Biological and Economic Aspects of Management of the Red Hind (*Epinephelus guttatus*) Fishery of Antigua and Barbuda

Aspectos Biológicos y Económicos de la Gestión del Mero Cabrilla (*Epinephelus guttatus*) Pesca de Antigua y Barbuda

Aspects Biologiques et Économiques de la Gestion de Mérou Couronne (*Epinephelus guttatus*) Pêche d'Antigua-et-Barbuda

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ABSTRACT

Catch and effort, biological, and costs and earnings data for red hind were collected from commercial fishing trips and inspections of fish retail and processing facilities in Antigua and Barbuda. The objectives were to: 1) determine important biological parameters (spawning period, size at female maturity, size at sex reversal, length-weight relationships, etc.); 2) determine trends and status of the fishery; 3) assess the financial viability of the most typical fishing unit using net present value (NPV); and 4) appraise the economic impact of a recently established closed season. Mean monthly indices of the weight of the gonad as a percentage of the body weight (gonadosomatic indices, GSIs) indicated a single distinct spawning period spanning from December 1st to March 31st. In terms of status and trends, no significant negative trends were detected for mean size landed or mean catch per unit effort. Positive NPV was generated for a typical pirogue hand-liner, indicating that investment into the unit was a worthwhile venture. A stochastic model of the unit, under condition of targeting an alternative species (yellowtail snapper) during the closed season, did not generate a significantly increase in the probability of a negative return and profits were comparable to those prior to the introduction of the closed season. Based on the theory that under an open access management regime, profits tended to attract excessive effort, resulting in the depletion of resource in the long run, the newly established closed season was consider an essential tool toward ensuring the sustainability of the fishery.

KEY WORDS: Red hind, *Epinephelus guttatus*, Antigua and Barbuda, fisheries management, closed season, economics

INTRODUCTION

The red hind (*Epinephelus guttatus*) fishery of Antigua and Barbuda was valued at EC$4.16 (US$1.54) million in 2012 and accounted for 8% of the total ex-vessel value of capture production (EC$54.79 or US$20.29 million); in term of quantity, this was equivalent to 199 metric tons (live weight) or 70% of Serranidae production. Commercially, bottom hand-line is the predominant gear used to target red hind, followed by traps (fish pot) and spear gun, respectively. A typical hand-line for red hind consists of two to three baited hooks ranging in size from No. 6 to 8 on an 80 to 100 pound test line; in recent times 1/0 to 2/0 hooks have become equally common allegedly due to greater efficiency with respect to hook removal and few incidences of fish being gut-hooked. Squid is the preferred bait and fishing generally takes place overnight (dusk to dawn). Traps are normally constructed from 38.1 mm hexagonal-mesh chicken wire and braced with *wattle* (stick) or steel. The target species for traps in Antigua and Barbuda are either the Caribbean spiny lobster (*Panulirus argus*) and reef (*mix*) fish or deep-water groupers and snappers (queen, silk, and blackfin snappers, etc.). The few fishers that target red hind using traps normally bait with squid and haul every four to six hours; traps, in general, are baited with coconut and / or cowhide and hauled every seven days for spiny lobster and reef fish. Other targeted species of the red hind line fishery include coney (*Cephalopholis fulvus*), queen triggerfish (*Balistes vetula*) and various grunts (Haemulidae). Note, line fishers who target red hind may also target other species during a fishing trip or at other times during the year, for example yellowtail snapper (*Ocyurus chrysurus*), blue runner (*Caranx crysos*), and dolphinfish (*Coryphaena hippurus*); hence the hand-line fishery is multi-species and multi-geared (i.e., there are various types of hook and line configuration depending on the target species). In terms of demersal finfish, snappers tend to be the preferred alternative species due to its higher ex-vessel value relative to red hind (US$8.17 per kg versus US$7.35 per kg).

The typical hand-liner is a 25-foot fibreglass pirogue operated by a crew of one to two individuals (not including the skipper) and powered by a 40 horsepower outboard engine. Typical investment (including vessel, gear and equipment) ranged from EC$48,000 to EC$60,000 (US$17,778 to US$22,222) depending on whether one or two 2-stroke engines are used; some vessels utilise two engines for reasons of occupational safety. Over the past five years, 4-stoke outboard engines have become more common in the fishery.

As of February 2013, the Fisheries Act, No. 22 of 2006 and the Fisheries Regulations, No. 2 of 2013 are the primary legislative basis for fisheries management and development. The new pieces of legislation make provision to move any fishery from an "open access" to a "limited entry" management regime. Under section 30 (4) of the Fisheries Act 2006, an application for a local fishing licence can be refused on the ground that it necessary to do so in order to give effect to any programme to limit fishing effort as specified in a fisheries management plan. Section 76 of the Act also makes provision for the Minister of Fisheries to make regulations for conservation measures such as minimum mesh sizes, gear standards, minimum species sizes, closed seasons, closed areas, prohibited fishing methods, and gear.

In 2014, a closed season for red hind (*Epinephelus guttatus*), Nassau grouper (*Epinephelus striatus*) and coney (*Cephalopholis fulvus*) was implemented for the first time in Antigua and Barbuda under the Fisheries Regulations, No. 2 of 2013; it extends from 1st January to 31st March of every year until otherwise declared by the Minister. During this period, a person shall not fish for, take, place for sale, purchase, or have in his possession any of the fore mentioned species; if caught the forementioned species shall be immediately released.

The Fisheries Act as well as the Marine Areas (Preservation and Enhancement) Act (1972), both makes provision for the declaration of marine protected areas. Thus far, four marine protected areas have been designated in Antigua and Barbuda: Salt Fish Tail (Diamond Reef); Palaster Reef; Cades Reef; and the North East Marine Management Area. These sites include important nursery areas for red hind and other fish species as well as for the queen conch and Caribbean spiny lobster. In addition to these protected areas, Codrington Lagoon in Barbuda has been declared as a national park under the National Parks Act (1984) whilst the Nelson Dockyard National Park in Antigua also includes marine areas. With respect to the North East Marine Management Area, enclosed are some of the spawning aggregation sites for red hind (*Epinephelus guttatus*) and grey snapper (*Lutjanus griseus*). In terms of violations, the Fisheries Act allows for the compounding of offence, whereby a fine can be imposed according to the prescribed schedule of fees for compounding of offence in the Regulations; the maximum fine is EC$50,000 (US$18,518) with respect to red hind conservation measures.

A survey in 2003 of fishers, fisheries officers, and other knowledgeable individuals, and observation of catches at fishing ports and landing sites in the north-eastern Caribbean (included Antigua-Barbuda), concluded that stocks of the red hind appeared to be in relatively good condition in most areas and many spawning aggregation sites are known (Munro and Blok 2003). Conversely, stocks of larger groupers have been greatly reduced although spawning aggregations of Nassau grouper (*Epinephelus striatus*) have been observed on the Antigua and Barbuda Shelf and in the British Virgin Islands. Survey results also suggest that the relative economic status of fishers affects grouper stocks, in that countries with "good spiny lobster stocks" would tend to target lobster (Munro and Blok 2003), thereby reducing fishing effort.

In terms of the biology of the species, the red hind are protogynous hermaphrodites, female to male sex changers (Sadovy et al. 1992, Shapiro et al. 1993) that form spawning aggregations at particular locations and at specific time. The predictability of spawning aggregations has made red hind especially susceptible to overfishing. Large species of grouper (e.g., Nassau grouper) have become rare over most of their range due to a similar reproductive strategy (Sadovy 1993, Munro and Blok 2003).

In light of the fore mentioned and the absence of local quantitative studies, the specific objectives of this research was to:

i) Determine important biological parameters (spawning period, sex ratio, size at female maturity, size at sex reversal, length-weight relationships, etc.),
ii) Determine trends and status of the fishery
iii) Assess the financial viability of the most typical fishing unit using net present value (NPV), and
iv) Appraise the economic impact of the recently established closed season.

MATERIALS AND METHODS

Data used in this study came from Antigua and Barbuda Fisheries Division's catch and effort, finfish biological and licensing and registration programmes; the latter captured the techno-economic and operational characteristics of the individual fishing units. Catch and effort, biological, and costs and earnings data were collected from commercial fishing trips, fish retailing and processing facilities. Operational costs and investment costs provided by vessel operators / owners were cross-checked with suppliers of marine and fishing equipment, shipwrights, boat dealers and marine mechanics. For each biological sample, the following data were collected (where possible): area fished; depth fished; fishing method or gear; landed status (whether samples landed whole, gutted, etc.); total length to the nearest 0.1 cm; body weight to the nearest 1 g; and sample type (whether samples were sorted or unsorted). Sample type was recorded to avoid potential bias in fishery performance indicators (e.g., annual or area mean total length). To determine spawning period and size at maturity, the following additional data were recorded from collected subsamples: body weight of whole fish (before dissection) to the nearest 0.1 g; gonad weight to the nearest 0.1 g after dissection from the other visceral organs; and sex and stage of maturity (where possible) based on macroscopic examination of gonads' morphology, size and colour adapted from Holden and Raitt (1974).

The stages of maturity were: I) immature; II) mature inactive; III) active (developing); IV) ripe; and V) spent. An additional stage, VI (undetermined), was used to classify specimens whose gonads could not be sexed by macroscopic means (this included specimens that may be in a stage of sexual transition). Thompson and Munro (1983) highlighted that the sex of groupers cannot be determined with any degree of certainty by macroscopic means unless the gonads are in an active, ripe, or early spent state. According to Sadovy and Shapiro (1987), histological methods are the only reliable means of determining sex and maturity of hermaphrodites. In this study, no histological work was done due to financial constraints; however, a Rolson 6-LED Illuminated Magnifying Glass was used to enhance macroscopic examination. Based on the forementioned limitations of the macroscopic analysis, mean monthly indices of the weight of the gonads as a percentage of the body weight (gonadosomatic indices, GSIs) were used to determine spawning period for those specimens whose sex were determined. Gonad weight increases with maturity up to the ripe stage and declines after spawning. This approach was considered more reliable due to its impartiality (i.e., it relies on quantitative measurements as opposed to a maturity key that is subject to user discretion).

Logistic regression using the probit analysis feature in IBM SPSS Statistics Version 20 was used to estimate the size at maturity. Midpoints of length classes, the number of females that were mature in each length class and the total number of females in each length class were imported into SPSS. A logit model was selected where the covariate (the midpoints of the length classes) were transformed to natural log. The proportion (p) of mature female in each length class was converted to logit, Y = logit(p) = ln[p / (1 - p)]. The logit data (Y) were then plotted against the natural log of the length midpoints (X), and a linear regression line fitted to the data points. The output of the regression analysis provided an estimate of the length associated with a maturity rate of 50% for females. This is possible since Y = ln[p / (1 - p)] = ln[$e^{a + bX}$] = a + bX, and when p = 50% (0.5), then Y = 0; hence the estimated size at maturity is then equivalent to e^{X} or $e^{(-a / b)}$. The fore mentioned approach was also used to estimate size at sex reversal in light of the fact that previous histological and field studies (Sadovy and Shapiro 1987, Shapiro et al. 1993) have provided conclusive evidence of sex reversal in red hind. Hence, midpoints of length classes, the number of males that were mature in each length class, and the total number of matured individuals in each length class (i.e., maturity stages II to V) was used to estimate the length at which 50% of mature females had changed sex to mature males.

Statistical analyses were conducted using Microsoft Excel 2010 and IBM SPSS Version 20. To determine the relationships between total length and body weight, simple linear regression was used on common log transformed data. Analysis of variance was used to determine if the following conditions existed: significant difference amongst the mean monthly GSIs; and significant spatial and / or temporal variability in fishery performance indicators (e.g., mean size landed, mean catch per unit effort). The status of the sex ratio (whether unbiased or biased) was determined by a Chi-square Goodness of Fit Test. The sex ratio during the spawning period and outside the spawning period was also evaluated using the Chi-square Goodness of Fit Test.

Financial viability of capital investment in the most typical fishing unit and the economic impact of the closed season were assessed using net present value (NPV). NPV is based on the principle that an investment is a worthwhile undertaking, if the money derived from the investment is greater than the money put in, provided that the time value of money is taken into account in the assessment (Lumby and Jones 2003). NPV can be expressed as the sum of its net discounted future cash flows:

$$NPV = \sum_{t=0}^{n} A_t \,/\, (1+r)^t$$

Where:

A_t is the project's cash flow in time t,

n represents the point in time when the project comes to the end, and

r is the annual discount rate.

The decision rule for NPV, is to accept projects if their NPV is greater than or equal to zero (i.e., positive or zero); and reject if their NPV is less than zero (i.e., negative) (Lumby and Jones 2003).

Once the various parameters and quantitative data were entered into Microsoft Excel spreadsheets, a stochastic model for a typical hand-lining unit was developed using Excel RAND function according to Horsford (2007). By using the actual variations in revenue and expenditure data (costs and earnings, catch and effort, etc.), numerous iterations of the NPV can be produced and the frequency distribution of the profit outcome generated. Note the discount rate was taken as 11.5% and the time horizon was 10 years, at the end of which it is assumed that the salvage value of the vessel and equipment was zero. Cash flows were discounted at 11.5% based on the maximum prime lending rate for commercial banks. Capital items were assumed to be purchased or replaced with the following frequencies according to presumed life span: vessel and equipment every 10 years; engine every 5 years; and gear (hooks, lines, etc.) every year. The typical hand-liner was a 25-foot fibreglass pirogue with a 40 horsepower outboard 2 -stroke engine, operated by a single crew (not including the owner / skipper). In terms of labour costs, the single crew retained two-thirds of his catch; a third goes to the vessel owner to cover vessel expenses. Catch rates for the various species (red hind, yellowtail snapper, etc.) was assumed to be maintained at 2012 levels. To appraise the economic impact of the red hind closed season on a typical hand-lining unit, the stochastic model was operated under the scenario that fishers targeted yellowtail snappers for the three months of the closed season.

RESULTS

Figure 1 summarises the mean monthly gonadosomatic indices (GSIs) for female and male red hind from Antigua and Barbuda waters. The monthly GSIs indicated a single distinct spawning period starting in December and ending in March. Analysis of variance indicated significant temporal difference amongst the monthly GSIs for females (Figure 1); Welch and Brown-Forsythe F-ratios respectively were: F (11, 31.55) = 17.51, $p < 0.001$ and F (11, 21.95) = 34.44, $p < 0.001$. Games-Howell post hoc test indicted that mean female GSI for January (4.7%) was significantly higher than any other month, $p < 0.01$ (Figure 1). While the monthly GSIs for males emulated the trend for females, with the highest mean value recorded in January (1.0%), too few samples were collected for statistical analysis to be conclusive. However, mean GSI for males during the spawning period of December to March (0.6%), was significantly higher than all other months combined (0.1%) (Figure 1); Welch and Brown-Forsythe F-ratios were both equivalent to F (1, 26.09) = 20.06, $p < 0.001$. During the spawning period, female GSI ranged from 0.1% to 11.9% whilst male GSI ranged from 0.1% to 1.6%; in both cases the maximum GSI was recorded in January.

Chi-square Goodness of Fit Test indicted that commercial fishing favoured the harvest of female red hind, with 74.8% of the sexed sample being females or a male to female ratio of 1:2.96, X^2 (1, n = 151) = 37.25, $p < 0.001$. During the spawning period (December to March) the male to female ratio was 1:2.24 or a proportion of 30.9% and 69.1% respectively, whilst outside the spawning period (April to November) the male to female ratio was 1:4.38. Chi-square Goodness of Fit Test confirmed that the fore mentioned ratio or proportion was significantly different from that during the spawning period, X^2 (1, n = 70) = 4.98, $p < 0.05$. The only month that the sex ratio favoured males was the month of February (Figure 1), where the male to female ratio was 1:0.46.

The size at maturity for red hind from Antigua and Barbuda could not be established from current study since 97% of the sexed samples were mature (i.e., commercial fishing gears disproportionally sampled mature specimens). Length-frequency distributions of mature male and female red hind (Table 1) showed that males were of a significantly larger mean size than females [35.5 cm versus 31.1 cm, F (1, 149) = 29.82, $p < 0.001$], although the length distributions of the sexes overlapped considerably, with the percentage of males increasing steadily with increasing total length (Table 1).

In terms of size at sex reversal or change, the estimated regression line obtained from the logistic regression was Y = -31.511 + 8.720X, hence the estimated size at 50% sex reversal was 37.1 cm. The lower and upper 95% confidence limits for the size at sex reversal were 35.2 and 40.7 cm respectively. Pearson's Goodness-of-Fit Test provided no evidence to reject the null hypothesis, hence the fitted model was correct, X^2 (8, n = 10) = 8.52, $p = 0.385$. Note the last two length groups in Table 1 were excluded from the analysis due to limited sample size.

Table 2 summarises the relationships between body weight and total length by sex for red hind collected from Antigua and Barbuda waters; in all cases, regressions were significant ($p < 0.001$). The size ranges were as follows: male, 24.0 to 42.4 cm; female, 22.6 to 44.1 cm; and unsexed, 18.2 to 46.9 cm. The adjusted coefficient of determination was characteristically higher for males than for females. Regression for males accounted for as much as 97% of the variance that can be explained by the regression model; regression for females accounted for 91% of the variance at best. The 95% confidence intervals for the slope of the regression line ranged from 2.97 to 3.32 for males and 2.99 to 3.36 for females. The overlap for the confidence intervals was pronounced suggesting that males and females length-weight relationship were statistically equivalent. Hence the regression equation for unsexed sample is also presented in Table 2.

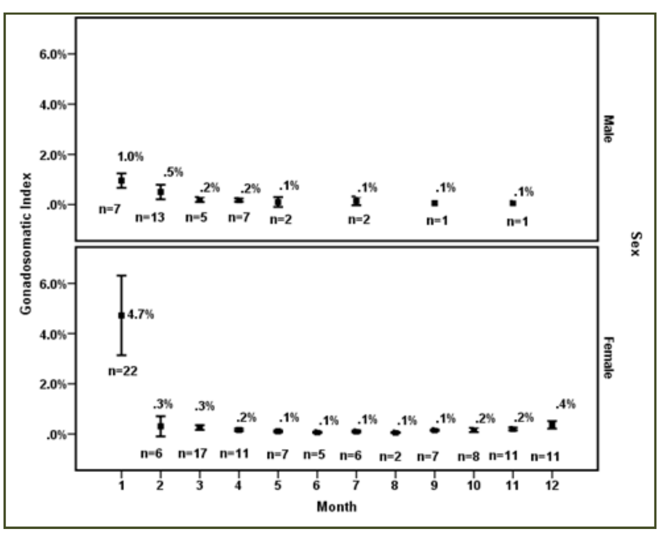

Figure 1. Mean monthly gonadosomatic indices for female and male red hind (*Epinephelus guttatus*) from Antigua and Barbuda waters. Error bar is for the 95% confidence interval and n = sample size.

The mean size of recruitment into the red hind fishery differed significantly amongst fishing gear; Welch F-ratio was F (3, 41.14) = 2.97, $p < 0.05$ (Figure 2). The mean size of recruitment for hand line was significantly larger than for trap ($p < 0.05$, Games-Howell post hoc test). In all cases, the mean size of recruitment into the fishery was greater than reported size at maturity from various Caribbean islands (21.5 to 25.0 cm total length) (i.e., the 95% confidence intervals for the mean size of recruitment did not include the fore mentioned values). Note Sadovy et al. (1994) reported the size at maturity for red hind in terms of folk length (FL). In this study, size is measured in total length (TL), however due to the morphology of the red hind the difference between the two metrics is negligible. The global fish species database FishBase by Froese and Pauly (2000) reported the following length-length relationship, TL = 0.000 + 1.003FL.

There was significant temporal variability in the mean size of red hind landed in Antigua and Barbuda (Figure 3); Welch and Brown-Forsythe F-ratios respectively were: F (13, 57.93) = 3.63, $p < 0.001$ and F (13, 131.72) = 3.95, $p < 0.001$. Games-Howell post hoc test indicted that only red hind landed in 2004 were significantly larger than those landed in 2000, 2002, 2003, 2005, 2007 and 2013 ($p < 0.05$). For all other comparisons up to 2014 there was no significant difference in the mean size of hind landed, $p > 0.05$. In all case, the mean size landed was larger than reported size at 50% maturity. In terms of spatial variability (Figure 4), red hind landed from the south coast of Antigua were statistically equivalent in size to those from the east or west coast ($p > 0.05$, Turkey post hoc test), but significantly smaller than those from Barbuda, the north coast and the central portion of the Antigua and Barbuda Shelf ($p < 0.05$, Turkey post hoc test).

Figure 5 summarises the mean catch per unit effort (CPUE) by year for hand-line vessels targeting red hind. Analysis of variance indicated that the mean catch per unit effort were statistically equivalent over the years; Welch and Brown-Forsythe F-ratios respectively were: F (6, 21.61) = 2.63, $p = 0.05$ and F (6, 41.20) = 3.89, $p > 0.05$. Mean catch per unit effort at the vessel level (kg *E. guttatus* / day-trip) also established that there was no significant temporal variability, $p > 0.05$, Games-Howell post hoc test. Note, it was critical to develop a criterion to define when vessels where targeting red hind due to the fact that fishers generally target other species during a trip and the unit of effort used (a day-trip as oppose to hours fished for red hind) was imprecise to account for the alternative species targeted.

Table 3 provides a sample output from the stochastic model of a typical hand-liner targeting red hind. In the initial year (year 0), investment costs and running costs were the main components of the total cash outflow. In subsequent years, running costs (fuel, lubricant, ice, bait, food, licence, etc.) was generally the largest component of the total cash outflow, ranging from 42% to 62%, whilst labour costs was the second largest component, ranging from 29% to 49%. Vessel costs (dry docking, engine and hull maintenance and repairs, etc.) was the third largest component (3% to 7%), followed by investment costs in years 1 to 10; only in year 6 was the investment costs greater than the vessel costs when there was a major capital investment in replacing the engine. Fuel accounting for

Table 1. Length-frequencies of mature male and female red hind (*Epinephelus guttatus*) from Antigua and Barbuda waters and the percentage of males in successive length groups.

Length Group Total Length (cm)	Midpoint (cm)	No. of Mature Females	No. of Mature Males	Total Mature	Percent Mature Males
22.0 – 23.9	22.95	2	0	2	0%
24.0 – 25.9	24.95	6	1	7	14.3%
26.0 – 27.9	26.95	15	2	17	11.8%
28.0 – 29.9	28.95	26	2	28	7.1%
30.0 – 31.9	30.95	23	4	27	14.8%
32.0 – 33.9	32.95	19	3	22	13.6%
34.0 – 35.9	34.95	11	7	18	38.9%
36.0 – 37.9	36.95	3	7	10	70.0%
38.0 – 39.9	38.95	1	3	4	75.0%
40.0 – 41.9	40.95	4	8	12	66.7%
42.0 – 43.9	42.95	2	1	3	33.3%
44.0 – 45.9	44.95	1	0	1	0%
Total		113	38	151	

Table 2. Regression equations for body weight (W) as a function of total length (TL), by sex for red hind collected from Antigua and Barbuda waters. Lengths are in cm, weights are in g, A is the *Y* intercept, *B* is the slope of the estimated regression line and CI is the confidence interval.

Group	Regression Equation *Y = A + B(x)*	Relationship	Adjusted Coefficient of Determination, R^2	Sample Size, *n*	Lower Bound for the 95% CI for *B*	Upper Bound for the 95% CI for *B*
Male	Log(W) = -2.020 + 3.142Log(TL)	W = 0.0095 TL^3.142	0.973	38	2.968	3.316
Female	Log(W) = -2.077 + 3.176Log(TL)	W = 0.0084 TL^3.176	0.909	113	2.988	3.364
Unsexed	Log(W) = -1.891 + 3.050Log(TL)	W = 0.0129 TL^3.050	0.907	1059	2.991	3.109

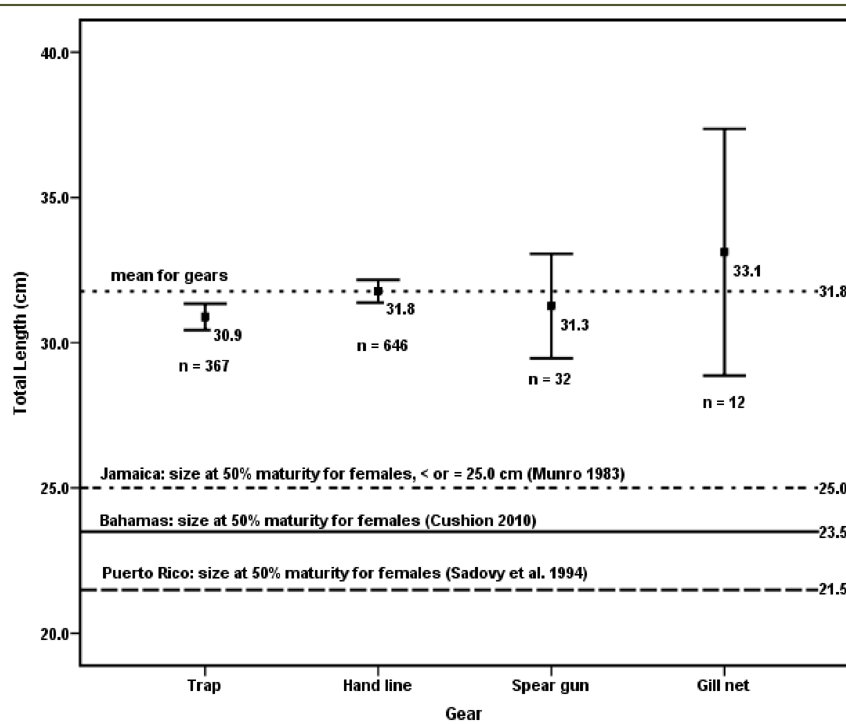

Figure 2. Mean total length by gear for red hind (*Epinephelus guttatus*) landed from Antigua and Barbuda waters. Error bar is for the 95% confidence interval and n = sample size. Standard gear: trap, 38.10 mm hexagonal mesh; hook, No. 6 to 8 or 1/0 to 2/0; and bottom gill net, 76.25 mm mesh.

34% to 60% of the running costs or 15% to 32% of total expenses (cash outflow). In terms of vessel costs, insurance was not included since less than 10% of the fleet had insurance. The positive NPV after ten years (EC$45,727 or US$16,936) indicated that investment in a typical hand-liner targeting red hind was a worthwhile venture under the defined scenario.

Figures 6 and 7 summarise the probability distribution of potential profit outcomes for a hand-lining unit targeting red hind under the following: scenario 1) no closed season; and scenario 2) closed season plus targeting of yellowtail snapper as an alternative species during the period. Under scenario 1 (Figure 6), the mean expected return was about EC$50,000 (US$18,518) over a period of 10 years and there was an 78.4% chance of a positive return ranging up to EC$200,000 (US$74,074) over the same period. Under scenario 2 (Figure 7), the mean expected return over the 10 year period was comparable however the chance of a positive return was marginally higher (79.7%) and ranging up to EC$200,000 (US$74,074).

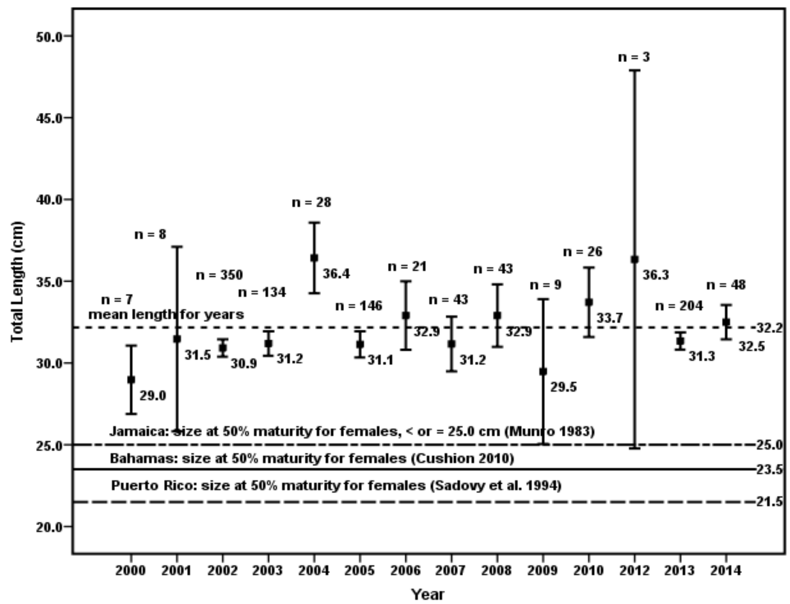

Figure 3. Mean total length by year for red hind (*Epinephelus guttatus*) landed from Antigua and Barbuda waters. Error bar is for the 95% confidence interval and n = sample size.

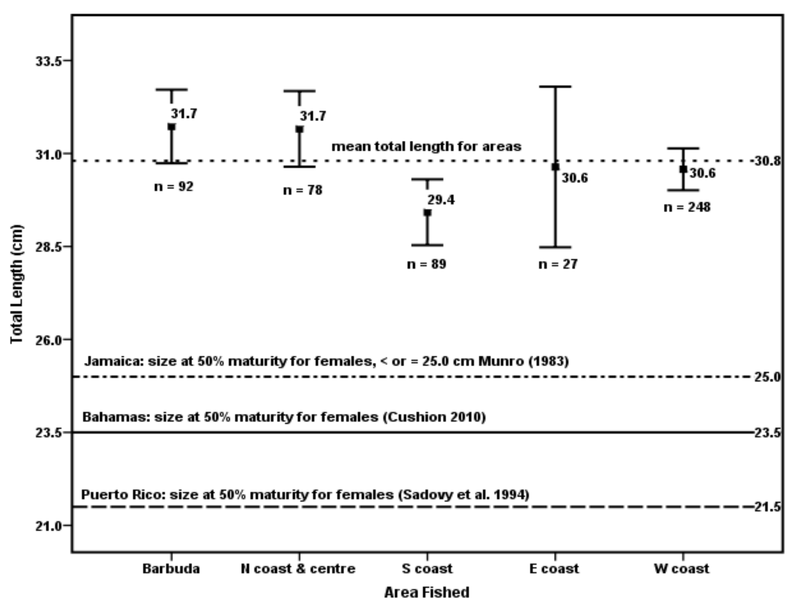

Figure 4. Mean total length by area for red hind (*Epinephelus guttatus*) landed from Barbuda and the various coasts of Antigua (depth range: 12-119 m). Error bar is for the 95% confidence interval and n = sample size.

DISCUSSION AND CONCLUSION

This study obtained a single distinct spawning period for red hind starting in December and ending in March, with January being the peak month for spawning activity as indicated by the fact that the highest mean monthly gonadosomatic index was recorded in January for both sexes (Figure 1). These findings are in line with results obtained for Bahamas (Cushion 2010), Jamaica (Thompson and Munro 1983), Puerto Rico (Shapiro et al. 1993), and the neighbouring British Virgin Islands (Eristhee et al. 2006) and US Virgin Islands (Whiteman et al. 2005). Based on the preliminarily results of this study, a closed season extending from 1st January to 31st March was implemented for the first time in Antigua and Barbuda in 2014. Originally, a four-month closed season was proposed (including the month of December), however only three months were agreed to through negotiations with fisher-folks, Barbuda Council (the local fisheries management authority for the island of Barbuda) and other stakeholders. During the negotiations, closed areas for spawning aggregation sites was considered as an alternative, however this option was rejected due to the challenges associated with policing numerous sites during the spawning period. Colin et al. (2003) highlighted that closed seasons are particularly relevant where aggregations cannot be patrolled or site protection readily enforced, plus there is the additional benefit of protection of unknown sites.

In terms of red hind population structure, Chi-square test indicated that the population was biased in terms of females ($p < 0.001$), with 74.8% of the samples being female or a male to female ratio of 1:2.96. In addition, males were significantly larger than females and the percentage of males increasing steadily with increasing total length (Table 1). These results are attuned with the protogynous hermaphroditic nature of the species (Sadovy et al. 1992, Shapiro et al. 1993). Thompson and Munro (1983) reported an annual male to female sex ratio of 1:2.81 for unexploited oceanic banks and a sex ratio of 1:5.60 for Port Royal, Jamaica. The high proportion of females in the population of Port Royal was attributed to high fishing pressure where the largest, mostly male, individuals became relatively less abundant. The annual male to female ratio obtained in this study (1:2.96) was closer to that of the unexploited oceanic banks of Jamaica; hence there was no evidence of a highly skewed sex ratio as a result of fishing pressure.

During the spawning period in this study (December to March) the male to female ratio was 1:2.24, whilst outside the spawning period (April to November) the male to female ratio was 1:4.38. Whiteman et al. (2005) recorded a comparable sex ratio of 1:2.9 (male: female) for the reproductive season of December to February for St Thomas, US Virgin Islands; the research also concluded that the sex ratio differed between months and days within

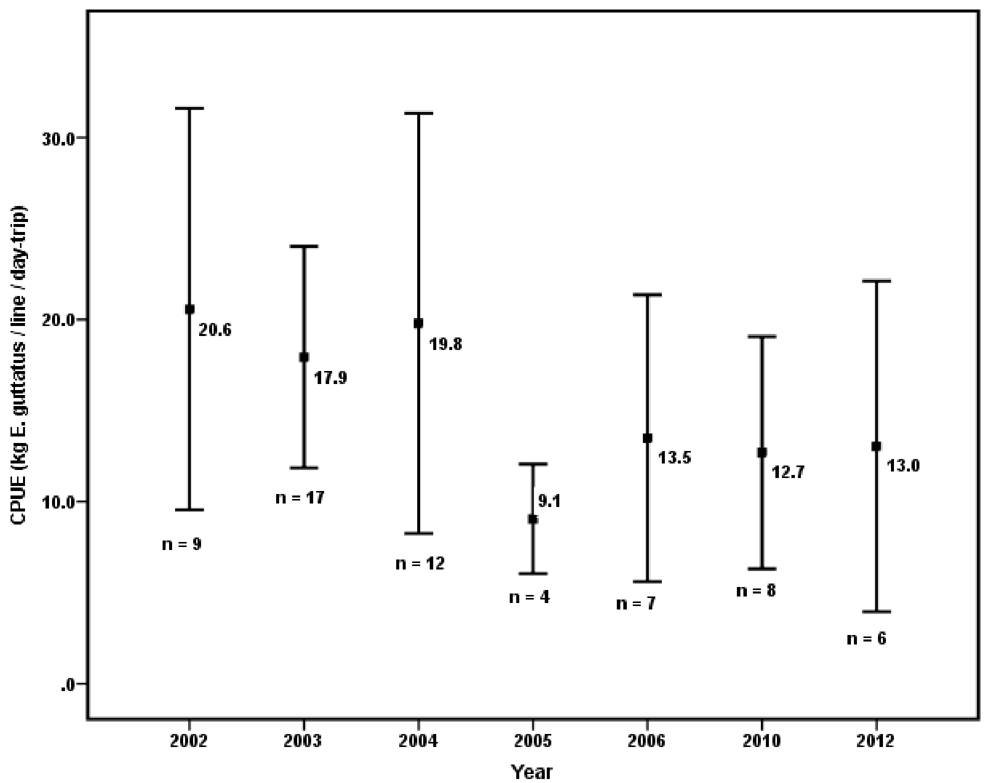

Figure 5. Mean catch per unit effort (CPUE) by year for hand line vessels targeting red hind (*Epinephelus guttatus*) in Antigua and Barbuda waters; in all samples catch ≥ 40% red hind. Error bar is for the 95% confidence interval and n = sample size.

Table 3. Sample net and discounted cash flows (in EC$) generated from a stochastic model for a typical hand liner (25ft. fibreglass pirogue with 40 hp outboard 2-stroke engine) targeting red hind. NPV = net present value and US$1.00 = EC$2.70.

Year	0	1	2	3	4	5	6	7	8	9	10	NPV
Fishing days	115	123	108	117	109	108	98	124	99	104	125	
Total revenue	27,438	91,527	73,901	138,432	85,702	111,015	81,477	113,022	72,428	94,462	64,180	
Invest-ment cost	48,000	2,000	2,000	2,000	2,000	2,000	14,000	2,000	2,000	2,000	2,000	
Running cost	32,877	26,491	40,646	57,168	26,718	34,488	37,522	45,543	23,468	27,073	45,610	
Vessel cost	3,749	3,953	3,324	3,433	3,515	3,666	4,129	3,728	3,914	4,238	4,043	
Labour cost	9,146	30,509	24,634	46,144	28,567	37,005	27,159	37,674	24,143	31,487	21,393	
Net cash flow	-66,334	28,574	3,297	29,687	24,902	33,857	-1,332	24,077	18,904	29,663	-8,866	
PV net benefits	-66,334	25,627	2,652	21,416	16,111	19,646	-693	11,238	7,913	11,136	-2,985	45,727

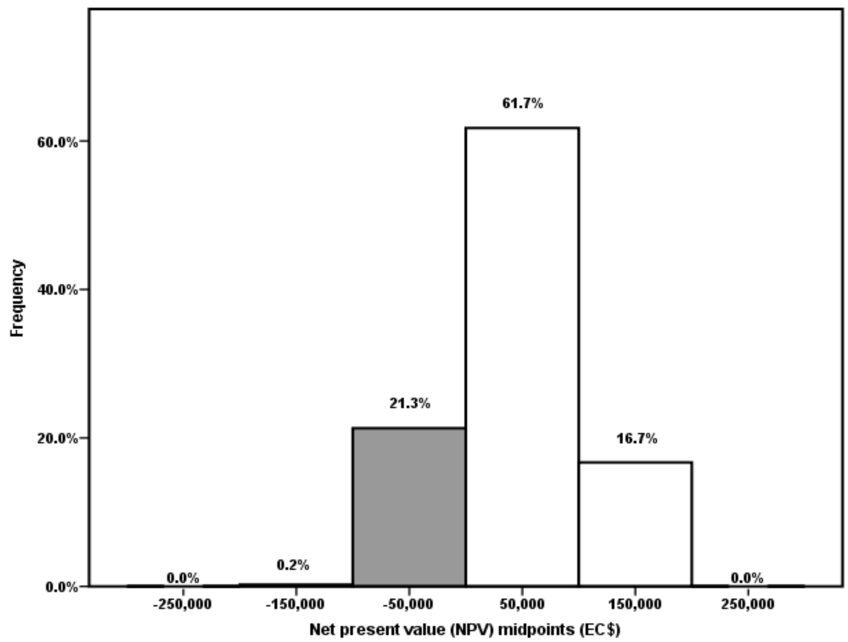

Figure 6. Probability distribution of potential profits (NPVs), for a typical hand lining unit (25ft. fibreglass pirogue with 40 hp) targeting red hind, assuming catch rates are maintained at 2012 level (no. of iterations = 41,300 and US$1.00 = EC$2.70).

months, and in February the sex ratio was male biased (1:0.8). Similar results were obtained for Antigua and Barbuda, where February was the only month that the sex ratio favoured males (1:0.46) (Figure 1). According to Whiteman et al. (2005) this may be attributed to an influx of small females in February and the arrival of larger males as indicated by the increase in mean male size from January to February.

As stated previously, commercial fishing gears (38.10 mm hexagonal mesh traps, No. 6 to 8 or 1/0 to 2/0 hooks and 76.25 mm gill nets) disproportionally sampled mature specimens, hence the size at 50% maturity for red hind from Antigua and Barbuda could not be established. In all cases, the mean size of recruitment into the fishery was significantly greater than the reported size at maturity from various Caribbean islands (21.5 to 25.0 cm total length) (Figure 2). Hence, the majority of commercial landings of red hind had the opportunity to reproduce at least once before capture, thereby contributing to the next generation. While the type of gears used tended to prevent growth overfishing, their impact on the largest, mostly male, individuals can be problematic if too much effort is applied during the spawning period when males are more vulnerable to capture due to their higher abundance (in February) and their territorial behaviour may make them more likely to take baited hooks (Colin et al. 1987). The implementation of the closed season should reduce the likelihood of reduce reproductive capacity as a result of sperm limitation

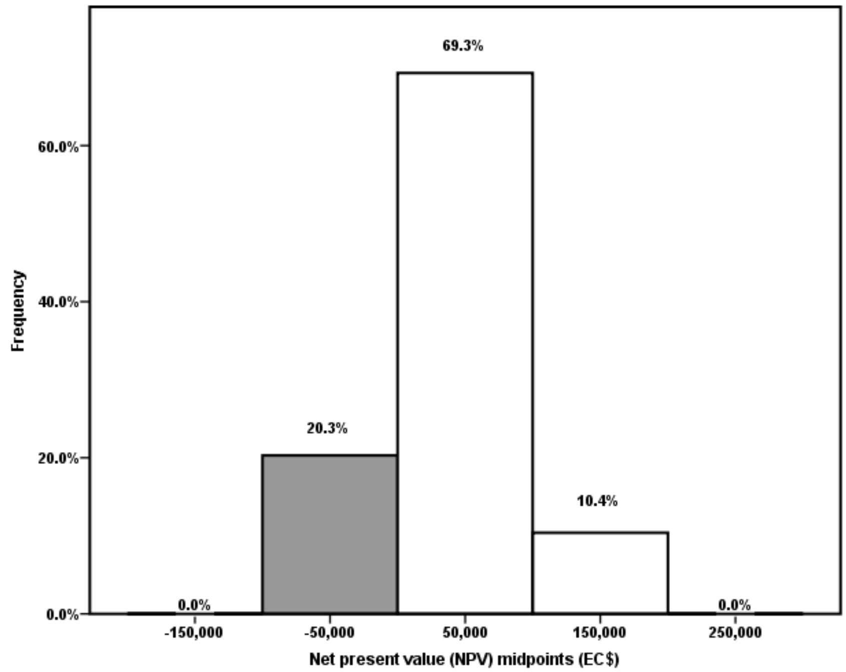

Figure 7. Probability distribution of potential profits (NPVs), for a typical hand lining unit (25ft. fibreglass pirogue with 40 hp) targeting red hind and yellowtail snapper, assuming catch rates are maintained at 2012 level (no. of iterations = 41,300 and US\$1.00 = EC\$2.70). Note yellowtail snapper is targeted during the red hind closed season (1^{st} January to 31^{st} March).

in the population from having less males.

The estimated size at 50% sex reversal was 37.1 cm from the logistic regression and the 95% confidence interval ranged from 35.2 to 40.7 cm. Thompson and Munro (1983) reported a mean size at sex reversal in the region of 38 cm total length for Jamaica, whilst Cushion (2010) noted sex reversal in the range of 25.7 to 40.1 cm total length (or 4-5 years old) for the Bahamas; both estimates were equivalent to the results for Antigua and Barbuda. The fact that sizes at sex reversal were similar amongst the islands might suggest that all the fisheries were operating at a similar stage of development or exploitation at the time the studies were conducted; Fishelson (1970) had postulated that high fishing pressure could induce earlier sex reversal.

The relationships between body weight and total length by sex for red hind (Table 2) were significant ($p < 0.001$). The adjusted coefficient of determination (goodness of model fit) was characteristically higher for males than for females; this was attributed to the smaller variation in weight associated with gonad development in males. Since the 95% confidence intervals for the slope of the regression lines for the sexes overlapped significantly, the relationship for all red hind could be expressed as: $W = 0.0129\ TL^{3.050}$. Thompson and Munro (1983) obtained comparable results (in terms of slope of regression line) for samples from Jamaica ($W = 0.0176\ TL^{2.960}$) whilst Beets and Friedlander (1992) reported $W = 0.0000145\ TL^{3.001}$ and $W = 0.0000195\ TL^{2.966}$ for samples from St. Thomas and St. Croix, respectively. Note samples from the US Virgin Islands were measured in mm.

There was significant temporal variability in the mean size of red hind landed, however only red hind landed in 2004 were significantly larger than those landed in 2000, 2002, 2003, 2005, 2007, and 2013 ($p < 0.05$) (Figure 3). For all other comparisons up to 2014, the mean size landed were statistically equivalent, $p > 0.05$; hence there was no evidence of recruitment overfishing (e.g., declining mean size). While there was significant spatial variability in the mean size of red hind landed, in all cases, mean sizes were greater than reported size at maturity (Figure 4). The fact that red hind from the south were significantly smaller than those from Barbuda and the north coast (29.4 cm versus 31.7 cm) was unexpected, particularly since most fishing effort for red hind tended to be concentrated historically on the north coast and Barbuda.

Analysis of catch rate trend was constraint by limited sample sizes ($n < 30$), gaps in the time series and targeting of alternative species (e.g., yellowtail snapper) during a day-trip (Figure 5). However, no significant temporal variability in the catch rate was detected ($p > 0.05$, Games-Howell post hoc test). Low catches of hind were typically associated with high catches of alternative species despite defining a red hind fishing trip to improve data set (i.e., issue of opportunity cost with respect to fishing effort). Further works should focus on fishery independent surveys to properly monitor catch rates trends whereby a more precise measure of the effort (e.g., hours fished for red hind) can be obtained since most commercial fishers can seldom provide this level of detail.

Under the two stochastic model scenarios 1) no closed season (Figure 6) and 2) closed season plus targeting of alternative species (yellowtail snappers) (Figure 7), profits were comparable ranging up to EC$200,000 (US$74,074) and probability of a negative return was 23.5% and 20.3%, respectively. Scenario 2 had a slightly better outcome due to the fact that the higher ex-vessel value for snappers (US$8.17 per kg versus US$7.35 per kg) compensated for the decrease in the catch per trip during the spawning period; catch per trip for red hind was significantly greater during the spawning period than any other period ($p < 0.01$). Hence, under both scenarios investment in the hand-liner was an economically viable undertaking and targeting the yellowtail snapper during the closed season could mitigate the negative impact on revenue stream. The fore mentioned strategy has already been adopted by a number of fishers to maintain their cash inflow during the closed season. Since yellowtail snappers have only been actively targeted in recent years in Antigua and Barbuda and reproductive activity does not appear to coincide with that of red hind (Figuerola et al. 1998 reported peak activity from April through July in Puerto Rico), it may be the ideal alternative species for red hind fishers to target both from a management and economic perspective. While net present values were positive, it should be noted that the models to some extent underestimated the "true" degree of risk associated with the investment since vessel insurance was not included due to unavailable or limited insurance coverage in the fishery sector; Horsford (2007) provided an estimate of 9.6% with respect to the percentage of the fleet having vessel insurance. When one considers economic sustainability and the projections with respect to climate change (e.g., more frequent and stronger storms), the issue of vessel insurance needs to be prioritised.

Based on the fact that:

i) No negative trend was detected for the mean catch per unit effort,
ii) The mean total length landed were relatively stable above reported size at 50% maturity (i.e., no evidence of recruitment overfishing), and
iii) Positive net present value was generated for the typical unit indicating that investment was a worthwhile venture, can only conclude that the red hind fishery is sustainable at current fishing effort.

However, profits tended to attract excessive effort in the long run resulting in the depletion of resource. The newly established closed season was considered an essential tool toward ensuring the sustainability of the fishery along with the future option of a "limited entry" regime. Future studies should focus on validating the current results through fisheries independent studies as well as improving the model given its potential as a decision-guidance tool for fisheries managers, investors, vessel owners, lending institutions, and policy analysts. For example, vessel owners were interested in the most economical mode of operation (fixed salary versus crew share system) whilst fisheries managers were interested in the long term economic benefit of the closed season such as a possible increase in catch.

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