Biology, Status, and Current Management of the Caribbean Spiny Lobster (*Panulirus argus*) in Antigua and Barbuda

Biología, Estado y Actual Administración de la Langosta Espinosa del Caribe (*Panulirus argus*) en Antigua y Barbuda

Biologie, l'état actuel et la Gestion de la Langouste Blanche des Caraïbes (*Panulirus argus*) à Antigua-et-Barbuda

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ABSTRACT

Catch and effort and biological data were collected from commercial fishing trips, at-sea stop and search, and from processing plants in Antigua and Barbuda. The objectives were to:

i) Determine important fishery-related biological parameters for the Caribbean spiny lobster (size of maturity, mating / breeding periods, length-weight relationships, etc.),
ii) Appraise management regimes (minimum size, close season, compliance with regulations, etc.), and
iii) Determine trends and status of the fishery.

In terms of size, sexual dimorphism was detected, with male lobsters being significantly larger than females ($p < 0.01$). The mean size of recruitment into the trap and SCUBA fisheries were significantly larger than for the free dive fishery ($p < 0.01$); however, in all cases mean values were greater than the minimum legal size of 95 mm carapace length. Estimates of the size of female maturity (95.7 and 97.7 mm) were slightly larger than the minimum legal size and defined as the size at which 50% of females have mated (i.e., those bearing spermatophores plus those that were egg-bearing). Despite this it was considered important to maintain the current minimum size since it was already a widely accepted harmonised management measure within the Organization of Eastern Caribbean States. In terms of status and trends, no significant negative trends were detected for mean size of lobster landed or mean catch per unit effort, even when compared with 1970s data. Based on the fore mentioned results, the lobster fishery was considered sustainable at the current level of fishing; however greater measures have to be taken to prevent growth overfishing.

KEY WORDS: Caribbean spiny lobster, Antigua and Barbuda, fisheries management, maturity, spawning, compliance rate

INTRODUCTION

The Caribbean spiny lobster (*Panulirus argus*) fishery of Antigua and Barbuda was valued at US$2.5 million in 2011 and accounted for 16% of the total ex-vessel value of capture production (US$15.6 million); in term of quantity, this was equivalent to 229 metric tons (live weight). Commercially, traps (fish pots) and the use of SCUBA with wire snares are the predominant methods used to target the spiny lobster. Free diving for lobster is still done to a limited extent in Barbuda while bottom gill nets contribute marginally in terms of incidental catch. Traps are typically constructed from hexagonal-mesh chicken wire and braced with "wattle" (stick) or steel. One or two funnel-shaped entrances are usually present, through which spiny lobster and reef fish can enter more easily than exit. Traps set to target solely lobster tend to have a larger funnel entrance than those used to target both lobster and reef fish. This is usually the case in Barbuda, where reef fish is of minor economic importance due to limited cold store and local demand. Traps are typically hauled every seven days and may be unbaited or baited with dried coconut meat (copra) and / or cowhide. The most common type of traps for lobster is the rectangular box; arrowhead and antillean Z traps are mainly used to target the deep-water snappers and groupers. Fishing vessels range from small pirogues to large fibreglass launches, with the latest equipment (global positioning system, depth sounder, hydraulic hauler, etc.). Typical investment (including vessel, gear and equipment) ranges from US$20,000 for a 22-foot fibreglass pirogue to US$78,000 for a 38-foot fibreglass launch. Studies have indicated that the trap fishery for spiny lobster and reef fish was an economically and financially viable undertaking, which generated sufficient revenue to cover the cost of depreciation, as well as the opportunity cost of capital and generated funds for reinvestment in addition to employment, income and foreign exchange earnings (Jeffrey 1990, Horsford 2001a, Tietze *et al.* 2001, Tietze et al. 2005).

In 2011, 180 Antiguan-registered vessels fished for both spiny lobster and reef fish, with much of the landings for lobster being consumed locally by the tourism sector (the key driver of the national economy). With much of the tourism infrastructure based on the island of Antigua and stay-over visitors at about 243,000 (Eastern Caribbean Central Bank 2011), the 480 fishers employed in the spiny lobster fishery in 2011 had a readily available market with competitive prices.

In contrast, the lobster fishery of the island of Barbuda, is export-driven, due to weak local demand (resident population only 1,810 in 2011 (Statistics Division 2012)) as well as strong demand as a "luxury good" for export to neighbouring French overseas territories in the Eastern Caribbean. At its peak, the fishery in Barbuda supported 118 fishers operating from 54 vessels. Approximately 26% of the population of Barbuda was directly dependent on the lobster fishery (Horsford 1999), which also offered the highest per capita earnings (Van der Meerin 1998). In 2011, decline in exports due to decrease demand related to the global economic downturn saw the number of active fishers decline to 55 individuals operating from 34 vessels. Limited data from 2000 indicted that 41.8% of the variation in the monthly lobster exports to Guadeloupe (including St. Barthelemy and St. Martin) can be explained by monthly tourist arrivals at hotels in Guadeloupe, $p < 0.05$ (Fisheries Division 2009).

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, as of February 2013. These pieces of legislation replace the Fisheries Act (1983) and the Fisheries Regulations (1990). The new regulations move the fishery for any species of lobster (including *Panulirus argus*, *Panulirus guttatus, Panulirus laevicauda*, and *Scyllarides* spp.) from an "open access" to a "limited entry" management regime through the requirement for a special permit. The Fisheries Regulations (2013) prohibits the possession or place for sale of:

i. Any lobster carrying eggs,
ii. Any moulting lobster,
iii. Any lobster that has been speared, hooked, or otherwise impaled,
iv. Any lobster carrying an intact tar spot (spermatophore), or
v. Any undersize Caribbean spiny lobster (*Panulirus argus* whose carapace length is less than 95 mm or weigh less than 680 g or having a tail weighing less than 200 g).

The Regulations limits fishing of lobster to only by hand, loop, pot or trap with approved biodegradable panel and minimum wire mesh aperture of 38.1 mm; hookah compressor diving rigs are prohibited. It also requires lobster to be landed whole and prohibits the removal of eggs or spermatophores from lobster. In terms of close season, it extends from 1st May to 30th June of every year until otherwise declared by the Minister in the *Gazette*. The Fisheries Act (2006) 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). The Fisheries Act as well as the Marine Areas (Preservation and Enhancement) Act (1972), both makes provision for the declaration of marine protected areas.

Other important fisheries-related legislation include: the Barbuda Local Government Act (1976), which gives the local governing council of the island of Barbuda, authority over its fisheries including the right to retain taxes on exported seafood such as lobster; and the Barbuda Shooting and Fishing By-Law of 1959, which limits the authority of local council to one maritime league (5.56 km) from the shores of Barbuda. By-laws gazetted by the local council have the full force and effect in Barbuda however they shall only operate in addition to and not in derogation of any other law of Antigua and Barbuda.

The first major assessment of the spiny lobster fishery of Antigua and Barbuda was done by Peacock (1974) under a British Overseas Administration project. The assessment was in response to a decline in lobster landing from 0.68 kg per trap in 1969 to 0.45 kg per trap in 1972 (Peacock 1974). In 1995, a comprehensive data collection (including catch and effort and biological) programme was established under the Canadian-funded Caribbean Community (CARICOM) Fisheries Resources Assessment and Management Programme. In 2001, this programme was completely revised to improve the quality of biological and catch and effort data (e.g., proper accounting for zero-catch trips) as well as monitor the high degree of variability associated with the artisanal nature of the fisheries; the fisheries sector acts as an economic "safety net" for the tourism and construction sectors, hence upturns / downturns or seasonality in these related sectors can impact fishing effort due to the practice of occupational pluralism. To address this a census of active fishing vessels is conducted annually to improve estimates of total fishing effort, employment (number of active fishers by primary fishing method) and compliance rates with respect to licensing of local fishing vessels (Horsford 2001b).

Assessments conducted in the 2000s (Horsford 2004, Horsford and Archibald 2006, Horsford 2008) concluded that spiny lobster stock was sustainable at the current level of fishing based on the fact that current production was in line with the most conservative estimate of the maximum sustainable yield and no negative trends were detected with respect to the mean catch per unit effort or mean carapace length for almost a decade. The report of the Western Central Atlantic Fishery Commission (WECAFC) (Food and Agriculture Organization of the United Nations 2007) listed the stock as fully-exploited or stable based on the results of the 2004 and 2006 studies.

In light of the fore mentioned and the limited studies conducted, the specific objectives of this research was to:

i) Determine important fishery-related biological parameters for the Caribbean spiny lobster (size of maturity, mating / breeding periods, length-weight relationships, etc.),
ii) Appraise previous and current management regimes (minimum size, gear restrictions, close season, compliance with regulations, etc.), and
iii) Determine trends (catch and effort, carapace length, etc.) and status of the fishery.

MATERIALS AND METHODS

Data used in this study came from Antigua and Barbuda's Fisheries Division catch and effort, lobster biological and fisheries compliance programmes (this includes a registry of breaches of fisheries legislation). In certain cases datasets date as far back as 1992. Catch and effort and biological data were collected from commercial fishing trips, at-sea stop and search, and inspection of retail and export facilities. For the biological programme, lobsters were sexed and their development stage coded according to the following criteria:

i) Female with no eggs or tar spot (spermatophore),
ii) Female with tar spot (spermatophore) intact,
iii) Female with tar spot (spermatophore) eroded,
iv) Female with orange eggs,
v) Female with brown eggs
vi) Moulting (soft shell) female
vii) Male; and
viii) Moulting (soft shell) male.

For each sample, the following data were collected (where possible):

i) Carapace length (measured from the front edge of the carapace along the medial dorsal line to the maximum concavity of the rear edge of the carapace),
ii) Carapace width (measured from the lateral edge of the carapace at the point of maximum convexity),
iii) Live weight of intact animal; gear or fishing method used
iv) Depth fished, and
v) Area fished.

The status of biological samples were also recorded (i.e., whether samples were sorted or unsorted). This was done to avoid potential bias in fishery performance indicators (e.g., annual or area mean carapace length). Live weight was to the nearest 1 g, whilst carapace length and width were measured to the nearest 0.1 mm using calipers.

Statistical analyses were conducted using Microsoft Excel 2010 and IBM SPSS Statistics Version 20. Excel Solver and the trend line or regression curve estimation features of the fore mentioned software were used to best estimate the size at maturity and peaks in the breeding periods. Logistic regression using the probit analysis feature in SPSS was used as an alternative method for determining the size at maturity. Midpoints of carapace 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 carapace 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 carapace length midpoints (X), and a linear regression line fitted to the data points. The output of the regression analysis provided an estimate of the carapace 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; substituting this value in the estimated regression line and solving for X = ln (carapace length midpoints) = -a / b (Hubert 1996). The estimated size at maturity is then equivalent to e^{X} or $e^{(-a/b)}$. Note the size at maturity was defined as the size at which 50% of females had evidence of mating and / or breeding (i.e., those bearing intact or eroded spermatophore plus those that were egg-bearing).

Simple linear regression was used to investigate the relationships between carapace dimensions (length and width). To determine the relationships between live weight and carapace dimensions, simple linear regression was used on common log transformed data. Analysis of variance was used to determine if the following conditions existed: sexual dimorphism (i.e., significant difference in size between the sexes); and significant spatial and / or temporal variability in fishery performance indicators (mean catch per unit effort and carapace length). The status of the sex ratio (whether unbiased or biased) was determined by a Chi-square Goodness of Fit Test. Odds Ratio was used to compare management performance with respect to fisheries enforcement during different periods.

RESULTS

Figure 1 summarises the percentage of female spiny lobsters that were mature by size class for 1,374 samples collected from Antigua and Barbuda waters ranging in depth from 3 to 110 m. Evidence of maturity included the presence of intact or eroded spermatophore (tar spot), and / or the presence of eggs. Solving the natural log equation for the best-fit-line in Figure 1, when y = 0.5, provided an estimate of 97.7 mm as the size at 50% maturity for females. In terms of the goodness of logarithmic fit to the

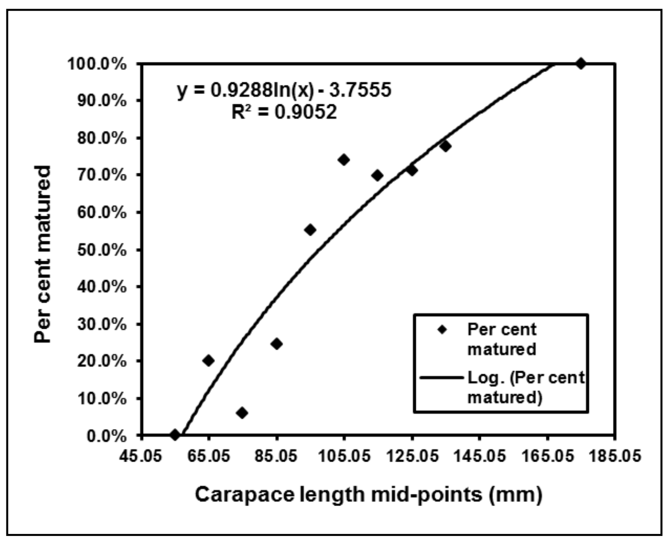

Figure 1. The percentage of female Caribbean spiny lobsters that were mature by size class for samples collected from Antigua and Barbuda waters (sample size n = 1,374; depth range: 3 - 110 m). Evidence of maturity included the presence of intact or eroded spermatophore (tar spot), and / or the presence of eggs.

data, the regression model accounted for 90.5% of the total variation in the percentage of female spiny lobsters that were mature. The estimated regression line obtained from the logistic regression was Y = -25.044 + 5.490X, hence the estimated size at 50% maturity was 95.7 mm. The lower and upper 95% confidence limits for the size at maturity were 83.3 and 103.9 mm, respectively.

In order to determine peak periods in mating and / or breeding, a 4^{th} order polynomial curve was fitted to the percentage of female Caribbean spiny lobsters that had evidence of mating by month (Figure 2). The regression model explained 87.5% of the total variation in the percentage of females that had evidence of mating. Data associated with breeding (i.e., the external presence of eggs) was not disaggregated from mating due to the fact that few samples were berried; of the 1,374 lobsters possessing evidence of mating, only 54 were berried (40 had orange eggs while 14 had brown eggs). For about nine months of the year greater than 50% of females had evidence of mating (Figure 2) and reproductive activity was year-round with possibly a major peak (April to August inclusive) and a minor peak (November to February inclusive). According to the fitted polynomial curve and the regression equation (Figure 2), the major peak occurred in June with 79.0% of females showing signs of mating and the minor peak occurring in January with 56.4% of females showing signs of mating. The lowest observed frequency of mating occurred in October (34.7%), as opposed to November estimated from the fitted polynomial curve and the regression equation using Excel Solver.

Significant sexual dimorphism was detected for carapace length [Welch and Brown-Forsythe *F*-ratios: F (1, 2811.00) = 108.80, $p < 0.001$] and carapace width [Welch and Brown-Forsythe *F*-ratios: F (1, 146.25) = 11.63, $p < 0.01$]. The carapace of male lobsters were 6% longer (Figure 3) and 8% wider than their female counterpart. Despite reaching statistical significance, the actual difference in mean carapace length between sexes was small (108.7 mm versus 102.5 mm); the effect size, calculated using eta squared was 0.04. For mean carapace width, the actual difference between sexes was moderate (86.1 mm versus 79.8 mm); eta squared was 0.07. Chi-square Goodness of Fit Test indicted that the sex ratio was

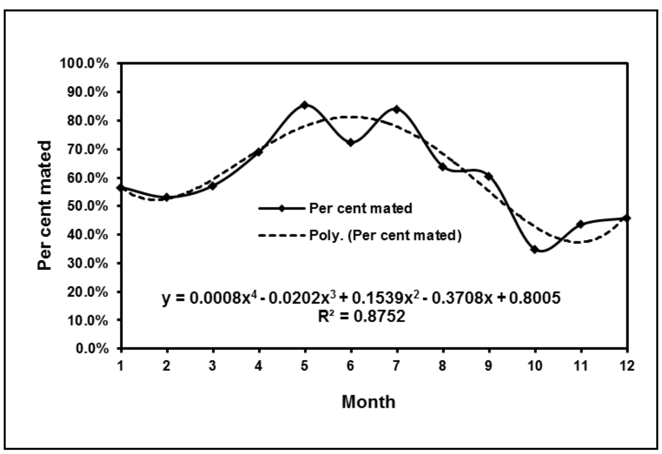

Figure 2. The percentage of female Caribbean spiny lobsters that had evidence of mating by month for samples collected from Antigua and Barbuda waters (sample size n = 1,374; depth range: 3 - 110 m). Evidence of mating included the presence of intact or eroded spermatophore (tar spot), and / or the presence of eggs.

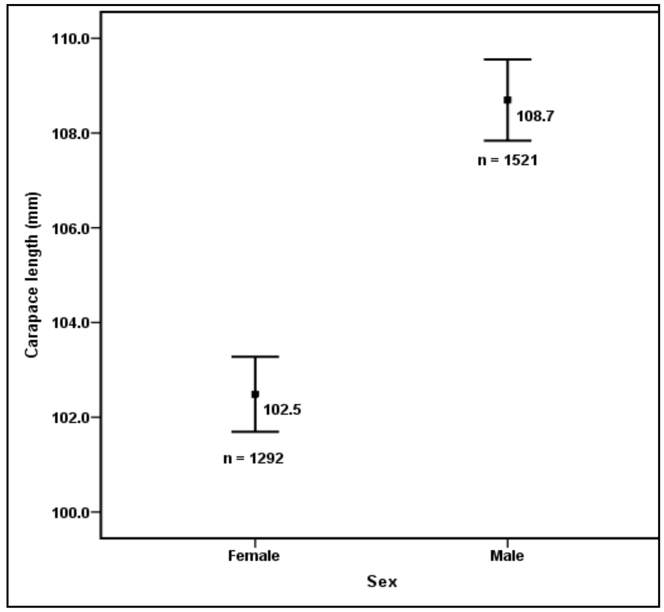

Figure 3. Mean carapace length by sex for Caribbean spiny lobster landed from Antigua and Barbuda waters. Error bar is for the 95% confidence interval and n = sample size.

Table 1 summarises the relationships between live weight and carapace dimensions by sex for Caribbean spiny lobster collected from Antigua and Barbuda waters; in all cases, regressions were significant ($p < 0.001$). For all regressions, 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 89% of the variance at best. The 95% confidence intervals for the slope of the regression line ranged from 2.54 to 2.64 for males and 2.40 to 2.55 for females. The confidence intervals overlapped slightly suggesting that males and females may differ significantly in their live weight-carapace length relationship at this level of significance; *t*-test confirmed slopes were statistically different ($p < 0.05$). For live weight-carapace width relationship, there was a more pronounced overlapping of the 95% confidence intervals for the slope for males and females, suggesting the difference in the relationship was not significant; *t*-test confirmed slopes were not statistically different ($p > 0.05$). Hence the regression equation for the pooled sample (males and females) is also presented in Table 1.

Table 1. Regression equations for live weight (W) as a function of carapace length (CL) and carapace width (CW), by sex for Caribbean spiny lobster collected from Antigua and Barbuda waters. Lengths are in mm; 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) = -2.27 + 2.59Log(CL)	W = 0.00533CL^2.59	0.94	649	2.54	2.64
Female	Log(W) = -2.01 + 2.48Log(CL)	W = 0.00979CL^2.48	0.89	479	2.40	2.55
Pooled	Log(W) = -2.06 + 2.49Log(CL)	W = 0.00869CL^2.49	0.92	1128	2.45	2.54
Male	Log(W) = -2.19 + 2.72Log(CW)	W = 0.00641CW^2.72	0.97	99	2.63	2.82
Female	Log(W) = -1.76 + 2.50Log(CW)	W = 0.01737CW^2.50	0.86	76	2.27	2.73
Pooled	Log(W) = -2.00 + 2.63Log(CW)	W = 0.00998CW^2.63	0.94	175	2.53	2.73

Table 2 summarises the regression parameters for carapace length as a function of carapace width and vice versa for male and female spiny lobsters. In all cases, regressions were significant ($p < 0.001$), with the adjusted coefficient of determination being characteristically higher for males than for females. For males, 97% of the variation in the carapace length can be explained by the carapace width, in contrast, regression model for females accounted for 91% of the variance in the carapace length. According to the regression equation for carapace width as a function of carapace length: for males, every additional 10.0 mm of carapace length was associated with an increase in carapace width of 7.0 mm; and for females, every additional 10.0 mm of carapace length was associated with an increase in carapace width of 7.4 mm. This difference in relationship was not significant (*t*-test, $p > 0.05$); the confidence interval for males ranged from 0.67 to 0.73, while for females it ranged from 0.69 to 0.80.

The mean size of recruitment into the spiny lobster fishery differed significantly among fishing methods [F (2, 2765) = 7.46, $p = 0.001$] (Figure 4). The mean size of recruitment into the trap and SCUBA fisheries were significantly larger than for the free dive fishery ($p < 0.01$, Turkey post hoc test). In all cases, the mean size of recruitment was greater than the minimum legal size of 95 mm carapace length (i.e., the 95% confidence intervals for the mean size of recruitment did not include the minimum legal size). In terms of compliance with minimum size regulations, the trap and SCUBA fisheries had the highest rates of compliance, with 72.9% and 77.1% of the respective samples being equal to or greater than the 95 mm carapace length (Figure 4); the free dive fishery had the lowest compliance rate (63.2%) with the majority of samples being landed in Barbuda.

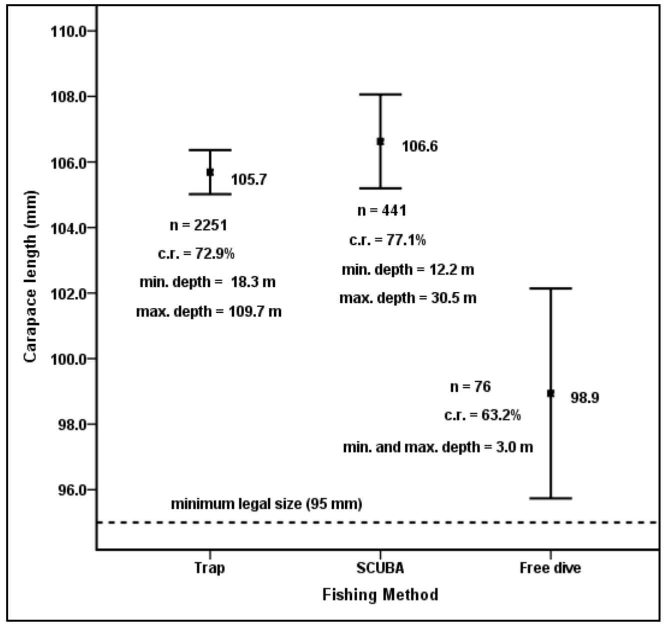

Figure 4. Mean carapace length, compliance rate (c.r.) and depth range by fishing method for Caribbean spiny lobster landed from Antigua and Barbuda waters. Error bar is for the 95% confidence interval and n = sample size.

There was significant temporal variability in the mean size of lobster landed in Antigua and Barbuda (Figure 5); Welch and Brown-Forsythe F-ratios respectively were: F (13, 535.67) = 11.82, $p < 0.001$ and F (13, 1326.44) = 11.61, $p < 0.001$. Games-Howell post hoc test indicted that lobsters landed in 2009 were not significantly different in size from those landed in 2001, 2002, 2003, 2004, 2006, 2008, 2010, 2011 and 2013 ($p > 0.05$), however they were significantly larger than those landed from 1996 to 1999 ($p < 0.05$). From 1996 to 2004 there were significant increas-

Table 2. Regression equations for carapace length (CL) as a function of carapace width (CW) and vice versa, by sex for Caribbean spiny lobster collected from Antigua and Barbuda waters. Lengths are in mm; 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)*	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	CL = -4.36 + 1.38CW	0.97	99	1.33	1.44
Female	CL = 6.74 + 1.22CW	0.91	76	1.13	1.31
Pooled	CL = -3.46 + 1.36CW	0.95	175	1.32	1.41
Male	CW = 6.06 + 0.70CL	0.97	99	0.67	0.73
Female	CW = 2.27 + 0.74CL	0.91	76	0.69	0.80
Pooled	CW = 6.52 + 0.70CL	0.95	175	0.68	0.72

es in the mean size of lobsters landed ($p < 0.05$). In 2004, lobsters landed were significantly larger than any other year ($p < 0.05$) with the exception of 2003 and 2009. In general, lobsters landed during the 1990s (the early stages of fisheries management), were smaller than those from early 2000s to current. Table 3 compares management performance with respect to fisheries enforcement during the fore mentioned periods to ascertain if there was a relationship. The odds of vessel owners / captains being fined, warned, and / or have their catch confiscated for the current management period (2000 - 2011) was 1.7 times that for the period (1992 - 1999). Since the approximate 95% confidence interval for the odds ratio did not include the value 1, then the true odds ratio was significantly different from 1. Therefore the odds of vessel owners / captains being fined, warned, and / or have their catch confiscated during the current management period (2000 - 2011) was significantly greater (1.7 times more likely) than the 1990s. In order to minimise the impact enforcement may have on the mean size landed, analysis of variance was conducted on samples with carapace greater than or equal to 95 mm, to determine if the general increase in mean size landed reflected an actual increase in the mean size (or age) of adult lobster population over time (i.e., using the scenario of 100% compliance rate with respect to minimum size as a substitute for fisheries-independent sampling at sea). Adult lobsters landed in 2004 were significantly larger than those landed from 1996 to 1999 ($p < 0.05$, Games-Howell post hoc test), but not significantly different from any other year with the exception of 2013. Hence there is evidence to support a general increase in the mean size (or age) of adult lobster population in the post-1990s era.

There was significant spatial variability in the mean size of spiny lobster landed (Figure 6); Welch and Brown-Forsythe F-ratios respectively were: F (4, 23.14) = 3.88, $p < 0.05$ and F (4, 227.29) = 6.24, $p < 0.001$. Lobsters from the west coast of Antigua were significantly larger than those from Barbuda or the north coast of Antigua and the central portion of the Antigua and Barbuda Shelf ($p < 0.05$, Games-Howell post hoc test). The mean size landed for the east coast was excluded from the analysis due to limited sample size (n = 4). The 95% confidence intervals for the areas were as follows: Barbuda, 104.4 to 107.3 mm; north coast and centre, 102.1 to 108.4 mm; south coast, 106.9 to 112.9 mm; east coast, 94.7 to 115.6 mm; and west coast, 109.2 to 117.2 mm. The smallest and largest lobsters landed were from Barbuda (71.0 and 178.6 mm carapace length, respectively).

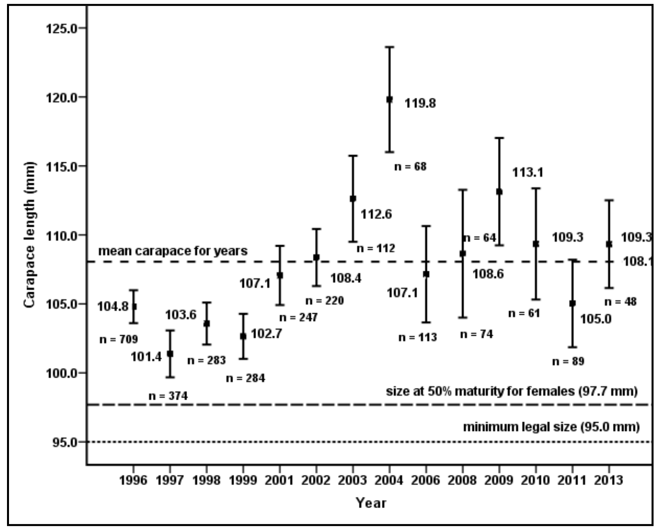

Figure 5. Mean carapace length by year for Caribbean spiny lobster landed from Antigua and Barbuda waters. Error bar is for the 95% confidence interval and n = sample size.

Analysis of variance indicated significant temporal difference amongst the mean catch per unit effort (Figure 7); Welch and Brown-Forsythe F-ratios respectively were: F (10, 211.69) = 3.52, $p < 0.001$ and F (10, 388.10) = 3.89, $p < 0.001$. Only the mean difference between 2001 and 2003 was significantly different ($p < 0.05$, Games-Howell post hoc test); hence the catch per unit effort did not reveal any negative trend. In order to compare recent catch rates with historical data (1969 and 1974), the mean non-zero catch per unit effort by year for Antiguan-registered trap vessels was calculated; proper accounting for zero-catch trips only came into effect in 2001 (data collectors in gen-

Table 3. The odds of local vessel owners / captains being fined, warned, and / or have their catch confiscated for breach of fisheries legislation in Antigua and Barbuda waters for current and previous management period (Fisheries Division and Antigua and Barbuda Defence Force Coast Guard, unpublished data).

	Risk factor for vessel owners / captains: management period		
Condition:	2000-2011	1992-1999	Total
Local vessel owners / captains fined, warned and / or have their catch confiscated	123	44	167
Local vessel owners / captains not fined, warned or have their catch confiscated	3,920	2,382	6,302
Total	4,043	2,426	6,469
	Sample odds ratio (*r o*)		1.699
	Lower 95% confidence limit for the odds ratio parameter *(Ψ)*		1.199
	Upper 95% confidence limit for the odds ratio parameter *(Ψ)*		2.406

eral did not record zero catches dating as far back as the 1960s). There was significant temporal variability in the mean non-zero catch rate (Figure 8); Welch and Brown-Forsythe F-ratios respectively were: F (10, 134.90) = 3.76, $p < 0.001$ and F (10, 226.53) = 3.98, $p < 0.001$. However, only the mean differences between 2009 and 2002, and 2003 and 2006 were significantly different ($p < 0.05$, Games-Howell post hoc test). In general, recent non-zero catch rates were not significantly different ($p > 0.05$) from those reported for 1969 and 1974 (Figure 8). The reported catch rate for 1969 (0.68 kg / trap haul) was comparable to the catch rates for the years 2002, 2003, 2005, 2006 and 2007 whilst the catch rate for 1974 (0.45 kg / trap haul) was comparable to the catch rates for 2001, 2004, 2005, 2007, 2008, 2010, and 2011.

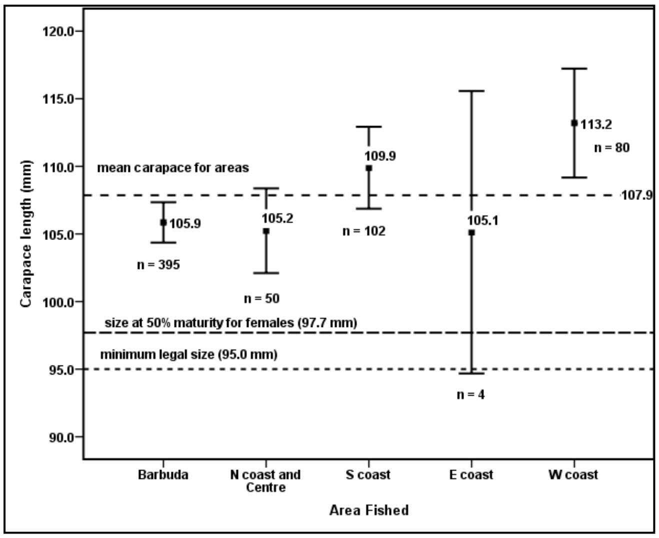

Figure 6. Mean carapace length by area for Caribbean spiny lobster landed from traps hauled from Barbuda and the various coasts of Antigua (depth range: 18-110 m). Error bar is for the 95% confidence interval and n = sample size.

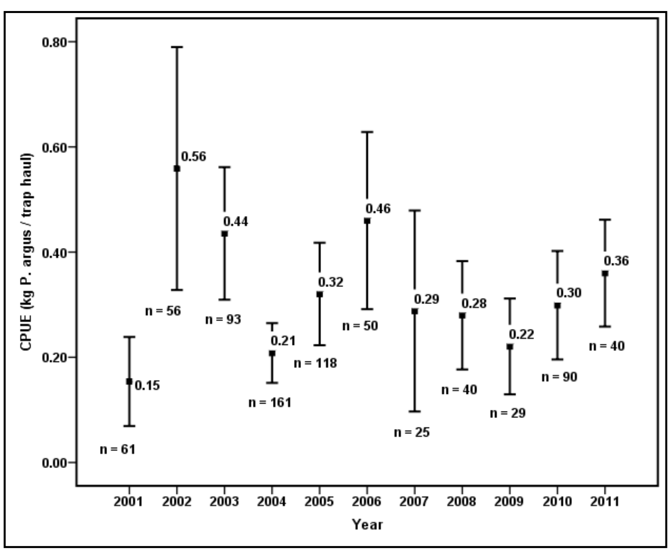

Figure 7. Mean catch per unit effort (CPUE) by year for Caribbean spiny lobster from Antiguan registered trap vessels. Error bar is for the 95% confidence interval and n = sample size.

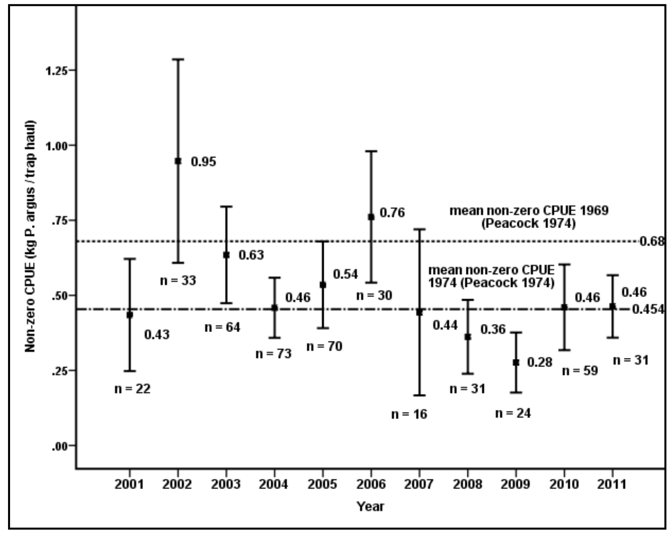

Figure 8. Mean non-zero catch per unit effort (CPUE) by year for Caribbean spiny lobster from Antiguan registered trap vessels compared to historical data (Peacock 1974). Error bar is for the 95% confidence interval and n = sample size.

There was significant spatial variability in the mean catch per unit effort for spiny lobster from the Antigua and Barbuda Shelf (Figure 9); Welch and Brown-Forsythe F-ratios respectively were: F (4, 105.21) = 36.45, $p < 0.001$ and F (4, 112.93) = 31.36, $p < 0.001$. Barbuda, north coast of Antigua and centre, and the east coast of Antigua had similar catch rates with respect to traps ($p > 0.05$, Games-Howell post hoc test). The mean catch rates for the west and south coast of Antigua were significantly less than that for Barbuda or the north coast of Antigua and the central portion of the Antigua and Barbuda Shelf ($p < 0.001$, Games-Howell post hoc test). While catch rates for Barbuda and north coast and centre were statistically equivalent (0.69 and 0.68 kg / trap haul, respectively), they were about five-times that of the south coast of Antigua (0.12 kg / trap haul) and about four-times that of the west coast of Antigua (0.18 kg / trap haul). In order to compare catch rates from the Antigua and Barbuda Shelf to other areas in the Caribbean, the mean non-zero catch rates for the fore mentioned areas were also calculated since data sets from most countries in the sub region typically collect information on species caught as oppose to including unsuccessful trips or zero-catch trips. Analysis of variance yielded similar significant spatial variability with respect to the mean non-zero catch rates; Welch and Brown-Forsythe F-ratios respectively were: F (4, 70.38) = 27.72, $p < 0.001$ and F (4, 73.92) = 20.89, $p < 0.001$. The mean non-zero catch rates for Barbuda, north coast and centre, and the east coast were statistically equivalent (0.85, 0.94 and 0.84 kg / trap haul respectively; $p > 0.05$, Games-Howell post hoc test). However, mean catch rates for the west coast (0.30 kg / trap haul) and south coast (0.33 kg / trap haul) were significantly less than that for Barbuda or the north coast of Antigua and centre ($p < 0.001$, Games-Howell post hoc test). The 95% confidence intervals for the areas were as follows: Barbuda, 0.75 to 0.95 kg / trap; north coast and centre, 0.68 to 1.19 kg / trap; south coast, 0.26 to 0.41 kg / trap; east coast, 0.41 to 1.27 kg / trap; and west coast, 0.25 to 0.35 kg / trap.

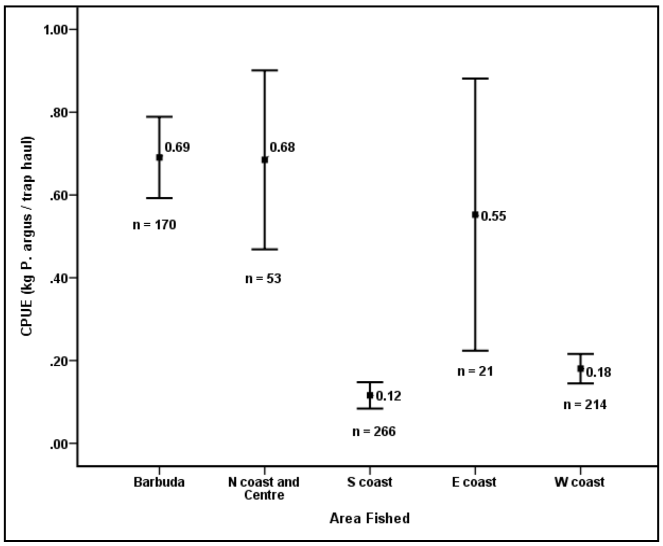

Figure 9. Mean catch per unit effort (kg / trap haul) by area for Caribbean spiny lobster from Barbuda and the various coasts of Antigua. Error bar is for the 95% confidence interval and n = sample size.

DISCUSSION AND CONCLUSION

The current minimum legal size for Caribbean spiny lobster for Antigua and Barbuda and most member states of the Organization of Eastern Caribbean States (Grenada, St. Lucia, St. Vincent and the Grenadines, Anguilla, and St. Christopher and Nevis) as well as Turks and Caicos Islands and the Caribbean Netherlands is 95 mm carapace length. The framework for harmonised fisheries regulations in areas such as minimum size came from three workshops held by the Organization of Eastern Caribbean States (OECS) and the Food and Agriculture Organization of the United Nations (FAO) in 1983 and 1984. This led to the preparation of draft Harmonised OECS Fisheries Act which all member states have enacted with minor changes as well as harmonised regulations (Chakalall 1992); in 1993 the Revised Harmonised OECS Fisheries Laws supplanted earlier draft. At the time, limited lobster maturity studies in the eastern Caribbean resulted in the adoption of 95 mm carapace length as the legal size of maturity based on management recommendations for Jamaica (Munro 1983). Munro (1983) estimated the mean size at maturity for females to be about 95 mm carapace length and recommended that it should be the lowest acceptable limit under any circumstance. This study estimated the size at 50% maturity for females to be 97.7 mm based on logarithmic curve fitting and 95.7 mm based on the logit model. These values were at most 2.7 mm greater than the current legal minimum size (95 mm), thereby validating the extrapolation made for OECS member states. Estimates of size at 50% maturity were consistent with the findings of Peacock (1974), where first sexual activity in terms of external characteristics were observed in lobsters 80 to 90 mm and at its maximum in lobsters 100 to 130 mm. In terms of studies from neighbouring islands, Dilrosun (2002) cited 93 mm carapace length as the size at 50% fecundity and 108 mm at full fecundity for Saba Bank. When one considers the marginal benefit of increasing the minimum size by at most 2.7 mm versus the increase likelihood of illegal intraregional trade in the absence of harmonised regulations, it was considered prudent to maintain the status quo.

The polynomial trend line in Figure 2 estimated two maxima for mating and / or breeding with a major peak occurring in June and a minor peak occurring in January. Aiken (1977) reported an analogous major breeding peak in June and a minor peak in March for lobsters from Jamaican waters. Reproductive activity was year-round, consistent with Peacock's (1974) findings, with greater than 50% of females having evidence of mating for about nine months of the year. The two peaks observed during the major mating period was attributed to annual variation in environmental conditions since samples from different years were pooled; the observed percentage of females with evidence of mating were 85.4% for May and 84.1% for July. In 2014, a closed season will be implemented for the first time in Antigua and Barbuda from 1st May to 30th June of every year according to the newly enacted Fisheries Regulations, No. 2 of 2013. Originally, a four-month closed season was proposed that covered the major breeding period (1st May to 31st August), and in line with the harmonised closed season in the Organization of Eastern Caribbean States, however only two months were agreed to through negotiations with the Barbuda Council, fisherfolks, exporters and other stakeholders. This raises the issue of how best can a "bottom up" approach to local and national governance (e.g., co-management) fit into a regional ecosystem approach to governance which is "top down".

Significant sexual dimorphism was detected for carapace length and width ($p < 0.01$). The carapace of males was 6% longer (Figure 3) and 8% wider than those of females. One possible consequence of sexual dimorphism is differential selection between the sexes. Chi-square test indicated that more males than females were landed ($p < 0.001$), with 54.1% of the sample being male. This was in line with the findings of Munro (1983) and Dilrosun (2002); Aiken (1977) and Peacock (1974) obtained contrasting results with the sex ratio being equivalent. The extent to which the differential selection was due to sexual dimorphism and / or the response by fishers to regulations skewed towards protecting berried (and more recently spermatophore-bearing) females remains to be determined. MacDiarmid and Sainte-Marie (2006) suggested that many fisheries have the potential to alter population sex ratio, where one sex may be more vulnerable to capture due to its greater spatial and / or temporal exposure to fishing gear. In this study samples were collected via a variety of fishing methods (traps, SCUBA, free dive, etc.) in the hopes of avoiding or mitigating potential bias associated with collection method. Regardless of the cause of the skewed sex ratio, the recent enactment of a closed season should mitigate to some extent the distortion in the landings. Recently, Robertson and Butler (2013) observed that females *Panulirus guttatus* nearly always chose males larger than themselves (92% of laboratory trials), and if females mated with smaller males, then fertilization success was reduced. If this scenario holds true for *Panulirus argus* in the wild, then differential landings in favour of males (depending on the extent) may have a long-term impact on fertilization success rates and ultimately recruitment.

Results from *t*-test indicated that the live weight-carapace length relationship for male and female spiny lobsters was significantly different ($p < 0.05$). This is contrary to the findings of Munro (1983) and Haughton and King (1990). The 95% confidence intervals for the slope of the regression line ranged from 2.54 to 2.64 for males and 2.40 to 2.55 for females. The estimates for the slope were 2.738 for both sexes in the case of Munro (1983), whilst Haughton and King (1990) obtained 95% confidence intervals ranging from 2.64 to 2.78 for males and 2.52 to 2.73 for females. In general, these estimates were greater than those obtained in this study, however *t*-tests or analysis of covariance on the datasets would have to be conducted to confirm if the difference between or among the slopes were significant; note for both sexes the confidence intervals overlapped slightly. For live weight (W in g)-carapace width (CW in mm) relationship, the difference between slopes for the sexes was not significant ($p > 0.05$), hence the relationship for all lobsters could be expressed as: $W = 0.00998CW^{2.63}$. For carapace width (CW) as a function of carapace length (CL in mm), the difference in relationship between the sexes was also insignificant ($p > 0.05$). Therefore the relationship for all lobsters can be expressed as: $CW = 6.52 + 0.70CL$. Munro (1983) reported the maximum carapace width is about 0.78CL for males and 0.73CL for females. For all regressions, the adjusted coefficient of determination (goodness of model fit) was characteristically higher for males than for females. In the case of weight-length relationships, this was attributed to the variation in weight associated with the various stages of development for females (spermatophore intact or eroded, eggs absent or present, etc.).

The mean size of recruitment into the trap and SCUBA fisheries (105.7 and 106.6 mm, respectively) were significantly larger than for the free dive fishery (98.9 mm) ($p < 0.01$); however in all cases mean values were greater than the minimum legal size (95 mm) or estimates of size at 50% maturity (95.7 and 97.7 mm). In the early 1970s, Peacock (1974) found that the mean size of recruitment for the free dive fishery in Barbuda was 88.6 mm in the absence of implementing a 229 mm total length minimum size (i.e., regulation was only enforced for exports). The 95% confidence interval for recruitment into the free dive fishery under the current minimum size regime (95 mm carapace length) ranged from 95.7 to 102.1 mm, considerably larger than the 1970s estimate. Data sets were considered comparable since data from commercial fishing trips were complemented by data from enforcement and inspection activities hence bias associated with different management regime was mitigated or eliminated.

The marginal free dive fishery had the lowest compliance rate with minimum size regulation (63.2%) as oppose to 72.9% for traps and 77.1% for SCUBA (Figure 4). Dilrosun (2002) obtained a comparable compliance rate of 72% for traps hauled from Saba Bank for the period April 1999 to May 2000. Results for the free dive fishery validated earlier management decision to divert fishing effort away from shallow, nursery areas typically utilised by free divers. This was done through the establishment of a series of marine protected areas in 1999 and 2005 to complement those established in the 1970s. The relatively high compliance rate of fishers utilising SCUBA supported not implementing a ban on its use. SCUBA was not listed as a prohibited method due to the topography of the Antigua and Barbuda Shelf; the 3,400 km^2 shelf (to the 200 m contour) has a mean depth of about 27 m. From 1996 to 2008, the overall mean compliance rate with respect to minimum size was 73.5% (Horsford 2010), whilst the mean compliance rate from 2009 to 2013 was 83.5%. In 2001, a compliance rate of 85% or greater was set as an informal performance standard or reference point for the fishery (Horsford 2010).

There was significant temporal variability in the mean size of lobster landed ($p < 0.001$). In general, lobsters landed during the early stages of fisheries management (the late 1990s), were significantly smaller ($p < 0.05$) than those from early 2000s to current. Also, most of the mean sizes of lobsters landed from 2000s to current were significantly greater ($p < 0.05$) than the estimate of the size at 50% maturity for females (95.7 mm); 95% confidence intervals for the mean sizes generally did not overlap with the 95% confidence interval for the size at maturity (83.3 to 103.9 mm carapace length) (Figure 5). The increase in the mean size landed was attributed to the enactment and enforcement of Fisheries Regulations No. 10 of 1990. The odds ratio with respect to fisheries enforcement confirmed that the odds of vessel owners / captains being fined, warned, and / or have their catch confiscated during the current management period (2000 - 2011) was significantly greater (1.7 times more likely) than the late 1990s (Table 3). This is a testament to the enhanced capability of the Antigua and Barbuda Defence Force Coast Guard and the Fisheries Division in the area of monitoring, control and surveillance as well as greater support from fishers and other stakeholders. A re-analysis of the data using only samples equal to or larger the minimum size (i.e., the scenario of 100% compliance with respect to minimum size) provided evidence to support a general increase in the mean size (or age) of adult lobster population in the post-1990s era. Adult lobsters landed in 2004 were significantly larger than those landed from 1996 to 1999 ($p < 0.05$), but equivalent to any other year with the exception of 2013.

Lobsters landed via traps from the west coast of Antigua (e.g., Sandy Island) were significantly larger than those from Barbuda or the north coast of Antigua and the central portion of the Antigua and Barbuda Shelf ($p < 0.05$). Neither the minimum legal size (95 mm carapace length) nor estimates of size at 50% maturity for females (95.7 and 97.7 mm) were included in the 95% confidence intervals for the mean size landed for the areas (Figure 6). Further, the 95% confidence intervals for the fore mentioned areas were, in general, significantly greater than the 95% confidence interval for the estimate of the size at 50% maturity for females, which ranged from 83.3 to 103.9 mm carapace length. Peacock (1974) cited 113.6 mm as the mean size for the trap fishery based on offshore banks on the west and in between both islands. This estimate from the 1970s was not significantly different from the estimate obtained for the west coast (113.2 mm) which was predominantly offshore banks; the 95% confidence intervals for the west (109.2 to 117.2 mm) included the 1970s estimate. Munro (1983) found that males from an unexploited part of Pedro Bank in the early 1970s became available to traps with a mesh size of 41.3 mm at a mean size of 106.3 mm carapace length, and females at a mean size of 92.3 mm carapace length. The 95% confidence intervals for both sexes from the fore mentioned areas were at a minimum comparable to males from the unexploited part of Pedro Bank, with lobsters from the west coast being possibly significantly larger than those from Pedro Bank despite using traps with smaller mesh size (38.1 mm). In theory, one would expect that the larger mesh size would yield larger lobsters than the current study if they were present in the unexploited area.

Significant temporal difference exited amongst the mean catch per unit effort ($p < 0.001$); however only the mean difference between 2001 and 2003 was significantly different ($p < 0.05$) (Figure 7). Interestingly, the smallest mean for the catch rates occurred in 2001, and all subsequent means were of a greater value, however not statistically greater with the exception of 2003. These results coincided with the improvement in fisheries enforcement as well as the general increase in the mean size of lobsters landed in the early 2000s (Figure 5). Re-analysis of the data using non-zero catch trips yielded comparable results with most of mean non-zero catch rates after 2001 being marginally (but not statistically) greater (Figure 8); this collaborated the fore mentioned conclusion. In terms of comparison with historical data, recent non-zero catch rates were generally statistically equivalent ($p > 0.05$) to those cited by Peacock (1974) for 1969 (0.68 kg / trap haul) and 1974 (0.45 kg / trap haul); the 95% confidence intervals for the mean non-zero catch rates generally included the 1969 and 1974 estimates (Figure 8). The largest mean non-zero catch rate for spiny lobster occurred in 2002 (0.95 kg / trap haul) and may be statistically greater than the 1974 estimate, although Peacock's 1974 study did not provide sufficient data to confirm this point.

Barbuda, north coast of Antigua and centre, and the east coast of Antigua had similar catch rates with respect to traps ($p > 0.05$). In contrast, mean catch rates for the west and south coast of Antigua were significantly less than that for the fore mentioned areas with the exception of the east coast of Antigua ($p < 0.001$) (Figure 9). One might expect that the area with the largest (oldest) lobsters (i.e., the west coast) would coincide with the area with the highest abundance, however Peacock (1974) found that catch rates associated with traps from a lagoon in Barbuda were 2.5 times greater (in terms of weight) than offshore banks due to the fact that it functioned as an important nursery area for juvenile lobster recruitment to offshore areas. This was one of the main reasons for the establishment of the Codrington Lagoon National Park in Barbuda in March 2005. The mean non-zero catch rates calculated for the same areas had similar significant spatial variability, with rates for Barbuda, north coast and centre, and the east coast being statistically equivalent (0.85, 0.94 and 0.84 kg / trap haul respectively; $p > 0.05$), whilst rates for the west coast (0.30 kg / trap haul) and south coast (0.33 kg / trap haul) were significantly less than that for Barbuda or the north coast of Antigua and centre ($p < 0.001$). Toller and Lundvall's (2008) study of Saba Bank found that the mean non-zero catch rate for lobster traps using similar mesh size as Antigua and Barbuda (38.1 mm) was 1.09 kg per haul. Values for the north coast and centre and the east coast were comparable to Saba Bank (i.e., 95% confidence intervals for the areas included the Saba Bank estimate), despite traps were mainly set for both lobster and reef fish.

Based on the fact that:

i) No negative trends were detected for the mean catch per unit effort for both non-zero and zero inclusive estimates,
ii) The mean carapace lengths have increased since the post-1990s era, and
iii) All of the fore mentioned indicators were at a minimum not significantly different from 1970s estimates, one can only conclude that the spiny lobster fishery is sustainable at the current level of fishing.

Nevertheless, greater measures have to be taken to prevent growth overfishing. The setting of a compliance rate of 85% or greater (with respect to minimum size) as an informal performance target for the fishery, as well as other measures (such as increased fines) outlined in the *Antigua and Barbuda Plan of Action to prevent, deter & eliminate IUU Fishing* are steps in the right direction. In terms of restricting fishing effort in the lobster fishery, Antigua and Barbuda has moved from an open access to a limited-entry management regime in 2013 through the need for a "special permit". Future works should focus on validating the current results through fisheries independent studies as well as the application of more formal stock assessment methods. Due to the limited time frame of the data set, current maximum sustainable yield estimates and their confidence intervals vary too widely to be of practical use.

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