# Aggregation dynamics and lessons learned from five years of monitoring at a Nassau grouper (*Epinephelus striatus*) spawning aggregation in Little Cayman, Cayman Islands, BWI.

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**ABSTRACT**

The Nassau grouper spawning aggregation off the west end of Little Cayman, Cayman Islands was monitored for five consecutive years (2002-2006). An aggregation of approximately 2,000 Nassau grouper (*Epinephelus striatus*) appears to be stable over the last three years of the study period. Over five years, times of peak numbers of Nassau groupers ranged from one to five days after the full moon (January or February). Nearly 300 spawning bursts were recorded over the study period. On average, spawning bursts were recorded 21 minutes before sunset to 11 minutes after sunset, but were observed as early as an hour before sunset to 20 minutes after sunset. The timing and number of spawning bursts were variable each year. All spawning bursts were observed in the months of January or February. Spawning periods ranged from three to six days in duration and ranged in moon phase from one day after the full moon to eight days after the full moon. The month for the major spawning event appeared to be influenced by the date of January's full moon. Late January full moons (occurring 30 days or more after the winter solstice) resulted in major spawning events in January. Conversely, early January full moons resulted in major spawning events in February. Currents were slack or negligible during nights of spawning.

Over a period of 24-48 hours and during sunset dives, prior to the first spawning night, the percentage of Nassau groupers in the bicolor phase increased to 80%, at which time spawning occurred. This shift in color phase may be used to predict when spawning will occur. The formation and the physical location of the Nassau grouper aggregation had low variability throughout the monitoring period. Aberrant colorations of individual Nassau groupers were observed at the study site. Subsequent sightings both on and off the spawning site suggests permanent anomalous pigmentation that was useful for tracking inter-year survivorship. Twenty-one other fish species displaying spawning coloration or behavior were recorded at the site.

KEY WORDS: *Epinephelus striatus*, Little Cayman, spawning aggregation, moon, Nassau grouper

# La Dinámica de Agregaciones y lo que Aprendimos en Cinco Años de Monitorear la Agregación Reproductiva de *Epinephelus striatus* que Desova en la Isla Pequeño Cayman, Islas Cayman, BWL

Se ha monitoreado por cinco años consecutivos (desde 2002 hasta 2006) la agregación de *Epinephelus striatus* que desova en las aguas del extremo occidental de la isla Pequeño Cayman, Islas Cayman. La agregación de aproximadamente 2,000 individous de *E. striatus* parece ser estable durante los últimos tres años del período de estudio. Durante los cinco años de estudio, los eventos de mayor número de *E. striatus* ocurrieron de uno a cinco días después de la luna llena (enero o febrero). Casi 300 liberaciones de gameto ocurrieron durante el período del estudio. En promedio, liberaciones de gameto fueron observadas desde 21 minutos antes de la puesta del sol a 11 minutos después de la puesta del sol; pero fueron observados tan temprano como una hora antes de la puesta del sol a 20 minutos después de la puesta del sol. El tiempo y el número de liberaciones de gameto variaron durante cada año. Todos los liberaciones de gameto fueron observadas durante los meses de enero y febrero. Los ciclos de desove duraron de tres a seis días y ocurrieron en la fase lunar de un día después a ocho días después de la luna llena. El mes de mayor desove parece ser influienciado por la fecha de la luna llena del mes de enero. Las últimas lunas en enero tuverion resultaron en los eventos de mayor de desove. Opuestamente, las lunas llenas tempranas en enero resultaron en eventos de mayor de desove en febrero. Dos agregaciones relativamente menores de aproximadamente 200 a 300 individuos de *E. striatus* fueron observados la semana de luna llena en marzo 2003 y 2004, pero ningún desove ocurrió. Las corrientes eran inexistentes o insignificantes durante las noches de desove.

Durante un período de 24 a 48 horas y durante inmersiones de la puesta del sol, antes de la primera noche del desove, el porcentaje de individous de *E. striatus* en la fase de bicolor aumentó al 80%, en este momento ocurrió el desove. Este cambio en la fase de colores se puede utilizar para predecir cuando ocurrirá el desove. La formación y la ubicación física de la agregación de *E. striatus* eran variables a través del período del monitoreo. Las coloraciones aberrantes de individuos de *E. striatus* que se observaron en el sitio del estudio, y vistas posteriormente en otros sitios del desove sugiere pigmentación

anómala permanente. Se han registrado veintiun especies distintas de peces demostrando la coloración o conducta del desove en el sitio.

PALABRAS CLAVES: *Epinephelus striatus*, agregación reproductive, luna, Nassau grouper

## INTRODUCTION

Nassau grouper, *Epinephelus striatus*, aggregate to spawn near the full moon during the winter months in the Caribbean (November through February) (Bolden 2000, Domeier and Colin 1997, Sadovy and Eklund 1999, Sala *et al.* 2001). Historical data show that Nassau grouper spawn only during the winter (Aguilar-Perera 1994, Colin *et al.* 1987, Colin 1992, Olsen and LaPlace 1979, Smith 1972, Tucker *et al.* 1994).

The locations of many of Nassau grouper spawning aggregations in the Caribbean have been known for at least a century. Approximately one-third of these aggregations no longer exist due to fishing pressure and their decline is well documented (Aguilar-Perera 1994, Carter *et al.* 1994, Paz and Grimshaw 2001, Sadovy and Eklund 1999, Sala et al 2001). However, Little Cayman (Cayman Islands, British West Indies (BWI)) is one of the few places where Nassau grouper still aggregate in the thousands (Whaylen *et al.* 2004).

In 1987, the Cayman Islands Department of the Environment began monitoring Nassau grouper populations in Grand Cayman and Cayman Brac at the request of fishermen who reported decreased fish size and catch. In 2001, the need for monitoring at the site at Little Cayman's west end fish spawning aggregation was urgent; that year approximately 2,000 Nassau groupers were harvested by hook and line fishing over nine days during the spawning period (Bush *et al.* 2003, Whaylen *et al.* 2004). Monitoring at Little Cayman's west end began during the January 2002 aggregation period at which time another 2,000 Nassau groupers were harvested. This active aggregation site, along with seven other designated historical aggregation sites in the Cayman Islands, was protected under legislation enacted in 2003 that prohibits fishing year-round within the protected areas.

Nassau groupers are large, long-lived fish with a late age of maturation (Sadovy 1994, Sadovy and Eklund 1999). Typically solitary animals, Nassau groupers congregate at spawning aggregation sites once or twice per year in sequential months, during which time they adopt different colorations and behaviors (Aguilar-Perera and Aguilar-Davila 1996, Carter *et al.* 1994, Colin 1992). The four courtship colorations for this species during the spawning season are barred (normal) phase, white belly, dark, and bicolor (Aguilar-Perera 1994, Aguilar-Perera and Aguilar-Davila 1996, Carter *et al.* 1994, Colin 1992). At dusk near spawning time, Nassau groupers move from the reef terrace to the shelf edge, where the fish form a band (dense school) in the water column (Carter 1989, Colin 1992, Whaylen *et al.* 2004). It is during this re-location that the shift in coloration also occurs (Carter *et al.* 1994, Whaylen *et al.* 2004).

This paper is a review of five years of monitoring at the spawning aggregation site off Little Cayman's west end (Figure 1). Monitoring data collected included spawning aggregation dynamics, environmental parameters potentially influencing the timing and duration of spawning, aberrant coloration of individuals, and the migration of Nassau groupers. The usefulness of the percentage of fish in a particular spawning coloration to gauge the predictability of spawning is discussed. Additional information on multi-species use of the aggregation site is presented. Although data were collected for both spawning months (January and February), this paper focuses mostly on the major spawning event for each year. A major spawning event is characterized by the largest numbers of spawning bursts, highest abundance of groupers, and longest duration of spawning. Typical behavior of a migratory Nassau grouper was characterized by rapid swimming along the wall, either towards or away from the aggregation site. Spawning bursts (gamete releases) are defined as sudden convergence of individuals and simultaneous release of milt or eggs. Spawning period is defined as the length of time Nassau groupers were observed spawning. Monitoring events are defined as the length of time more than 50 Nassau

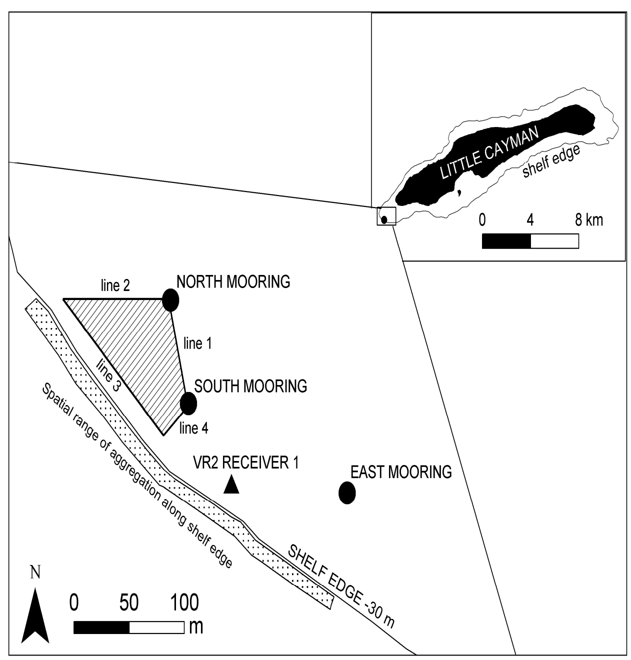


**Figure 1**. Map of study site off the west end of Little Cayman.

groupers were observed at the study site.

## METHODS

### Study Area

The Cayman Islands, BWI, are comprised of Grand Cayman, Cayman Brac, and Little Cayman. The latter lies between 19º 39' N and 19º 43' N latitude and 80º 6' W and 79º 58' W longitude. The study area is located at the west end of Little Cayman and consists of a reef promontory with a deep terrace at 24-33 m, sloping quickly at the shelf edge (Whaylen *et al.* 2004). Benthic habitat at this location features broad ridges (4 to 5 m in height, oriented northeast to southwest) with intermittent wide (30 m) valleys of sand (Whaylen *et al.* 2004). It supports an active Nassau grouper spawning aggregation.

### Field Observations

Monitoring of Little Cayman's west end fish aggregation, implemented in January 2002, continued annually for five years. Major efforts concentrated on the spawning periods in January and February, although the aggregation was monitored in other months during a year-round monitoring effort in 2002. Surveyors included staff from Cayman Islands Department of the Environment, staff and volunteers from Reef Environmental Education Foundation (REEF), and local partners. Survey efforts ceased each year when the number of Nassau groupers at the aggregation site during the dusk dives was approximately 50 individuals or less.

Monitoring data collected included (1) abundance of Nassau groupers; (2) spawning behavior; (3) location of aggregation relative to permanent moorings; (4) configuration of aggregation; (5) number and timing of spawning bursts; (6) aberrant coloration of individuals; and (7) migration of Nassau groupers.

Two mooring pins (South mooring and North mooring) were installed at the study site in 2002 and a third (East mooring) in 2004 (Figure 1). The moorings were used as geographic reference points to determine the relative position of the aggregation at any given time. Mooring lines were installed at the beginning of each monitoring trip and were removed at the conclusion of diving operations. Additionally four polypropylene lines were deployed near the substrate to aid with underwater navigation and safety: Line 1 connected the North and South mooring pins (depth: approximately 27 m), Line 2 was attached to the North mooring pin and stretched out west toward the shelf edge (wall), Line 3 was attached to the west end of Line 2 and stretched parallel to the shelf edge (Figure 1), and Line 4 was attached to the South mooring pin and stretched southwest to the shelf edge.

Presence/absence surveys for Nassau grouper were conducted in the early morning during drift dives. Dive teams were equipped with a line and surface buoy to assist with diver tracking and safety. An aggregation was confirmed when divers observed the presence of more than 50 Nassau groupers in a single location.

Two to three dives per day were conducted at the spawning aggregation site when conditions permitted. In addition, periodic reconnaissance drift dives were done at the historical aggregation sites on the east end of Little Cayman, and the east and west ends of Cayman Brac.

According to a policy set by the Cayman Islands' Marine Conservation Board, the number of divers in the water at the study site at any time was restricted to a maximum of eight. Each diver was tasked with specific responsibilities such as recording visual observations, videography, and photography. Morning and afternoon dives were focused on estimating Nassau grouper abundances and pinpointing the location of the main aggregation. Dusk dives were used to record spawning behavior and abundances.

At the beginning and end of each dusk dive, the numbers and spatial distribution of groupers were recorded on the reef terrace and off the shelf edge ('wall'). Divers estimated the spatial area of the aggregation using navigation or mooring lines as geographical references. Nassau groupers were counted by visually estimating abundances within several imaginary cubes (each measuring 3.3 m per side). Those values were then extrapolated to calculate a total number in the aggregation. During a typical dive, divers conducted at least 10 abundance estimates. Daily counts were averaged. Divers also recorded color phase composition of the aggregation on the reef terrace and the wall at the beginning and end of a dive. For each spawning burst, the time and number of participating fish were recorded. Divers also recorded any other fish species exhibiting spawning coloration or behavior.

One or two divers equipped with a video camera obtained video footage of the entire aggregation for estimating the Nassau grouper abundances. This task was accomplished in two ways: (1) for compact aggregations (approximately 25 m in length), video of the entire aggregation was filmed from the reef terrace within a narrow panning angle; and (2) for elongated aggregations (25-100 m in length), a diver equipped with a video camera rapidly swam the length of the aggregation with the video camera aimed towards the aggregation, capturing one continuous video clip. The video footage was reviewed on television to count the total number of Nassau groupers in the aggregation and to compare this number with visual estimates.

In 2004, time lapse videography of the aggregation was taken during daylight hours when divers were not in the water. The video housing was attached to an underwater platform and placed on the substrate where the Nassau groupers were congregated most densely. Cameras were programmed to take 0.5 to 2.0 second video clips every 10 minutes. The video camera was deployed during morning dives and retrieved during dusk dives.

From 2002 to 2005, REEF volunteers collected information on migrating Nassau grouper around Little Cayman. At each dive site, divers recorded the number of Nassau grouper, color phase, depth, and direction of movement. Divers remained above or near the wall. Migration surveys typically commenced 1 to 3 days before the full moon (DBFM) and continued until 5 days after the full moon (DAFM). Divers conducted two morning dives per day.

**Sea Surface Temperature**

Sea surface temperatures were characterized using remote sensed data one week prior and after the full moon of the major spawning months. These data were downloaded from the Institute for Marine Remote Sensing at University of South Florida (http://imars.usf.edu/). Resolution of the remotely sensed data was 2.8 km x 4.1 km. Data were acquired 0.4 nm northeast of the aggregation site (19.6536° N latitude and 80.115° W longitude). Values ± 2 standard deviations from the sea surface temperature means for each year were eliminated from the dataset. Statistical tests were applied to the dataset to test between year differences (Zar 1984).

## RESULTS

In January 2002, over 5,000 Nassau groupers were observed at the study site. This number decreased to just over 2,000 groupers during the 2003 spawning season. The abundance of Nassau groupers has remained stable since 2003.

The major spawning events for Nassau grouper from 2002 to 2006 occurred in January or February. Two relatively minor aggregations of approximately 200-300 Nassau groupers were observed the week of the full moon in March of 2003 and 2004, but no spawning was observed. Two of the five years (2002 and 2005) had major spawning in January and the three other years had peak spawning in February (2003, 2004, and 2006). Dates of the major spawning events were examined in relationship to the winter solstice for each year (Table 1). If the span of time from the winter solstice to January's full moon was less than 30 days, then February was the major spawning month. Conversely, if it was greater than 30 days, January was the major spawning month.

Spawning bursts varied from year to year, ranging from 17 in February 2003 to 99 in February 2004. Spawning periods ranged in length from a minimum of three days in February 2006 to a maximum of six days in February 2004 (Table 1). Spawning bursts were recorded as early as 1 DAFM and as late as 8 DAFM. Nearly 300 spawning bursts were recorded over the five years of monitoring. However, these data are subjective due to the limits of of visual observations on SCUBA. Because of the depth at the aggregation site, dive time was limited. Often Divers reported ongoing spawning bursts when they ended dives or even when they began their observations. The number of spawning bursts reported here is therefore highly conservative. Spawning bursts were recorded as early as 59 minutes before sunset (MBS) to as late as 20 minutes after sunset (MAS), but on average, spawning bursts were recorded 21 ± 15 MBS to 11 ± 6 MAS (Table 2).

The number of Nassau groupers on the aggregation peaked as early as full moon (February 2004; 1,750 groupers) and as late as 5 DAFM (January 2005; 1,800 grou-

Table 1. Little Cayman West end Nassau grouper spawning aggregations, 2002-2006: timing and duration of major spawning activity, peak spawning day, total number of spawning bursts, timing and duration of minor spawning events, full moon dates in January and February, and winter solstice dates [DAFM = days after full moon].

| Major Spawning Month | Spawning Period (DAFM) | Peak Spawning Day (DAFM) | Total Number of Spawning Bursts | Minor Spawning Month | Full Moon January | Full Moon February | Winter Solstice |
|---|---|---|---|---|---|---|---|
| Jan. '02 | 5 to 8 | 6 | 52 | Feb '02 | 1/28/2002 | 2/27/2002 | 12/22/2001 |
| Feb. '03 | 4 to 7 | 4 | 17 | Jan '03: 5 DAFM | 1/18/2003 | 2/16/2003 | 12/22/2002 |
| Feb. '04 | 1 to 6 | 5 | 99 | no spawning | 1/7/2004 | 2/6/2004 | 12/21/2003 |
| Jan. '05 | 3 to 7 | 7 | 46 | no spawning | 1/25/2005 | 2/24/2005 | 12/21/2004 |
| Feb. '06 | 3 to 5 | 4 | 78 | Jan '06: 5 DAFM | 1/14/2006 | 2/13/2006 | 12/22/2005 |

pers; Figure 2). These peaks did not appear to be correlated with number of spawning days, month, or full moon date.

Time lapse videography demonstrated fluctuations in the abundance of Nassau groupers at the study site as well as captured several reef sharks on film.

**Bicolor phase spike**

The percentage of grouper in the bicolor phase on the aggregation spiked rapidly over a period of 24 to 48 hours followed by observations of spawning bursts (Figure 3). This spike in bicolor phase fish may serve as the best indicator of intent to spawn. Most spawning bursts occurred when the percentage of bicolor phase was 80% during the dusk dive, although limited spawning bursts were recorded with lower percentages (60%) in the bicolor phase.

**Configuration change over time**

During the first year of monitoring (2002), the aggregation was observed in a 'cone' configuration. The base of the cone was near the shelf edge (near the substrate) and contained the majority of grouper. The cone then tapered in numbers and spatial extent higher in the water column. Spawning bursts were observed throughout the cone configuration (from a water depth of 33 m to 12 m from the surface), though the majority of spawning bursts occurred in the middle to upper layers of the cone. Beginning in February 2003, a significant change occurred in the aggregation configuration: Nassau grouper remained closer to the shelf edge along the bottom at an average depth of 33 m. Furthermore, the aggregation dispersed over a longer distance along the shelf edge and spawning bursts were observed at greater depths (42 m to 30 m).

In addition to a change in configuration during the study period, the aggregation also slightly shifted geographically. In 2002, the aggregation was originally located between the North and South moorings at the shelf edge near a sand plateau (Figure 1). During subsequent monitoring years, the aggregation shifted 137 m along the wall towards the East mooring. However, the aggregation during the beginning of the monitoring each year was typically found between the North and South mooring pins, and then later shifted to the East mooring.

**Table 2.** For each year, ranges of time of spawning bursts in relationship to sunset times. Standard deviations are included with the mean times of spawning bursts before sunset and after sunset.

| Year | Date | Spawning time | Mean MBS | Mean MAS | Max MBS | Max MAS |
|---|---|---|---|---|---|---|
| 2002 | 2-Feb | 13MBS | | | | |
| 2002 | 4-Feb | 25MBS-3MAS | | | | |
| 2002 | 3-Feb | 26MBS-15MAS | | | | |
| 2002 | 5-Feb | 6MBS | | | | |
| 2002 | | | 18 ±10 | 9 ± 8 | 26 | 15 |
| 2003 | 23-Feb | 12MAS | | | | |
| 2003 | 20-Feb | 2MBS-12MAS | | | | |
| 2003 | 22-Feb | 4MBS-4MAS | | | | |
| 2003 | 21-Feb | sunset-16MAS | | | | |
| 2003 | | | 2 ± 2 | 11 ± 5 | 4 | 16 |
| 2004 | 7-Feb | 11MBS | | | | |
| 2004 | 9-Feb | 17MBS-13MAS | | | | |
| 2004 | 10-Feb | 24MBS-2MAS | | | | |
| 2004 | 12-Feb | 44MBS-18MAS | | | | |
| 2004 | 11-Feb | 59MBS-16MAS | | | | |
| 2004 | | | 31 ± 20 | 12 ± 7 | 59 | 18 |
| 2005 | 30-Jan | 19MBS-16MAS | | | | |
| 2005 | 28-Jan | 23MBS-20MAS | | | | |
| 2005 | 31-Jan | 35MBS-17MAS | | | | |
| 2005 | 1-Feb | 36MBS-8MAS | | | | |
| 2005 | | | 28 ± 9 | 15 ± 5 | 36 | 20 |
| 2006 | 16-Feb | 15MBS-3MAS | | | | |
| 2006 | 17-Feb | 17MBS-2MAS | | | | |
| 2006 | | | 16 ± 1 | 3 ± 1 | 17 | 3 |
| Study Period | | | 21 ± 15 | 11 ± 6 | 59 | 20 |

**Table 3.** Mean sea surface temperature (SST) off the west end of Little Cayman

| Year | n | Mean SST | Variance |
|---|---|---|---|
| 2002 | 53 | 26.4751 | 0.3654 |
| 2003 | 37 | 26.1589 | 0.6710 |
| 2004 | 37 | 26.1008 | 0.5075 |
| 2005 | 14 | 25.2200 | 0.6107 |
| 2006 | 15 | 25.3900 | 1.2592 |
| **Overall Mean** | | **25.8690** | |

**Table 4.** Results of paired t-test to compare sea surface temperatures during the study period. Highlighted cells denote non-significant differences.

| | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|
| **2002** | | | | |
| **2003** | 0.0190 | | | |
| **2004** | 0.0043 | 0.3728 | | |
| **2005** | 0.0000 | 0.0003 | 0.0002 | |
| **2006** | 0.0000 | 0.0042 | 0.0042 | 0.3210 |

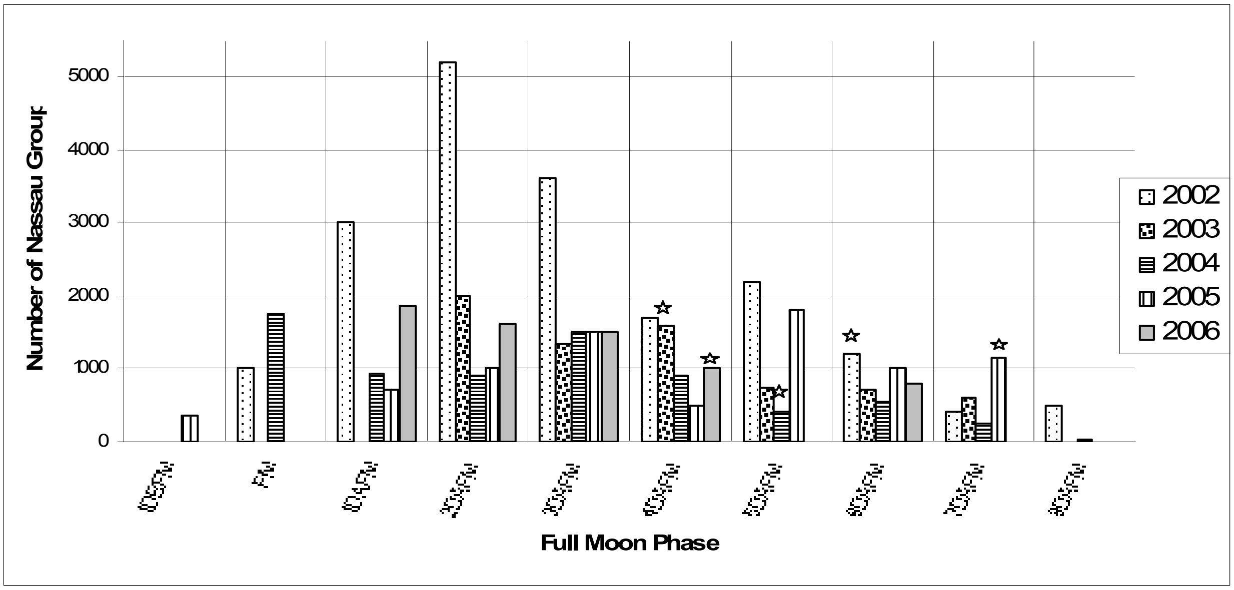


**Figure 2.** The number of Nassau groupers present each day at the aggregation site over the major-month monitoring period for each of the five years of monitoring (2002-2006). Stars denote peak spawning day for each year.

**Environmental variables**

Currents varied in direction and strength at the study site during the monitoring events. However, divers reported slack or negligible currents during the dusk dives of the major spawning months. When a slight current was noted for these dusk dives, the directions were to the southwest or northwest, away from the island.

Mean sea surface temperatures ranged from 25.2°C to 26.5°C, with an overall mean of 25.9°C for the study period (Table 3). Results of an ANOVA test found a significant difference in mean sea surface temperatures between years. Paired t-tests comparing year to year also found significant differences. However, no significant differences were found between Years 2003 and 2004 and Years 2005 and 2006 (Table 4).

**Aberrant colorations**

Several aberrantly colored Nassau groupers were repeatedly observed at the aggregation over the study period (Figure 4). Aberrant colorations are not one of the four color phases. These individual fish retain their unique (abnormal) coloration and are easily recognized by divers from year to year at the study site as well as on their home reef territories. At least six aberrant colored individuals have been observed. Many of these 'naturally tagged' individuals were recorded at the aggregation for both spawning months within a single year and were useful for tracking inter-year survivorship. No spawning bursts were recorded for these Nassau groupers; however, when these individual groupers were in the bicolor or dark phases, the ability to distinguish them from other individuals greatly diminished.

**Migration surveys**

Migrating Nassau grouper were seen at the shelf edge, typically at depths ranging from 20 to 33 m. Most migrating grouper were in the dark color phase, although the white belly phase was not uncommon. Migration surveys typically commenced 1 to 3 DBFM and continued until 5 DAFM. Peak numbers of migrating groupers were observed 2 to 3 DAFM with clusters of up to 100 groupers traveling together along the wall towards the aggregation site.

**Multi-species usage of the aggregation site**

Over the study period, divers witnessed changes in color patterns, courtship and spawning behavior in 22 species of fish in 8 families (Table 5). Over the span of five years, divers observed spawning bursts in 7 of these 22 species: *Epinephelus striatus, Mycteroperca tigris*, *Caranx latus*, *Caranx ruber*, *Caranx lugubris*, *Decapterus macarellus*, *Lutjanus jocu*, and *Acanthostracion polygonia*. Divers observed spawning bursts in the tiger groupers during most monitoring years. In 2006, divers observed a Nassau grouper attempting to spawn with a *M. bonaci*, with gamete release recorded in the Nassau grouper. Unusually large schools of *Elagatis bipinnulata* (rainbow runner) were also seen almost every year during the monitoring and were most likely predating on grouper eggs.

## DISCUSSION

**Spawning Aggregation Dynamics**

Until nearly 4,000 Nassau groupers were harvested in 2001 and 2002, negligible fishing pressure existed at this site. Today, Little Cayman's west end supports an active aggregation of approximately 2,000 Nassau groupers. In

February 2002, legislation passed by the Cayman Islands Government banned the harvest of Nassau grouper at the aggregation site. Since then, no illegal poaching has been observed. This is a testament to the community support for the conservation of their marine resources.

The west end of Little Cayman most likely supported an original aggregation population of over 7,000 Nassau groupers. Nearly 2,000 groupers were harvested in 2001. When pre-harvest monitoring began in January 2002, we estimated that over 5,000 Nassau groupers were present. Following the removal of 2,000 groupers after the 2002 count, a population of approximately 3,000 Nassau groupers should exist. Highest estimates over the next four years of monitoring recorded a maximum of 2,225 Nassau groupers (Figure 2). In January 2003, a concurrent hydroacoustic study conducted during the evening of peak grouper abundance reported 1,458 groupers (Eggleston *et al.* 2003). Divers' visual estimates and video analysis for the same night was 1,500 and 1,014 groupers, respectively.

In three of the five study years (2002, 2003, 2006), spawning was observed several days after the peak numbers of groupers. While the dynamics of the reproductive population over the spawning season are not fully understood, post peak spawning activity may be due to particularly large and fecund individuals spawning over different days, late arrivals, or both. Nassau grouper spawning bursts took place in January or February during a three to six day

**Table 5.** Species displaying spawning or courtship behavior at the aggregation site during the study period.

| Family | Scientific Name | Common Name |
|---|---|---|
| Balistidae | *Canthidermis sufflamen* | ocean triggerfish |
| Carangidae | *Caranx bartholomaei* | yellow jack |
| Carangidae | *Caranx crysos* | blue runner |
| Carangidae | *Caranx latus* | horse-eye jack |
| Carangidae | *Caranx lugubris* | black jack |
| Carangidae | *Caranx ruber* | bar jack |
| Carangidae | *Decapterus macarellus* | mackerel scad |
| Carangidae | *Trachinotus falcatus* | permit |
| Haemulidae | *Haemulon album* | white margate |
| Kyphosidae | *Kyphosus* spp. | chub |
| Labridae | *Clepticus parrae* | creole wrasse |
| Lutjanidae | *Lutjanus analis* | mutton snapper |
| Lutjanidae | *Lutjanus cyanopterus* | cubera snapper |
| Lutjanidae | *Lutjanus jocu* | dog snapper |
| Lutjanidae | *Oxyurus chrysurus* | yellowtail snapper |
| Ostraciidae | *Acanthostracion polygonia* | honeycomb cowfish |
| Serranidae | *Epinephelus guttatus* | red hind |
| Serranidae | *Epinephelus striatus* | Nassau grouper |
| Serranidae | *Mycteroperca bonaci* | black grouper |
| Serranidae | *Mycteroperca interstitialis* | yellowmouth grouper |
| Serranidae | *Mycteroperca tigris* | tiger grouper |
| Serranidae | *Mycteroperca venenosa* | yellowfin grouper |

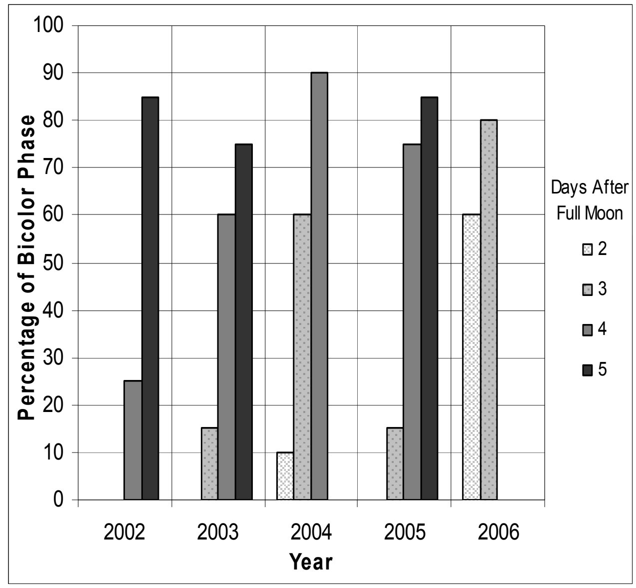


**Figure 3.** Spike in bicolor phase of Nassau groupers by year (2002-2006) at the aggregation site over a 24 to 48 hr period per study year.

period, ranging from 1 to 8 DAFM (Table 1). The number of spawning bursts varied from year to year but was probably biased by the timing of the dusk surveys.

The presence of sharks may influence the configuration and location of the spawning aggregation. The evolution of this study's aggregation from a compact cone formation in 2002 to an elongated formation that was closer to the substrate in subsequent years may be attributed in part to the presence and aggressive behavior of Caribbean reef sharks (*Carcharhinus perezii*). Divers observed an increase in numbers and level of aggression of Caribbean reef sharks during the study period. Hammerhead sharks (*Sphyrna* spp.) were reported on several occasions during the study period, but did not display any aggressive or unusual behaviors. The harvesting of Nassau groupers in 2001 and 2002 led to a reduction of the spawning aggregation by more than 50%, which, in turn, may have induced a behavioral change in the sharks or a behavioral change in the groupers that led to a shift in their spawning configuration. Other studies have also noted movements in spawning aggregations due to sharks (Matos-Caraballo *et al.* 2006) or fishing (Aguilar-Perera 1994).

**Self- and Downstream- Seeding**

Nassau grouper fertilized eggs originating from the aggregation off Little Cayman's west end may be a local and a regional source of fish larvae for downstream reefs. Though currents at the study site can exceed 2 knots, spawning bursts usually took place when currents were slack or negligible which must favor fertilization. Little Cayman's Nassau grouper population probably benefits from the local dispersal of fertilized eggs. More informa-

**Figure 4.** "Phantom," an aberrant colored Nassau grouper, has been sighted annually at the aggregation since 2002.

tion on local circulation is needed to understand this potential self-seeding. The westward dominant sea surface flow probably disperses fertilized Nassau grouper eggs to downstream reefs including Grand Cayman, northern Cuba, and possibly the Florida Keys. The protection of the Little Cayman west end aggregation site is of high importance, assuming that some of the long distance dispersal of Nassau grouper fertilized eggs and subsequent recruitment are successful. Furthermore, more than twenty other fish species have been documented to use this site, presumably for reproductive purposes.

**Environmental Parameters**

Using the days from winter solstice may prove useful to researchers at other fish spawning aggregations and is explored further in the discussion section. In Little Cayman, the month for the major spawning events is probably influenced by the time between the winter solstice and the date of the January full moon. The number of days between the winter solstice and the January full moon may provide a useful predictor for the timing of spawning across the Caribbean.

During the study period, mean sea surface temperatures at the aggregation site (25.2°C to 26.5°C) were similar to optimal temperatures reported for spawning aggregations at other locations (Colin 1992, Heyman *et al.* 2005, Tucker *et al*. 1993). Daily sea surface temperatures between major spawning months did not differ significantly between 2003 and 2004 and coincidentally February was the major spawning month for both of these years. On the other hand, despite temperature similarities between 2005 and 2006, Nassau grouper spawned during different months.

**Recommendations for Future Surveys**

Surveys for aggregations should occur in the morning or evening. In addition to monitoring the active aggregation, reconnaissance drift dives at the historical aggregations on the east end of Little Cayman and the east and west ends of Cayman Brac should also be conducted. Active aggregations with fewer fish may occur at or near these historical sites. No aggregations were observed, but the chance exists that active aggregations with fewer fish occur at or near these historical sites. For example, at the primary study site, Nassau groupers were more closely aggregated during sunrise and sunset dives, increasing the probability of locating the aggregation. In the late morning to afternoon, fish scattered across a larger reef area, which made spotting them difficult. Had we been able to dive at the historical aggregation sites during sunrise or sunset times, active aggregations may have been located. Therefore, reconnaissance drift dives should be conducted in the early morning just after sunrise or at dusk just before sunset.

If possible, dive entry times should be consistent each day, relative to sunset, in order to capture the same behavior on consecutive days during the monitoring period. Dive entry times during this study period varied from an hour before sunset to 15 MBS. Allowing for safety conditions and logistics, a dive entry time of 20 MBS is recommended since observed spawning bursts were typically observed from 20 MBS to 15 MAS. At least two teams of two divers are recommended for locating the aggregation and for conducting visual counts. However, if multiple teams of divers are available, staggered entry times will enhance the accuracy of locating the aggregation and will increase the span of observations. All divers should synchronize watches and computers. This seemingly small task can alleviate problems that arise in data entry and analyses. Local sunset times should also be obtained from a GPS.

The dramatic spike in the percentage of aggregating fish in the bicolor phase over a 24 to 48 hour period prior to spawning (Figure 3) can be used in future monitoring years as a gauge for predicting the likelihood of major spawning. As the aggregation reaches 80% bicolor phase fish, more resources (i.e., divers, boat, and equipment) can be mobilized for nights of mass spawning.

Time lapse videography provided a useful insight into the dynamics of the aggregation over a multi-hour span of daylight and into grouper behavior without diver influence. These fluctuations in Nassau grouper abundances could be explained by the relatively narrow field of the video frame compared to the area of the aggregation or by the scattering of Nassau groupers during the day similar to what divers noted during afternoon dives. Using an array of cameras deployed at the aggregation site may provide useful information.

Lastly, all attempts to garner public or community support when implementing protected areas are beneficial. Education and outreach efforts to the fishermen are strongly encouraged. Collaborating with fishermen who have vast experience and local environmental knowledge can provide valuable information to researchers on historical and active aggregation sites. Although efforts should be focused on active aggregation sites, historical sites should also be periodically monitored in case the aggregation rebounds.


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