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ASSESSMENT OF THE SPINY LOBSTER (*PANULIRUS ARGUS*) OF BELIZE BASED ON FISHERY-DEPENDENT DATA

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ABSTRACT

The Spiny lobster (*Panulirus argus*) is the most valuable fishery resource of Belize. The lobster fishery is artisanal and uses low technology. Fishing has been done for the past 60 years as an "open access" system. Lobster tails are mostly destined for foreign markets and fishing cooperatives only has done exports. An attempt was made to assess the Spiny lobster of Belize based on fishery-dependent lobster tails export data collected from two fishing cooperatives. The results showed that lobster catches consist of two age groups (ages 2 and 3), which represent about 98% of catches. The few age groups identified did not allow for an adequate age-based cohort analysis and therefore caution should be observed in the interpretation of results. Catch per unit effort, stock size and recruitment levels appear to have declined during the period 1999 to 2009. Also, fishing mortality appears to be high and the fishery could be experiencing some over-fishing. Management intervention to reduce fishing effort could benefit the fishery. An increase in the minimum size limit is recommended.

Keywords: Belize, spiny lobster, age-based cohort analysis, CPUE, stock size, recruitment, fishing mortality.

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1 INTRODUCTION

The spiny lobster (*Panulirus argus*) is the most important lobster species in the Caribbean and Central American regions in terms of abundance and value. Lobster fisheries generate considerable foreign exchange, contribute to the Gross Domestic Product and provide jobs and income for fishermen and their families in many countries in these regions.

The average annual lobster landings in the Caribbean during 1992-2001 were estimated at around 37,000 tons (live weight) with an estimated value of US$500 millions. Some 50,000 fishermen carry out lobster fishing in the region and an additional 200,000 people are employed in positions related to the lobster fishery (FAO 2003).

In recent years countries in the region have reported declines in lobster catches and there is a general concern that lobster stocks may be overfished in some areas and there is the possibility that many livelihoods could be affected (FAO 2007). In consideration of these concerns the Food and Agriculture Organization of the United Nations (FAO) through the Western Central Atlantic Fisheries Commission (WECAFC) has organized five workshops since 1997 to discuss the assessment and management of the spiny lobster in the Caribbean region.

In 2006, FAO/WECAF organized a lobster workshop in Merida, Mexico to review and update the assessments of the status of Caribbean spiny lobster at national and regional levels and to consider the current levels of exploitation and recent trends in the fishery and to evaluate the nature and current problems in the fishery. The recommendations of the workshop were to allow about 50% of the stock to reach maturity and a minimum harvest size of 74 mm (2.91 inches) in carapace length. It was recommended that countries with minimum size limits greater than 76 mm should retain the larger minimum size limits because of the additional conservation and economic benefits they provide. It was agreed that managing fishing mortality also is necessary to achieve sustainable use of the resource. It was further agreed that countries that already have minimum size limits in place should take action to implement and enforce them effectively to reduce the currently high catches of juveniles in order to protect and allow the species to rebuild throughout its distribution area.

The conclusions of the workshop was that the spiny lobster are fully utilized or overexploited throughout much of its distribution area, although there were insufficient data from some areas to estimate the status reliably. It was also concluded that in most countries there was an urgent need to control, and in many cases, to reduce the fishing effort in the lobster fisheries. In some areas, the sizes of the lobsters being caught were smaller than desirable and in these cases, it was recommended that suitable minimum size restrictions should be implemented and enforced. It was also concluded that the clear interactions between the shared lobster resources of the different countries meant that collaboration in management and scientific exchange between these countries was essential.

The workshop identified several issues that were affecting lobster fisheries. One of them is open access, at least in the artisanal sector, which continues to be a problem in the region as a whole and has resulted in continued growth in fishing effort in an uncontrolled and unsustainable manner in a number of countries. Another problem identified was the unacceptably high levels of catches of under-sized and juvenile lobsters.

In February 2005 Honduras and Nicaragua, under the auspices of Central American Fisheries and Aquaculture Organization (OSPESCA), signed a lobster agreement that established new lobster management regulations for these countries. The most important aspects of the memorandum included a minimum lobster tail weight of 142 g (range of 128g to 156g), an escape gap of 5.4 cm between the first side strip and the bottom of the lobster trap, a maximum of 2500 traps per industrial fishing vessel, and prohibition of sale of lobster tail meat without the shell (OSPESCA 2005). The memorandum also encouraged other OSPESCA countries to sign similar agreements. Nicaragua and Honduras are the largest lobster producers in Central America and both countries have artisanal and industrial lobster fishing. In recent years however, lobster production in these two countries has declined due to overfishing and the problem is compounded by continued industry difficulties associated to the many diving accidents and even deaths of mostly poor indigenous fishermen as a result of diving accidents.

The fishing industry of Belize is characterized as small scale and artisanal in nature and is divided into two components; capture fisheries and aquaculture sectors. In the capture fisheries sector, commercial fishing started in the mid to late 1950s with lobster and conch as the principal target species harvested mainly for export to the USA. At present, the capture fisheries sector remains as an important economic activity and fishermen are organized in fishing cooperatives. Traditionally, the fishing cooperatives have been the only organizations licensed to export lobster, conch and other fishery products. Currently, there is no deep-water fishing done in Belize but is considered an area that is ready for development as some local and foreign nationals have expressed high interest in developing this sector.

The capture fisheries sector has low fishing technology. In 2008, the capture fisheries sector contributed US$10.25 million to the national economy. The sector is socially and economically important to Belize. Capture fisheries landings increased by 2.2% from 535 tons in 2007 to 544 tons in 2008 (including lobster tails) but export earnings decreased by 9.6% from US$11.35 million in 2007 to US$10.25 million in 2008 (Belize Fisheries Department 2008b).

Declining lobster catches is a major problem identified in the lobster fishery but there are others such issues of importance such as the “open access” nature of the capture fisheries sector, inadequate lobster fisheries research, insufficient data collection and monitoring programs and unavailability of reliable scientific data. The sector is also affected by illegal fishing of undersized lobsters during open and closed fishing seasons and more recently low market prices for lobster tails.

Thus, there is a need to carry out of a comprehensive lobster assessment. The goal of this project is to improve the management of Belize’s spiny lobster fishery through the achievement of the following objectives:

a) Carry out a spiny lobster stock assessment based on fishery-dependent data collected for the period 1999 – 2009 using age-based cohort analysis.
b) Provide management recommendations for conservation and sustainable use of the spiny lobster.

2 BACKGROUND

2.1 Biology of the lobster

The Spiny lobster (Figure 1) occurs from North Carolina south to Brazil including Bermuda, the Gulf of Mexico, West Indies and Caribbean. The northernmost extent of the range is North Carolina (Williams 1984).

The spiny lobster exhibits dimorphism with clear differences between the male and female individuals. After mating the female lobster releases eggs that are fertilized externally by the male sperm. The fertilized eggs develop while attached for up to four few weeks (Simmons 1980) to the pleopods on the underside of the female lobster until they hatch into larvae, which remain floating for 6-10 months in oceanic waters (Silberman and Walsh 1994, Arce and Leon 2001) before settling to the seafloor as puerulus, which eventually transform to juvenile lobster and finally grow up to become adult lobsters.

During the planktonic phase stage, the larvae can become widely distributed in the western central Atlantic region and wider Caribbean (Chakalall and Cochrane 2007). Some genetic studies of the spiny lobster indicate a single stock structure (Lipcius and Cobb 1994; Silberman and Walsh 1994) throughout its range and thus the management of this resource from a regional perspective is important.

Mature and old lobsters are usually found in deep waters while juveniles are found near mangrove areas and shallow sea grass beds and coral reefs. Juvenile and young lobster are mostly found in shallow marine habitats and because of this reason, overfishing of local populations has occurred in some countries, especially where there is little or no control of fishing effort and mortality of young recruits is high.

Wild lobsters had an estimated average growth rate of 5 mm (0.2 inches) per month for the first 9 -10 months post-settlement in Florida (Eldred *et al*. 1972). If we assume a post-settlement growth rate of 4.0 mm (0.16 inches) per month, the spiny lobster likely reaches legal harvest size in 20 – 40 months, depending on location and degree of injury (Little 1972, Davis and Dodrill 1989). The spiny lobster reaches sexual maturity at carapace lengths of approximately 70 – 80 mm (2.8 – 3.2 inches) (Witham *et al.* 1968, Olsen *et al*. 1975, Davis 1979).

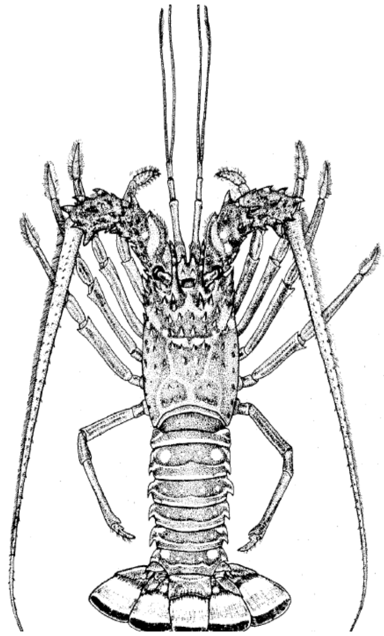

Figure 1. Diagram of a Spiny lobster (FAO 2001).

2.2 Lobster fishery of Belize

2.2.1 Lobster Catches

Lobster fishing as an economic activity started in Belize in the mid to late 1950s and landings were initially low but the fishery developed and catches increased rapidly until it reached the highest recorded level of 1021 tons (live weight) in 1981 and has decline since then. A declining trend in lobster catches were observed during the study while fishing effort gradually increased (Figure 2). [1]

While there have been some highs and lows, in the last two decades lobster production has remained fairly stable averaging around 700 tons per year (live weight). In August 2007, Hurricane Dean hit the coast of Belize and lobster catches for 2008 was expected to decline due to poor recruitment as result of habitat destruction. Lobster tail production increased by 1.4% from 630 tons (210 tons lobster tails) in 2007 to 642 tons (214 tons lobster tails) in 2008. The increase in lobster catches was associated to an increase of 7 % in the number of licensed fishermen compared to 2007 (Belize Fisheries Department 2008a).

Lobster accounted for 67% in export earnings for the capture fisheries sector in 2008. It is noted that lobster prices in the US market fell sharply in the latter half of 2008 and caused a decline of almost 19% in lobster export earnings from US$8.5 millions in 2007 to US$6.9 millions in 2008 (Belize Fisheries Department 2008a).

[1] Fishermen deliver only lobster tails to the fishing cooperatives. Therefore, lobster live weight (whole weight) was estimated by multiplying the lobster tail weight by three.

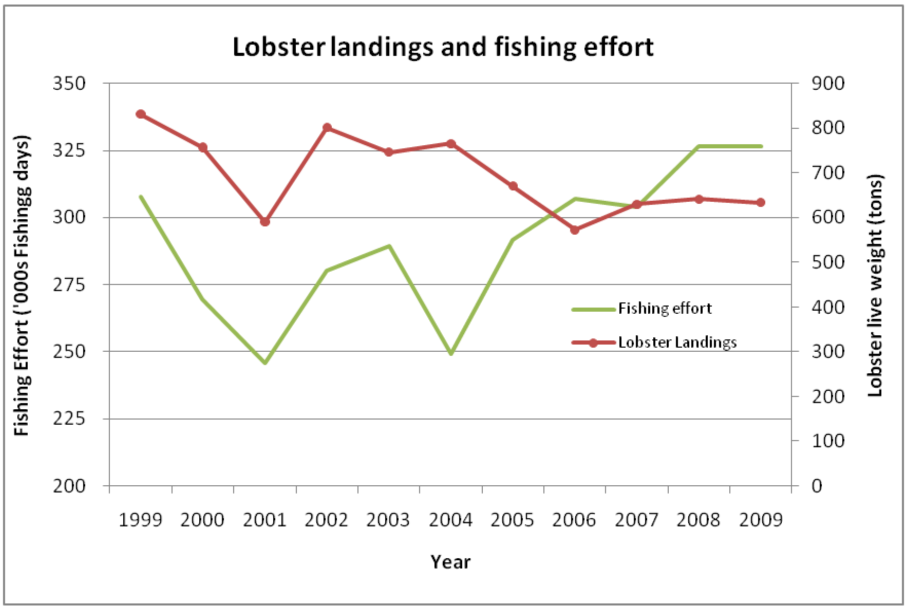

Figure 2. Lobster landings (live weight) and fishing effort during the period 1999 to 2008.

2.2.2 Fishing cooperatives

Fishermen are organized into five fishing cooperatives in Belize. The fishing cooperatives have played a vital role in the development of the fishing industry (are owned and operated by the fishermen members). The cooperatives are managed by qualified administrative, technical, secretarial and support staff. The operations of the cooperatives are led by a manager who is guided by decisions of a managing committee, which is elected by majority voting of the general membership at the annual general meeting of the cooperative. Each member of the committee serves for a term of two years and is eligible for re-election.

Northern Fishermen Cooperative Soc. Ltd. is Belize's first fishing cooperative and was established in Caye Caulker Village in 1961. The formation of the cooperative, enabled fishermen to obtain fair market prices for their lobster tails. The first lobster buying companies that operated in Belize during the early development of the lobster fishery in the late 1950s paid as little as US$0.05 per pound of lobster tails to fishermen from Caye Caulker and in turn sold it for much higher prices in the United States of America.

In the years following the establishment of Northern Fishermen Cooperative Soc. Ltd., other fishing cooperatives were registered in San Pedro (Ambergris Caye), Sarteneja Village, Belize City, Placencia Village and Punta Gorda Town. Presently, only five fishing cooperatives are in operation but only two (Northern Fishermen Cooperative Soc. Ltd. and National Fishermen Producers Cooperative Soc. Ltd.) export fishery products. The other cooperatives sell fishery products locally or export through one of the export fishing cooperatives. Many members of the non-exporting fishing cooperative are not full-time fishermen as they also work as tour guides and provide services to the tourism industry.

Spiny lobster (*Panulirus argus*) and Queen conch (*Strombus gigas*) have been since the start of the fishing industry to present day the main fishery products exported by the fishing cooperatives. Currently, there are some 2200 fishermen and it is estimated that 85-95% are members of the fishing cooperatives. The cooperatives purchase the catches from fishermen, process and package and finally export the products.

The fishing cooperatives play a key role in providing catch and effort data to the Belize Fisheries Department. Meetings and workshops are held regularly with fishing cooperatives to keep them informed about fisheries issues and to foster good communication, for training and education and general interaction with the fishermen. These activities contribute to improve fisheries management in Belize.

2.2.3 Fishing areas and fishing effort

Commercial fishing for lobster is carried out primarily in the shallow waters (5-15 m) within the reef lagoon, an area between the barrier reef and the mainland (Figure 6) and along the entire length of the barrier reef, which extends for about 300 km from north to south along the coast. The coral reef complex covers 22,800 km^2, as a unique assemblage of lagoon patch reefs, fringing reefs and offshore atolls (Kramer *et al*. 2000). The barrier reef actually joins the landmass at Rocky Point (Ambergris Caye) in northern Belize but gradually separates from the mainland to a distance of approximately 50 km in the south. Lobster fishing is done exclusively by free (skin) diving. Use of SCUBA gear is strictly prohibited by the fisheries regulations.

Young and strong fishermen usually venture to the fore reef (seawards of the main barrier reef) to catch lobsters hiding in the corals, ledges and crevices in this portion of the continental shelf. The strongest and best fishermen also fish in even deeper areas (approx. 15 -20 m) at the edge of the continental shelf to catch lobsters.

In 2008, the Capture Fisheries sector provided employment for 2267 fishermen and 643 fishing vessels were used. In addition to these direct jobs it is estimated that some 15,000 Belizeans also benefited indirectly from fishing activities. The number of licensed fishermen increased from 1,731 in 2004 to 2,267 in 2008, representing a cumulative increase of 30% and an increase of more than 7% in comparison to 2007 when 2,110 fishermen were licensed to fish. The number of boats also increased from 621 to 643 during the same period showing an overall increase of over 8%. Despite the increase in fishing effort however, catches increased by only 2.42% when compared to 2007 (Belize Fisheries Department 2008b).

The fishing effort resulting from lobster traps and shades is unknown as these fishing gears do not require a special license. Lobster traps and shades have high gathering capacity and therefore the resulting fishing mortality is increased with the use of these gears.

2.2.4 Fishing gears and equipment

Lobsters are caught throughout the inner reef system of the Barrier Reef using lobster traps or pots (Figure 3), shades or “casitas” (Figure 4) and hook sticks (Figure 5). The fishing vessels used in lobster fishing are constructed of fiberglass or wood and are powered by outboard engines (25-75HP). Wooden boats equipped with cloth sails and outboard engines are also used. These wooden boats carry up to 8 small canoes and 8 divers per fishing trip that can last up to 8-10 days.

Figure 3. Traditional lobster trap (hard wood frame (with side strips of "pimenta" wood sticks")

Figure 4. Lobster shade (saltwater palmetto tree trunks, zinc sheets are also used).

Figure 5. Free diving fisherman harvesting lobster using a "hook stick" (made of wooden or fiberglass rod with a 6-inch J-shaped fishing hook fastened to one end).

2.3 Management system

2.3.1 Fishing regulations

The Fisheries Act and Regulations were enacted in 1977 with amendments and additions in the following years. These laws establish the legal framework for fisheries management and law enforcement functions of the Belize Fisheries Department (BFD).

The BFD is responsible for overall fisheries management in the country. The BFD is led by the Fisheries Administrator who is assisted by a staff of about 45 officers that are distributed among the main office in Belize City, sub-office in Punta Gorda Town and at the headquarters of eight marine reserves located on the offshore islands.

The fisheries regulations are applicable to marine and inland waters. They include regulations on minimum size limits, closed fishing seasons, marine reserves, and regulations for spiny lobster, queen conch (*Strombus gigas*), marine shrimp (all marine species), Nassau grouper (*Epinephelus striatus*) and a freshwater turtle locally known as Hicatee (*Dermatemys mawii*). The fisheries regulations prohibit commercial fishing using SCUBA gear. The regulations also prohibit the capture and possession of marine turtles, whale shark, bonefish and corals.

2.3.2 Marine reserves

The marine protected areas (MPAs) of Belize play an important role in the conservation and management of the fisheries resources, at the species and ecosystems level. Presently, there are 13 marine reserves located along the coast of Belize with an estimated total marine area of 237,899 ha (Coastal Zone Management Authority and Institute 2001). In addition to the aforementioned marine reserves there are also 12 fish spawning aggregation sites are located on various points along the barrier reef and on the 3 offshore atolls. These sites are generally small areas and were specifically designated for protection of spawning stocks of groupers, snappers and other reef fish species. Three marine reserves have been successfully managed under co-management agreements with local non-governmental organizations. The Fisheries Department however, maintains oversight and law enforcement responsibilities in these reserves.

The MPAs help to maintain fish stocks and the marine ecosystem in healthy conditions and provide opportunities for visitors to appreciate the diverse marine life in these areas. By virtue of the presence of no-take zones as part of the zoning schemes employed in the management of MPAs, species of commercial importance such as the spiny lobster and queen conch have been observed at much higher densities than in open fishing areas (Fisheries Department 2007, unpublished data).

2.4 Lobster stock assessments

The assessment of the lobster stock is a priority of the BFD but due its limited technical expertise, studies have always been carried out in joint collaboration with expert assistance from organizations such as Caribbean Regional Fisheries Mechanism (CRFM) and OSPESCA. The BFD has in the past hired independent experts to conduct lobster assessments.

One of the first assessments of the lobster stock was carried in 2005. The results of the study indicated that the spiny lobster population in Belize appeared to be heavily exploited. A relatively high fishing mortality was estimated for the fishery. However, it was suspected that this observed fishing mortality only applies to a proportion of the stock and therefore the overall state of the stock remained uncertain at the time (Belize Fisheries Department 2005).

The second assessment was done in 2007. This study was based on cohort analysis using seven years of tail weight data (1999 to 2006) collected from the two main fishing cooperatives in Belize. The tail weight data was transformed to carapace lengths using the Cuban tail weight-carapace length relationship. The results of the study showed that fishing mortality (F) was as high as 0.7 per year and that annually 40% - 60% of the stock was harvested (Belize Fisheries Department 2007).

The most recent study of the lobster stock was carried out in 2008. The results of the study showed that lobster catches stabilized during the period 1985 to 1995 and since then catches have decreased. This study also showed that the average size of harvested lobster increased over time and particularly during the last 5 years (Belize Fisheries Department 2008b).

The result of 2008 lobster stock assessment in relation to an increase in the average size of harvested lobster may mean that fishermen are diving in deeper areas and harvesting more of the adult spawning stock. It could also be interpreted as fishermen venturing in much deeper waters due to scarcity of lobsters in shallower areas such as the barrier reef. The analysis of age structure of lobsters shows a significant decrease in the abundance of 2nd and 3rd year old lobsters in the last 6 years. The results also show steady recruitment, though small, of 4-year-old lobsters.

3 MATERIALS AND METHOD

3.1 Study area

Figure 6 shows a map of Belize, which is geographically located in the Central American mainland at 17°15′N and 88°45′W and has a land area of 22,966 km^2 (8,867 sq mi). The lobster tails data used in this study were harvested in the six fishing areas as shown on the map.

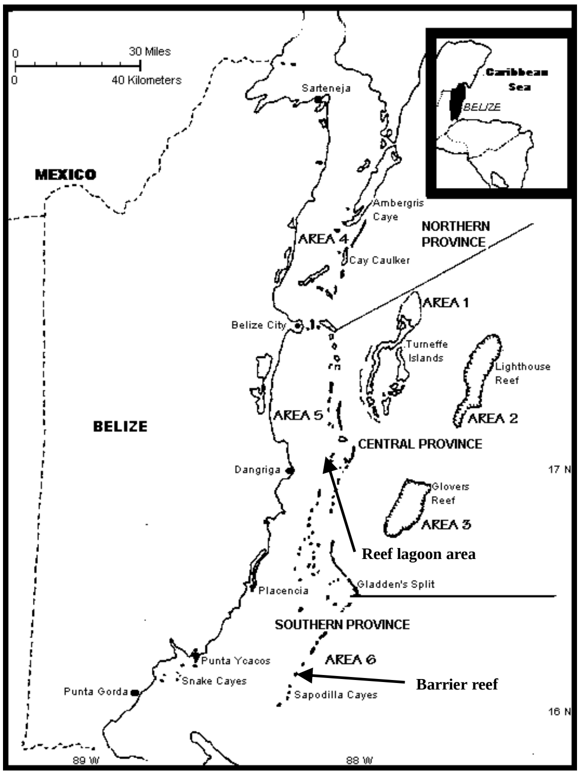

Figure 6. Map of Belize showing main lobster fishing areas.

3.2 Data collection and processing

Two sets of fishery-dependent lobster data were used in this study.

The first lobster data set was lobster carapace lengths collected from fishermen working at sea during the period June to December of 2009. Data collection was done during the first 15 days of each month to maintain consistency. No distinction on the type of fishing method was made and therefore lobster tails captured by hand using “hook stick”, traps or shades were treated as one data set. A total of 1528 carapace lengths were collected and analyzed using a Microsoft Excel spreadsheet. The lobster carapace length (CL) data was used to prepare the length frequency distribution graphs. The same CL data was also imported as a text file to R statistical package for analysis. The outputs of the R analysis were: growth parameters, length frequency distribution and estimates of mean length, standard deviation and proportions at age.

The second data set was collected from historical records of lobster tail exports by weight classes (ounces) for the period 1999-2009 from the two lobster exporting fishing cooperatives in Belize (Table 1 in Appendix). The data set was analyzed using a Microsoft Excel spreadsheet. From the export data the number of lobsters per weight class per year were estimated by dividing the export volume by the corresponding weight in ounces (Table 2 in Appendix). Lobster tails are exported in 11 commercial weight classes: 4 oz, 5 oz, 6 oz, 7 oz, 8 oz, 9 oz, 10-11 oz, 12-13 oz, 14-15 oz, 16-19 oz and 20-24 oz. The tail weights (TW) were converted to grams and then the corresponding carapace lengths (CL in mm) were calculated using the relationship:

$$CL = 16.31*TW^{0.311} \text{ (Wade et al. 1992)}$$

The number of lobsters estimated for each CL size class was used in the slicing of the age classes estimated using von Bertalanffy growth model:

$$L(t)=L\infty*[1-\exp(-k\hat{}(t-t_0))]$$

The growth parameters used were: $L\infty = 183$mm, $k = 0.24$ and $t_0 = 0.44$.

These same values have been used previously to analyze Belize’s lobster stock in 2006 and were similar to those reported for Southwestern Cuba (Leon *et al.* 1995). A natural mortality (M) value of 0.34 was used and this was value was adopted from Cruz *et al.* (1981).

A matrix of catch at age in numbers per year was prepared from the results of the Slicing method (Sparre and Venema 1998). This method treats the length frequency data sampled each year separately, identifying recruitment variation and changes in fishing mortality. To achieve this, lobster must be referred to age groups of the same time span, usually one year, when there is annual spawning. When annual samples over a series of years are being sliced, it is important that all individuals of one cohort (year class) go into the same age group. The cohorts are not distributed over two age groups by the slicing. First for each age group assigned, the mean length is calculated. The corresponding length class for each age group is also determined. Then the fraction in lower groups is calculated. This fraction is the difference between the mean length at age and the minimum length of the length class divided by the length class interval. The total catch by length class is known. The catch at age group is obtained by multiplying the fraction of length classes by the catch.

The resulting catch-at-age values were used as the initial data for the cohort analysis (Table 3 in Appendix).

3.2.1 Age-based Cohort Analysis

The Virtual Population Analysis (VPA) or cohort analysis method was used to do the lobster stock assessment. The calculations were done using Microsoft Excel. The catches at age (1999 to 2009) values, obtained from the Slicing method were used as the primary data set in the VPA. The two basic equations in the VPA are the stock (1) and the catch (2) equations:

Stock equation $$N_{a+1,y+1} = e^{-Z_{ay}} * N_{ay} \tag{1}$$

Catch equation $$C_{ay} = \frac{F_{ay}}{Z_{ay}} * (1-e^{-Z_{ay}}) * N_{ay} \tag{2}$$

By combining these two equations one can calculate the stock size in the last year

$$N_{ay} = \frac{C_{ay}}{F_{ay}/Z_{ay}\,(1-e^{-Z_{ay}})} \tag{3}$$

So if F is known then the stock size in the last year can be calculated. MacCall (1986) provided an approximate solution where the knowledge of F is not needed:

$$N_{ay} = N_{a+1,\,y+1} e^{M} + C_y\,[M/(1-e^{-M})] \tag{4}$$

where:
N_{ay} = population size at age *a* in year *y*
$N_{a+1,\,y+1}$ = population size at age *a*+1 in year *y* + 1
C_{ay} = catch size at age *a* in year *y*
M = natural mortality

If a value of F*y* and the catch-at-age in the final year are available, the numbers-at-age for the incomplete cohorts may be estimated using:

$$N_y = \frac{C_y}{1-e^{-Z_y}} \; \frac{F_y + M}{F_y} \tag{5}$$

In this study the natural mortality used was 0.34 and according to Haddon (2001) this equation (4) gives better results than Pope's approximate solution when values of natural mortality (M) are higher than 0.3 and are also less sensitive under the assumption that the catch was harvested in the middle of the year and natural mortality will only affect the stock before and after the fishing season. Natural mortality was assumed to be constant in all age groups in each year. Using this equation we can calculate stock size back in time for the compete cohorts

The fishing mortality of the incomplete cohorts, except for the oldest age, was derived by:

$$F_{ay} = \ln(N_{ay}/N_{a+1,\,y+1}) - M \tag{6}$$

The fishing mortality of the oldest age group was set as the average of the two preceding ages, in this case age groups four and five.

If we have auxiliary information such as CPUE series, we can estimate F in the last year and derive from there the stock size in the last year. We need a selection pattern for the last year.

A selection pattern is estimated as:

$$S_{ay} = F_{ay} / F_{bar,y} \tag{7}$$

where:
S_{ay} = Selection pattern (selectivity) for the age *a* in the year *y*
F_{ay} = Fishing mortality rate of selected age *a* group in year *y*
$F_{bar,\,y}$ = The average fishing mortality rates for some age groups (here age groups four and five in year *y* were used)

The selection pattern in the last year (2009) was taken as the average of the selection patterns for the last three years (2006, 2007 and 2008).

The fishing mortality rate for the last year (2009) was estimated by multiplying the selection pattern (S_{term}) of each age group in the last year by F terminal, Fterm:

$$F_y = S_{term} * F_{term} \tag{8}$$

F terminal was estimated by optimizing the SSR value using the Solver function of Microsoft Excel, where.

$$SSR = \sum (\text{Observed CPUE} - \text{Predicted CPUE})^2 \tag{9}$$

The index of abundance in this study was the Catch Per Unit of Effort (CPUE) and this was estimated using the following equation:

$$CPUE_{ay} = C_{ay}/E_y \tag{10}$$

where:
$CPUE_{ay}$ = catch per unit of effort for age *a* in the year *y*
C_{ay} = Catch (kg) in year *y*
E_y = Effort (days) in year *y*

The predicted CPUE (CPUEhat) was calculated using the following equation:

$$CPUEhat = a * biomass_y + b \tag{11}$$

where:
a = slope of the linear regression (biomass plotted against the observed CPUE)
b = intercept of the linear regression (biomass plotted against observed CPUE)
$biomass_y$ = sum of the biomass for year *y*

The exploitation rate (E) was estimated by dividing fishing mortality (F) by total mortality (Z). The exploitation rate gives an indication of the level of fishing pressure that is applied and it has been suggested that a fish stock is optimally exploited when the fishing mortality is equal to the natural mortality rate or E is equal to 0.5.

$$E = F/Z \tag{12}$$

3.2.2 Yield per recruit and spawning stock biomass per recruit

Yield per recruit and spawning stock biomass per recruit was estimated using the values of weight at age, an estimation of the selectivity curve, an assumption for the natural mortality and fishing mortality. The equations used are the same as described previously and following this procedure:

a) The stock number (N_a) was estimated using the equation 1
b) The catch (C_a) at age was estimated using the equation 2
c) The yield for each age (Y_a) was estimated by multiplying the catch by the weight at age:

$$Y_a = C_a W_a \tag{13}$$

The yield per recruit (Y/R) was estimated using the equation:

$$Y/R = \sum Y_a/R \tag{14}$$

Where:
C_a = catch at age
W_a = mean weight at age
R = recruitment

To simplify calculations the initial stock size in numbers is set as 1000. Then we have the yield from 1000 lobsters. We have to do this for different fishing mortality rates (F) to get the different yield in relation to F. We then plot Y/R against F. From this curve we can derive some target points such as Fmax and F0.1. The value of F0.1 is determined numerically by finding the mortality rate at which the slope of the Y/R curve is 10% of that at the origin (Haddon 2001). The F0.1 strategy appears to be, at least, empirically, more conservative or risk averse to departures from the assumption of the yield-per-recruit analysis (Haddon 2001). Fmax, which is the F that gives rise to the maximum yield, can also be derived from this Y/R. Fmax tends to be too high and leads to stock declines. The F 0.1 is considered a reasonable fishing mortality rate and many fisheries worldwide use F0.1 as a fishing strategy because it appears to be robust.

The maturity proportion was adopted from the maturity levels at age described by Cruz and León (1991). The maturity level according to age was as follows: age two = 0.44, age three = 0.86, age four = 0.95, age five = 0.98 and age six = 1.0. Although the female lobster may spawn more than once during the year, in this study it was assumed that it spawn only once. The spawning stock biomass at each age a (SSB_a) was estimated using the following equation:

$$SSB_a = M_{pa} * W_a * N_a \tag{15}$$

Where:

M_{pa} = proportion maturity by age
W_a = mean weight at age

The spawning stock biomass per recruit (SSB/R) was estimated using the following equation:

$$SSB/R = \sum SSB_a/R \tag{16}$$

3.2.3 Prediction for the following year

The size of the stock in the following year was estimated using the value of the stock size at the beginning of the last year of the data set.

In simple terms this means that the number of fish at the end of the year *y* is the same as the number of fish in the same cohort (year-class) at the beginning of the following year *y+1* and is estimated using the following equation:

$$N_{a+1,\ y+1} = e^{-Z_{ay}} N_{ay} \tag{17}$$

Where, N_{ay} denote the number of fish of age (*a*) in the sea at the beginning of year *y*. At the end of the year, i.e. beginning of the following year, these fish are one year older *y+1*.

For the youngest age group an estimate was taken as the geometric mean of the last eight years (2001-2008).

4 RESULTS

4.1 Fishermen data set

The analysis of the length frequency data showed that lobster carapace length oscillated between 50–126 mm for males and 50-103 mm for females. The mean length for male lobsters was estimated at 83.8 mm and 79.9 mm for females. The lobster sex ratio was estimated as 1:1 (770 males and 775 females). Figure 7 shows the length frequency distribution by separate sexes and Figure 8 shows the sexes combined.

When the Slicing method was applied to the length frequency distribution data the result showed only two lobster age classes; age 2 and 3 (Table 1). Age two was the largest age group representing 67.7% o and age three lobsters accounted for 30.2%.

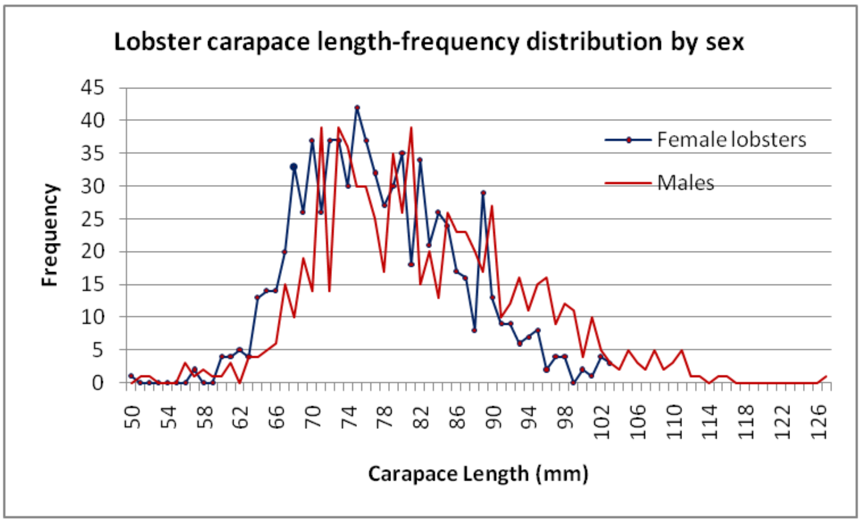

Figure 7. Graph showing lobster length-frequency distributions by sex.

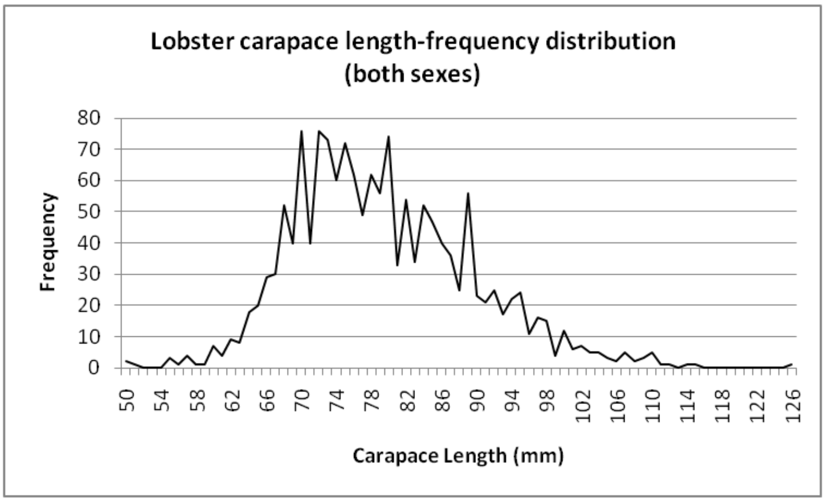

Figure 8. Graph showing lobster length frequency distribution (combined sexes).

Table 1. Lobster catch at age (fishermen data).

Age	Frequency	Proportion (%)
1	7	1
2	1046	68
3	466	30
4	9	1
5	16	1

The analysis of the data using the R package estimated the following lobster growth parameters: $L\infty$ = 183, K = 0.24 and t_0 = -0.032 with a residual sum-of-squares of 0.001050. The estimated proportions, mean length and standard deviation by age are shown in Table 2.

Table 2. Estimated proportions, mean length and standard deviation by age.

Age	Proportion	Mean	Standard Deviation
1	1.61×10^{-07}	57.54	22.82
2	0.63	73.53	6.10
3	0.37	89.19	7.59
4	5.01×10^{-08}	104.54	7.19
5	4.72×10^{-07}	119.57	7.19
6	3.04×10^{-08}	134.29	7.19

Figure 9 show graphic representations of length-frequency distribution, estimated mean length at age, estimated standard deviation at age and estimated proportions at age of the lobster field data set only.

An analysis of the estimated proportions by age shows only two lobster age groups (ages two and three) are represented in the data set. Two-year old lobsters (73.53 mm mean length) represented the largest proportion in the data set accounting for 63%, while age three lobsters (89.19 mm mean length) accounted for 37%. The proportions of the older age groups (ages four, five and six) were negligible. Lobster recruits probably enter the fishery at age two and therefore harvesting two-year old lobsters could mean that these young recruits are fished as soon as they enter the fishery on an annual basis (lobster recruitment pattern will be discussed later in this report).

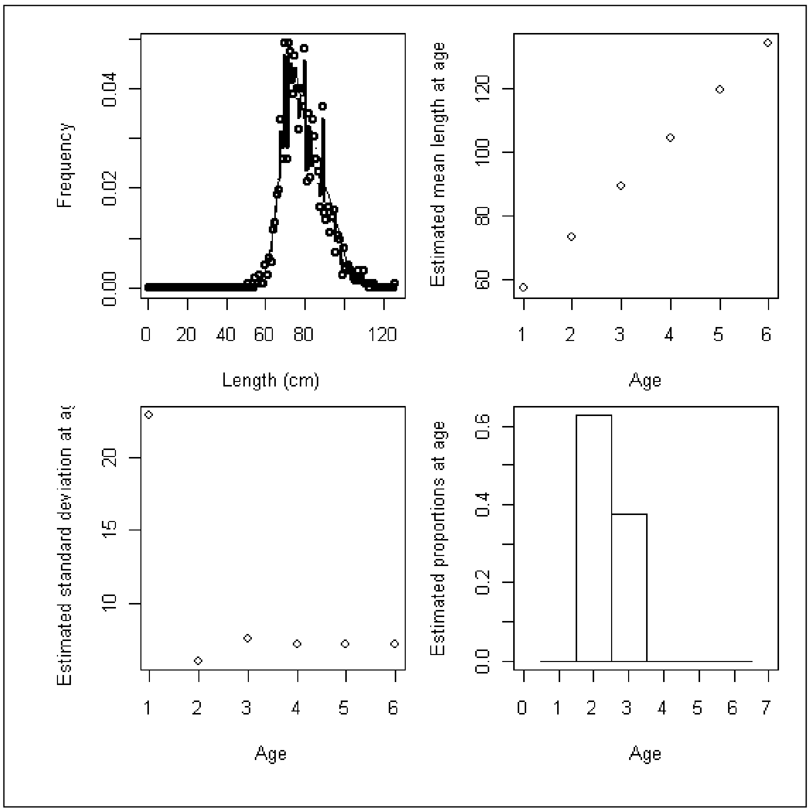

Figure 9. R generated graphs showing length frequency, estimated mean length, standard deviation and proportions at age for the lobster field data set.

4.2 Fishing cooperatives data set

A simple analysis of lobster export trends from 1999 to 2009 shows relatively stable exports during the first few years, a decreasing trend from 2004 to 2007 and a recovery or an increasing trend from 2008 onwards (Figure 10).

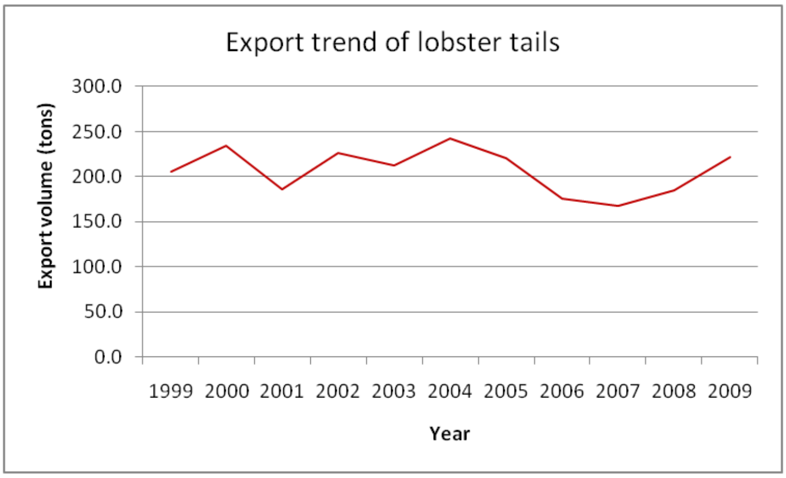

Figure 10. Export trend of lobster tails (all size classes) of two fishing cooperatives during 1999 to 2009.

The analysis of exports by weight class shows that 4-5 oz lobster tails represented 41% of total exports by Northern Fishermen Cooperative and 29% by National Fishermen Producers Cooperative (Figure 11). The exports of 6-8 oz lobster tails represented 33% of total lobster tail exports by Northern Fishermen Cooperative and 40% by National Fishermen Producers Cooperative (Figure 12).

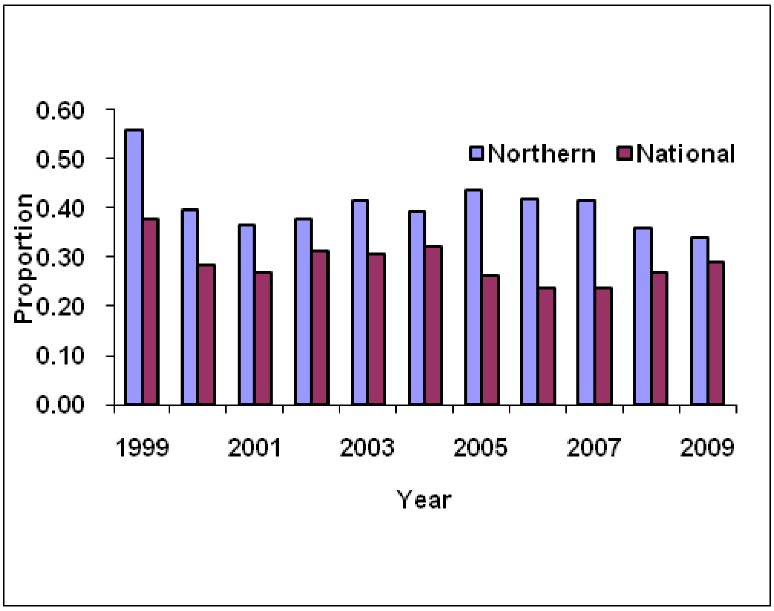

Figure 11. Proportions of 4-5 oz lobster tail exports of two fishing cooperatives during 1999 to 2009.

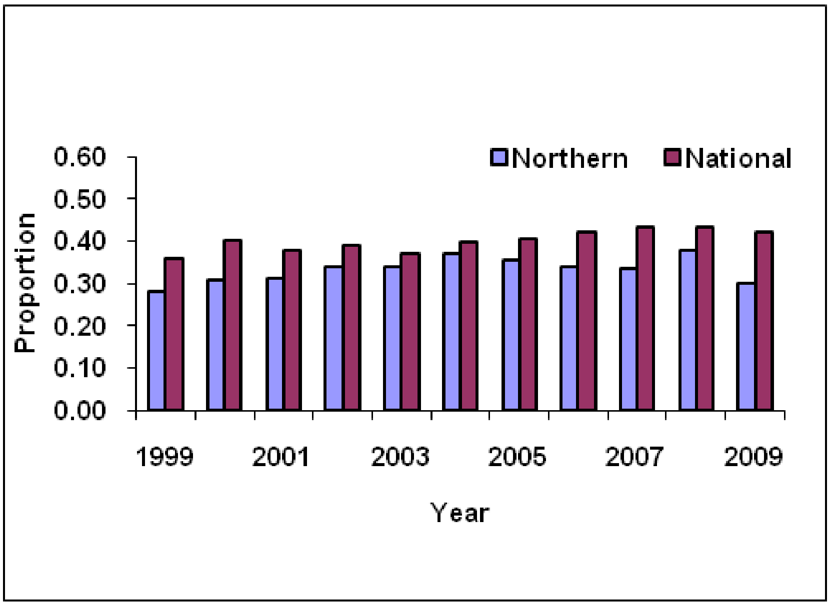

Figure 12. Proportions of 6-8 oz lobster tail exports of two fisihing cooperatives during 1999 to 2009.

Figure 13 shows the average annual quantities of lobster tail exports by weight classes. The three smallest weight classes dominated exports. The largest average quantity was represented by the five-ounce size class (37.1 tons) followed by four-ounce size class (34.7 tons) and six-ounce size class (30.8 tons).

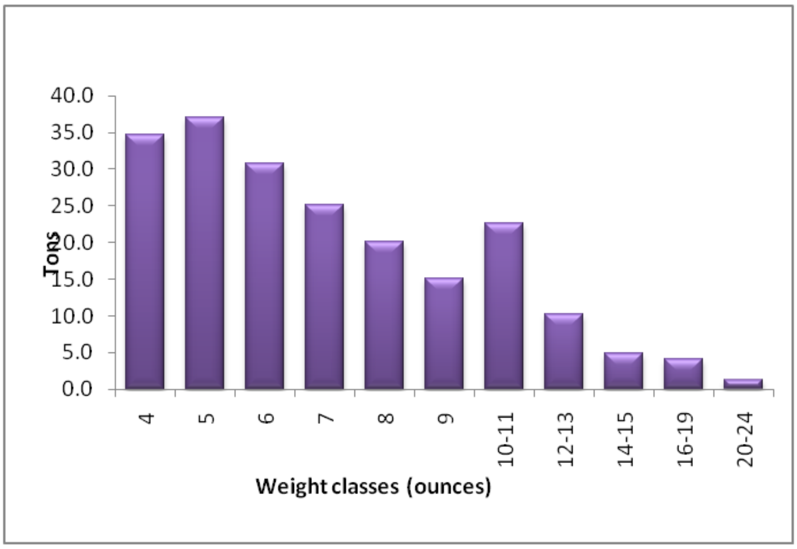

Figure 13. Average annual quantity of lobster tails (by weight classes) exported by two fishing cooperatives during 1999 to 2009.

The large proportion observed for the 10-12 ounce size class is the result of the grouping arrangement of the weight classes.

4.2.1 Lobster landings

Table 4 in the Appendices shows annual lobster landings and Catch Per Unit Effort (CPUE) for the period 1999 to 2009. Overall, lobster landings declined by 24% from 277 tons in 1999 to 211 tons in 2009 (Figure 14). The steep decline observed in 2000-2001 is associated to declines in fishing effort (number of licensed fishermen) during these two years. Lobster landings declined from 255 tons in 2004 to 191 tons in 2006 and since then it increased slightly and appears to be stable at present. The CPUE follows the trend of the landings.

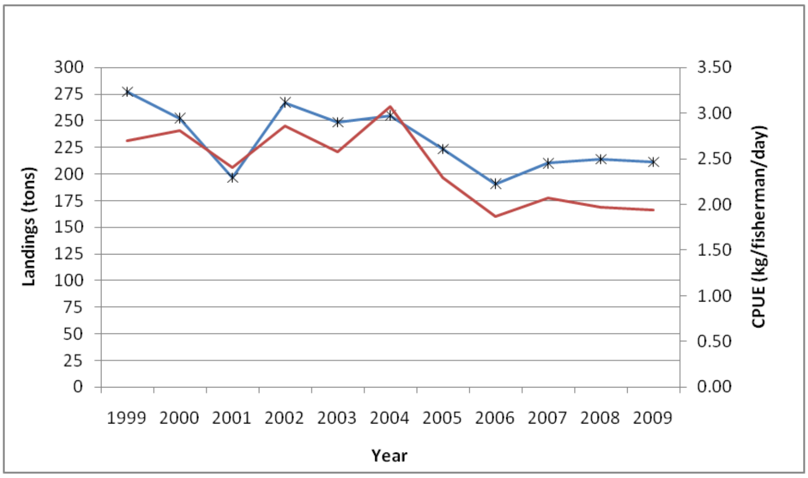

Figure 14. Lobster landings (tail weight only) by two fishing cooperatives and CPUE during the period 1999 to 2009.

On August 2007 Hurricane Dean hit the northern coast of Belize and caused major damages to the marine ecosystem. Lobster catches were expected to decline in the following year but results show catches were stable in 2008 and 2009.

4.2.2 Estimated fishing effort

The total number of fishing days per year was estimated assuming that a full-time fisherman fish for lobsters on an average of 18 days per month (three fishing trips of six fishing days each) for the 8-month lobster fishing season (June 15 to February 14). The rest of the days in the month are spent as follows: two days of rest between each fishing trip (6 days rest) and two days travel to and from fishing grounds for each fishing trip (6 days travel).

Considering these assumptions, the estimated fishing effort (fishing days) increased by six percent (6%) from 307,728 fishing days in 1999 to 326,448 fishing days in 2009. However, fishing effort shows a substantial increase from 249,264 fishing days in 2004 to 326,448 fishing days in 2009. If just this portion of the study period is considered then the increase in fishing effort is 31% with respect to 2004, which is five times higher than the increase in the value of fishing effort during the entire study period (Figure15). Due to unavailability of data, the fishing effort for 2009 was assumed the same as in 2008.

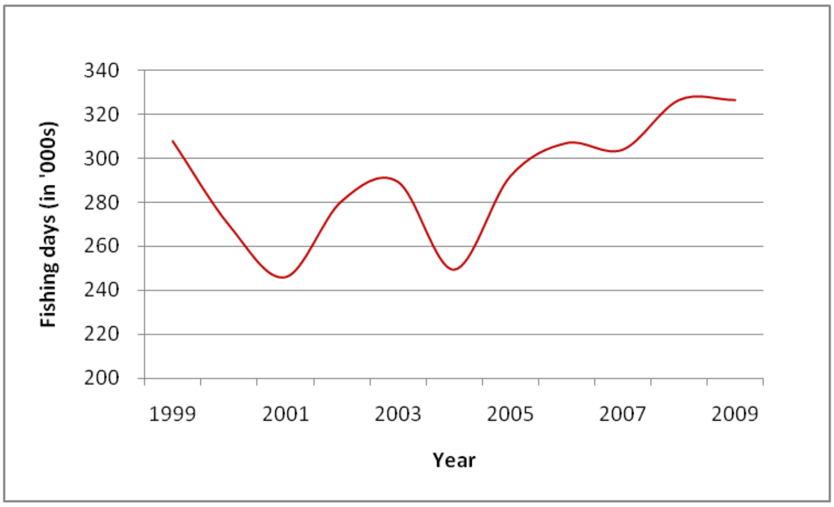

Figure 15. Estimated fishing effort during 1999-2009.

4.2.3 Catch per unit effort (CPUE)

The CPUE was estimated by dividing the overall annual estimated catch (kg) by the annual estimated fishing effort (fishing days). Figure 16 shows the evolution of the estimated CPUE during the period 1999 to 2009. The CPUE declined by 28% from 2.7 kg/fishing day in 1999 to 1.94 kg/fishing day in 2009. The increase observed in CPUE during 2004 is as a result of a decline in fishing effort in that year and not due to an increase in lobster biomass because landings only increased by 2.5% (746 tons in 2003 to 765 tons in 2004) in that particular year (Appendices Table 4).

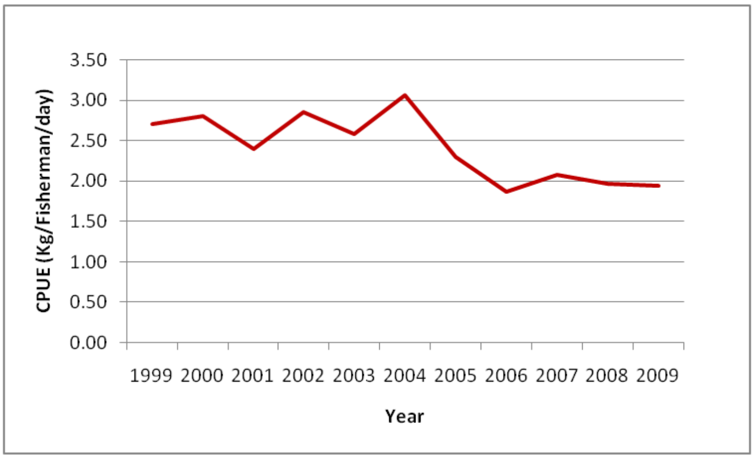

Figure 16. Estimated lobster CPUE during the period 1999 to 2009.

4.2.4 Lobster catch-at-age by year

The catch-at-age data obtained by the Slicing method (Sparre and Venema 1998) is shown in Table 3 in the Appendix. Lobsters of ages two and three dominated the catches throughout the study period. A consistent high annual recruitment (age 2) is observed each year.

Age five lobsters catches were consistently higher than age four lobsters catches from 2001 to 2009. This irregular increase could not be reasonably explained and it is assumed to be the result of large lobsters caught in deep fishing areas in southern Belize by some fishermen. It can also be the result of the parameters used in the Slicing method.

The analysis of the data shows that annual average percentage composition was 61.4% for age two lobsters and 36.6% for age three lobsters. Lobsters of ages four and five accounted for less than 1% each, while age six lobsters were negligible.

4.2.5 Virtual Population Analysis (VPA) or Cohort Analysis

The VPA analysis assumes that the catch at age matrix is known without error. The catch-at-age matrix was made by the Slicing method and is not considered precise but an attempt was made to run a VPA. Catch per unit effort was used as an index of abundance in the cohort computations to estimate terminal fishing mortality rate (F_{term}) and the selection pattern (S)

Figure 17 shows the general trends in the estimated lobster fishing mortality rate and exploitation rate during the study period. Fishing mortality rate increased by 46% from 0.89 in 1999 to 1.3 in 2008. The fishing mortality observed for 2009 is possibly the result of common uncertainty in the estimation of fishing mortality rates for the last year in VPA analysis and is therefore considered imprecise. Also, fishing effort is not considered to have increased substantially in 2009 to have caused such a large increase in fishing mortality. Therefore, the mortality for 2009 should be considered with caution. The exploitation rate follows a similar pattern to the fishing mortality rate showing a slow increasing trend during the study period. It increased by 9.7% from 0.72 in 1999 to 0.79 in 2008. The exploitation rate for 2009 was not considered precise.

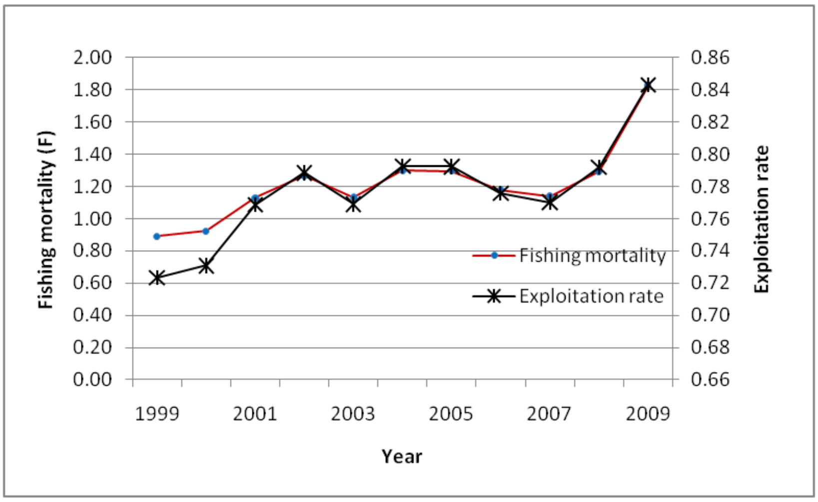

Figure 17. Lobster fishing mortality and exploitation rate during the period 1999 to 2009.

Figure 18 shows a general decreasing pattern in the estimated lobster stock size during the study period. The lobster stock has decreased by 26.1% from 2.48 million individuals in 1999 to its record low of 1.83 million individuals in 2009. Despite the observed declining pattern it is noted that the stock actually grew in size from 2001 to 2004 when it reached 2.51 million individuals but since then it has gradually declined to its current level.

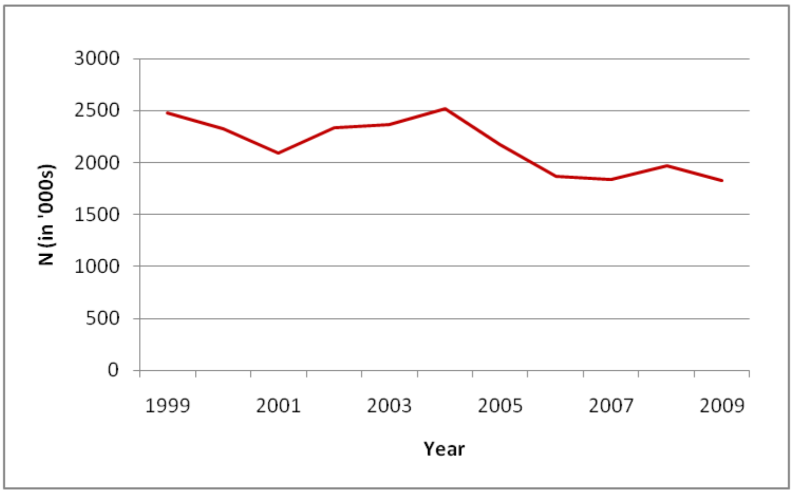

Figure 18. Lobster biomass during the period 1999-2009.

Figure 19 shows a general decreasing trend in the estimated lobster recruitment (age two lobsters) during the study period. Lobster recruitment level decreased by 36.1% from 1.98 million individuals in 1999 to a record low of 1.26 million individuals in 2009. Despite the general declining pattern observed it is noted that recruitment actually grew from 2001 to 2004 when it reached 1.83 million individuals but since then it gradually declined. In the last four years lobster recruitment has remained relatively stable at approximately 1.33 million individuals per year.

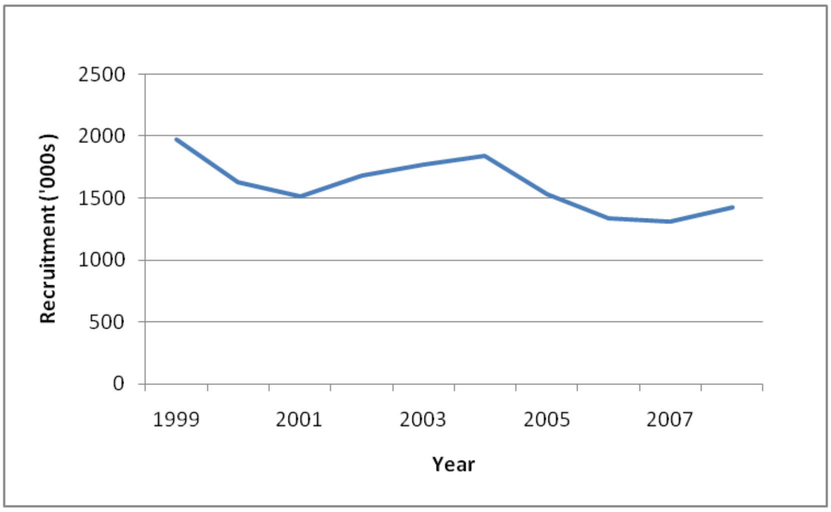

Figure 19. Lobster recruitment during the period 1999 to 2009.

Figure 20 shows a general declining pattern in the estimated lobster stock (calculated as tail weight) biomass volume during the study period. The stock biomass decreased by 17.4% from 352 tons in 1999 to 292 tons in 2009. It is noted that biomass volume showed an increasing pattern from 2000 to 2004 when it reached its highest level of 386 tons but since then it declined to about 300 tons in 2006 and has remained stable in the last four years.

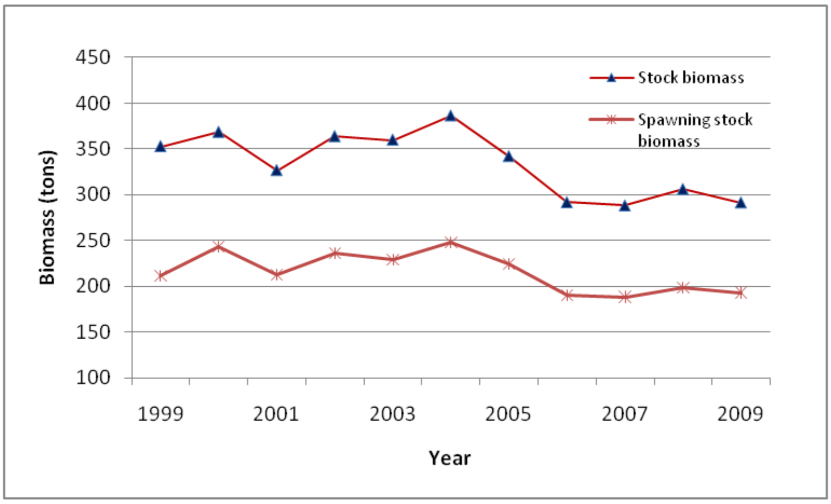

Figure 20. Lobster stock (calculated as tail weight) and spawning biomass during the period 1999 to 2009.

There was a slight decline in the estimated lobster spawning stock biomass (SSB) during the study period. The SSB decreased by 8.74% from 212 tons in 1999 to 193 tons in 2009. It is noted however, there was a slightly increase during 1999 to 2004 when it reached 248 tons. This period was followed by a declining pattern that leveled off in 2006 with 191 tons. Since then it has remained relatively stable during the last four years at around 200 tons.

4.2.6 Spawning stock- recruitment relationship

Figure 21 shows the lobster spawning stock biomass (SSB) and recruitment (R) relationship. No significant relationship exists between these two variables as only a cloud of scattered points was observed in the plot. Considering that lobster recruit to the fishery at two years of age then the recruitment data set initiated from 2001 while the spawning stock biomass started from 1999. The SSB oscillated between 188 and 248 tons and R oscillated between 1.2 and 1.8 million individuals. Since no relationship was observed then the geometric mean of recruitment was calculated at 1.5 million. This recruitment level is therefore assumed to enter the fishery every year, especially when we consider that the spawning stock remained relatively stable at about 200 tons during the last 4 years.

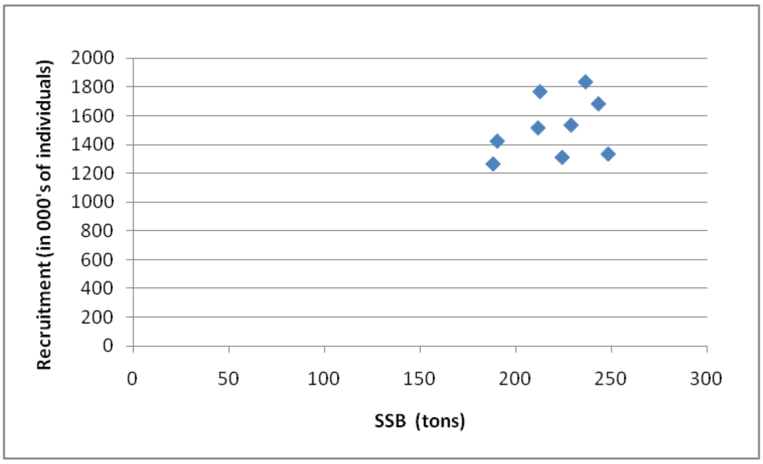

Figure 21. Lobster SSB-R relationship

4.2.7 Catch per unit effort-biomass relationship

Figure 22 shows the linear regression relationship of observed CPUE and estimated biomass. The result shows a strong relationship of 92% of the observed CPUE as determined by the biomass level.

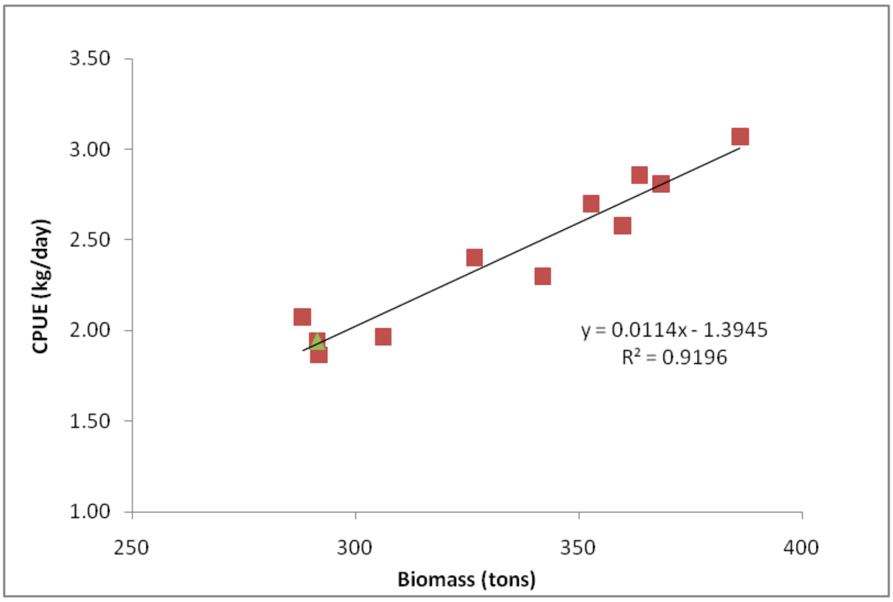

Figure 22. Lobster CPUE plotted against biomass.

Figure 23 shows the lobster CPUE was relatively stable during the period from 1999 to 2004. Then the CPUE declined in the following two years to1.87 kg/day in 2006 and has remained around 2.0 kg/day since then.

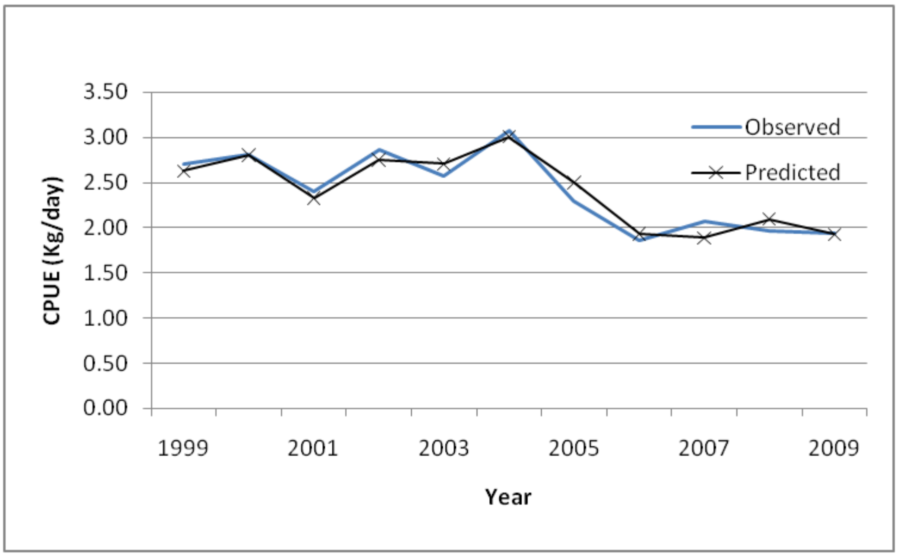

Figure 23. Observed and predicted lobster CPUE for 1999-2009.

4.2.8 Yield and spawning stock per recruit and fishing mortality (Fmax and F0.1)

Figure 24 shows the yield and spawning stock per recruit graph. The yield and spawning stock biomass per recruit values was calculated using the estimated selection pattern, maturity proportion and mean weight at age used in the VPA. The Fmax was estimated at 0.85 with a Y/R value of 0.39 kg and F0.1 was estimated at 0.49 with a corresponding Y/R value of 0.37.

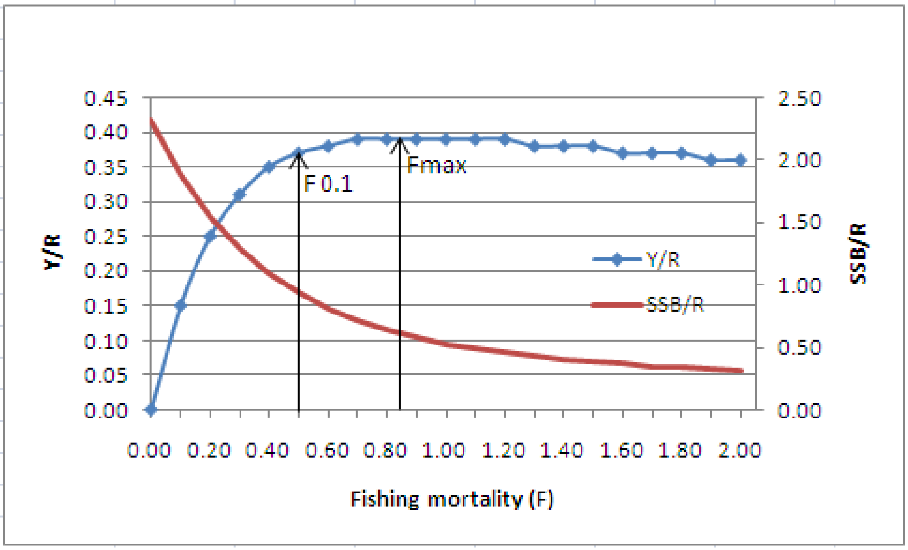

Figure 24. Yield and spawning stock per recruit analysis graph showing F0.1 and Fmax

4.2.9 Prediction of yield in the following year

Table 5 shows the prediction of yield and spawning biomass stock values for 2010 corresponding to various F mortality rates including the estimated F0.1 and Fmax values (from the Y/R analysis). The stock (1) and catch (2) equations were used to estimate the yield and SSB. The maturity proportion and mean weight at age were the same values used in the VPA but the selection pattern was estimated as the average of the last three years by age groups as the selection patterns by age groups for the last few years do not change much.

The highest yield (206 tons of lobster tails) was observed at Fmax but decline thereafter as F increases. The SSB declines consistently as F increases. It is observed that the yield at F0.1 is 575 tons and when the F is at 2 (four times greater F0.1) the yield is the same but the SSB decline to about one-third of its value at F0.1. This shows that yield decrease under higher fishing mortality rates after Fmax has been reached. It is also observed that SSB at F0.1 was almost three times greater than the value at an F rate of 2.0, which leads to conclude that SSB decline at higher F rate and thus the corresponding recruitment would be lower at high F rates.

Table 3. Predictions of yield and SSB for 2010 under various F values.

Reference Point	F rate	Yield (tons)	Tails (tons)	SSB (tons)
F0.1	0.49	575	192	1542
	0.67	609	203	1228
Fmax	0.85	619	206	1017
	1.30	606	202	723
	1.50	596	199	654
	2.00	573	191	537

5 DISCUSSSION

Two growth parameters used in the von Bertalanffy growth model ($L\infty$ = 183, k = 0.24) were obtained from the analysis of the fishermen data. These parameters were similar to those obtained by Leon *et al.* (1995) for SW Cuba. The third growth parameter t_0 (-0.032) from the fishermen data differed and may be due to inadequate and insufficient sampling of all size classes (particularly the young and old age classes) during the data collection process. Therefore, the t_0 reported for SW Cuba was used. In the FAO workshop on the assessment of the Caribbean spiny lobster, the growth estimates for spiny lobsters in Cuba obtained by Leon *et al*. (1995) were considered the most reliable during the 1998 working group session. These estimates were derived using the SLCA method and were based on a large sample size collected during the 1990s covering the widest range of size classes (FAO 2001).

The mean carapace lengths (CL) and proportions by age for the lobster data set collected from fishermen obtained with the R package (2-year old lobster was 73.53 mm and 3-year old lobster was 89.19 mm) were similar to those obtained by the Slicing method (2-year old was 70.99 mm and 3-year old was 88.07 mm). The similarity of these CL estimates leads to a conclusion that a 4-ounce lobster tail is two years old and an 8-ounce lobster tail is three years old. Since the bulk of lobsters harvested in Belize consist of lobster tails of four to eight ounces in weight then it can be reasonably assumed that these lobsters fit into only two age groups (year 2 and year 3). This is in line with findings of the 2008 lobster assessment that reports two and three year old lobsters as constituting the bulk of the lobster stock. The same study reported a significant decline in the abundance of two and three year old lobsters during the period 2002 to 2007.

The percentage compositions of two and three year old lobsters in the results of the R analysis (fishermen data) were also similar to the results of the Slicing method (fishing cooperative data) and this gives a good idea of the age structure of the lobster stock. The results of the Slicing of fishing cooperative data set shows the youngest lobsters fished were two years old (4 ounces or 113.2g) and these constituted 60% of catches. Considering this information, it can be reasonably assumed these lobsters may not have reached optimal size. A continuation of fishing of small lobsters (4 ounces) is not considered a good lobster harvesting strategy. An increase in the minimum lobster tail weight is recommended to avoid over-fishing. Other lobster producing countries such as Nicaragua and Honduras have established their minimum lobster tail size to 5 ounces (141.7 g) with a lower limit of 4.5 ounces (127.6 g) (OSPESCA 2006) since 2006. The USA recently passed legislation, which established the minimum lobster tail weight to 5 ounces (141.7 g) with a lower limit of 4.2 ounces (119.1 g) and an upper limit of 5.4 ounces (153.1 g) (Federal Register 2009).

The estimated CPUE values of this study provide a general idea of lobster abundance and serve as a guide to explain the general situation of current lobster catches. It is noted that lobster tails export data was used in the calculation of CPUE, which is slightly lower than the total annual lobster landings. However, since lobster tail exports are more than 95% of total lobster landings then the CPUE values would have been only slightly higher if the total lobster production volume was used.

Fishing effort could not be estimated as the number of actual fishing days by each fisherman from the fishing cooperatives. Therefore, it was estimated by taking the number of licensed fishermen as a starting figure and multiplying it by the assumed number of fishing days of each fisherman per fishing season. This estimate was based entirely on personal experience and knowledge of lobster fishing practice in Belize and therefore an accurate fishing effort may be estimated in the future.

Also, the estimation of total number of fishing days assumed that all licensed fishermen were free-divers working on small fishing boats equipped with sails and outboard motors (sail boats). It was recognized that fishing effort by lobster trap fishermen who work with fast-moving speedboats (skiffs) equipped with outboard motors may be higher fishing effort because of their increased fishing capacity and ability to travel faster to the fishing grounds and return to the landing site. Many lobster trap fishermen who work with speedboats usually stay in their fishing camps for a few days, to reduce fuel expenses, before delivering their lobster tails to the fishing cooperatives. Therefore, the final values for fishing effort would not have changed significantly if a differentiation were made by fishing method (free-diving fishermen working with sail boats and trap fishermen working with speedboats).

The exploitation (E) rates observed during the study period are higher than the recommended 0.5, which is considered as the optimum level. The exploitation rate follows the trend of the fishing mortality and is in line with findings reported by Chavez (2009) that indicates Belize’s lobster stock as overexploited with a catch of over 150 tonnes. Chavez (2009) also reported that the exploitation rate (E) was above 0.5 in the last five years and recommended a reduction in catch levels. FAO (2007) reported that the lobster fishery of Belize was fully exploited or stable.

5.1 VPA results

An Adapt VPA type of an assessment was made. The assessment assumes that catches-at-age are without error. Any aging errors are source of bias (Haddon 2001). The method is also sensitive to the estimates of terminal F values. If the estimates are flawed the analysis will be biased (Haddon 2001). The catch-at-age matrix contains only five age groups, which is rather few groups for a VPA. This assessment is not considered very accurate. We may see the trend but the actual levels may not be true and therefore the results should be interpreted with caution.

This study showed similar results as those obtained in lobster stock assessments done in the last five years. High exploitation rates and fishing mortality rates were reported in this study and are similar to results obtained in 2005 when it was reported that the spiny lobster appeared heavily exploited and fishing mortality was high (Belize Fisheries Department 2005). In this study, the fishing mortality rate increased from 0.89 in 1999 to 1.3 in 2008 and is considered high.

In 2007, the fishing mortality rate was estimated at 0.7 for the lobster fishery and a removal of 40-60% of the lobster stock on an annual basis (Belize Fisheries Department 2007). The results of this study also showed high fishing mortality rates.

In a lobster assessment report for 2008, lobster production was reported as stable from 1985 to 1995 with a declining trend thereafter. A decrease in the abundance of 2 and 3 year old lobsters was reported for the period 2002 to 2008 (Belize Fisheries Department 2008). In this study, a declining trend was observed in lobster landings from 2002 to

2006 with relatively stable landings in the last four years. Lobster recruitment (age 2 lobsters) also declined during the study period.

There was a slow declining trend in the lobster spawning stock biomass during the study period. A small decline of 8.74% was observed but relative stability at about
192 tons has been observed during the last four years. This slow declining pattern however, is not reflected parallel to lobster recruitment, which showed a decline of 36.1% during the study period. Similarly, to the spawning stock trend, some relative stability was observed in recruitment during the last four years. The decline in lobster recruitment is possibly an indication that the lobster stock is experiencing high fishing pressure on an annual basis and the result is that it is becoming reduced below the level where it can produce sufficient new recruits to replace those that are fished or die of natural causes. It should be noted that the lobster stock size also decreased by 26.1% during the study period. Constant growth over-fishing can lead to a further decline in the stock size.

The SSB/R analysis shows no correlation of these two parameters. Even though no relationship is observed it is important to protect Belize's deep-water lobster spawning stocks. According to Haddon (2001) if stock recruitment relationship did not exist then stock collapses would be less common. Considering the long pelagic phase, the lobster larvae can be carried for long distances by ocean currents and therefore it is possible that Belize's lobster spawning stock may be supplying lobsters larvae to other countries in the western Caribbean region, Mexico and Florida.

5.2 Yield per recruit analysis and fishing mortality

The analysis showed that yield per recruit remained at a constant level even though fishing mortality increased (Figure 24). The yield increased by only 0.02 kg from 0.37 kg at F0.1 (0.49) to 0.39 kg at Fmax (0.85). This shows that only a small percentage in yield is lost with a significant reduction (42.3%) in fishing mortality. A fishing mortality rate of 0.49 would help to create a resilient stock that should perform well in poor recruitment years and other uncertainties. Fmax is the fishing mortality rate that gives the maximum yield but can lead to stock decline. F0.1 has been used as a reference point in many fisheries as the fishing mortality rate and gives a reasonable yield while not applying high effort on the fishery.

The mean fishing mortality rates for the study period are higher than the Fmax and F0.1 obtained in the yield per recruit analysis. There is a need to control and reduce fishing effort. This can be achieved through the implementation of a new lobster fishing licensing system for fishermen, boats and fishing gears used in the lobster fishery.

It is noted that the estimation of fishing effort (number of fishing days in this study) did not incorporate lobster traps and shades used for lobster fishing because of unavailability of data. It is known however, that lobster traps increase the fishing capacity of a fisherman and therefore the use of these fishing gears contribute to fishing mortality. For this reason there is a need to carry out a national survey of fishing gears (traps, shades and other devices). The control on numbers of these fishing gears used should help to reduce fishing effort.

6 CONCLUSIONS AND RECOMMENDATIONS

Taking into consideration the various assumptions and the uncertainties associated with the fisheries stock assessment models, the main conclusions of the lobster assessment for the period 1999 to 2009 are:

a. Ninety eight percent (98%) of annual lobsters catches are lobsters of age two (4 ounces or 113.2 g) and three years (8 ounces or 226.4 g).
b. The lobster fishery appears stable at present but fishing efforts need to be reduced.
c. Growth over-fishing is possibly occurring.
d. CPUE has declined by 28.15%.
e. Stock size has declined by 25%.
f. Biomass has declined by 17.4%.
g. Spawning stock biomass has declined by 8.74%.
h. Recruitment has declined by 36.1%.
i. Fishing mortality is high (increased by 46%).

The main recommendations are:

a. More lobster sampling (frequency and location) is necessary in order to obtain improved estimates of growth parameters of the population.
b. There is a need to implement a lobster recruitment study program to estimate juvenile abundance index.
c. The use of a length-based assessment method could provide useful comparison of results.
d. The fishing mortality rate is high and needs to reduce.
e. The traditional licensing system that entitles each and every fisherman to fish for lobsters should be revised.
f. The lobster fishery should be designated as a limited entry fishery.
g. A new lobster fishery licensing system for fishermen and fishing boats should be considered for implementation.
h. A national lobster traps and shades survey should be carried out.
i. A new lobster traps and shades registration and licensing system should be considered for implementation.
j. The minimum lobster tail weight of 4 ounces (113.4 g) should be increased to 4.5 ounces (127.6 g).
k. A deep-water lobster stock assessment should be carried out.

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APPENDICES

Table 1

Total export (Northern + National) of lobster tails (tons)											
Year	**4 OZ**	**5 OZ**	**6 OZ**	**7 OZ**	**8 OZ**	**9 OZ**	**10-11 OZ**	**12-13 OZ**	**14-15 OZ**	**16-19 OZ**	**20-24 OZ**
1999	58.0	40.3	29.3	20.4	15.1	11.2	16.5	7.6	3.6	2.5	0.6
2000	38.8	38.7	34.2	27.9	22.2	18.1	28.4	12.8	6.0	5.1	1.6
2001	29.4	29.3	25.6	20.8	18.2	14.6	24.4	11.3	6.0	4.9	1.5
2002	40.8	37.9	33.2	26.7	22.2	16.6	25.4	11.6	5.6	4.6	1.6
2003	39.9	39.4	28.7	25.9	20.1	14.4	23.1	10.6	5.1	4.3	1.4
2004	41.5	44.2	38.8	31.3	23.8	17.4	22.9	11.6	4.9	4.3	1.7
2005	32.1	39.8	33.7	28.4	22.8	16.8	23.8	12.4	4.8	4.2	1.3
2006	23.3	32.0	26.2	22.8	18.6	14.1	21.1	8.4	4.0	3.7	0.9
2007	21.5	29.2	25.2	22.8	18.4	14.2	20.5	7.3	3.7	3.4	1.0
2008	19.4	37.9	30.2	25.0	19.8	13.9	20.2	8.3	4.1	4.3	1.1
2009	19.2	50.2	35.9	29.1	22.4	17.0	27.6	9.5	4.8	4.2	1.2

Table 2

Estimated number of lobster tails per CL (tons*2200*16/weight category)											
Carapace lengths in millimeters obtained using CL-TW relationship (Wade, B. *et. al* 1992)											
Year	**71**	**76**	**81**	**85**	**88**	**91**	**96**	**101**	**106**	**112**	**121**
1999	510400	283520	172053	102674	66240	43957	55284	21402	8739	5120	902
2000	341280	272640	200373	140206	97620	70969	95360	35942	14676	10304	2596
2001	258880	206208	150400	104549	79920	57173	81798	31923	14455	9838	2473
2002	359120	266496	194773	134034	97760	65102	85029	32768	13594	9234	2545
2003	351040	277376	168640	130286	88320	56391	77318	29798	12447	8594	2255
2004	364800	311232	227360	157531	104560	67922	76815	32768	11829	8741	2735
2005	282560	280320	197920	142720	100160	65636	79634	34893	11652	8455	2007
2006	205440	225171	153989	114560	81760	55253	70583	23552	9754	7424	1513
2007	189120	205568	148053	114651	81040	55538	68693	20582	8960	6912	1571
2008	170880	266880	177067	125714	87220	54187	67596	23501	10063	8667	1833
2009	168816	353248	210651	146469	98400	66564	92642	26875	11686	8452	1917

Table 3

Catch at age in '000s of individuals (calculated from CL frequencies using Slicing method of Sparre and Venema 1998)											
Age	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
2	931.60	774.00	585.00	782.00	763.20	857.60	721.40	553.40	513.40	579.60	690.80
3	323.40	480.00	385.00	454.00	415.80	485.40	463.60	376.80	371.60	394.40	474.20
4	14.00	25.00	10.28	9.28	9.24	9.24	8.24	7.20	7.18	9.20	9.24
5	0.34	1.02	15.00	14.74	12.44	12.78	12.44	10.48	9.50	10.48	12.44
6	0.66	1.98	1.32	1.98	1.32	1.98	1.32	1.32	1.32	1.32	1.32

Table 4. Landings, fishing effort and CPUE table.

Year	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Tails (lbs)	609,523	555,254	432,884	587,872	547,180	561,148	491,616	419,863	462,152	470,485	464,968
Tails (tons)	277	252	197	267	249	255	223	191	210	214	211
Live weight (tons)	831	757	590	802	746	765	670	573	630	642	634
Live weight (kg)	831,168	757,165	590,296	801,644	746,155	765,202	670,385	572,540	630,208	641,570	634,047
No. of fishermen	2,137	1,872	1,707	1,947	2,009	1,731	2,026	2,131	2,110	2,267	2,267
Effort (days)	307,728	269,568	245,808	280,368	289,296	249,264	291,744	306,864	303,840	326,448	326,448
Effort ('000s days)	308	270	246	280	289	249	292	307	304	326	326
Estimated CPUE	2.70	2.81	2.40	2.86	2.58	3.07	2.30	1.87	2.07	1.97	1.94