings may suggest relatively higher vulnerability to traps for females than males. If females are more vulnerable overall (i.e. all gear types), the removal of greater numbers of females than males would reduce the overall reproductive output (as egg output). Conversely, the removal of more males could lead to sperm limitation, reducing the number of fertilized females, i.e., some females go unfertilized. The former scenario (selection of females) has not been shown in nature for groupers, although sexual selection (and possible sperm limitation) has been shown for gag grouper (*Mycteroperca microlepis*) (Koenig et al. 1996). It would be impractical, based on this limited data, to suggest that sexual selection is occurring on the Sandbore FSA. However, given the potential for sexual selection shown during trapping efforts, closer monitoring and scrutiny of fishing on this and other

FSA is warranted. A sex ratio imbalance could partially explain why the Nassau FSA at Glover's Reef continues to decline under MPA protection, although a number of other explanations are possible.

Temporal variations suggest that individual aggregations (i.e., within a single spawning month) represent a sub-set of the total spawning population. This finding is supported by the fact that only 1 of 34 tagged individuals was present during all spawning months following initial tagging. While it is possible that this can be explained by tag-induced mortality, similar findings are shown elsewhere (e.g. Nemeth et al. 2007, Starr et al. 2007; Rhodes and Tupper *in review*). Thus, having an open season during a portion of the reproductive period would be unlikely to eliminate the entire adult population, although reductions in both the population and the reproductive output could be anticipated. Nonetheless, since there is currently an incomplete understanding of FSA dynamics for this or any other aggregating species of grouper, precautionary management is advised that includes a total ban on FSA fishing and protection of reproductive individuals at FSA site, reproductive migratory pathways (RMP) and within reproductive seasons.

For monitoring, findings highlight the need for consistency in monitoring times and an *a priori* understanding of aggregation dynamics and fish behavior. The findings shown here clearly show that abundances change both throughout the spawning season, within months and within a single day. While most fish demonstrated a presence at the site for 1-2 months of the spawning season, a substantial change in arrival and departure times was observed among months and few fish appeared to return to the site in either March or April. Similarly, changes in activity, such as shown in Figure Z illustrate the need to identify variations in behavior. Based on detections, fish move into and out of the aggregation during daylight hours, thereby creating variable abundances throughout the day. Finally, there are some indications that the aggregation may move along with reef within the spawning season, since some individuals in March, for example, were detected for only a few days. This finding suggests that the animals were present, but were outside receiver range and aggregating in a slightly different area than in previous months. Thus, monitoring protocols that rely on fixed transect or areas for counts are unlikely to detect

all of the individuals present within the FSA site. Alternatively, monitoring should be consistent in the time of the day that observations are made and recognize that natural changes are occurring that are independent of fishing. Recognizing when these variations occur can help maintain accuracy in abundance estimates and prevent unnecessary or ineffective management actions.

No determinations were made in regards to spatial habitat use or patterns of movement to and from the FSA because of receiver malfunction, primarily flooding of older VR1® receivers. Therefore, there is insufficient evidence of RMP for Sandbore and no recommendations for improving the existing MPA are possible. An increase in the number of receivers at and away from the FSA site would allow determinations for improvements to be made, including RMP and daily movement patterns for some individuals that may take them outside existing MPA boundaries (e.g., Fig. X).

From a conservation standpoint, recent evidence, including that from this study, suggests that FSA fishing is detrimental to population persistence. A number of Nassau grouper spawning aggregations have been reduced or eliminated throughout its range as a direct result of FSA fishing (Sadovy and Eklund, 1999). Moreover, based on evidence supplied by Starr et al. (2007), existing MPAs are ineffective in protecting Nassau grouper during the spawning season since (1) none provide protection for individuals along RMP, (2) fishing that likely includes poaching continues to occur at and away from FSA, resulting in continued declines for reproductive populations, and (3) enforcement is completely lacking at all existing MPAs and at landing sites where Nassau grouper are likely to occur during catch ban periods. To improve existing management and protection for Nassau grouper, enforcement needs to be vastly improved by (1) enforcing the existing catch ban during the reproductive season and (2) introducing a 'skin-on' policy that provides a mechanism for enforcement officials to identify illegal catch. While MPAs are a popular conservation tool, as currently monitored and enforced in Belize, they are currently ineffective. The ineffectiveness of Belizean MPAs is in part due to ineffective enforcement, but also due to the fact that RMP are not incorporated into protected areas. For Nassau grouper, as shown for Glover's Reef, the incorporation of RMP into MPAs would likely be impractical owing to the large areas used by migrating

Nassau grouper during spawning. Management should consider improving MPAs through strict enforcement and by ensuring areas completely incorporate the actual spawning aggregation area. Recent evidence suggests that in spite of MPA protection for the Glover's Reef Nassau FSA, the spawning population continues to decline and will likely be extirpated entirely in as few as 6 years. This evidence clearly shows that additional measures are needed for enforcement and monitoring.

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