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Comparative Investigations of Red Hind (*Epinephelus guttatus*) spawning aggregations under different management strategies; fully protected Marine Reserves in the United States Virgin Islands and an unmanaged fishery on the Saba Bank in the Netherlands Antilles

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EXECUTIVE SUMMARY

A red hind spawning aggregation was found on the northeast edge of the Saba Bank, a large submerged platform in the leeward Antilles of the Caribbean. The bank, 5 km west of the island of Saba and 140 km southeast of St. Croix, rises from the sea floor 1000 m to form an extensive plateau, over 1600 km^2 of which is shallower than 50 m. The bank is entirely enclosed in the Exclusive Economic Zone of the Netherlands Antilles. Fisheries on the Saba Bank, particularly lobster and snapper, are economically important to the small island economy of Saba (pop 1600), employing 50 people and contributing 1.1 million US$ to the gross domestic product. Except for prohibition of foreign fishing vessels however, little fisheries management exists. The red hind spawning aggregation on the Saba Bank was found with the assistance of the Saba National Marine Park and local Saban fishers. The area was fished and investigated with SCUBA over the weeks around the full moon of December 2005, and January and February 2006. The majority of fish collected were tagged and released. The primary aggregation area is located at 17º33.6’ N, 63º 17.9’ W, which lies 750 m southwest of the Moonfish Bank, a locally well known area used as an aggregation site by queen triggerfish. The red hind aggregation site runs in a northwest/southeast direction at least 2.1 km along the edge of an old spur and groove reef, but is only 20-30 m wide. The benthic habitat is low in both complexity and coral cover. A series of shallow ledges and undercuts in the reef edge provide what little fish habitat there is, and red hind, when aggregating, schooled around these in the 10’s to 100’s. As a result, fish densities across the site were very patchily distributed. During the 2005/2006 spawning season red hind aggregated and spawned in January. Relatively few fish were observed or collected in December or February and sex ratios were very highly skewed in favor of males during those months. Average daily water temperature fell through January and ranged from 26.5ºC to 26.7ºC during the week of the full moon. The average weekly current speed on both the surface and bottom slowed to 0.15-0.18 cm/s and 0.10-0.11 cm/s respectively during January. Catch per unit effort and red hind densities in fish transects peaked the day of the full moon. Sex ratios were variable throughout the week but favored males until 2 days before the full moon, when ratios approached 1:1 (M:F). Two days after the full moon this changed back to a

male dominated sex ratio (3.0:1). Gonadosomatic indices, which indicate readiness to spawn, were high in January and peaked the day before the full moon, dropping slightly the following two days. Fish were not observed exhibiting any usual pre-spawning or heremic behavior such as aggression, territoriality or "displaying". This, as well as the 1:1 sex ratio, patchily distributed fish and very high densities around ledges and caves suggested that these fish may spawn in larger groups as opposed to small harems as do most red hind. Two tagged fish were collected approximately 2 k west of the aggregation site in February, 2006 by St. Maarten fishers. These fish, which were tagged sequentially, were caught on the same line holding 4 hooks. The Saba Bank aggregation was compared to a red hind aggregation which occurs south of St. Thomas, USVI. The aggregation site on the Saba Bank differs from the site south of St. Thomas in both biotic and abiotic features. While the Saba Bank site is on the leeward edge of the bank in a shallow area of low coral cover, the site off St. Thomas is in deep water close to the windward edge of the Puerto Rican insular shelf and has high coral cover and diversity. This site has been protected since 1999 in a no-take marine reserve. Fish on the site off St. Thomas are larger than the Saba Bank red hind and sex ratios are skewed toward females. Densities within the St. Thomas aggregation area have not been reported as high as those from the Saba Bank but the area is larger and the total spawning population, estimated at 84,000 fish, is probably over 4 times as high. This may be a function of the holding capacity of the bank itself or early signs of exploitation. Although not fished by Sabans who primarily target lobster, deep water snappers, and pelagics, the aggregation area on the Saba Bank is fished annually by St. Maarten fishers. The importance of the Saba Bank as an economic and natural resource for Saba and the Netherlands Antilles warrants consideration for at least seasonal protection of the red hind spawning aggregation area. The prevailing southwest current suggests larval retention and local recruitment of red hind from the aggregation site. We recommend swift action by the biologists and managers of the Saba Bank fisheries to enact some type of proactive protective management while there is little dependence by local fishers on the aggregation area.

GOALS

The primary goals of this project were to 1) assess the population size and structure of a red hind spawning aggregation on the Saba Bank, Netherlands Antilles and compare it to the spawning population in the Red Hind Marine Conservation District in the US Virgin Islands, 2) establish a collaboration between the University of the Virgin Islands and an international Caribbean partner to provide scientific technical assistance and training and 3) increase environmental and societal consciousness regarding spawning aggregations in stakeholders and citizens of the Virgin Islands and across the Caribbean.

BACKGROUND

In the Caribbean and tropical Atlantic hinds and groupers (Serranidae) make up one of the most valuable components of the commercial fishery. Red hind (*Epinephalus guttatus*) is presently the dominant grouper in the US Virgin Islands (USVI) fishery and makes up one fifth of the total commercial finfish landed in the territory (Cummings et al. 1997). In both Bermuda and Puerto Rico red hind constitutes approximately one third of the grouper fishery (Appledorn and Meyers 1993, Luckhurst 1996) and nearly 20% by weight of the entire annual commercial landings in the British Virgin Islands (BVI, Eristhee et al. 2005).

Red hind form large aggregations to spawn annually, returning to specific locations year after year (Shapiro et al. 1993, Sadovy et al. 1994b, Beets and Friedlander 1997). Like all commercially important aggregate spawners, during that time they are especially vulnerable to exploitation by fishers. This is due to site fidelity and temporal predictability as well as sheer concentrations of fish in relatively small areas. Because spawning aggregations are the primary if not sole source of larval production, some or much of which may be retained to replenish the local fishery (Roberts 1996, Sadovy 1996), over-exploitation of spawning aggregations may reduce local populations and cause short and long term fisheries declines.

Spawning aggregation population dynamics and structure have been studied on serranids around the world (Smith 1972, Colin et al. 1987, Johannes 1988, Johannes 1989, Colin 1992, Sadovy et al. 1994a, Aguilar-Perera and Aguilar-Davis 1996, Samoilys 1997, Coleman et al. 1999, Rhodes and Sadovy 2002) and specifically on red hind in the Caribbean and western Atlantic (Sadovy et al. 1992, Shapiro et al. 1993, Sadovy et al. 1994b, Luckhurst 1998, Beets and Friedlander 1999, Whiteman et al. 2005, Nemeth 2005, Nemeth et al. in press). Red hind are protogynous hermaphodites, changing from female to male at about 32 to 38 cm total length (Sadovy et al. 1992, Nemeth 2005, Whiteman et al. 2005). They reach a maximum age of 22 years and maximum lengths of 50 to 55 cm or longer (Sadovy 1992, Luckhurst et al. 1992). Spawning is dictated by changes in the lunar and solar cycle as well as seasonal seawater temperature declines and occurs in December, January and/or February (Sadovy et al. 1994b, Nemeth et al., in press). Approximately one week before spawning, red hind migrate up to 33 km to form aggregations of tens to thousands of fish (Nemeth 2005). Fish may disperse soon after spawning, or may remain on the site until the following moon phase to spawn again (Sadovy et al. 1994b, Nemeth et al., in press).

Intensive fishing of red hind aggregations in the 1980's may have contributed to declines in mean length of the commercial catch in St. Thomas USVI between 1984 and 1988 (Beets and Friedlander 1992). Seasonal protection of the main aggregation site south of St. Thomas beginning in 1990 resulted in a significant increase in length and biomass of red hind at the spawning aggregation as well as in the local commercial fishery (Beets and Friedlander 1999, Nemeth 2005). Further protection with the establishment of a no-take marine reserve in 1999, the Red Hind Marine Conservation District (MCD), resulted in a 60% increase in the average density and biomass of the spawning population as well as a 7 cm increase in maximum fish size (Nemeth 2005). The establishment of the MCD not only increased reproductive output for the red hind but also enhanced the perception of marine reserves within the local fishing community by producing noticeable increases in size and abundance of an economically valuable resource (Kelly 2006).

The Saba Bank, one of the few isolated submarine banks in the Caribbean Sea (Macintyre et al. 1975) is arguably one of the largest atolls in the world (Van der Land 1979). Presently the Saba Bank is entirely enclosed in the Exclusive Economic Zone (EEZ) of the Netherlands Antilles (NA). Economic benefits of the bank are derived solely from fisheries, which are dominated by spiny lobster (*Panularus argus*) and snapper (*Lutjanus vivanus* and *L. buccanella*). Presently Saban fishers are the primary users of the bank, which contributed an estimated 1.1 million US$ to the gross domestic product of that small island economy in 1999 (Dilrosun 2000). The neighboring Caribbean islands of St. Maarten and St. Eustatius also fish the bank heavily with gear restrictions, targeting reef and bottom fish. There is no reporting system in place for these catches, and no current estimates on the annual yield.

Prior to 1996, when the Coast Guard of the Netherlands Antilles started active patrolling of the Saba Bank, the area was highly exploited by foreign vessels, primarily from the French Islands, Venezuela, Puerto Rico and St. Croix (Meesters et al. 1996). During the eighties and early nineties catches declined dramatically and many Saban boats dropped out of the fishery. Groupers other than hinds and coneys virtually disappeared and snapper catch per unit effort (CPUE) and average size greatly decreased (Dilrosun 2000). A stock assessment was conducted in 1999 and 2000 (Dilrosun 2000), focusing on the dominant lobster and snapper fishery. Data on other species of finfish caught commonly as bycatch in the lobster fishery, including red hind, was also collected. Although Dilrosun had insufficient data to make conclusions and recommendations for finfish management, his general recommendations included restricting fish and lobster traps, establishing permanent closed areas that included fish nurseries, implementing an accurate catch and effort data collection program and strengthening fisheries regulation and enforcement. Short of prohibiting foreign fishing vessels, very little fisheries management currently exists on the Saba Bank, however the NA government now distinguishes over-fishing as being potentially the most environmentally and economically dangerous activity affecting it (Meesters et al., 1996).

Anecdotal reports of spawning aggregations come from the Saba Bank, primarily those of queen triggerfish (*Balistes vetula*) and squirrelfish (*Holocentrus adscensionis*). The queen triggerfish reportedly aggregates from December through February on a site called locally Moonfish bank, located on the northeast edge of the Saba Bank. A red hind aggregation area was reported at this site as well (Munro and Blok 2004) based on traditional knowledge of local fishers. The aim of this research project was to investigate the red hind aggregation area on the Saba Bank and to compare it to the aggregation currently protected in the MCD south of St. Thomas. By comparing population parameters and dynamics we hoped to determine the relative health of the aggregation on the Saba Bank, thereby enabling us to make recommendations to the NA government regarding appropriate management options. This research project was to be in cooperation and collaboration with the Saba National Marine Park and the people of Saba.

METHODS

Locate primary aggregation site

To locate the spawning aggregation site on the Saba Bank, informal interviews were conducted with local Saban fishers in September 2005. Exploratory dives on SCUBA were conducted with the Saba National Marine Park manager David Kooistra and his staff, at locations provided by fisher Frank Hassell. In December 2005 Saban fisher Capt. Leroy Pieterson was contracted to provide a fishing vessel and crew with navigational and fishing expertise for the project. Fish traps were set in and around the area demarcated by Hassell. Trap catches were plotted by latitude and longitude and subsequent fishing and diving was conducted in areas with high CPUE and high densities of observed red hind.

Spawning density, fish size, movement, and fecundity

Fish were collected using Antillian fish traps baited with Japanese sardines and hook and line. Generally two sets of traps were baited and deployed (12-15 traps/set) each day. GPS coordinates and catch was recorded for each trap pulled. Red hind were measured for total length (to the nearest mm) and were tagged through the dorsal fin pterygiophores with a numerically coded Floy dart tag (green in December, red in January and February). Tags contained following information: identification number, reward $20, Saba National Marine Park and a contact telephone number. Prior to release, the gender of each red hind was determined using an ultrasound or by gently squeezing the body cavity above the vent to extract milt or possibly eggs. Fish were released close to the collection site using a release cage that could be remotely opened when the cage reached the sea floor, thereby minimizing predation. Between 1 and 16 red hind were sacrificed daily in order to collect weight and fecundity data. Total body weight, gonad weight and volume, and ovary samples were taken on sacrificed fish. Ovaries were examined macroscopically and gonadosomatic indices (GSIs) were calculated (gonad weight/somatic weight * 100) to determine time of spawning. Fish collected in traps as bycatch were measured for total or fork length (depending on species) and were released. Queen triggerfish, also in reproductive condition, were sexed by squeezing gently above the vent to extract milt or eggs.

Fish transects were conducted by divers on Nitrox at two stations on the bank where red hind densities were high and between these stations at randomly selected spots. During surveys, each diver held a 1 m wide t-shaped bar constructed of 1.27 cm PVC pipe marked with 5 cm increments which was used to estimate transect width and fish length in the following size classes: <20 cm, 20-29 cm, 40-49 cm, and > 50 cm. A minimum of nine 30 x 2 m belt transects were conducted per day. Fish densities were compared by month and day to determine temporal and spatial dynamics of the aggregation.

Characterization and assessment of benthic habitat

A diver-operated Sony TR400 digital video camera in a Light in Motion Stingray 2 underwater housing was used to record benthic composition along six 10 m transects at the primary aggregation site on the Saba Bank. Transects were random and were set by divers swimming in a pre-chosen random direction before beginning the video transect in a second pre-chosen random direction. Video transects were recorded using the protocol established by Aronson *et al.* (1994). This involves the diver swimming at a slow and uniform speed videotaping along a 10 m transect with the camera perpendicular to and approximately 40 cm above the substratum. Digital transects were processed and analyzed using the random dot methodology developed by the US Geological Service in the St. John National Park, St. John USVI.

Characterization and comparison of temperature and current strength and direction

An acoustic doppler current profiler (ADCP) was deployed on Moonfish Bank (17º34.00’ N, 63 º17.45’ W) on 11 December 2005. This site was within 750 m of the primary aggregation site. The ADCP was programmed to record temperature and current speed and direction every 30 min. at 1 m intervals from the bottom to the surface. It was retrieved on 12 February 2006. Data was downloaded and compared to temperature and current data collected during the same period by an ADCP deployed in the Red Hind MCD on St. Thomas.

Production of spawning aggregation video entitled: Seas of Change

A video production company, Friday’s Films from San Francisco, CA, was contracted to produce an educational video with the aim of exposing the public to the importance of grouper and snapper spawning aggregations, their over-exploitation and the problems associated with management and conservation of aggregation sites.

Videographers made three trips to the USVI from December 2004 to May 2005. They interviewed numerous fishers, biologists, marine managers, politicians and citizens, as well as participating in CMES field work and collecting underwater and topside video footage.

In March 2006 the video was completed and 500 copies were released. In June 2006 it was presented to stakeholders and the public in press releases, private viewings and public television.

RESULTS

Primary spawning aggregation site

The Saba Bank (17º25’, 63º39’) lies approximately 5 km southwest of the small volcanic island of Saba in the leeward islands of the Caribbean. It is 140 km east-southeast of St. Croix, USVI. The bank, rising from the general sea floor 1000 m, is a completely submerged platform 20-30 m below sea level. With a length of 60 to 65 km and width of 30 to 40 km, the total surface area less than 50 m in depth is approximately 1600 km^2 (Macintyre et al. 1975). The origin of the bank has been controversial and hotly debated for a century, one theory describing it as the infilling of an ancient atoll lagoon (Davis 1926), another as a remnant of coastal plains on the Caribbean edge of the mountainous Antillean ridge (Spencer, 1904), and the third as a submerged but living atoll (Van der Land 1974). There was believed to be minimal reef development on the bank until 1974 (Macintyre et al. 1975) when an extensive Dutch expedition led by Van der Land discovered large areas of actively growing coral reefs on the windward edge (east to south) covering an area which totaled over 150 km^2. The center and leeward regions of the bank are dominated by sand, rubble, seagrass, soft coral meadows and algae plains, with very low stony coral cover.

The red hind aggregation site is located on the northeast edge of the bank in approximately 17 m of water (Fig 1). The area with the highest densities of red hind lay on the edge of a shallow ridge running northwest along the Saba Bank, dropping from 17 m on top to about 25 m in the sand off of the north/northeast edge. A sponge and gorgonian dominated reef appeared to be growing on the remains of a very old spur and groove limestone foundation. Along the edge of the reef, a series of small caves and undercut ledges provided habitat and protection for red hind using the aggregation site. The fish were relatively abundant on the top of the reef less than 30 m from the edge, however around ledges the red hind schooled in the tens to hundreds (Fig 2). Two stations were established in January 2006 on the most developed ledges and fish transects were conducted each day in the area immediately adjacent to them. Ledge 1, located at 17º33.623' N, 63º17.616' W, had an average density of 44.2 $\pm$ 16.5 red hind/100 m^2 in January 2006 and Ledge 2, located at 17º33.827' N, 63º17.905' W, averaged 41.3 $\pm$ 21.3 red hind /100 m^2. The area between the two ledges (636 m apart) had an average density in January of 26.9 $\pm$ 9.3 red hind/100 m^2.

The spawning aggregation terminated to the northwest at 17º34.05' N, 63º18.35' W, where the reef edge flattened and rugousity was markedly decreased. The southeast extent of the spawning aggregation area was never conclusively determined. In January 2006, dives were conducted and traps were set in a continuous fashion along the reef southeast to 17º33.45' N, 63º17.35' W. High densities of red hind were found patchily distributed along the reef edge, which continued to provide some protection and fish habitat. Although time did not allow the study to be extended further southeast, commercial trap catches were reported to decline not far away in that direction (Pieterson pers. comm.).The distance from the northwest end of the aggregation area to the southeast extent of our study was 2.1 km. The width of the area was 20 to 30 m providing an aggregation area of 0.052 km^2.

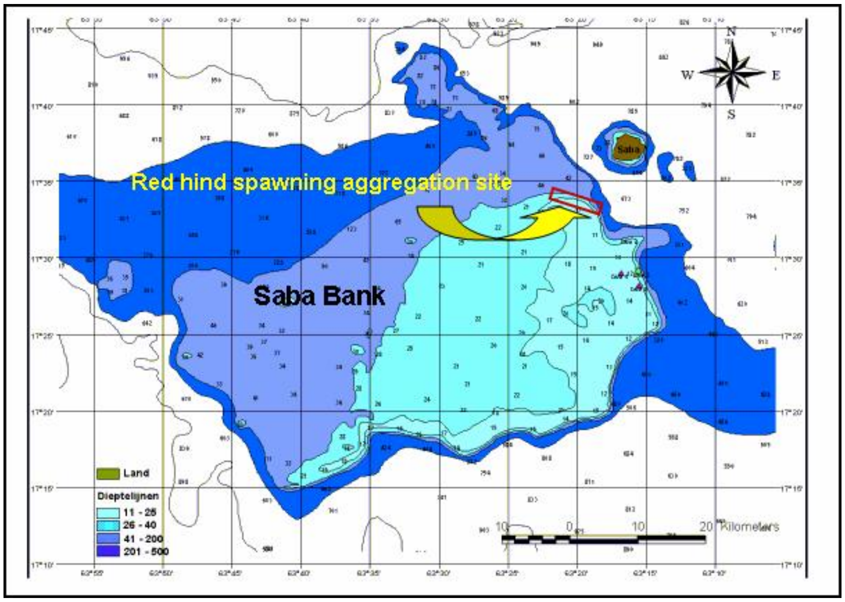


Fig 1.Bathymetric chart of the Saba Bank in the Netherlands Antilles showing the red hind aggregation study area.

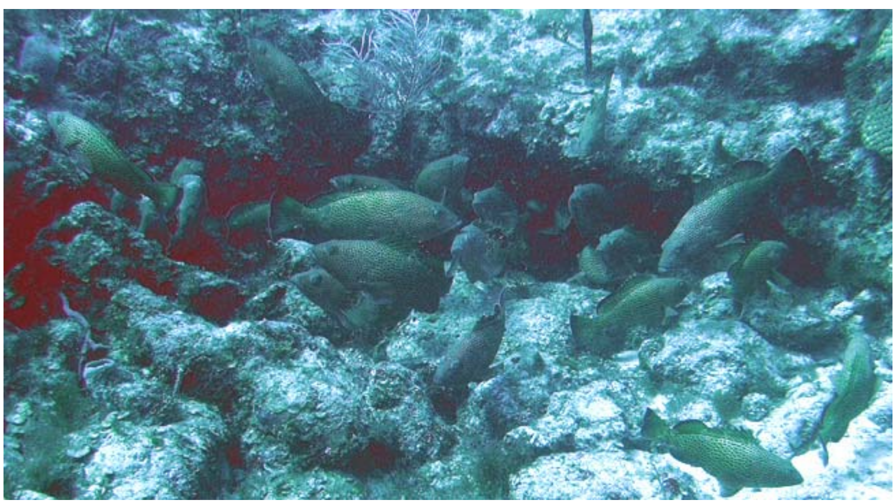


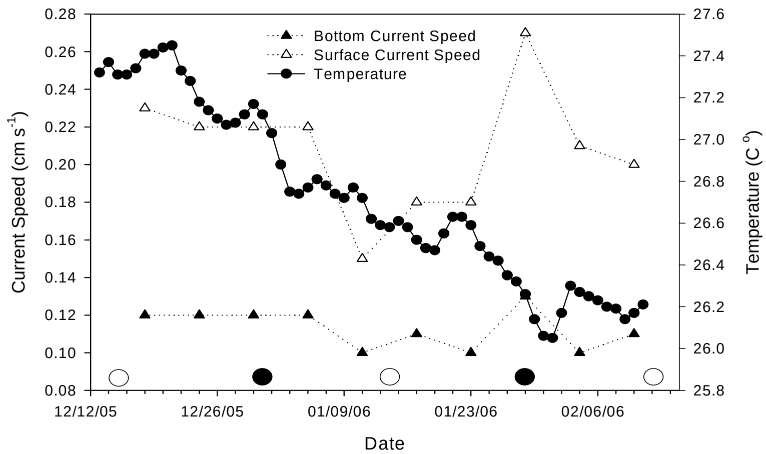
Fig 2. High densities of red hind were observed under low limestone ledges which provided habitat in an area of low coral cover.

Temperature and current

Water temperature, taken approximately 1 m from the bottom, dropped sharply in December and January and leveled out in February both on the Saba Bank and in the St. Thomas MCD in 2005-2006. The maximum average daily temperature recorded on the Saba Bank during the study period was 27.5ºC (20 December) and minimum was 26.1ºC (1 February). In the MCD south of St. Thomas water temperature ranged from 27.5º C (18 December) to 26.0º C (3 February). Sharp drops in water temperature occurred on both sites just prior to the full moon of January and February (Fig 3).

Average weekly current speed ranged from 0.14 cm/s to 0.27 cm/s on the surface at the Saba Bank site and 0.10 cm/s to 0.13 cm/s near the bottom (2.5 m), one tracking the other. On the red hind bank in the MCD, in much deeper water, bottom current speed appeared independent from surface current speed. In the MCD surface current speed ranged from 0.19 cm/s to 0.28 cm/s and near the bottom 0.13 cm/s to 0.19 cm/s. Average weekly current speed on both sites did not appear to coincide with any particular lunar phase. On the Saba Bank, the average weekly currents were slower in January than December or February (Fig 3).

A. Saba Bank



B. St. Thomas MCD

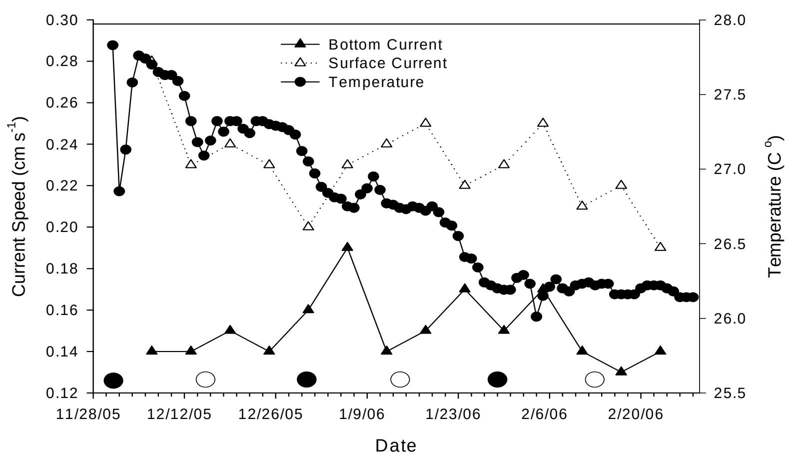


Fig 3. Temperature and surface and bottom current speed measured in relation to lunar phase on (A) Saba Bank and (B) the St. Thomas MCD from December 2005 to February 2006.

Cyclic tidal water movement across the Saba Bank was recorded on the ADCP and was from northeast to southwest. The daily average current direction on the bank from the December to February study period was predominately to the southwest (Fig 4). This changed to east-southeast for 4 days during and after the full moon in January (when average currents speeds were low) but reverted to a strong average west-southwest current over the next week.

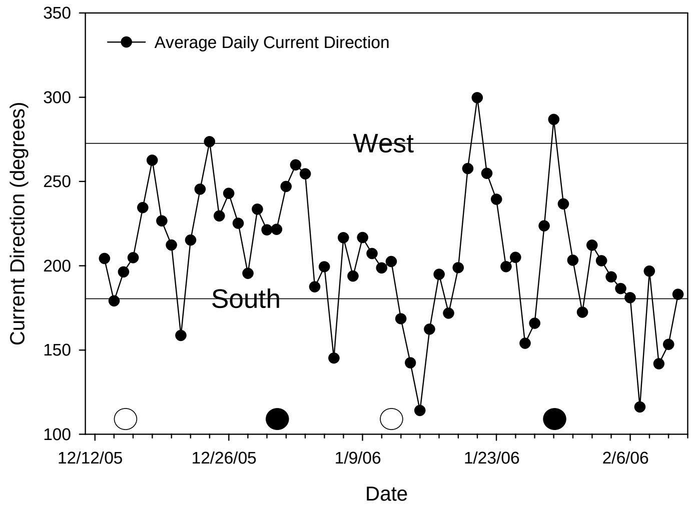


Fig 4. Average daily current direction on the Saba Bank red hind aggregation site from 12 December 2005 through 10 February 2006.

Red hind abundance and sex ratios

From December 2005 to February 2006, 361 traps were deployed on the Saba Bank in the red hind aggregation area and 230 fish transects were conducted. A total of 1094 red hind were collected (Table 1), most of which were tagged (584) and/or released (965). Catch per unit effort (CPUE) ranged from 0.155 $\pm$ 0.525 in February to 0.791 $\pm$ 1.866 in January. Red hind densities averaged from 1.50 $\pm$ 2.25 fish/100 m^2 in December to 34.27 $\pm$ 21.90 fish/100 m^2 in January (Table 1). Both trap CPUE and observed fish densities were significantly different from December to January and January to February, but not significantly different from December to February (ANOVA, $p<0.05$).

Table 1. Survey and catch information for a red hind spawning aggregation from December 2005 through February 2006, located on the Saba Bank off of Saba, Netherlands Antilles

Field dates	Full moon date	Sampling days (n)	Fish transects (n)	Average red hind density (fish/100 m^2)	Traps set (n)	Trap catch CPUE	Red hind collected
Dec. 11-17	12	7	70	1.50 $\pm$ 2.25	129	0.204 $\pm$ 0.518	122
Jan. 10-17	14	6	98	34.27 $\pm$ 21.90	121	0.791 $\pm$ 1.866	886
Feb. 10-13	13	4	62	1.56 $\pm$ 3.16	111	0.155 $\pm$ 0.525	86

Catch per unit effort and fish abundance was low in both December and February but in January was relatively high (Fig 5 and 6). Catch per unit effort increased with the filling moon in January and sharply declined the day following the full moon. Densities observed in fish transects on the aggregation site ranged from 6.7 to 80.0 fish/100 m^2 in January and peaked slightly the day before the full moon. Standard deviation was also very high, reflecting the patchiness of the aggregation site.

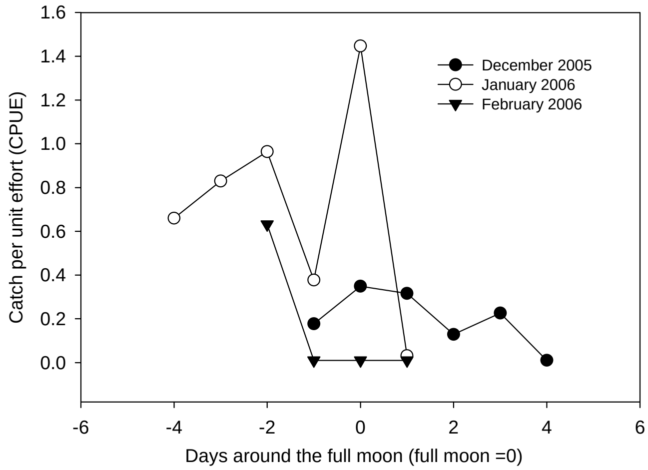


Fig 5. Daily CPUE in relationship to days around the full moon in December 2005 and January-February 2006.

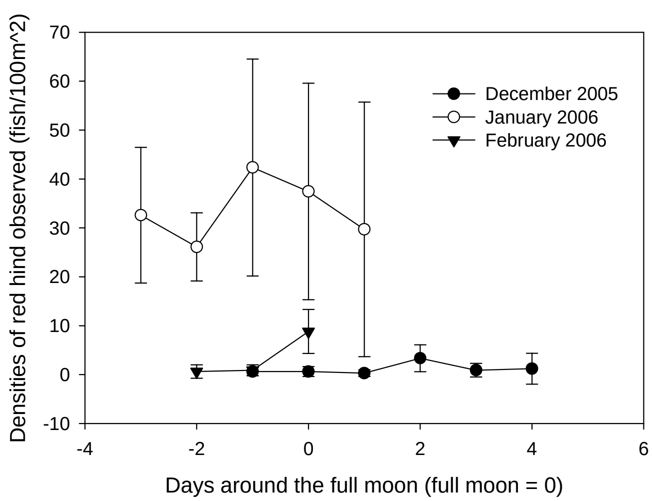


Fig 6. Daily average density of red hind (± SD) observed in relation to days around the full moon in December 2005 and January-February 2006.

The sex ratio for red hind collected from December 2005 to February 2006 was variable from month to month and day to day within months. Male fish normally dominated the catch, especially in December and February when sex ratios for all fish collected were 4.7:1 and 3.7: 1 (M:F) respectively . The overall sex ratio in January was 1.14:1. On the day of the full moon and the day after the full moon in January the sex ratio was 0.8:1, in favor of females (Fig 7). This changed two days after the full moon in January when the number of males to females increased to 3.0:1 (Fig 7).

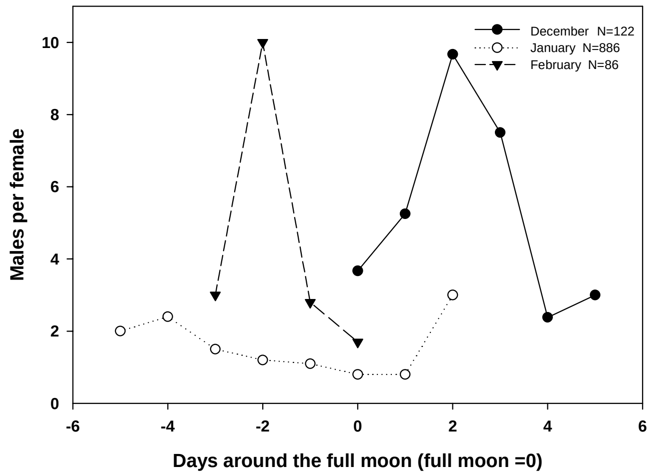


Fig 7. Male to female ratio of red hind collected from December 2005 to February 2006 in relationship to the days around the full moon

Red hind size frequencies

Size frequencies collected when compared by sex reflected the protogynous hermaphroditic life history characteristic of the red hind (Fig 8). Females collected on the Saba Bank ranged from 24.6 cm to 40.1 cm TL with a mean size of 31.8 ± 2.5 cm TL. Males ranged from 27.3 cm to 45.1 cm TL with a mean size of 35.4 ± 2.9 cm TL.

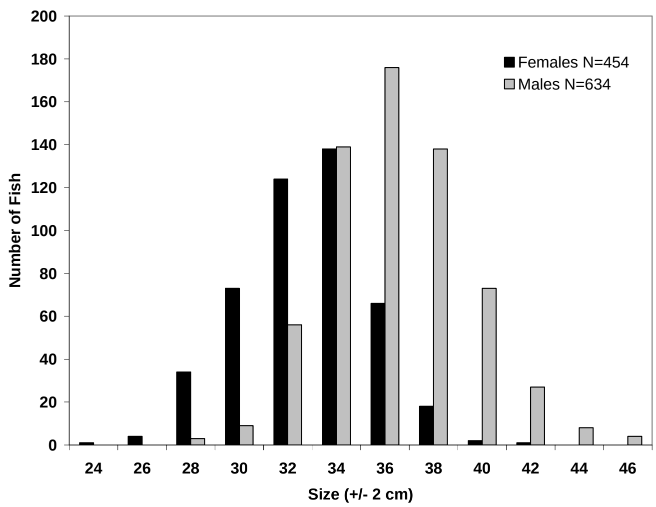


Fig 8. Size frequencies of red hind from the Saba Bank aggregation site by sex.

In December the majority of red hind observed in fish transects (48%) were in the 20-30 cm size class (Fig 9). An additional 12% were large fish, over 40 cm TL. In January densities were very high and 88% of fish recorded in transects were between 30 and 40 cm TL. In February red hind densities returned to a relatively low level (1.56 fish/100 m^2) and fish were normally distributed between size classes. Forty two percent were in the 20-30 cm size class and 48% were in the 30-40 cm size class. An additional 5% were large fish (> 40 cm TL) and 5% were subadults.

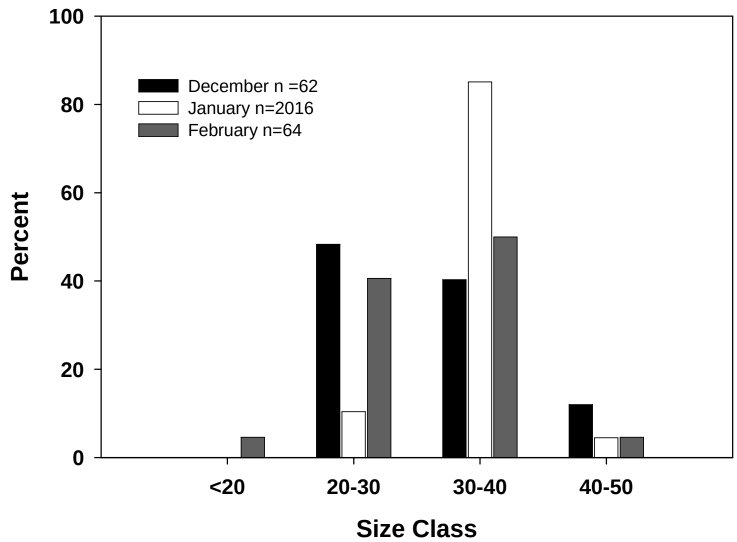


Fig 9. Size frequencies of red hind observed in fish transects from December to January on the Saba Bank.

Timing of spawning

Although fish with reproductively developed ovaries were collected in January and February, average gonadosomatic indices (GSIs) were significantly higher in January (ANOVA, $p<0.05$). In both months GSIs peaked on the day before or the day of the full moon (14 January and 12 February) however large decreases in GSIs were not seen as would be expected with a spawning event (Fig 10).

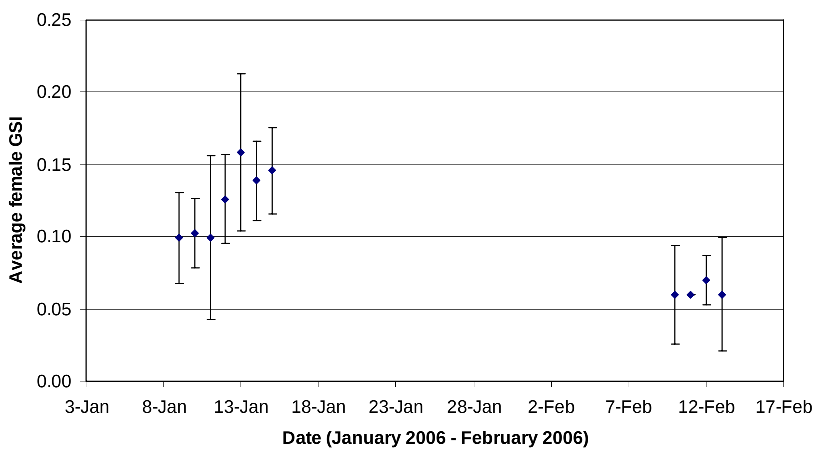


Fig 10. Daily average GSIs for female red hind sacrificed in January (n=84) and February (n=17) on the Saba Bank. Full moon = 14 January and 12 February 2006.

Behavioral indicators of spawning readiness such as aggression or physical contact between fish were not observed at any time on the bank. The heremic distribution seen on other red hind spawning aggregation sites appeared to be absent and fish showed little obvious territoriality.

Recaptures and Tag Returns

The total number of fish tagged on the Saba Bank was 584, 8 of which were recaptured while sampling the aggregation site. One red hind was recaptured in December, 6 in January and 1 in February. Two of the fish recaptured in January had been tagged in December, and the recapture in February had been tagged in January. Two tagged fish were caught by St. Maarten fishers approximately 3 km due west of the aggregation site at 17º33.815' N, 63º20.860' W. These fish had been tagged sequentially on 14 December 2005 and were caught together on the same line 11 February 2006. The fishers reported catching approximately 100 kg of red hind in the same location that day.

Bycatch - Queen triggerfish

Queen triggerfish were present in many trap hauls, especially in the northeastern area of the site along Moonfish Bank. A total of 179 queen triggerfish were collected from December 2005 to February 2006. Statistically males were larger than females (ANOVA, $p < 0.001$). Males ranged from 31.5 to 43.2 cm FL and averaged 37.8 $\pm$ 2.7 cm FL. Females ranged from 21.5 to 40.4 cm FL and averaged 28.9 $\pm$ 2.7 cm FL. Size frequencies are shown in Fig 11 by sex.

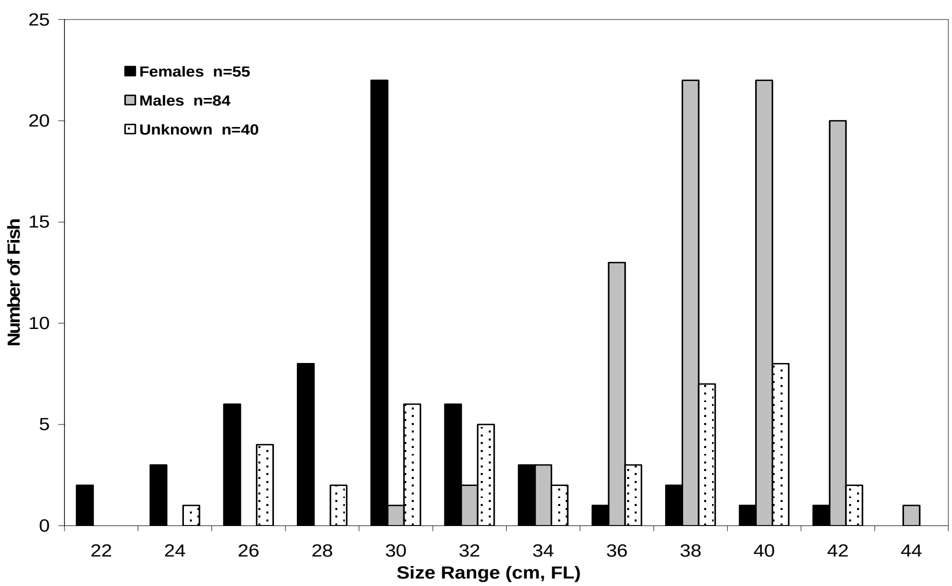


Fig 11. Length frequencies by sex of queen triggerfish collected on the Saba Bank from December 2005-February 2006.

Males were not significantly different in size between December and January but were significantly smaller in February (ANOVA, $p < 0.05$). Females were significantly larger in December than January, but were also significantly larger in February than January (ANOVA, $p<0.05$). The number of queen triggerfish caught in February was low compared to December and January because the Moonfish Bank queen trigger aggregation site was not fished as extensively. Most of the queen triggerfish collected were either ripe or gravid. We were unable to determine the gender of 28.7% of the fish using the squeezing method.

Bycatch-other species

Twenty five species of by-catch were collected in the traps set on the Saba Bank from December 2005 to February 2006. Bycatch was dominated by cottonwicks (*Haemulon melanurum*, n=189), followed by doctorfish (*Acanthurus chirurgus* n=75), coneys (*E. fulvus*, n=42) and white grunts (*H. plumeri*, n=40, Fig 12). Length frequencies for these species are shown in Fig 13. Parrotfish collected consisted of princess (*Scarus teaniopterus*, n=19) redband (*Sparisoma aurofrenatum*, n=14) and redtail (*S. chrysopterum*, n=3). Additional species caught were ocean surgeonfish (*A. bahianus*, n=24), banded butterflyfish (*Chaetodon striatus*, n=13), squirrelfish (*Holocentrus adscensionis*, n =10), scrawled cowfish (*Lactophys quadricornis* n=8), vermillion snapper (*Rhomboplites auroruben*), n=2), saucereye porgy (*Calamus calamus*, n=2) yellowtail snapper (*Ocyurus chrysurus*, n=2), four-eye butterflyfish (*C. ocellatus*, n=2) and yellowfin grouper (*Mycteroperca venenosa*, n=1). Bycatch collected are listed in Appendix I by month.

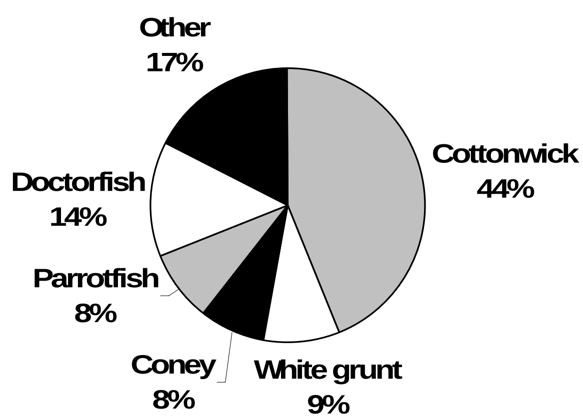


Fig 12. Composition of bycatch collected on the red hind aggregation area on the Saba Bank from December 2005- February 2006.

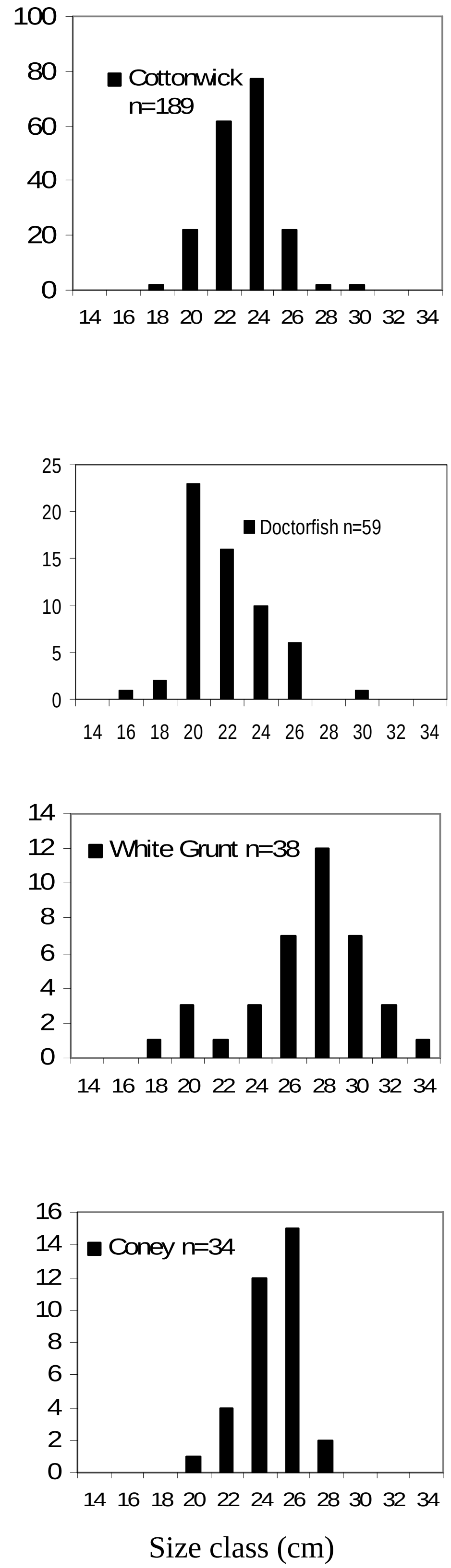


Fig 13.Length frequencies for the four most common species of bycatch caught on the red hind spawning aggregation site on the Saba Bank from December 2005 through February 2006.

Habitat and coral cover

The bottom on the red hind aggregation site was a pavement substrate with little sand or rubble. The benthic cover was dominated by macroalgae. Scleractinian corals, sponges and gorgonians were in low abundance (Fig 14). The dominant algae species was *Dictyota spp*. Coral species included *Diplora strigosa, Montastrea cavernosa* and *Colpophyllia natans* (Appendix II) but all colonies were small (< 50 cm). Severe coral bleaching was observed on the site in September 2005 and although recovering, was evident in the February 2006 transects.

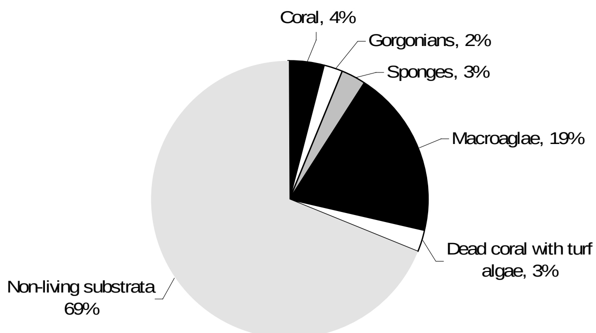


Fig 14. Benthic composition by percentage of the red hind spawning aggregation site on the Saba Bank.

DISCUSSION

The Saba Bank red hind aggregation site was found on the northeast side of the extensive submerged plateau, in a relatively shallow area with little living coral reef. The site differed from the St. Thomas MCD red hind aggregation site in physical orientation, bathymetry and benthic habitat composition and complexity. The spawning aggregation site in the MCD sits on a well developed linear reef on the windward edge of the insular Puerto Rican shelf in 35 to 40 m of depth. Coral cover, composed primarily of large colonies of *Montastrea franksi*, *M. faveolata* and *M. cavernosa,* exceeds 25% (Herzlieb et al. in press). The Saba Bank spawning aggregation site is more similar to a site on the Lang Bank, 16 km east of the island of St Croix, USVI, that also hosts a red hind aggregation annually. This site is in 30 to 35 m of water and lies several km from the shelf edge. The reef has lower relief than the spawning aggregation site south of St. Thomas, and coral cover is less than 7% (Nemeth et al. in press). Although areas of seemingly more desirable coral reef exist off St. Croix and on the Saba Bank, aggregations have developed and persisted in these areas. This could be explained by the local current regimes, which may be important for larval retention and local recruitment. On the Saba Bank fluctuations in current direction are primarily tidal, rotating from northeast to southwest twice daily. The predominant current direction is to the southwest, undoubtedly a significant factor for the location of an aggregation site in an area isolated and separated by deep water from other islands and major land masses. The Saba Bank spawning aggregation site, located on the northeast edge of the bank, may play a major role in the stability of the entire Saba Bank red hind population. No data for current speed or direction is available for the St. Croix site, which also sits on an isolated platform, however it would be interesting to know if the aggregation site location and orientation compliment the current regime as they appear to on the Saba Bank.

On the Saba Bank as well as in the USVI, timing of spawning coincided with decreasing water temperature and increasing photoperiod (Beets and Friedlander 1999, Nemeth et al. in press). The preferred temperature and current speed for spawning, which occurred in January 2006, was between 26.5 and 27.0º C and 0.15 to 0.18 cm/s respectively. These are within the limits delineated by USVI studies. Using a model developed by Nemeth et al. (in press) January was predicted to be the only month spawning aggregations would form during the 2005/2006 red hind spawning season. Saba Bank followed this prediction as did the aggregation on Lang Bank east of St. Croix (Nemeth, unpub. data). After a large aggregation formed in January in the MCD, a small number of fish remained for the February full moon (Nemeth, unpub. data). This was possibly due to competition for habitat caused by the huge spawning population (ca. 84,000, Nemeth 2005) driving the fish to spawn in sub-optimal months.

In the MCD and other sites around the Caribbean, red hind aggregate in high densities during the week preceding the full moon and peak in number on the full moon (Shapiro 1987, Sadovy et al. 1994b, Nemeth 2005, Nemeth et al., in press). Females leave the site immediately after spawning for inshore areas and may return three weeks later to spawn again (Nemeth 2005). While on the aggregation site, red hind form spawning clusters comprised of a male and several females (Colin et al. 1987, Shapiro et al. 1993, Sadovy et al. 1994b). Healthy sex ratios at the time of spawning are close to 1:4 (M:F, Beets and Friedlander 1999, Nemeth 2005). It is believed that this reproductive strategy, spreading fish across the reef, protects them somewhat from short term fishing pressure and allows aggregations to rebound when pressure is removed (Nemeth 2005). Red hind density on the Saba Bank, based on CPUE and fish transects, also peaked on the full moon in January and dropped the day after. Changes in gonadosomatic indices, although not large, indicated that fish spawned 0-1 day before the full moon. Unlike the sex ratio of other reported red hind aggregations, the site on the Saba Bank was highly skewed toward males however, and was only slightly female dominated during the spawning period (0.8:1). This male/female ratio is more similar to fish that form larger groups prior to or during spawning such as the Nassau grouper (Colin et al. 1987, Carter et al. 1994) or yellowfin grouper (Nemeth, unpub. data). Due to the flat topography and lack of benthic complexity on the Saba Bank aggregation site, very high densities of fish occur in the small areas with any type of structure or rugousity. An alternative type of spawning strategy may have developed to better utilize this environment, in which the formation of clusters or harems is impossible. Without observing actual spawning it was impossible to predict if fish were spawning in harems, groups or clusters within groups. The organization of high densities of fish on the narrow margin of reef however renders the aggregation extremely sensitive to over-fishing.

The spawning population size on the Saba Bank can be estimated based on the site area (0.053 km^2) and average density of red hind on the site in January 2006 (36.11 fish/100m^2). This estimate of 19,128 fish is significantly smaller than the number utilizing the MCD south of St. Thomas in an area over 0.24 km^2 (Beets and Friedlander 1999, Nemeth 2005) but much higher than reports of exploited aggregations from Puerto Rico (Shapiro 1987, Shapiro et al. 1993, Levin and Grimes 2002). Average size of males and females were larger in the MCD (42.3 cm TL and 36.5 cm TL respectively, Nemeth 2005) as were size ranges for both sexes (males ranged from 30 to 55 cm and females from 26 to 46 in 2003). The predominant factor affecting the size and abundance of groupers in the Caribbean is fishing pressure (Sluka et al. 1997, Chiappone et al. 2000, Nemeth 2005) and change in catch composition from larger to smaller individuals in an exploited population has been well-documented (Luckhurst 1996, Chiappone et al. 2000). Red hind reach a maximum size of 50.0 to 55.0 cm (Olsen and La Place 1978, Thompson and Munro 1978, Colin et al. 1987, Sadovy et al. 1992) and specimens have been reported at 62.0 to 72.0 cm (Luckhurst et al. 1992). The average size of red hind in the commercial fishery of the Saba Bank is 32.9 cm (Dilrosun 2000) which is considerably smaller than red hind in the St. Thomas region (Nemeth, unpubl. data).

The level of exploitation on the red hind spawning aggregation on the Saba Bank is unknown. Although in proximity to the island, in general fishers from Saba have little interest in the aggregation per se. Targeting primarily lobster and deep water snappers, red hind are considered by-catch in the Saban fishery. Fishers of both Saba and neighboring islands however fish queen triggerfish during December through February, which are popular for the roe the females produce during that time (Pieterson, pers. comm.). Due to the close proximity and temporal overlap of spawning aggregations for these two species of fish, red hind are a commonly caught as well. In addition, boats from St. Maarten regularly fish the red hind aggregation. Two boats were observed fishing the site during January and February 2006, and estimates of 600 lbs (ca. 300-350 red hind) per 2 d fishing trip were reported by one boat (Pieterson, pers. comm., Lake, pers. comm.). The sensitivity of the aggregation site is obvious and it appears based on fish size that the fishery is somewhat over-exploited. A proactive, precautionary approach to managing the bank would warrant protection in the form of at least seasonal closure for all bottom fishing gear.

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Appendix I: Bycatch collected on the Saba Bank from December 2005 through February 2006.

			December 2005				January 2006				February 2006			
Common Name	Species Name	Family	Total Number	Avg. Size	Min. Size	Max. Size	Total Number	Avg. Size	Min. Size	Max. Size	Total Number	Avg. Size	Min. Size	Max. Size
Blue Tang	*Acanthurus coeruleus*	Acanthuridae	0	>	>	>	7	19.2	17.8	20.0	5	18.1	16.3	20.6
Doctorfish	*Acanthurus chirurgus*	Acanthuridae	6	20.1	18.0	24.0	53	21.2	15.8	29.8	34	21.1	16.0	25..4
Ocean Surgeon	*Acanthurus bahianus*	Acanthuridae	22	20.1	15.7	24.7	2	22.4	22.0	22.8	0	>	>	>
Spotfin Butterfly	*Chaetodon ocellatus*	Chaetodontidae	0	>	>	>	1	14.1	>	>	2	16.8	16.5	17.0
Banded Butterfly	*Chaetodon striatus*	Chaetodontidae	5	13.8	13.0	15.0	8	13.3	12.3	14.2	14	13.6	10.8	17.6
Four-eye Butterfly	*Chaetodon capistratus*	Chaetodontidae	1	13.6	>	>	1	13.0	>	>	2	12.0	11.5	12.5
Bluestripe Grunt	*Haemulon sciurus*	Haemulidae	0	>	>	>	0	>	>	>	1	30.2	>	>
Cottonwick	*Haemulon melanurum*	Haemulidae	111	21.7	17.9	28.4	78	23.0	19.4	30.0	44	21.5	17.8	25.5
White Grunt	*Haemulon plumieri*	Haemulidae	23	25.4	17.6	32.5	15	27.4	22.5	31.0	7	29.2	24.0	38.2
Squirrelfish	*Holocentrus acensionis*	Holocentridae	5	20.8	19.2	22.5	5	20.3	18.5	21.0	5	20.6	19.5	23.0
Vermillion Snapper	*Rhomboplites aurorubens*	Lutjanidae	1	26.3	>	>	1	26.7	>	>	0	>	>	>
Yellowtail Snapper	*Ocyurus chrysurus*	Lutjanidae	2	23.1	20.5	25.6	0	>	>	>	1	21.5	>	>
Scrawled filefish	*Aluterus scripta*	Monacanthidae	2	17.6	16.5	18.7	1	45.5	>	>	0	>	>	>
Honeycomb Cowfish	*Acanthostracion ploygonia*	Ostraciidae	0	>	>	>	2	16.4	13.2	19.6	6	21.9	20.3	24.9
Scrawled Cowfish	*Lactophrys quadricornis*	Ostraciidae	2	20.7	20.1	21.2	6	21.5	17.4	28.4	0	>	>	>
Smooth Trunkfish	*Lactophrys triqueter*	Ostraciidae	0	>	>	>	0	>	>	>	0	>	>	>
Rock Beauty	*Holacanthus tricolor*	Pomacanthidae	0	>	>	>	0	>	>	>	1	17.3	>	>
Princess parrotfish	*Scarus taeniopterus*	Scaridae	10	25.6	20.9	29.3	9	24.6	21.0	29.2	3	28.2	24.0	35.9
Redband parrotfish	*Sparisoma aurofrenatum*	Scaridae	3	23.0	22.0	24.5	11	24.3	21.3	28.0	1	23.1	>	>
Redtail parrotfish	*Sparisoma chrysopterum*	Scaridae	2	27.3	21.9	32.7	1	30.4	>	>	0	>	>	>
Coney	*Cephalopholis fulvus*	Serranidae	22	24.5	20.8	26.2	12	23.5	19.0	25.4	19	23.3	14.0	26.2
Yellowfin Grouper	*Mycteroperca venenosa*	Serranidae	1	49.5	>	>	0	>	>	>	0	>	>	>
Saucereye Porgy	*Calamus calamus*	Sparidae	1	27.6	>	>	1	26.5	>	>	0	>	>	>

Appendix II: Percent benthic cover by transect of the primary red hind spawning aggregation area on the Saba Bank.

Categories	T1	T2	T3	T4	T5	T6	Mean % Cover
Hard coral species							
Colpophyllia natans (CN) - coral	0.35	0.47	0.44	0.42	0.40	0.42	0.42
Montastraea annularis (MA) - coral	0.35	0.47	0.44	0.42	0.40	0.42	0.42
Montastraea cavernosa (MC) - coral	1.42	1.86	1.77	1.69	1.61	1.68	1.67
Gorgonians (GO) - go	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Briareum asbestinum (BRIA) - go	0.00	0.00	0.00	0.00	0.00	0.00	0.00
*Erythropodium caribaeorum (*ERYTH)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Encrusting Gorgonian (ENGO) - go	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soft Coral - Sea Fan (FAN) - go	1.42	1.40	0.88	0.00	0.40	0.00	0.68
Soft Coral - Plume form (PLUME) - go	0.00	0.00	1.33	2.12	0.80	0.00	0.71
Soft Coral - Rod form (ROD) - go	4.26	0.00	0.88	5.51	2.01	1.68	2.39
Soft Coral - Whip form (WHIP) - go	1.42	0.00	1.33	2.97	3.61	0.42	1.62
Clionia delitrix (CLIO) - spo	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ball Sponge (BALL) - spo	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Barrel/Vase Sponge (BASP) - spo	0.00	0.93	0.00	0.00	0.40	0.42	0.29
Boring Sponge (BOSP) - spo	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Encrusting Sponge (ENSP) - spo	0.00	0.00	0.44	0.00	0.00	0.84	0.21
Rope Sponge (ROPE) - spo	0.35	0.00	0.44	0.00	0.40	0.42	0.27
Tube Sponge (TUBE) - spo	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sponge (SPO) - spo	0.00	0.00	0.88	1.27	2.41	1.26	0.97
Palythoa caribaeorum (PALY) - zo	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zoanthus sociatus (ZOSO) - zo	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zoanthids (ZO) - zo	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Anemone (ANEM) - other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corallimorpharians (CMOR) -other	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macro Algae (MACA) - maca	41.84	26.05	43.36	32.20	36.95	19.33	33.29
Amphiroa spp. (AMPH) - maca[calc]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cladophora spp. (CLAD) - maca	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dictyota spp. (DICT) - maca	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Halimeda spp. (HALI) - maca[calc]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Microdictyon spp. (MICRO) - maca	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Liagora spp. (LIAG) - maca	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lobophora variegata (LOBO) - maca	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sargassum spp. (SARG) - maca	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Schizothrix spp. (SCHIZ) - maca	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coralline Algae (CALG) - calg	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dead coral w/ turf algae (DCA) - dca	6.74	0.47	0.00	5.93	1.20	2.52	2.81
Boulder (B)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sand/Sediment (S)	0.35	0.00	0.00	0.00	0.00	0.00	0.06
Rubble (R)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pavement (P)	41.49	66.51	50.00	43.22	50.20	68.91	53.39
Other Organisms (O)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unknown (UNK)	0.00	0.00	0.00	0.00	0.00	0.00	0.00