UNITED NATIONS UNIVERSITY
Fisheries Training Programme

unuftp.is

Final Project 2009

THE USE OF PRODUCTION MODELS AND LENGTH FREQUENCY DATA IN STOCK ASSESSMENTS IN JAMAICAN FISHERIES, BUILDING ON THE CARIBBEAN SPINY LOBSTER OBSERVATIONS

Anginette O. Martin-Murray
Fisheries Division, Ministry of Agriculture and Fisheries
P.O. Box 470, Marcus Garvey Drive, Kingston, Jamaica
anginettem@yahoo.com

Supervisor:

Gudmundur Thordarson
Marine Research Institute.
Reykjavik, Iceland.
gudthor@hafro.is.

ABSTRACT

Jamaica has had an active data collection programme since 1996 covering six of its major fisheries. Data are collected by fishery type and landing sites and are primarily catch, effort and biological. Experts outside of the country usually do stocks assessments periodically on the two main fisheries. As part of strengthening the Fisheries Division's capabilities to conduct independent stock assessment on possibly all fisheries for which there are available data, the use of length-frequency methods and production models was applied to the spiny lobster fishery. The concepts and principles grasped from this will become the platform for future analyses for other fisheries of Jamaica with similar data. After data exploration, length frequency distributions were fitted followed by fitting the data to surplus production model (Schaefer model) and length-based models (Jones' cohort analysis and the Thompson and Bell prediction model), thereby estimating fishery performance indicators MSY, $B_{(MSY)}$, $F_{(MSY)}$ and E_{MSY}. Given the uncertainties of model outcomes, the effects of alternative management options including those generated by the surplus production model were explored. Data exploration indicated some level of inconsistency with meeting sample targets however, a great portion of landings were below the minimum legal size of 76 mm. Schaefer model for performance indicators estimated MSY at 222 tons, E_{MSY} at 3529 fishing days. However, forward projections showed that fishing at a fixed catch of 222 tons proved to be unsustainable since the estimated biomass was already depleted (that is $B<B_{MSY}$) whereas fishing at the fixed effort of E_{MSY} showed stock recovery within 3 years. Despite the various limitations of the models used, Jamaica should pay close attention to both the current effort and catch levels imposed on the lobster stock, as there appears to be potential dangers for the fishery if these levels of exploitation are continued.

This paper should be cited as:
Murray, A.O. 2010. *The use of production models and length frequency data in stock assessment in Jamaica fisheries, building on the Caribbean Spiny lobster observations*. United Nations University Fisheries Training Programme, Iceland [final project]. http://www.unuftp.is/static/fellows/document/anginette09prf.pdf

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Overview

In 1996 Jamaica worked along with CARICOM Fisheries Resource Management Programme (CFRAMP) to develop the so-called Jamaica Fisheries Sampling Plan (JFSP), which was implemented the same year. This was not the first sampling plan for Jamaica fisheries but was based on previous sampling programs with many new components. Previously, the sampling programs did not include landings from two major offshore fishing grounds (the Morant and Pedro Cays) or the recreational fishery. Also, there was no specific data collection system in place for the different fisheries and the only record of lobster, shrimp and conch was from the artisanal inshore. The large industrial catches were not being monitored. The sampling program also noted fish by type but there was no systematic biological data collection. Consequently, the new plan was developed that addressed the weaknesses of the previous sampling designs.

Since the commencement of the revised sampling plan in 1996 Jamaica has been collecting catch and effort and biological data according to fishery types – Queen Conch (*Strombus gigas)*, Caribbean spiny lobster (*Panulirus argus*), Atlantic thread herring (*Opisthonema oglinum*) and shrimp (*Penaeus sp*).

Stock assessment tools are used to assess the state of marine stocks and to predict how fish populations will respond to harvesting (Witherell and Ianelli 1997). Stock assessments often produce two main types of information for use by managers:

- ‘Reference Points’ for the fishery, showing the desired harvest point for the fishery.
- ‘Indicators’ showing where the fishery is at the moment or predicting where it might be in the future if different management measures are applied.

Stock assessments therefore provide scientific information, which advises the fishery management process.

In this project the main aim was to evaluate the JFSP by investigating the data collected to date on spiny lobster and furthermore to use the data to conduct a stock assessment.

1.2 Rationale

Jamaica being a developing country has limited resources for collection of fisheries information and data. Nevertheless, the Jamaican marine resources must be managed sustainably to ensure food, employment and export earnings in both the near term and in the future. To conduct stock assessment information/data must be collected and sometimes this can be costly. Inadequate or inappropriate theory or data will cause stock assessments to be inaccurate. Given the limited resources and in some cases the difficulty of ageing species, Jamaica will most likely have to depend on length frequency data (which has been the main biological data often easily collected from commercial fisheries) and length based assessment methods. These length frequency data can in some cases be used to estimate age composition and provide other estimates of population parameters.

Jamaica has had an active data collection programme since 1996 covering six of its major fisheries. Ideally, three principal types of data are collected, broken down by fisheries and landing sites:

(1) Total catches in weight for each commercial group, fleet and period.

(2) Size and species frequencies within fleet commercial groups based on sampling.
(3) Total effort by fleet and by period.

The gathered data are used mainly in production estimates but only two fisheries are assessed frequently, the conch and the lobster fisheries.

The second most important fishery for Jamaica is the Caribbean spiny lobster. Over the years, lobster assessments have been presented at the scientific meetings hosted by the Caribbean Regional Fisheries Mechanism (CRFM). However, it should be noted that the consultants are the ones who do (most of) the analyses, the national officer reports on the findings but in most cases the officer leaves the meeting without having the intricate knowledge of how to apply various models (along with the limitations) to gathered data, due to the short time span of the meeting.

Using the lobster fishery as an example it should be possible to use length-frequency methods and production models to assess the stock. The concepts and principles can be further applied to the remaining commercially valuable species. This study, will therefore apply production models and length-frequency based methods to the lobster fishery and by extension become the platform for future analyses for other fisheries of Jamaica for which there is limited data. Specific objectives were as follows:

1. To review the quality of the available data for the Caribbean spiny lobster thereby making recommendations for improvement.
2. To review and document previous assessments conducted on the data available for the spiny lobster fishery, which used production and length frequency methods thereby grasping concept of methods, and look at ways to improve upon previous work.
3. Utilize these analyses to demonstrate the use of such methods to other fisheries in Jamaica.
4. Investigate the possibility of using alternative stock assessment methods.

2 BACKGROUND INFORMATION ON THE CARIBBEAN SPINY LOBSTER WITH EMPHASIS ON THE FISHERY OF JAMAICA

The Caribbean spiny lobster (*P. argus*) is the most valuable lobster species in the western Atlantic with fisheries extending from North Carolina in the USA to Rio de Janeiro in Brazil. This large lobster grows to 45 cm total length and may live more than ten years in the absence of fishing. The larval stages of this species can spend from six months to as much as a year in the planktonic stage, drifting with the ocean currents. The juveniles, when settling on the bottom, inhabit shallow coastal areas such as mangrove and sea grass beds and move into deeper water and offshore reefs as they grow and mature.

The spiny lobster is a transboundary species, which indicates that some countries are supplying larvae to neighbouring and even farther countries. Therefore, the harvest of one country may affect the potential harvest of the neighbouring countries (Martinez *et. al*. 2007). Several institutions have recognised the importance of the lobster fisheries and their management in the Caribbean and include the Gulf and Caribbean Fishery Institution (GCFI), Western Central Atlantic Fishery Commission (WECAFC - FAO), Caribbean Regional Fisheries Mechanism (CRFM), Caribbean Fishery Management Council (CFMC), National Oceanic and Atmospheric Administration (NOAA). It has been usually accepted that the lobster populations within individual Caribbean countries are part of a regional population and so there is the call for a regional approach to assessment and management.

The spiny lobster is widely distributed in the coastal waters and on the offshore banks around Jamaica. This resource represents an important component of the total landings of the Jamaican commercial fishery. There are six types of lobsters that are found in Jamaican waters viz., *P. argus, Panulirus guttatus, Justitia longimanus, Palinurellus gundlachi, Scyllarides aequinoctialis and Parribacus antarcticus*. *P. guttatus* and *P. argus* are the only two species that are commercially valuable (Aiken 1984). Lobster is an important, highly prized and sought after delicacy in the Jamaican tourist industry. A major portion of the lobsters landed in western Jamaica is sold to the tourist industry. This portion has not yet been quantified. The peak demand for lobsters within the export and tourist industries is just before the start of the three-month closed season (April - June). This demand coincides with increased fishing effort as consumers try to stock up on lobster a month prior to its closure.

A large concentration of lobsters is found on Pedro Bank (Figure 1), which accounts for about 60% of the total landings in the industrial fishery. During the 1980s about 60% of total lobster landings came from the Pedro Bank but declined to 20% during 1996 -1997. The contributions of lobsters landed in Jamaica that comes from the island shelf and the banks have not been recently quantified (Fisheries Division pers. comm.).

Figure 1. Jamaica's Fishing Grounds (Offshore and Inshore Banks) emphasizing main lobster fishing grounds

2.1 Components of the lobster fishery

The fishery has two components, artisanal and industrial.

The artisanal fishery: This fishery has two categories of fishers; these are mainland and offshore artisanal fishers discussed below.

a) Mainland artisanal fishers use antillean z-traps, diving (free lung, SCUBA and Hookah) and gill nets. The lobsters are sold to the catering and tourist industry, and households as well as some also go to processing plants.
b) Offshore artisanal fishers are based mainly on Pedro and Morant Banks. Fishers in this category are mainly divers. The catch is marketed to 'packer boats' that subsequently distribute to the same markets as the mainland artisanal fishers.

The crew size for the artisanal fishery often consists of three persons. The fish pot or trap is considered to be the primary gear; however, lobsters are usually by-catch in the trap fishery. Divers on the mainland target lobsters. A maximum of ten divers may travel in one vessel to respective fishing grounds, and the captain keeps watch while the divers harvest lobsters. Trammel nets are also commonly used. Lobster is sold locally to the public either at the boat side or via vendors. Vendors then distribute the lobster to the catering industry. Sometimes the catch is sold to fish processors (CFRAMP 2000).

The industrial fishery: Fishers within this fishery are based on the mainland but operate mainly on the Pedro and Morant Banks from 20-35 m length vessels. These fishers are licensed to use Florida (wooden slated) traps only. Most times, processors to whom they solely sell their catch contract them. Fish processors cater primarily for the export market. The vessels are steel hulled and have an inboard engine up to 500 hp. Crew size on these vessels ranges from 8 – 12. Vessels transport about 1000 traps and about 500 traps are deployed in the water at any one time. The average immersion time is about three days. Fishers spend up to three months at sea before returning to the mainland. Smaller quantities of lobsters may be transported back to the mainland by other vessels en route to the mainland (CFRAMP 2000). Lobsters are exported mainly to the United States, Canada, Panama, Netherlands Antilles, Cayman Islands and Martinique. The spiny lobster fishery is the second most lucrative export fishery. In 2007, the total production of lobster was estimated to be 111.5 tons, valued at US$1.8M (Statistical Institute of Jamaica (STATIN) pers. comm.). Landings for lobsters usually peak in March and late September.

2.2 Biology/Research

Studies have shown that *P. argus* reaches a maximum length of approximately 45 cm, but is more commonly found at lengths of approximately 20 cm. The growth of the spiny lobster is largely correlated with the frequency of moulting and increment growth while moulting (Aiken 1980). In general, the frequency of the moult and increment growth decline with age. Growth in the first year averages 5 cm, with growth thereafter averaging approximately 2.5 cm per year. Females tend to grow somewhat more slowly than males (Little 1972, Olsen and Koblick 1975) and do not reach as large a size (Williams 1984). Spiny lobsters moult an average of 2.5 times per year, with most moulting occurring from March – July, or from December – February in Florida (Williams 1984). Growth rates in local populations are affected by variability in food quality and abundance, population density, water temperature, as well as rates of predation and injury (Aiken 1980, Waugh 1981).

The life history of the spiny lobster consists of five phases: egg, planktonic phyllosome larvae, swimming post-larval pueruli, benthic juvenile, and adult. Each has a distinctive behaviour and habitat that is characteristic of that stage in the life cycle (Marx and Herrkind 1986). The cycle begins with mating of two adults that are both physiologically and functionally mature (Evans *et al*. 1995). The mating individuals require good shelter, suitable water conditions (stable temperature and salinity, low surge and turbidity), and adequate larval transport by oceanic currents. Spawning takes place throughout the year with a peak in March to May (Arce and León 2001).

Once a suitable substrate is found, a brief courtship occurs and copulation takes place. During copulation, the male lobster adheres to the sternum of the female using a gray spermatophoric mass while holding her against his sternum. The female then expels eggs through her gonopore and fertilizes them by scratching at the spermatophore (Marx and Herrkind 1986). After spawning the eggs hatch as transparent phyllosome (leaf-bodied) larva, which are morphologically equipped for planktonic life. These flattened larvae develop through about 11 times while floating in the water column for six to 12 months. The phyllosoma then settle and become swimming pueruli (Sterrer 1992), which is a brief (several weeks), non-feeding, oceanic phase (Lyons 1980). During the night, the pueruli swim shoreward using specialized abdominal pleopods. Pueruli moult and become benthic juveniles when they encounter suitable inshore substrate, such as mangrove roots or seagrass beds. Most shelters provide partial camouflage, physically deter predators and provide refuge from physical stress. Early benthic lobsters are solitary but soon become aggregative and migrate offshore where they develop into adults. Moulting continues to occur in adults when growth is necessary (Marx and Herrnkind 1986). It should be noted that there is some doubt if the lobster population of a single country is a closed one. This is due to the distribution of the phyllosoma larvae throughout the Caribbean region due to sea current movements.

Several studies on lobsters have been conducted over the years, a few of which are mentioned here. Studies conducted by Aiken (1977), Aiken (1983), Munro (1983) and Haughton (1988) confirmed a significant reduction in the mean and modal size of the lobster population in Jamaica. Mean carapace lengths (CL) for males and females were reduced from 118.2 mm and 102.3 mm respectively to 100.5 and 92.5mm. Whereas, modal CL for males and females were reduced from 110-119 mm and 90-99 mm to 92.5-97.5 mm and 87.5-92.25 mm respectively. Haughton and King (1989) reported that the fishing effort had increased significantly and the level of fishing mortality at that time appeared to be greater than the optimum required for the fishery. The study also estimated the von Bertalanffy growth parameters, which were then used to generate a recruitment pattern. A length-converted catch curve was constructed from which total mortality and mean selection size was estimated. Population size and exploitation pattern, yield per recruit and biomass per recruit were also estimated.

In 1991, the Fisheries department staff conducted a tagging study, but recovery was too small for any significant quantitative analysis. Young (1992) did a study on puerulus settlement rates on the south coast of Jamaica and found that settlement was continuous throughout the year Gittens (2001) reported that 30% of lobsters landed from the Pedro Bank was below the size of 50% maturity and that spawning stock biomass was low. In 1975, the Fisheries Division reported that 76% of the commercial lobster consisted of immature females (by comparison, Florida showed 17-21% immature females harvested), suggesting that there was an urgent need for strict management and protection. For 2005, 30% of the total lobster sampled was under the minimum size. The most recent assessment carried out was at the 2009 CRFM Scientific Meeting and results (unpublished) showed that the assessments were highly uncertain due to wide confidence intervals for the indicators and reference points of interest. Also, the general indications were that the stock was not likely to be overfished (median B/BMSY = 1.25), and overfishing is not occurring (median F/FMSY = 0.49, and most recent catch (111 tonnes) < replacement catch (179 tonnes)). In addition, the production model used did not fit the data well and was dependent on what is being assumed for the priors. Nonetheless, the model was the only one available at the time and provided some guidance on appropriate levels of harvest.

In response to varying recommendations for conducting more research to clarify uncertainties the Fisheries Division has embarked on a new project called The Lobster Casita Project with the aim to investigate a more efficient and sustainable system for the lobster fisheries. This is hoped to be achieved through:

- Investigating the use of casitas (artificial shelters) in major fishery areas.
- Establishing juvenile enhancement systems.
- Establishing pueruli (lobster larvae) monitoring programmes, which is useful for forecasting lobster catches.

2.3 Management regime

The Fishing Industry Act of 1975 recommended a minimum size for spiny lobsters (*P. argus*) of 76 mm (3 ins). Aiken (1977) recommended a gradual increase to 85 mm CL and Haughton and King (1989) also called for an increase in the minimum size limit to 89 mm CL as they found that about 55% of the females were mature at this length. It is illegal to land lobsters below this minimum size or offer such lobsters for sale. Female lobsters with eggs are also protected by the Act. Both provisions carry a maximum penalty of J$500 or six months in jail. This penalty is inadequate and certainly does not serve as a deterrent to offenders. The Act is being revised to implement fines of greater magnitude.

In order to combat the decline of lobsters, further management measures were implemented such as a closed season, which runs from April 1 to June 30 annually. Since the 2009 close season the implementation of a new legislation came into effect that prohibits persons or entities from having in their possession any lobster or parts thereof after 21 days of the commencement of the annual close season. Individual or entities caught with lobsters found after this period are subject to the seizure of products and prosecution in a Court of Law. In addition, no lobsters must be kept alive in any holding device during the Close Season. Enforcement activities include end-of-season declarations of lobster by the processors and inspections of fish processing plants, hotels, beaches, and restaurants. Further restrictions were placed on the industrial vessels: limited entry and gear restriction (Florida traps only).

Licenses for the industrial lobster fishery are granted with the following conditions:

- All licensed lobster fishing vessels shall fish only in the areas specified by the license.
- No fishing shall take place on the island shelf of Jamaica or on any proximal bank.
- All licensed lobster motor fishing vessels shall only fish, catch or land spiny lobster and no other species.
- All lobsters caught, except undersized and/or berried, which should be returned to the sea, shall be landed on mainland Jamaica no later than eight weeks after the commencement of each fishing trip.

Lack of adequate resources continues to hamper the effective enforcement of management regulations.

2.4 Summary of Stock Assessment Methods

Table 1 (adapted from FAO (2001)) presents an overview of some stock assessment methods that can be useful for assessing spiny lobster and other stocks. For each method, an overview is presented of the products that can be obtained, the main assumptions and the basic theory.

Table 1. Overview of stock assessment methods (adapted from FAO (2001)).

MODEL	ESTIMATE	INPUTS	ASSUMPTIONS	EXPLANATION
RELATIVE ABUNDANCE AND STANDARDIZED EFFORT	Relative abundance over time in numbers or biomass. Standardized fishing effort.	CPUE or from scientific surveys (e.g. pueruli collectors).	Closed population.	Indices of abundance play a vital role in monitoring how a stock fluctuates through time. They are often used to calibrate some production models, depletion models, and Virtual Population Analyses (VPAs), but are useful by themselves as estimates of the percentage change in population size from year to year. These indices can be subdivided into two main categories: fisheries-independent (obtained from scientifically-designed surveys) and fisheries-dependent (where catch per unit effort (CPUE) forms the basis). Effort from lobster traps can be quantified in many ways
MORTALITY FROM MEAN LENGTHS	Mortality (Z)	Mean length. Maximum length. von Bertalanffy parameters. Size at full recruitment.	Closed population. Equilibrium conditions. Constant selectivity.	There are two types of methods to estimate the ratio Z/K and both require fish length frequency data. Firstly, estimators based on an assumed probability distribution of lengths (distributional methods) and secondly, those estimators based on regression methods. 1) Beverton and Holt (1956) method derived deterministically an estimator of Z based on mean length and assumes an infinite lifespan 2) Ehrhardt & Ault method does not assume an infinite life span for the individuals of the stock being analyzed and thus, it can be applied to both long- and short-lived species.
CATCH CURVES	Mortality (Z)	Abundance (relative) in numbers by size class. Growth rates. Age (size) at full recruitment.	Closed population. Equilibrium conditions.	The methods assume steady state. Since this is typically not the case, analyses are sometimes carried out by pooling length frequency samples from several years with the hope of approximating average conditions. This occurs in cases where aging have proven to be difficult and so catch curve abundance as a function of length have been developed.

Table 1 cont'd. Overview of stock assessment methods.

MODEL	ESTIMATE	INPUTS	ASSUMPTIONS	EXPLANATION
LENGTH-BASED COHORT ANALYSIS	Fishing mortality (F). Population size by length interval.	Catch by size interval. L∞. M/K. F/Z for the largest size interval.	Equilibrium conditions. Closed population.	Length-based cohort analysis (LCA) is a modified Pope´s cohort analysis that makes use of catch-at-length data rather than catch-at-age. An important assumption for this technique is that differences in length are largely determined by age (Jones, 1974). In other words, variability in the time required to grow from one size to another is relatively less than the variability of length-at-age. In an analogous manner to age-based VPA and cohort analysis, LCA is used to provide information in numbers of fish and mortality rates by size. LCA, unlike age-based Cohort Analysis and VPA, requires a length composition representative of the catch under steady-state conditions (a stable length-structure).
DYNAMIC DEPLETION MODELS	Population size (local abundance). F. Q.	Catch in numbers. Effort (CPUE) or other index of abundance.	CPUE proportional to population size. Closed population or recruitment. Immigration/emigration explicitly modelled. Np equilibrium or steady state is assumed.	There are two ways to classify these models: (1) Simple depletion (no recruitment or constant recruitment). The classical Leslie-Delury type of analyses assumes that fish die only from capture. In a closed population, initial population size can be estimated by monitoring how the relative abundance decreases as catches are taken. Various modifications to this model have been made (2) Depletion with non-constant recruitment: In many cases, recruitment (immigration) takes place in pulses of varying magnitudes. Letting the recruitment change with time can modify the basic depletion model. There are several ways to implement such a model for estimation purposes.

Table 1 cont'd. Overview of stock assessment methods.

MODEL	ESTIMATE	INPUTS	ASSUMPTIONS	EXPLANATION
AGE-STRUCTURED PRODUCTION MODELS	Population size in biomass and numbers by age. F by age over time. MSY-related statistics.	Yield, indices of population size (biomass) or CPUE. M. Growth parameters. Selectivity by fishery.	Closed population. Explicit stock-recruitment relationship.	Age-structured production models were developed in response to important criticism of lumped biomass production models that may be unable to account for lags in the rate of population change due to changes in the age structure of the stock. The basic population model is a basic age-structured projection but modifications do exist for such.
PRODUCTION MODELS	Population size in biomass. F over time. MSY-related reference points.	Catch (biomass weight). Indices of population size (biomass) (e.g. CPUE).	Closed population. Density-dependent population growth that is independent of age-structure. Some poorer approaches assume equilibrium conditions.	Models that describe the dynamics of the stock in terms of biomass, rather than numbers at age are referred to as: production models, surplus production models or biomass dynamics models. They assume that changes in the size of a fish population are caused by the interaction among four competing factors: tissue growth, recruitment to the fishery and natural and fishing mortalities (M & F). The fundamental assumption of Production Models is that the effects of three of these factors – tissue growth, natural mortality and reproduction - can be incorporated into a single function and that this is dependent on a single quantity or state (stock size) only. The types of models include: Schaefer production model, Fox production model and Pella-Tomlinson Production Model. The PM approach can be used to (a) Estimate the historical and current *status* of a stock in terms of F and biomass; (b) Estimate MSY, biomass at MSY and F at MSY and determine the *status* of the stock relative to these benchmarks.

Table 1 cont'd . Overview of stock assessment methods.

MODEL	ESTIMATE	INPUTS	ASSUMPTIONS	EXPLANATION
REFERENCE POINTS	Reference points to address issues of conservation and productivity, e.g. MSY-related statistics, yield-per recruit, and spawners per recruit as a percentage of the maximum.	Life history characteristics (growth, reproduction, mortality). Those used for production models in the case of MSY-related statistics.	Closed population, various others depending on the approach	Reference points (RPs) are used to give , depending on an assessment's results, an indication of where the stock is with respect to where it should (or should not) be. Some reference points are often used as targets (TRP). Common examples of TRPs are B_{MSY} and F_{MSY}, the biomass corresponding to maximum sustainable yield (MSY) levels, or the fishing mortality rate that results in MSY. Other reference points are treated as thresholds or limits (LRPs), and these are points beyond which the fishery should not operate.
TUNED AGE-STRUCTURED ASSESSMENTS	Numbers at age. Fishing mortality at age.	Catch-at-age matrix (by year). Natural mortality. Age-specific indices of relative abundance. Other auxiliary inputs are possible.	Closed population. Other assumptions depending on the model used and available data. For example, the ratio of fishing mortality of the oldest age group to that of the previous age.	"Tuned" or "calibrated" age-structured analyses are similar in concept to cohort analyses: They use catch-at-age data to reconstruct the history of cohorts in terms of fishing mortality and population sizes. The key difference is that these methods take out the "guess work" involved in specifying terminal fishing mortality rates. This is done by "tuning" the analyses to indices of relative abundance (or effective fishing effort). In essence, the methods seek to estimate parameters (fishing mortalities, catchability coefficients) that best explain the catch at age and relative abundance data.

3 METHODS

3.1 Lobster Data Collection Activities

Since September 1996, Jamaica has been collecting catch and effort data by gear from artisanal fishers through random stratified sampling. Data from the industrial fishers are collected by census. Biological data (mostly carapace length and sexual maturity) are collected where possible, usually by three gear types (SCUBA, free lung and gill net) and at two major landing sites – Hellshire and Bull Bay.

3.1.1 Mainland artisanal fishers

Fishers based on the mainland and near shore banks are defined as mainland artisanal fishers. Most use traps; however, there are many full time fishers for whom diving is the main method of fishing. The catch and effort system target catch by gear types, since catch rates and effort differs by gear type. Lobster is caught using many different gear types; antillean z-traps, SCUBA, free dive, hookah and nets.

The assumptions include:

- Catch rates by gear types within stratum are similar.
- The catch rates for SCUBA, hookah and free dive are significantly different, thus the gears should be treated separate.

Catch, effort and biological data are collected by gear type. Seven Miles Bull Bay (mainly Hookah) and Hellshire (mainly SCUBA) are visited twice per month with a target of 200 biological samples monthly. The Fisheries Division has been unable to collect landings information from Rocky Point, Clarendon – landing site that used mainly nets.

3.1.2 Offshore artisanal fishers

Offshore artisanal may be defined as fishers based mainly on Pedro and Morant Cays. Lobsters from the offshore artisanal are caught by traps, SCUBA and hookah, supplied to carrier vessels that land the catch on the mainland. Lobster processors send workers to the landing sites to purchase the lobsters. The Division collects the landings from the packer boats data collection programme. No effort data are collected.

3.1.3 Industrial fishers

Fishers who are based on the mainland but operate on the Pedro and Morant banks in 20 - 35m length vessels are defined as industrial fishers. These fishers are licensed to use lobster (Florida) traps. The processor sometimes owns the operation and 90% of the lobster is exported. At the processing plants, lobsters are landed tailed. Log sheets/books are issued to the captains of industrial vessels. At the end of a trip or fishing season the Fisheries Division collects the log sheets from vessel captains.

3.2 Summary of data used

For the purposes of this paper the data used to conduct the various analyses are summarised in Table 2.

Table 2. Description of available data on Jamaica spiny lobster fishery for assessments.

Name	**Description**
Catch and effort data	The catch and effort system notes catch by gear types, since catch rate differs by gear type. Lobster is caught using many different gear types: Antillean Z-traps, SCUBA, free dive, hookah and nets. The catch landed by each boat is recorded on a standard form and is submitted to the Data Unit.
Biological data	Samples (target of 200 individuals per month) were taken from landed catches, and data on sex, maturity stage, carapace and tail length was recorded for each sample. The total weight of the catch, as well as the sampled weight, was also noted. All biological data are linked to the boat from which the sample was taken.
CPUE Index	From trip interviews (TIP) 1995-1997, 2000-2002, and 2004-2006, catch per trap hour is available.
Total lobster exports	Annual exports were obtained from the 1979-2007 reports retained at the government statistics office (Statistical Institute of Jamaica, STATIN).

3.3 Data Exploration Methodology

The R statistical software was used to generate length-frequency distributions for the available data. These were plotted according to

a) Year.
b) Year and landing site.
c) Year, yearly quarter.
d) Year, sex.

In addition, the mean carapace length and ratio of lobsters caught below the minimum legal size of 76 mm were calculated by each quarter per year. This was done based on all landing sites combined and according to data from the two main landing sites (Hellshire and Seven-Miles Bull Bay).

3.4 Methodology for surplus production model

Russell wrote a simple algebraic expression, which describes what induces a gain or loss in a population of fish where the stock is being fished and emigration and immigration are irrelevant. He summarized stock biomass dynamics as:

(1) $B_{t+1} = B_t + A_t + G_t - \mathrm{M}_t - C_t$

where:

B_{t+1}: is the stock biomass in year t+1.
B_t: is the stock biomass in year t.
A_t: is the sum of the initial weights of all individuals recruiting to the stock each year.
G_t: is the sum of the growth in biomass of individuals already recruited to the stock.
M_t: is the sum of the weights of all fish, which die of natural causes during the year.
C_t: is the sum of weights of all fish caught.

Russell's model formed the foundation for mathematical methods by which estimates of how many fish are in a particular stock (abundance or biomass) could be determined. Russell's equation (equation 1) can be simplified for instances where only the catch is known thereby requiring certain assumptions to be made. The gain terms, recruitment and growth is generally referred to as production. Surplus production (P_t) is defined as the difference between production term (recruitment and growth) and natural mortality. Russell's equation can thus be simplified to the following form:

(2) $B_{t+1} = B_t + P_t - C_t$

which simply means that the biomass in the next time period is equal to the biomass in the previous time period plus surplus production minus the catch. It is generally assumed that the surplus production is a function of the biomass at any given time, i.e.

(3) $B_{t+1} = B_t + f(B_t) - C_t$

where B_t is the stock biomass at the beginning of year t, $f(B_t)$ is the production function of the biomass in year t, and C_t is the catches in year t. $f(B_t)$ is thus a function that describes the population dynamics: birth, gain in weight and natural mortality, as a function of the biomass; i.e. the agglomeration of the R, G and M terms in Russell's original formulation.

Three common forms of production model in use today include the classic Schaefer model, the modified Fox model and the modified Pella and Tomlinson model. These models differ in the assumption made about the response of the production as a function of biomass. The Schaefer model was used in this paper and is often referred to as the logistic model where the production term is described as:

(4) $f(B_t) = rB_t\ (1\text{-}B_t/K)$

where r is the intrinsic growth rate and K is the carrying capacity (the average biomass level prior to exploitation) or the virgin biomass. The Schaefer form of the basic equation of the production model is thus:

(5) $B_{t+1} = B_t + rB_t\ (1\text{-}B_t/K) - C_t$

Recognizing that catch is a product of fishing mortality (F) and biomass the equation can be written as:

(6) $B_{t+1} = B_t + rB_t\ (1\text{-}B_t/K) - F_t\ B_t$

This equation is usually referred to as the biological model, where the population trajectory is simply a function of the initial biomass, the intrinsic growth rate (r), the carrying capacity (K) and the fishing mortality (F).

Direct measures of biomass are rarely available in marine populations. Indices of stock size such as catch rate (catch per unit effort - CPUE) are however frequently collected. It is often assumed that these indices are proportional to the stock size, i.e.

(7) $\text{CPUE}_t = C_t/E_t = U_t = qB_t$

Here q stands for catchability, which acts as a simple scaling factor. The CPUE data can either be from the commercial fishery or based on survey abundance information.

3.4.1 Detailed outline of method applied to model

There are three methods used to estimate the parameters of the biomass dynamic model when only an index of abundance (CPUE, index of abundance from surveys etc.) is available. These are (1) The assumption of equilibrium conditions (2) Transformation of the equations into linear forms (3) Time series fitting. All three methods use the assumption that the relationship between CPUE and effort is linear. The method that is at present considered best, and which is also the most transparent, for estimating production model parameters is the nonlinear time-series fitting methods. This method was used in this paper. Here the parameters q, r, K and the biomass in the first year are (B1) in equations 5 and 7 are estimated directly by minimizing:

$$_{\min} SS = \sum_{t=0}^{t} \left(\ln U_t - \ln \hat{U}_t \right)^2$$

For this paper, the raw catch and effort data obtained from the artisanal fishers since 1996, was processed by combining similar fishing gears/techniques. Within each category the effort data (fishing days) by fishing gear/technique was summed and the CPUE calculated (kg/fishing days). Using the export data obtained from STATIN to represent the estimated total landings of lobsters the following were re-calculated (raised) for each groupings of fishing gear/technique; a) **Catch**: the total catch was estimated for each year by multiplying the proportion of the total sampled catch by the total landings (see Appendix I) i.e. Catch = % catch * total landings, b) **Effort**: the total effort was then calculated by multiplying the new raised catch figure by the CPUE (obtained from the sampled catch). This new total effort obtained was used to conduct further analyses such as in the Schaefer model.

The basis of stock production model is formed from equations 6 and 7. Observations of catch and stock indices were used to estimate catchability (*q*), but for the purpose of this exercise the intrinsic rate of growth (r) and the carrying capacity (K) were fixed values (as shown in C4 and C5 of Table 3). In addition, the biomass at the start of the time series available (B_0=K) was also estimated.

The catch and effort data for the Jamaica spiny lobster fishery were entered from rows 11 to 39 across columns A, B and C. Observed CPUE for the available effort data was calculated by inserting **=IF(B29="";"";C29/B29)** in cell D29 and copied down to row 39. This formula examines the contents of cells B (effort) and if empty, returns an empty value in corresponding D cells for Catch/Effort.

Expected CPUE (E11:E39) was calculated by multiplying the value of *q* by average biomass using the formula **=IF(G11="";"";$C$3*G11).**

The biomass for the first year is assumed to be the same as the virgin biomass. The remaining biomass at time *t* is calculated by inserting in the formula **=MAX(1;F11+$C$4*F11*(($C$5-F11)/$C$5)-C11)** in cell F12 and copied down to F39. This is the basic equation for the Schaefer production model shown in equation 5. The MAX function ensures that the stock biomass cannot go extinct when using the solver.

The average of the two biomass levels (B_{mid}) were calculated using the formula **=(F11+F12)/2.** This formula was copied from G11 through to G39. Taking the average of the two biomass levels relates to using the average biomass at the start and end of year *t* so that the catches relate to the biomass more realistically. The B_{mid} values were then used calculate a new observed catch by multiplying by value by the corresponding observed CPUE for each year. The formula used in cell H11 was **=D29*G29** and was copied down to H29. A sum was then taken using the formula **=SUM(H11:H38)** and pasted in cell H8. Each B_{mid} value obtained was squared (I11:I38) and the sum also taken and inserted in cell I8. From these two resulting sums the *q* parameter was calculated by dividing H8 by I8 (formula shown in table above, cell C3).

In J29 the formula **=(D29-E29)^2** was placed and copied down to J39 in order to obtain the squared normal residual errors. The sum of the errors were calculated using the formula **=SUM(J11:J38)** and placed in cell J9 which became the target cell for the solver. In the solver option the sum of squares were minimized by changing cells $C$4:$C$5 subject to the constraint $C$4<= 0.8

The expected catch (K29:K39) was obtained by using the formula **=IF(B29="";"";B29*E29)** that is, multiply the observed effort by the expected CPUE.

The instantaneous fishing mortality rate was estimated by converting the annual exploitation rate (catch/biomass), denoted by the formula **=C11/G11**. This satisfies the formula

(8) $F_t = C_t/((B_t+B_{t+1})/2)$

where F_t is the instantaneous fishing mortality rate in year t, C_t is the catch in year t and $(B_t+B_{t+1})/2$ is the mid-year biomass for year t.

The estimated parameters *r, q* and *K* were then used to calculate fishery performance indicators of maximum sustainable yield (MSY), Biomass that gives MSY ($B_{(MSY)}$), fishing mortality at MSY ($F_{(MSY)}$) and effort that should lead to MSY (E_{MSY}) as follows:

MSY = rK/4 in cell F3, formula **=C4*C5/4**
B_{MSY} = K/2 in cell F4, formula **=C5/2**
E_{MSY} = r/2q in cell F5, formula **=C4/(2*C3)**
F_{MSY} = r/2

Table 3. Schaefer production model fitted to the Jamaica spiny lobster data used in Microsoft excel spreadsheet.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Schaefer biomass dynamics model															
2		**Parameters**			**Reference points**											
3		**q**	=H8/I8		**MSY**	=C4*C5/4										
4		**r**	0.8000		**Bmsy**	=C5/2										
5		**K**	1109.45		**Fmsy**	=C4/(2*C3)										
6					**Fmsy**	=F3/F4										
7	K= B_0 (unexploited biomass)				$Bmsy/B_0\%$	=F4/C5*100										
8								=SUM (H11:H38)	=SUM (I11:I38)	target cell for Solver						
9										=SUM (J11:J38)						
10	**Year**	**Effort (Fishing Days)**	**Catch (Ton)**	**Observed CPUE (Ton/ Fishing Day)**	**Expected CPUE (Ton/ fishing day)**	**Bt (Ton)**	**Bmid (Ton)**	**ObsCPUE * Bmid (Ton)**	**Bmid^2 (Ton)**	**error^2**	**Expected catch (Ton)**	**F**	**F/ Fmsy**	**B/ Bmsy**	**C/ Cmsy**	**%B0**
11	1979		12.54		0.13	1109	1103					0.011	0.028	2.000	0.056	
12	1980		9.23		0.12	1097	1097					0.008	0.021	1.977	0.042	100.0
13	1981		28.52		0.12	1098	1088					0.026	0.066	1.979	0.129	98.9
14	1982		31.17		0.12	1078	1075					0.029	0.073	1.944	0.140	98.9
¬	¬	¬	¬	¬	¬	¬	¬	¬	¬	¬	¬	¬	¬	¬	¬	¬
29	1997	714	79.26	0.11	0.10	819	865	96.10	749028	0.0002	70.02	0.092	0.229	1.477	0.357	69.5
30	1998	2014	105.70	0.05	0.10	912	924	48.47	853262	0.0027	210.91	0.114	0.286	1.643	0.476	73.9
31	1999	4202	284.23	0.07	0.10	936	852	57.65	726519	0.0008	406.00	0.333	0.834	1.687	1.281	82.2
32	2000	4002	287.77	0.07	0.08	769	719	51.73	517447	0.0001	326.26	0.400	1.000	1.386	1.297	84.4
33	2001	2452	166.77	0.07	0.08	670	693	47.10	479771	0.0001	192.53	0.241	0.602	1.208	0.752	69.3
34	2002	715	130.24	0.18	0.09	715	752	136.88	565429	0.0094	60.98	0.173	0.433	1.290	0.587	60.4
35	2003		294.69		0.08	788	732					0.402	1.006	1.421	1.328	64.5
36	2004		450.81		0.06	676	556					0.810	2.025	1.219	2.032	71.1
37	2005	7436	367.60	0.05	0.04	437	359	17.74	128753	0.0001	302.43	1.024	2.561	0.787	1.657	61.0
38	2006	7643	97.32	0.01	0.04	281	316	4.03	99984	0.0005	273.94	0.308	0.769	0.506	0.439	39.4
39	2007	8368	111.54	0.01	0.04	351	351					0.317	0.793	0.634	0.503	25.3

3.5 Length frequency models

3.5.1 Estimation of catch in numbers

The measurements obtained for the length frequency distribution of the sampled population of spiny lobster were grouped into 5mm class intervals annually according to sex. For the purpose of this exercise the length-frequencies for three years (2005-2007) were considered for the cohort analysis and prediction models (later described). Initially, the total weight of a single animal for each length class was estimated using the length-weight relationship formula ($W= aL^b$) where a and b were obtained from Cuban estimates ($a = 0.243 * 10^{-5}$, $b = 2.764$). Once obtained the total weight sampled (by sex and then total) was obtained by simply multiplying the number sampled within each length class with the corresponding weight of the length class. A raising factor was then established for each year and was achieved by dividing the reported annual catches by the sum of the total weight per length class (males and females combined) for the corresponding year. This factor was then used to determine the estimated number of males and females that would have been landed based on the distribution pattern obtained from the samples by multiplying the frequencies within each length class with the yearly raising factor.

3.5.2 Virtual population methods

Methods that look at the historic data are referred to as virtual population analysis (VPA) or cohort analysis and were first developed as age-based methods. VPA and cohort analysis are used to determine the number of fish that must have been present in the sea to account for a known sustained catch and the fishing effort that must have been expended on each length group to obtain the numbers caught. The advantage of doing a VPA makes it easier to predict future catches. In cases where length composition data for the total fishery are available for a year (or the average length composition for a sequence of years) then it is assumed that the picture presented by all length classes caught reflects that of a single cohort during it entire life span.

Jones' length-based cohort analysis

The goal of the Jones' length-based cohort analysis is to use length frequency data of catches in a back-calculation algorithm to estimate population abundance and fishing mortality in a manner similar to cohort analysis (Quinn and Deriso 1999). Three assumptions are made for this method:

1) Catches in length are measured without error.
2) The assumptions for cohort analysis of age data are met.
3) Growth can be modelled using the deterministic von Bertalanffy model.

A detail of the formulae used in arriving at the population abundance and fishing mortality of the Jamaica spiny lobster using Jones' method is described in Table 4.

The von Bertalanffy growth parameters and natural mortality factor for the Jamaica spiny lobster have been estimated as:

K = 0.230 per year (male); 0.220 per year (female).
L_∞ = 185.4 mm (male); 158.3 (female).
M = 0.34 per year.

Table 4. Description of the formulae used in the Excel spreadsheet for the Jones' length-based cohort analysis.

Column Title	Excel Formula	Description
L_{mean}	None stated	The midpoint of each length group calculated by adding the lower and upper limit (L1and L2) and dividing by 2.
L1 , L2	None stated	Defines the length groups where L1 is the lower limit L2 the upper limit.
X	=(($B$3-C10)/($B$3-D10))^($B$6/(2*$B$4))	X represents the natural mortality factor. For each length class the fraction of the number of fish that attain length L1 which survived natural deaths during the time period from age L1 to age L2 was calculated based on the equation: $((L_\infty\text{-L1})/ L_\infty\text{-L2})^{(M/(2K))}$
C		Mean catch in numbers (by sex) was obtained from data for period 2005-2007 (process described in section 3.5.1 – Estimation of catch in numbers).
N_i	=F27/H27 =(G27*E26+F26)*E26	The number of lobsters attaining a length of 132mm (cell B27, the largest length class) was estimated by dividing the catch in numbers (F27) by the exploitation rate (H27). The model requires that an initial estimate of F/Z be made (0.885 for male, 0.9 for female). The equation being satisfied is: $C(L1,L2)=N(L1)*F/Z*[1-\exp(-Z*\Delta t)]$ where C(L1,L2) is the number of fish caught of lengths between L1 and L2; N(L1) is the number of fish that attain length L1 (survivors); F/Z is the exploitation rate; Δt refers to fishes longer than L∞ (Δt = ∞) therefore exp(-Z*∞)=0 Once these initial estimates were attained then the subsequent stock numbers were calculated (moving backwards) which satisfied the formula: $N(L1)=[N(L2)*X(L1,L2)+C(L1,L2)]*X(L1,L2)$ Where N(L2) is the number of fish that attain length L2; X(L1,L2) is the natural mortality factor and C(L1,L2) is the catch in numbers.
F/Z	=F26/(G26-G27)	This represents the exploitation rate where the initial was estimated and the remaining ones estimated by: $F/Z=C(L1,L2)/[N(L1)- N(L2)]$
F	=$B$6*((H11/(1-H11)))	Fishing mortality is for each length class is calculated based on the formula: $F= M*(F/Z)/(1-F/Z)$
Z	=I10+$B$6	Total mortality Z was computed by adding the calculated F and the estimated M i.e.: $Z = F + M$
W_{mean}		The estimate of body weight (kg) for each length group previously calculated from the length – weight relationship: $W_i= a[(L_i+L_{i+1})/2]^b$
W_i	=$E$3*C10^$E$4	This formula computes the body weights using the lower limit (L1) for each length class. The Cuban parameters for a and b were constants used in the length-weight relationship as stated above.
N_{mean}	=(G10-G11)/J10	The annual mean number of lobster within each length class is calculated by taking the difference of the number in current length class and the next then dividing by the total mortality of the length class being examined. The formula represented here is: $N_{mean}= [N(L1)- N(L2)]/Z$
B_i	=G10*L10/1000	The annual biomass (B_i) for each length class is calculated by multiplying the mean weight (W_i) of a single individual by the total number (N_i) within each length class. The estimate was then divided by 1000 to obtain the biomass in tons.
B_{mean}	=M10*K10/1000	The annual mean biomass of lobster during its life span of a cohort is calculated by multiplying the mean weight (W_{mean}) of a single individual by the annual mean number (N_{mean}) within each length class. The estimate was then divided by 1000 to obtain the annual mean biomass in tons.
Y(tons)	=K10*F10/1000	Calculation of total yield (weight of the catch) was obtained by multiplying the catch/capture in number (C) by average weight (W_{mean}) of each length class then divide by 1000 to convert to tons.
F/F_{mean}	=I10/$I$37	For each estimate of F per length class the ratio of F/F_{mean} was calculated and used as the basis for selectivity in the Thompson and Bell method described below. F_{mean} is the mean of all the F values obtained.

3.5.3 Prediction models

The Jones' length-based cohort analysis was used to analyse the history of the Jamaica spiny lobster fishery. From these results the knowledge obtained was then used to make predictions concerning the future yield and biomass at different levels of fishing effort.

Thompson and Bell method

The first prediction model to have been developed was the Thompson and Bell model and was used in areas where VPA and cohort analysis were applied. The two main stages of the model are:

a) Provision of inputs:
   i) Reference F-at-age-array: which is an array of F-values per age (length) group preferably from an analysis of historical data (VPA or cohort analysis).
   ii) Recruits: may also be obtained from historical data and is needed for predictions on yields etc. in absolute quantities.
   iii) Weight-at-age-array: this is the weight of individual fish per age (length) group.
b) Outputs:
   i) Catch in numbers.
   ii) Total number of deaths.
   iii) Yield.
   iv) Mean biomass.
   v) Value.

All outputs are per age group and related to values of F for each age group.

The method was applied to the spiny lobster fishery using MS Excel spreadsheets. Details of the formula used throughout the spreadsheets are outlined in Table 5. Analyses were conducted based on each sex however each column title and the formulae were applicable to both.

Once all analyses were completed, taking a mean value for F, the total yield and biomass (both sexes combined), these results were then used as a reference to make predictions of yield, mean biomass and ratio of biomass to unexploited biomass that corresponds to varying F-factors. From these results an estimate of MSY was obtained.

3.5.4 Projections

Model outcome poses some level of uncertainty and cannot inform resource managers about the risks associated with a particular management option (Haddon 2001). It is therefore necessary to project the population dynamics model into the future given varying management options. In this paper, various options were considered but specifically related to projections with 1) set catches and 2) set effort all based on the outcomes of the surplus production model described in section 3.4. Investigations of the implications of setting different catch levels were achieved through the use of the Schaefer dynamic production model as was previously described. Given the recommended effort level from the outcomes of the surplus production model, the catch implied (C) by the stock biomass (B), the catchability (q) and the effort (E) imposed was projected through the relationship $C = qEB$.

Table 5. Description of the formulae used in the Excel spreadsheet for the Thompson and Bell model.

Column Title	Excel Formula	Description
L1 , L2		Defines the length groups where L1 is the lower limit L2 the upper
L_{mean}	=(A13+B13)/2	This formula computes the midpoint of each length group by adding the lower and upper limit (L1and L2) and dividing by 2
X	=(($B$5-A13)/($B$5-B13))^($B$8/(2*$B$6))	X represents the natural mortality factor. For each length class the fraction of the number of fish that attain length L1 which survived natural deaths during the time period from age L1 to age L2 was calculated based on the equation: $((L_\infty\text{-L1})/ L_\infty\text{-L2})^{(M/(2K))}$
W_i kg	=$E$5*A13^$E$6	This formula computes the body weights of the lengths at the lower limit of each length group. The Cuban parameters for a and b are constants of the length-weight relationship are used in the calculations.
W_{mean} Kg	=$E$5*C13^$E$6	This is a repeat of the estimating body weight (kg) for each length group but takes the midpoint of each group as the length. Again the Cuban parameters for a and b are used in the calculation. The equation being satisfied therefore is: $W_i= a[(L_i+L_{i+1})/2]^b$
F	=$I$38*H13	Computes the fishing mortality for each length group by taking the product of current mean F (F_{mean}) and the selectivity pattern for each length class. Input values obtained from Jones' cohort analysis.
Z	=I13+$B$8	Calculate the total mortality by adding the calculated F and the estimated M
N	=+K6 =K13*((1/D13)-(I13/J13))/(D13-(I13/J13))	The first cell is the initial recruitment as defined in cell K6. Value obtained from Jones' cohort analysis. For the remaining cells, the formula was used to compute the total number of recruits/individuals within each length groups
N_{mean}	=(K13-K14)/J13	The annual mean number of lobster within each length class is calculated by taking the difference of the number in current length class and the next then dividing by the total mortality of the length class being examined.
C_{num}	=(K13-K14)*(I13/J13)	The capture in number is calculated by taking the number of deaths between length class (N_1-N_2) and then applying the proportion of fishing mortality (F) of the total mortality (Z)
Y(ton)	=M13*G13/1000	Calculation of total yield by multiplying the catch/capture in number (C_{num}) by average weight (w_{mean}) of each length class then divide by 1000 to convert to tons.
Bi(ton)	=$F13*K13/1000	The biomass (Bi) for each year class is calculated by multiplying the estimated weight of a single individual by the total number within each class. The estimate was then divided by 1000 to obtain the biomass in tons.
Revenue (US$)	=$P$6*N13*1000	The income (economic value) of the yield in US$ is calculated by multiplying the price per kg by the yield in kg. Mean price was calculated for period 2005-2007 from Export data provided.

4 RESULTS

4.1 Results from the Data Exploration

Figures 2, 3 and 4 are the graphical outputs of the length-frequency distributions generated by the R statistical software. Tables 6, 7 and 8 represent a summary of the mean carapace length and ratio of lobsters caught below the minimum legal size of 76 mm generated for each quarter per year for the combined data set and also separately according to the two main landing sites, Hellshire and Seven-Miles and Bull Bay. Note however that limited data were collected during the second quarter and was not shown here. This is mainly because the fishery is closed during this time.

The results of the exploration revealed three very important points:

1) The target sample size of 200 per month (or 600 per quarter) is not being met (Table 8). In fact, the target was met only once in 2007 for the first quarter. In general, the best samples were obtained from 2006 onwards.
2) Generally, the mean carapace length for each quarter was above the legal minimum size of 76 mm where the years 2001, 2005 and 2006 (quarters 4, 3 and 1 respectively) were the only years that exhibited mean carapace lengths below this minimum legal size.
3) In regards to the distribution of number of lobsters landed below the legal size by quarters (based on the total sample size) the data showed that 13 quarters had samples between 5-29%, 9 quarters between 30-60% samples and 3 quarters had more than 60% of the samples. The highest percentage (90%) was noted in 2005, which also corresponds to lowest mean size (65 mm CL). Table 7 shows that all these samples were taken from Seven-Miles Bull Bay.

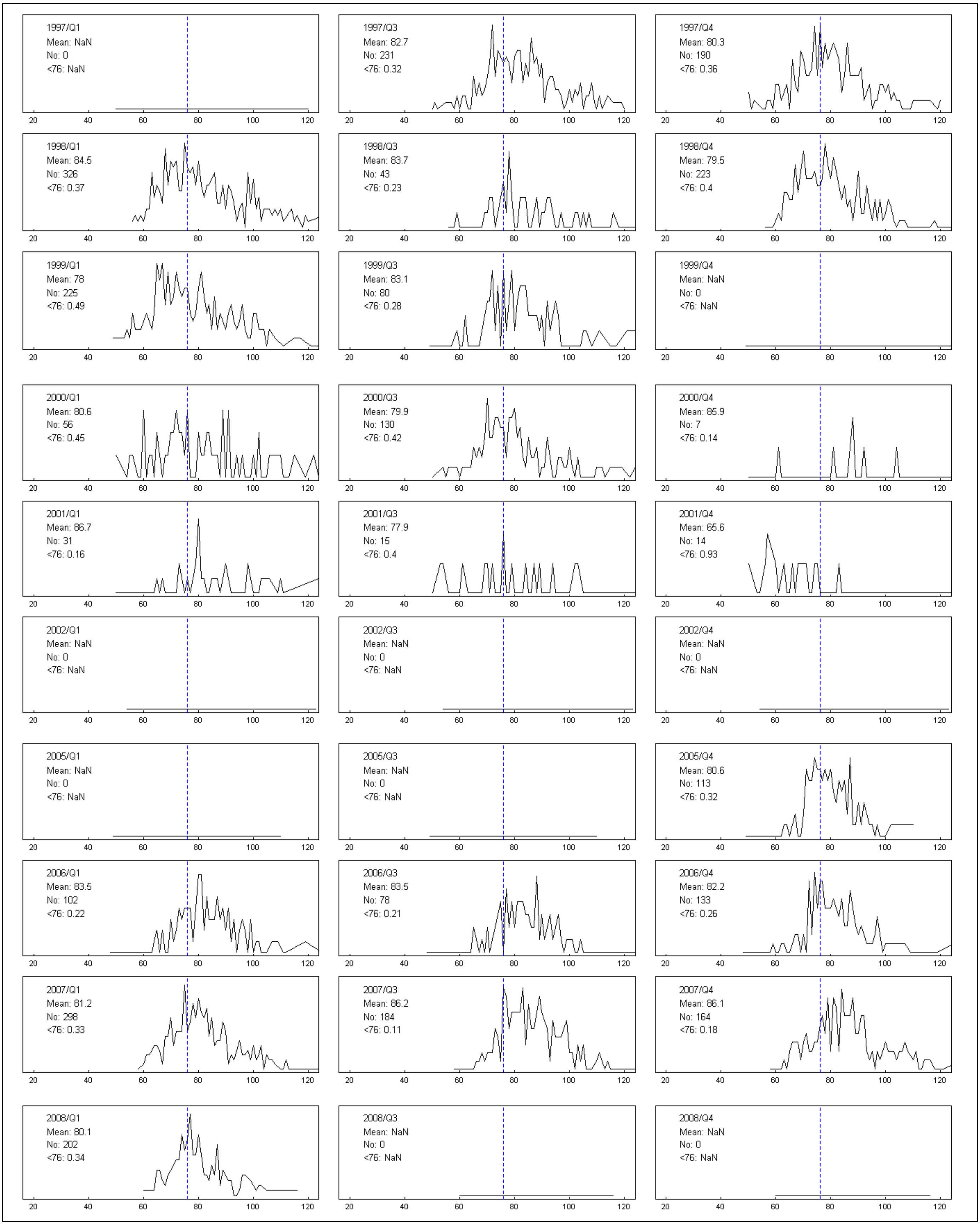

Figure 2. Length-frequency distributions generated by the R statistical software for Hellshire, based on three quarters by year.

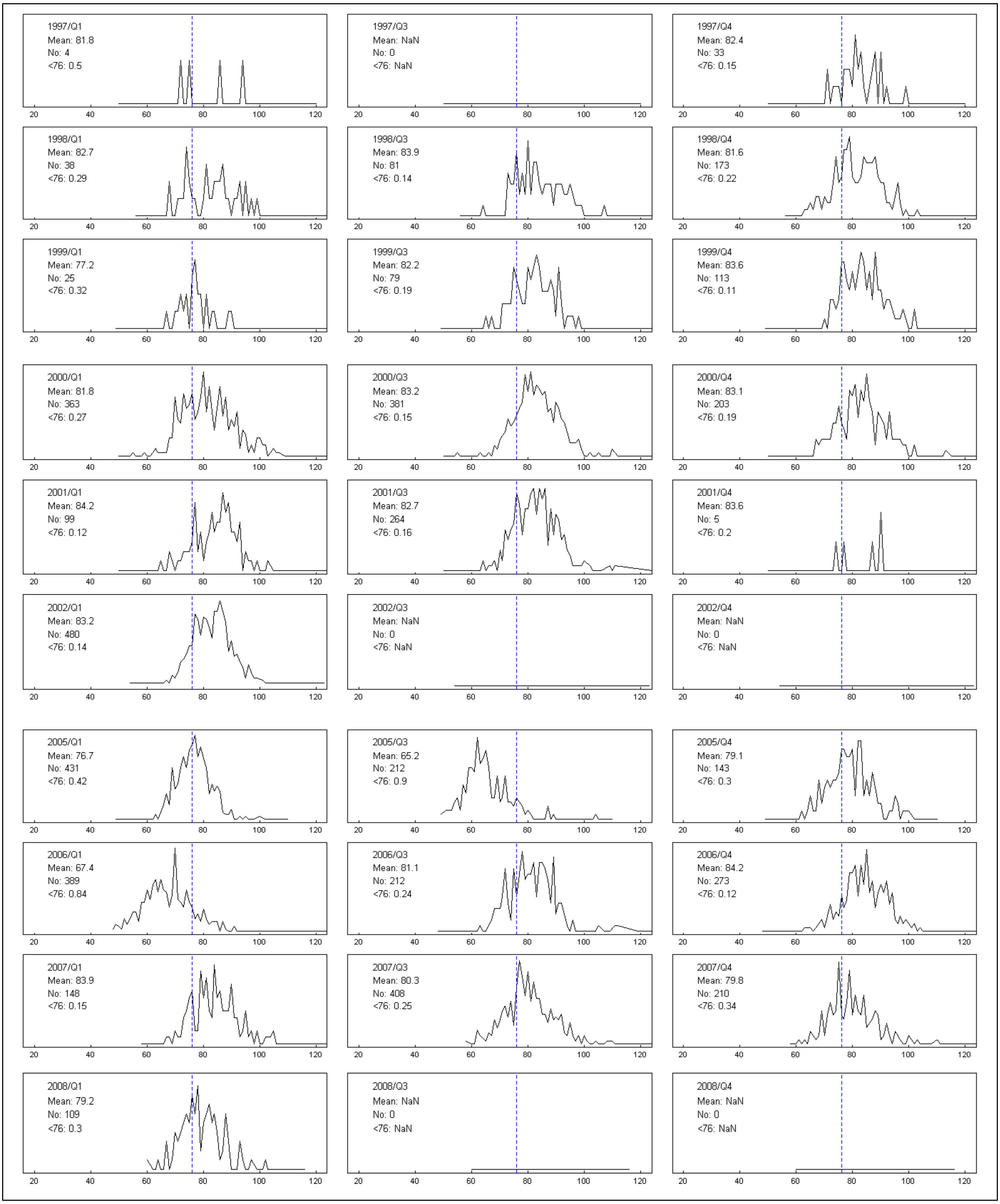

Figure 3. Length-frequency distributions generated by the R statistical software for Seven-Miles Bull Bay, based on three quarters by year.

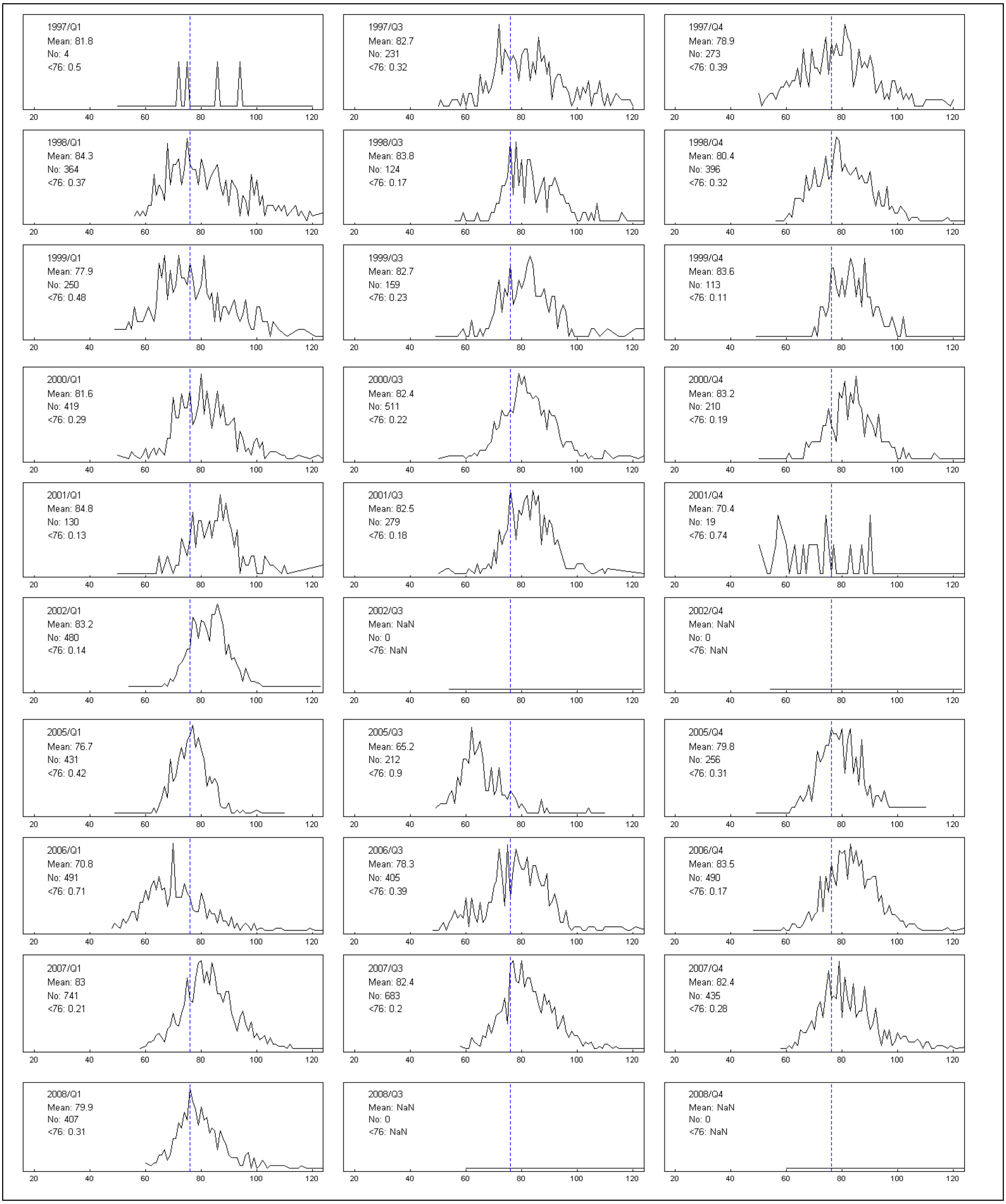

Figure 4. Length-frequency distributions generated by the R statistical software for all beaches, based on three quarters by year.

Table 6. Summary total sample size, mean sample size and ratio of lobsters sampled that are below the legal minimum size across the years per quarter for Hellshire.

	YEAR	SAMPLE SIZE	MEAN SIZE (mm)	RATIO BELOW LEGAL MIN SIZE (76 mm)
QUARTER 1 (JANUARY – MARCH)	1997	-		
	1998	326	84.5	0.37
	1999	225	78	0.49
	2000	56	80.6	0.45
	2001	31	86.7	0.16
	2002	-	-	-
	2005	-	-	-
	2006	102	83.5	0.22
	2007	298	81.2	0.33
	2008	202	80.1	0.34
QUARTER 3 (JULY – SEPTEMBER)	1997	231	82.7	0.32
	1998	43	83.7	0.23
	1999	80	83.1	0.28
	2000	130	79.9	0.42
	2001	15	77.9	0.4
	2002	-	-	-
	2005	-	-	-
	2006	78	83.5	0.21
	2007	184	86.2	0.11
	2008	-	-	-
QUARTER 4 (OCTOBER – NOVEMBER)	1997	190	80.3	0.36
	1998	223	79.5	0.4
	1999	-	-	-
	2000	7	85.9	0.14
	2001	14	65.6	0.93
	2002	-	-	-
	2005	113	80.6	O.32
	2006	133	82.2	0.26
	2007	164	86.1	0.18
	2008	-	-	-

Table 7. Summary of total sample size, mean sample size and ratio of lobsters sampled that are below the legal minimum size across the years per quarter for Seven-Miles Bull Bay.

	YEAR	SAMPLE SIZE	MEAN SIZE (mm)	RATIO BELOW LEGAL MIN SIZE (76 mm)
QUARTER 1 (JANUARY – MARCH)	1997	4	81.8	0.5
	1998	38	82.7	0.29
	1999	25	77.2	0.32
	2000	363	81.8	0.27
	2001	99	84.2	0.12
	2002	480	83.2	0.14
	2005	431	76.7	0.42
	2006	389	67.4	0.84
	2007	148	83.9	0.15
	2008	109	79.2	0.3
QUARTER 3 (JULY – SEPTEMBER)	1997	-	-	-
	1998	81	83.9	0.14
	1999	79	82.2	0.19
	2000	381	83.2	0.15
	2001	264	82.7	0.16
	2002	-	-	-
	2005	212	65.2	0.9
	2006	212	81.1	0.24
	2007	408	80.3	0.25
	2008	-	-	-
QUARTER 4 (OCTOBER – NOVEMBER)	1997	33	82.4	0.15
	1998	173	81.6	0.22
	1999	113	83.6	0.11
	2000	203	83.1	0.19
	2001	5	83.6	0.2
	2002	-	-	-
	2005	143	79.1	0.3
	2006	273	84.2	0.12
	2007	210	79.8	0.34
	2008	-	-	-

Table 8. Summary of total sample size, mean sample size and ratio of lobsters sampled that are below the legal minimum size across the years per quarter for all landing sites combined.

	YEAR	SAMPLE SIZE	MEAN SIZE (mm)	RATIO BELOW LEGAL MIN SIZE (76 mm)
QUARTER 1 (JANUARY – MARCH)	1997	4	81.8	0.5
	1998	364	84.3	0.37
	1999	250	77.9	0.48
	2000	419	81.6	0.29
	2001	130	84.8	0.13
	2002	480	83.2	0.14
	2005	431	76.7	0.42
	2006	491	70.8	0.71
	2007	741	83.0	0.21
	2008	407	79.9	0.31
QUARTER 3 (JULY – SEPTEMBER)	1997	231	82.7	0.32
	1998	124	83.8	0.17
	1999	159	82.7	0.23
	2000	511	82.4	0.22
	2001	279	82.5	0.18
	2002	-	-	-
	2005	212	65.2	0.9
	2006	405	78.3	0.39
	2007	683	82.4	0.2
	2008	-	-	-
QUARTER 4 (OCTOBER – NOVEMBER)	1997	273	78.9	0.39
	1998	396	80.4	0.32
	1999	113	83.6	0.11
	2000	210	83.2	0.19
	2001	19	70.4	0.74
	2002	-	-	-
	2005	256	79.8	0.31
	2006	490	83.5	0.17
	2007	435	82.4	0.28
	2008	-	-	-

4.2 Results from surplus production model

The MSY was estimated to be 222 tons. Figure 5 shows a plot of the reported annual catch and the MSY reference point estimated from the Schaefer biomass production model. The results illustrated that there has been a gradual increase in catch over the years. Up until 1994 the catch was well below the MSY. However, in subsequent years, the MSY was exceeded for up to six years. It was also observed that after periods of fishing over the MSY, the catch was then reduced for periods of 2-3 years.

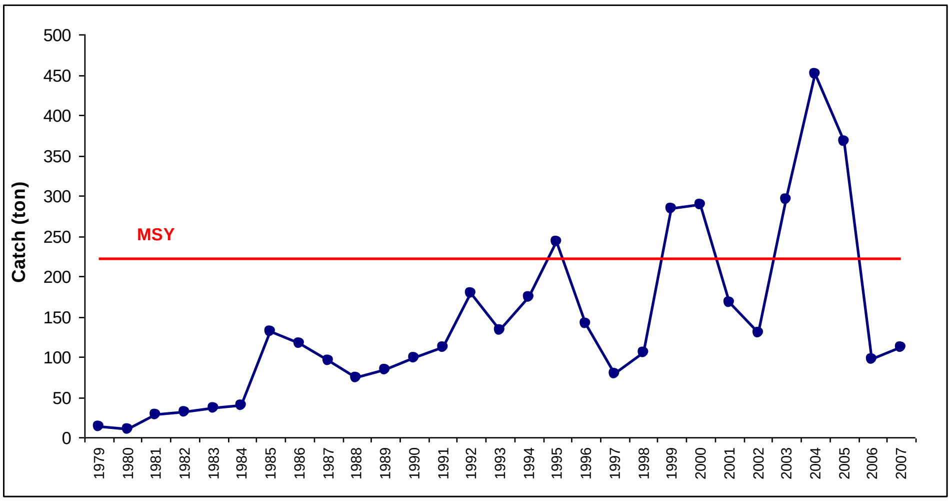

Figure 5. Reported annual catch and catch for Maximum Sustainable Yield (MSY) Reference Point from the Schaefer biomass dynamics model.

The fishing mortality rate for the MSY reference point (F_{MSY}) using the Schaefer biomass dynamics model was estimated to be 0.4. Figure 6 is a graphical representation of the annual fishing mortality rates (F) and the F_{MSY} reference point. The figure illustrated that annual F values were generally below the F_{MSY} with exceptions for F values in years 2000, 2003, 2004 and 2005, which were more than twice F_{MSY} (Table 9).

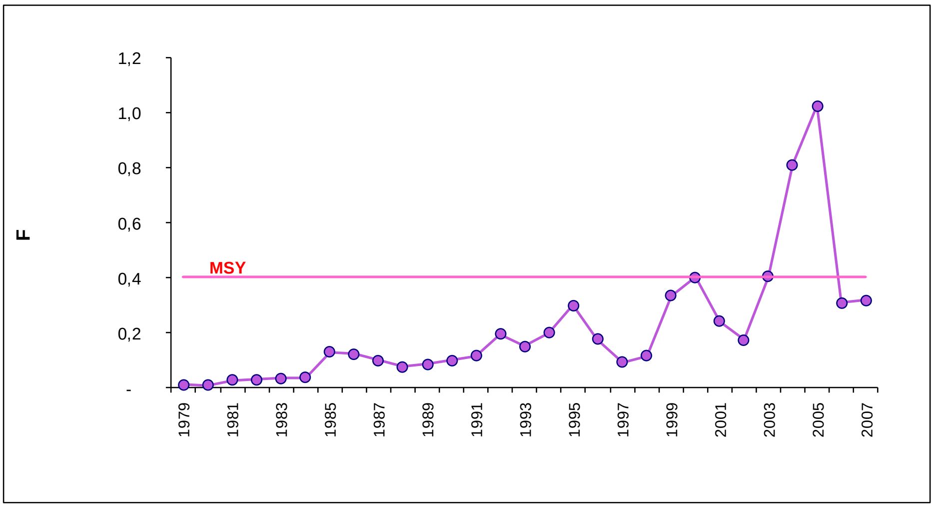

Figure 6. Estimated annual fishing mortality rate (F) and F for MSY Reference Point from the Schaefer biomass dynamics model.

Figure 7 illustrates the annual percentage of biomass (B) to unexploited biomass (B0) and for MSY Reference Point obtained from the Schaefer biomass dynamics model. The figure illustrates that for the period 2005-2007 there has been a decline in the biomass below the B_{MSY} thereby confirming the possibility that overfishing had occurred on previous years.

Table 9. Parameter estimates and management reference points determined from the time series fitting model of the Jamaica spiny lobster data.

Parameters	**Schaefer form using time series/objective function fitting in Excel.**
q	0.000113
K	1109
r	0.80
E_{MSY}	3529
F_{MSY}	0.400
B_{MSY}	555
MSY(mt)	222
$B<B_{MSY}$	
2005	0.787
2006	0.506
2007	0.634
$F>F_{MSY}$	
2000	1.000
2003	1.006
2004	2.025
2005	2.561

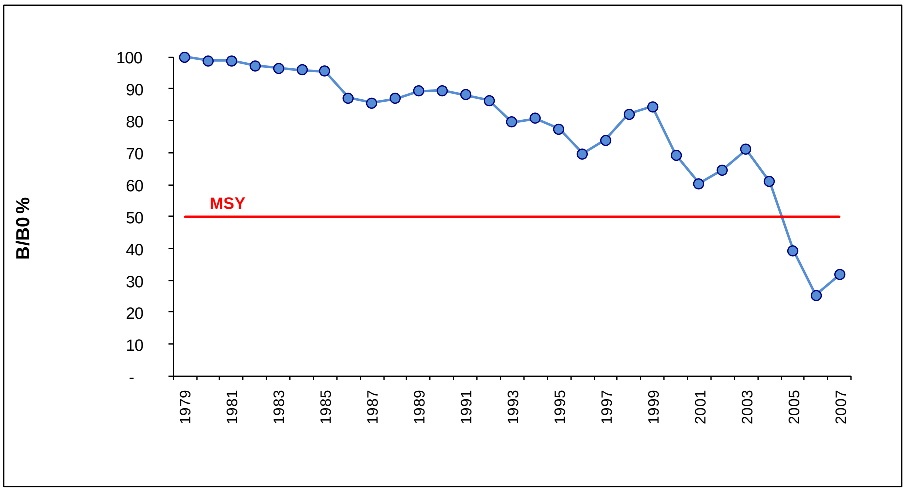

Figure 7. Estimated annual percentage of biomass (B) to unexploited biomass (B0) and for MSY Reference Point from the Schaefer biomass dynamics model.

The R^2 value (a measure of goodness-of-fit of a linear regression) obtained for the expected versus the observed CPUE was low (Figure 8). This is an indication that there is a 22% chance of predicting the expected CPUE given the observations made and hence the model is not fitting to the observed data very well.

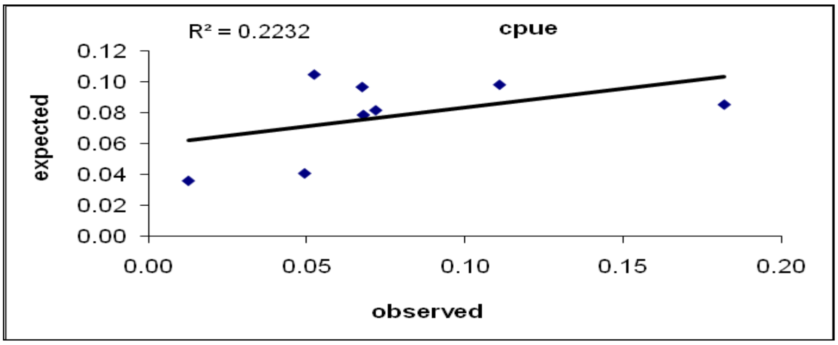

Figure 8. Observed and expected CPUE derived from the fitted model.

4.3 Results from length frequency modeling

4.3.1 Estimates of catch in numbers

The results of the process in estimating catch in numbers for Jamaica spiny lobster by sex are shown in Tables 10 and 11. Table 12 shows the results of the process in estimating catch in numbers for spiny lobster (male and female combined) where emphasis is placed on how the raising factor was obtained. The estimates obtained were based on a period of three years (2005 – 2007).

Table 10. The results of the process in estimating catch in numbers for Jamaica male spiny lobster based on data for 2005-2007.

Class Interval (mm)	Mean CL (mm)	Numbers in sample			Average Number 2005-2007	Individual wgt (kg) (*based on mean CL*)	Total Sampled Weight (kg) (*Frequency * Indiv weight*)			Raised # based on sample (*Raising factor *frequency)*			Raised Avg # 2005 -2007
		2005	2006	2007			2005	2006	2007	2005	2006	2007	
45-50	47		4		4	0.102	0.000	0.407	0.000	0	609.407	0	203
50-55	52	5	10		8	0.134	0.672	1.345	0.000	4806.157	1523.517	0	2110
55-60	57	13	29	1	14	0.173	2.253	5.026	0.173	12496.01	4418.201	107.5095	5674
60-65	62	40	60	16	39	0.219	8.747	13.120	3.499	38449.25	9141.105	1720.151	16437
65-70	67	61	74	38	58	0.271	16.527	20.050	10.296	58635.11	11274.03	4085.359	24665
70-75	72	83	136	111	110	0.331	27.438	44.959	36.694	79782.2	20719.84	11933.55	37479
75-80	77	142	122	202	155	0.398	56.514	48.554	80.393	136494.9	18586.91	21716.91	58933
80-85	82	112	133	239	161	0.474	53.040	62.985	113.184	107657.9	20262.78	25694.76	51205
85-90	87	59	123	226	136	0.558	32.907	68.603	126.051	56712.65	18739.26	24297.14	33250
90-95	92	15	80	154	83	0.651	9.764	52.072	100.239	14418.47	12188.14	16556.46	14388
95-100	97	7	40	94	47	0.753	5.274	30.137	70.822	6728.62	6094.07	10105.89	7643
100-105	102	5	12	50	22	0.866	4.329	10.389	43.286	4806.157	1828.221	5375.473	4003
105-110	107	0	7	23	10	0.988	0.000	6.917	22.727	0	1066.462	2472.717	1180
110-115	112	1	2	16	6	1.121	1.121	2.242	17.938	961.2314	304.7035	1720.151	995
115-120	117		3	3	3	1.265	0.000	3.795	3.795	0	457.0552	322.5284	260
120-125	122		1	1	1	1.420	0.000	1.420	1.420	0	152.3517	107.5095	87
125-130	127		1	1	1	1.587	0.000	1.587	1.587	0	152.3517	107.5095	87
130-135	132		0	1	1	1.766	0.000	0.000	1.766	0	0	107.5095	36

Table 11. The results of the process in estimating catch in numbers for Jamaica female spiny lobster based on data for 2005-2007.

Class Interval (mm)	Mean CL (mm)	Numbers in sample			Average Number 2005-2007	Individual wgt (kg) (*based on mean CL*)	Total Sampled Weight (kg) (*Frequency * Indiv weight*)			Raised # based on sample (*Raising factor *frequency)*			Raised Avg # 2005 -2007
		2005	2006	2007			2005	2006	2007	2005	2006	2007	
50-55	52	5	15		10	0.102	0.672	2.017	0.000	4806.157	2285.276	0	2364
55-60	57	20	39		30	0.134	3.466	6.759	0.000	19224.63	5941.718	0	8389
60-65	62	36	75	18	43	0.173	7.872	16.400	3.936	34604.33	11426.38	1935.17	15989
65-70	67	55	72	75	67	0.219	14.902	19.508	20.321	52867.72	10969.33	8063.209	23967
70-75	72	107	110	145	121	0.271	35.372	36.364	47.934	102851.8	16758.69	15588.87	45066
75-80	77	132	124	250	169	0.331	52.534	49.350	99.496	126882.5	18891.62	26877.36	57551
80-85	82	66	116	220	134	0.398	31.256	54.935	104.186	63441.27	17672.8	23652.08	34922
85-90	87	20	73	111	68	0.474	11.155	40.716	61.910	19224.63	11121.68	11933.55	14093
90-95	92	5	37	51	31	0.558	3.255	24.083	33.196	4806.157	5637.015	5482.982	5309
95-100	97	2	9	28	13	0.651	1.507	6.781	21.096	1922.463	1371.166	3010.265	2101
100-105	102	1	6	11	6	0.753	0.866	5.194	9.523	961.2314	914.1105	1182.604	1019
105-110	107	1	2	2		0.866	0.988	1.976	1.976	961.2314	304.7035	215.0189	494
110-115	112		1				0.000	1.121	0.000	0	152.3517	0	51

Table 12. Results of the process in estimating catch in numbers for spiny lobster (male and female combined) – emphasis on obtaining the raising factor.

Interval	Mean CL (mm)	Total (M+F) weight in sample (kg)		
		2005	2006	2007
45-50	47	0.000	0.407	0.000
50-55	52	1.345	3.362	0.000
55-60	57	5.720	11.786	0.173
60-65	62	16.618	29.520	7.435
65-70	67	31.429	39.558	30.616
70-75	72	62.810	81.322	84.628
75-80	77	109.048	97.904	179.889
80-85	82	84.296	117.920	217.370
85-90	87	44.062	109.318	187.961
90-95	92	13.018	76.156	133.435
95-100	97	6.781	36.918	91.919
100-105	102	5.194	15.583	52.809
105-110	107	0.988	8.893	24.704
110-115	112	1.121	3.363	17.938
115-120	117	0.000	3.795	3.795
120-125	122	0.000	1.420	1.420
125-130	127	0.000	1.587	1.587
130-135	132	0.000	0.000	1.766
Total (kg)		382.430	638.811	1037.444
Catch (ton)		367.604	97.324	111.535
Raising Factor (C*atch /Total *1000)*		961.231	152.352	107.509

4.3.2 VPA – Jones' length-based cohort analysis

The results of the length-based cohort assessment using Jones' cohort analysis on the Jamaica spiny lobster fishery by sex is shown in Tables 13 and 14. As mentioned in the methods section, these results were then used in the Thopmson and Bell prediction model, the results of which are presented in section 4.3.3.

Table 13. Results of the length-based cohort assessment using Jones' cohort analysis on the Jamaica spiny lobster fishery (male).

L mean	L1 (mm)	L2 (mm)	X	C	Ni	F/Z	F	Z	W_{mean} (Kg)	Wi (Kg)	N_{mean}	Bi (ton)	B_{mean} (ton)	Y (ton)	FxC	F/F_{mean}
47	45	50	1.0272	203.14	394997.1	0.010	0.003	0.343	0.0745	0.0902	60620.29	36	5	0.02	0.681	0.001973
52	50	55	1.0282	2109.89	374183.0	0.095	0.036	0.376	0.1017	0.1207	59372.74	45	6	0.21	74.978	0.020919
57	55	60	1.0293	5673.91	351886.4	0.224	0.098	0.438	0.1345	0.1570	57646.49	55	8	0.76	558.459	0.05794
62	60	65	1.0305	16436.84	326612.7	0.469	0.301	0.641	0.1733	0.1997	54645.08	65	9	2.85	4944.079	0.177066
67	65	70	1.0318	24664.83	291596.5	0.593	0.494	0.834	0.2187	0.2492	49884.28	73	11	5.39	12195.305	0.29106
72	70	75	1.0333	37478.53	249971.0	0.719	0.871	1.211	0.2709	0.3058	43047.64	76	12	10.15	32629.899	0.512509
77	75	80	1.0349	58932.89	197856.3	0.841	1.802	2.142	0.3306	0.3701	32697.78	73	11	19.48	106217.795	1.060982
82	80	85	1.0366	51205.15	127806.2	0.879	2.468	2.808	0.3980	0.4423	20744.97	57	8	20.38	126390.515	1.453012
87	85	90	1.0385	33249.68	69547.7	0.897	2.954	3.294	0.4736	0.5230	11254.33	36	5	15.75	98232.510	1.739146
92	90	95	1.0406	14387.69	32471.6	0.882	2.544	2.884	0.5577	0.6125	5655.062	20	3	8.02	36605.361	1.49769
97	95	100	1.0430	7642.86	16161.2	0.885	2.628	2.968	0.6509	0.7113	2908.725	11	2	4.97	20082.094	1.546755
102	100	105	1.0456	4003.28	7529.3	0.895	2.909	3.249	0.7534	0.8196	1376.006	6	1	3.02	11646.957	1.712634
107	105	110	1.0486	1179.73	3058.2	0.841	1.805	2.145	0.8657	0.9379	653.6459	3	1	1.02	2129.218	1.062447
112	110	115	1.0520	995.36	1656.2	0.900	3.062	3.402	0.9882	1.0666	325.0934	2	0	0.98	3047.572	1.802359
117	115	120	1.0560	259.86	550.3	0.858	2.054	2.394	1.1211	1.2061	126.5155	1	0	0.29	533.751	1.20911
122	120	125	1.0605	86.62	247.5	0.794	1.309	1.649	1.2649	1.3566	66.18994	0	0	0.11	113.357	0.770365
127	125	130	1.0660	86.62	138.3	0.885	2.623	2.963	1.4201	1.5187	33.0296	0	0	0.12	227.163	1.543779
132	130	135	1.0724	35.84	40.5	0.885	2.617	2.957	1.5868	1.6926	13.69623	0	0	0.06	93.767	1.540255

Table 14. Results of the length-based cohort assessment using Jones' cohort analysis on the Jamaica spiny lobster fishery (female).

L_{mean}	L1 (mm)	L2 (mm)	X	C	Ni	F/Z	F	Z	W_{mean} (Kg)	Wi (Kg)	N_{mean}	Bi (ton)	B_{mean} (ton)	Y (ton)	FxC	F/F_{mean}
52	50	55	1.0372	2363.81	326978.6	0.093	0.035	0.375	0.1017	0.1207	67498.53	39	7	0.24	82.781	0.021062
57	55	60	1.0391	8388.78	301665.3	0.277	0.130	0.470	0.1345	0.1570	64559.41	47	9	1.13	1090.029	0.078149
62	60	65	1.0412	15988.63	271326.3	0.439	0.266	0.606	0.1733	0.1997	59995.23	54	10	2.77	4260.942	0.160281
67	65	70	1.0435	23966.75	234939.3	0.569	0.448	0.788	0.2187	0.2492	53449.06	59	12	5.24	10746.779	0.269684
72	70	75	1.0461	45066.44	192799.9	0.755	1.048	1.388	0.2709	0.3058	43013.14	59	12	12.21	47217.753	0.630142
77	75	80	1.0490	57550.51	133109.0	0.859	2.069	2.409	0.3306	0.3701	27811.08	49	9	19.02	119091.401	1.244566
82	80	85	1.0523	34922.05	66102.7	0.882	2.541	2.881	0.3980	0.4423	13743.45	29	5	13.90	88736.819	1.528237
87	85	90	1.0561	14093.28	26507.9	0.876	2.404	2.744	0.4736	0.5230	5862.168	14	3	6.67	33881.780	1.445908
92	90	95	1.0605	5308.72	10421.5	0.862	2.118	2.458	0.5577	0.6125	2506.95	6	1	2.96	11241.741	1.273592
97	95	100	1.0656	2101.30	4260.4	0.847	1.884	2.224	0.6509	0.7113	1115.564	3	1	1.37	3958.046	1.132869
102	100	105	1.0717	1019.32	1779.8	0.863	2.138	2.478	0.7534	0.8196	476.6846	1	0	0.77	2179.646	1.286068
107	105	110	1.0791	493.65	598.4	0.911	3.473	3.813	0.8657	0.9379	142.1202	1	0	0.43	1714.686	2.08906
112	110	115	1.0881	50.78	56.4	0.900	3.060	3.400	0.9882	1.0666	16.59605	0	0	0.05	155.399	1.840382

4.3.3 Prediction models – Thompson and Bell method

The outputs generated by the Thompson and Bell method (Appendix III) are graphically represented in Figures 9 and 10. The graphs clearly show that the present level of fishing effort is well above that gives the maximum sustainable yield thereby indicating that the stock is overfished. Considering a reduction in effort would give a higher yield.

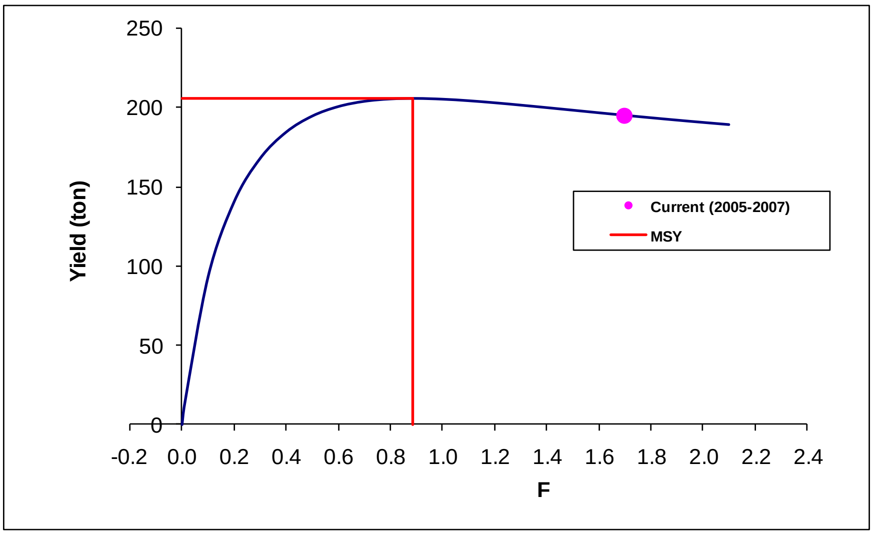

Figure 9. Equilibrium curve of catch (yield), as a function of F from the length-based Thompson and Bell model, showing current status and MSY Reference Point.

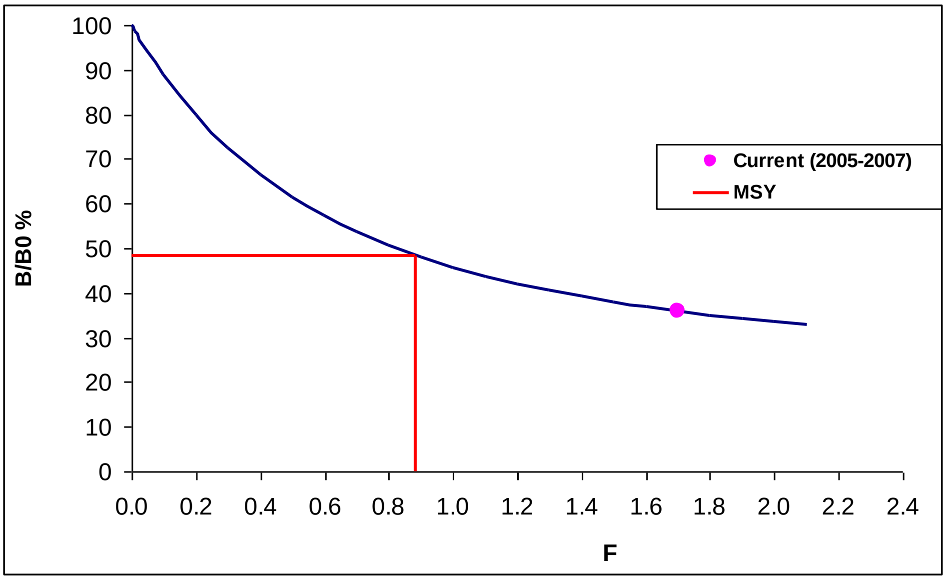

Figure 10. Graph showing equilibrium curve of percentage of biomass (B) to unexploited biomass (B0) as a function of F from the length-based Thompson and Bell model, showing current status and MSY Reference Point.

Table 15 summarises the results of the Schaefer biomass dynamic model and the length-based Thompson and Bell model indicating the estimated MSY reference points. Though the approach for both models is different, both MSY estimates are just above 200 tons.

Table 15. Summary of current status and MSY Reference Points for models used.

	Catch (tons)	F	B/B0 (%)
Schaefer biomass dynamic model			
MSY	222	0.40	50
Current (2005-2007)	192	0.55	32
Length-based Thompson and Bell Model			
MSY	205	0.88	48
Current (2005-2007)	192	1.70	36

4.3.4 Projections

Projections with set catches

Table 16 summarises the management options considered and their outcome. Figures 11 and 12 illustrate the outputs of management options with varying fixed catch levels. Figure 11 clearly illustrates that fishing at the MSY of 222 tons (Option A) never caused the stock to arrive at the B_{MSY} of 555 tons. The biomass that was equivalent to the catch was estimated to occur by 2016 after which the stock collapsed. Figure 12 shows that the fishing mortality rate increased significantly with Option A whereas the other two options (reduced catches) showed a decrease in F estimates well below the recommended F_{MSY}.

Table 16. Summary of outputs of management options for varying fixed catches.

Management options	**Option A** 222 tons based on estimated MSY	**Option B** 167 tons based on 75% of estimated MSY	**Option C** 111 tons based on 50% of estimated MSY
Biomass estimate by 2020 (tons)	1	824	947
Year when biomass (B) would become greater than B_{MSY}	never	2010	2011
Year when F exceeds F_{MSY}	2008	never	Never

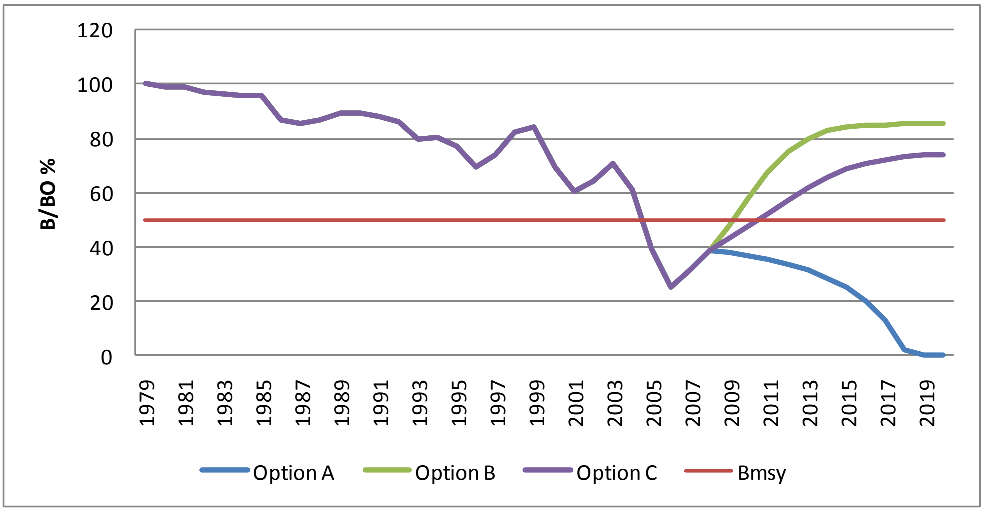

Figure 11. Projected estimated annual percentage of biomass (B) to unexploited biomass (BO) for various management options of set catches and for MSY reference point from the Schaefer model.

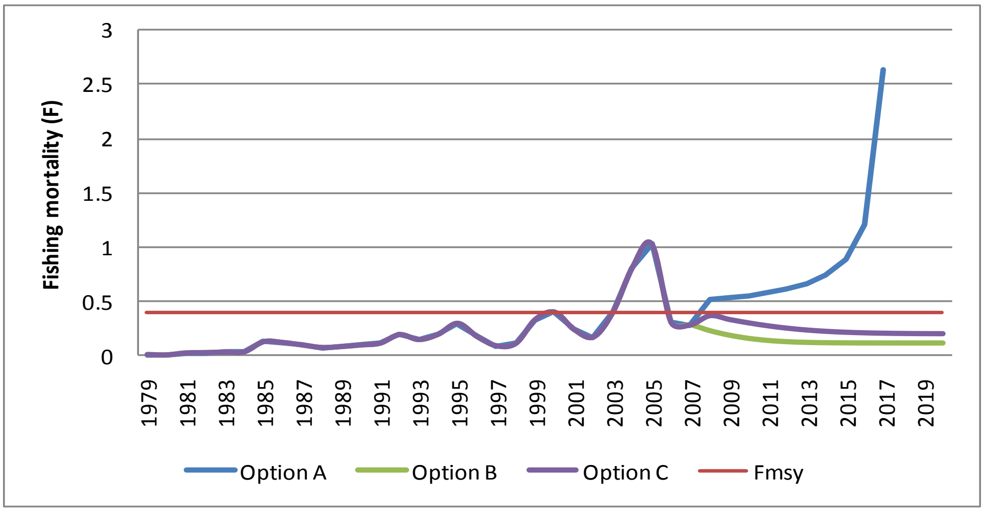

Figure 12. Projected estimated annual fishing mortality rate (F) for various management options of set catches and F for MSY reference point from the Schaefer model.

Projections with set effort

Table 17 summarises the management options considered and their outcome. Figures 13 and 14 illustrate the outputs of management options with varying fixed effort levels. The outputs clearly illustrates that fishing at the recommended E_{MSY} of 3529 (Option A) resulted in stock recovery within 3 years greater than the biomass at B_{MSY}. Higher effort levels did not achieve this. Also observed was that the projected catch for Option C was highest initially (above the C_{MSY}) for a few years but was depleted after the fourth year. Option B also showed an initial increase in catch above the C_{MSY} but was subsequently reduced to approximately 184 tons from 2020 onwards. Fishing at Option A showed a gradual increase in catches over a 6 year period after which the projected catch fell to the MSY of 222 tons from 2020 and only slightly varied by a few kilograms.

Table 17. Summary of outputs of management options for varying fixed effort.

Management options	**Option A** 3529 fishing days based on estimated E_{MSY}	**Option B** 5000 fishing days	**Option C** 7816 fishing days based on average from 2005-2007
Biomass estimate by 2020 (tons)	558	331	1
Year when biomass (B) would become greater than B_{MSY}	2011	never	never
Year when catch is equivalent to C_{MSY}	2020	never	never

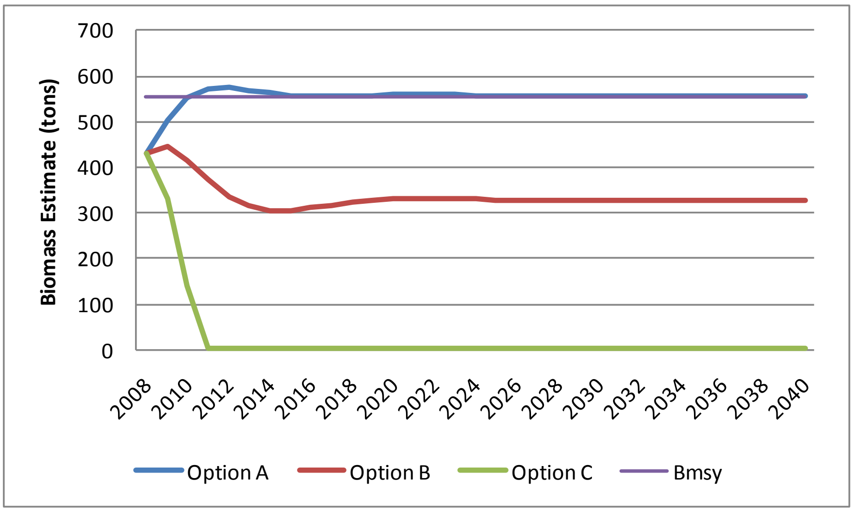

Figure 13. Projected estimated annual biomass (B) for various management options of set effort and for B_{MSY} reference point from the Schaefer model.

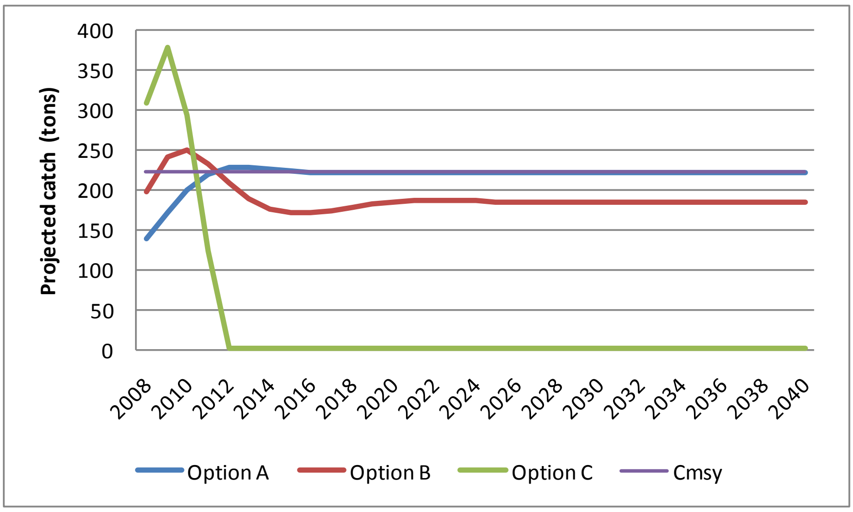

Figure 14. Projected estimated annual catch for various management options of set effort and for C_{MSY} reference point from the Schaefer model.

5 DISCUSSION

5.1 Data Exploration

In general, the results of the exploration revealed that data sampling is inconsistent and this will affect the interpretation of any assessment that may be conducted using the data. Nevertheless, in comparison to earlier years, Jamaica has seen an improvement in the sample size. In light of this measures should be taken to ensure that this is maintained and improved upon throughout the sampling program. Jamaica should adhere to the target set as best as possible.

Jamaica should also pay particular attention to enforcing the law with respect to the legal minimum size of 76 mm. Though the overall mean size is above the minimum legal size there is still far too great a portion that is being landed below this size. If this trend should continue then the possibility of the fishery experiencing recruitment overfishing exists. Figures 2 to 4 illustrated landings for only three quarters (i.e. quarters 1, 3 and 4). This is due to the fact that the second has been declared a close season. Observations were noted however during this period (also noted by CRFM 2008). Nevertheless, Jamaica should consider conducting fishery-independent studies during the close season providing total coverage in data of the lobster population. Other areas that need improvement are collection of effort data for estimating CPUE and better monitoring of landings from all the fisheries.

5.2 Surplus production model

CRFM (2008) conducted preliminary stock assessments for the Jamaica spiny lobster using the limited data available at the time. The major challenges posed by the data were the gaps in the data series, and uncertainty in the CPUE index as a good index of abundance. An alternative approach to Monte Carlo Markov Chain methods (MCMC) and the Bayesian techniques was used in the assessment. The method used allowed for either rejection sampling or sample-importance-resample (a detail of the method is discussed in the report). The fitting method worked well, and the results were therefore a reliable representation, but all uncertainties with respect to model and data still applied.

The results obtained by CRFM (2008) suggested that a MSY that yielded above median 200 tons were unlikely to be sustainable, and that catches in general should be kept below this level. Also lower catches would be more precautionary, and catches below 100 tons per year were unlikely to cause overfishing. The results also indicated that it was likely that the biomass in 2005 was above the MSY reference point (B/BMSY > 1) and implied that the stock was not being overfished for that year but that overfishing occurred in 2004 (at 450 tons). An estimate of the replacement yield (the current production from the stock) was also done where the results indicated that the 2004 catch was likely to be above this yield. This implied that the stock biomass would eventually fall.

With the two years (2006-2007) added data set the current assessments have estimated MSY to be 222 tons and 205 tons by use of the Schaefer production model and Thompson and Bell model respectively (Figure 5, Table 15). These estimates are above the recommended MSY as indicated by CRFM (2008). In light of these new MSY estimates the reported catches for the period 2003-2005 have also exceeded this new estimate.

CRFM (2008) examined the possible overfishing status (fishing mortality / fishing mortality at MSY) as a probability function based on the prior information and the available catch-effort data. The results indicated that overfishing (F/FMSY > 1) based on a 2004 exports of 450 tons was likely. There existed a very high level of uncertainty; however, based on the available information high levels of overfishing were possible. The results from this study (Figure 6) however revealed that there were four years (2000, 2003, 2004 and 2005) in which overfishing did occur with respect to the F_{MSY} estimate of 0.4.

Examining the biomass estimates for each year, the results showed that the stock is not likely to be overfished prior to 2005 (Figure 7, Table 7). However, since 2005 the results indicate that the estimated biomass for each year is well below the estimated B_{MSY}. Varying factors may have contributed to this decline in biomass. CRFM (2008) pointed out that stock biomass would eventually fall based on overfishing in 2004 when compared to the replacement yield. This decline was evident in the following years. It should however be noted that Jamaica had also experienced three hurricanes in 2005, one in 2007, among other weather systems that would have impacted the availability of the lobster stock for fishing. Lobsters naturally migrate to deeper water seeking refuge from the effects of any weather system that would impact their natural habitat. It is therefore possible that these hurricanes would have disrupted both fishing activities as well as the abundance of lobsters in the common fishing grounds. Additionally, a significant problem with surplus production models in assessing spiny lobster is that it is assumed that the population is self-recruiting, whereas it is generally thought that lobster recruitment is spread widely across islands throughout the Caribbean region. This will add considerably to the uncertainty of this assessment.

CRFM (2008) had obtained R^2 value of -0.31 from the fitted model and indicated that there was no trend in the observed CPUE and that the CPUE were not informative on the abundance for the model used. The low R^2 value obtained from this study (Figure 8) indicates a poor fit of the expected CPUE from an observed CPUE. That is, there is a 22% chance of predicting the expected CPUE given the observations made. Lobster recruitment and migration patterns vary on a yearly basis hence affect CPUE indices in general.

5.3 Projections

Haddon (2001) pointed out that the interpretation of management is not always straightforward and that the MSY is more like an average since it is unlikely that there will be equilibrium in a fished population. There exist many sources of error and uncertainty that are not accounted for in a model hence care should be given when attempting to interpret model outcomes. Conducting risk assessments then becomes necessary as it allows for fishery managers to consider possible outcomes of various proposed management options. Given the outputs of the Schaefer model two projections were considered for the lobster fishery, set catches and set effort.

Having set catches for a fishery is a vital management control once the catch levels are consistent with stock sustainability and optimisation of production. In this example, fishing at the recommended MSY of 222 tons (Table 16, Figures 11 and 12) proved to be very unsustainable. This was attributed to the estimated stock biomass being already depleted (i.e. $B<B_{MSY}$). However, limiting catches to 75% or even 50% of the MSY showed stock recovery within a 3-4 years span.

A fishery can also be managed by limiting effort to the E_{MSY}. However, if the stock biomass is depleted then the average long-term yield will not occur. In some cases the E_{MSY} effort level may be too high to permit stock rebuilding. In the options considered, the imposition of the effort at E_{MSY} resulted in stock recovery within 3 years of its proposed implementation (Table 17, Figures 13 and 14). But as is also expected increase in the effort level reduced the estimated catch levels as seen in Option B. If the effort continues at the current level then ultimately the results indicate a stock collapse within 5 years.

6 CONCLUSION

The approaches used by both CRFM (2008) and the present study is preliminary assessments of the spiny lobster fishery of Jamaica. Given the estimated biomass and current effort levels, both studies indicated that fishing at levels greater than 200 tons is not sustainable in the long term. The production model has several assumptions that are not always easy to test, the most important being that the CPUE index is directly related to population size. Though limitations of the models used exist (such as not really accounting for uncertainties associated with model assumptions), Jamaica should pay close attention to both the current effort and catch levels imposed on the lobster stock, as there appears to be potential dangers for the fishery if these levels of exploitation are continued. A significant problem with surplus production models in assessing spiny lobster is that it assumes that the population is self-recruiting, whereas it is generally thought that lobster recruitment is spread widely across islands. This will add considerably to the uncertainty of this assessment.

As Jamaica continues to improve on its data collection activities the analysis and interpretation of the data will become more meaningful to advise management on the necessary options to be taken thereby meeting its management objectives.

The methods applied in this study though specific to the spiny lobster fishery is a platform for future analyses on the other commercially valuable species for which there is available data. The data limitations presented here are also useful considerations when conducting sampling programmes for the other fisheries of Jamaica.

LIST OF REFERENCES

Aiken, D.E. (1980). “Moulting and growth”. In Cobb, J.S. and Phillips, B.F. eds. *The Biology and Management of Lobsters Vol. 1*. pp 91-147. New York: Academic Press.

Aiken, K. (1977). *Jamaica spiny lobster investigations*. FAO Fish Rep. 200. Rome: FAO.

Aiken, K. (1983). *Further investigation of the Jamaican spiny lobster fishery*. FAO Fish. Rep. 278. Rome: FAO.

Aiken, K. (1984). Lobsters – Their biology and conservation in Jamaica. *Jamaica Journal* 17(4):44-17.

Arce, A.M. and de León, M. E. (2001). "Biology". In FAO/Western Central Atlantic Fishery Commission Report on the FAO/DANIDA/CFRAMP/WECAFC Regional Workshops on the Assessment of the Caribbean Spiny Lobster (*Panulirus argus*). *FAO Fisheries Report* (619): 17-25.

CARICOM Fisheries Resource Management Programme CFRAMP (2000). *Jamaica National Marine Fisheries Atlas.* CARICOM Fishery Report No. 4. 53 pp.

Caribbean Regional Fisheries Mechanism CRFM (2008). CRFM Fishery Report - 2008 Volume 1. Report of Fourth Annual Scientific Meeting – Kingstown, St. Vincent and the Grenadines, 10-20 June 2008. 222 pp.

Evans, C.R., Lockwood, A.P.M. Evans, A.J. and Free, E. (1995). Field studies of the reproductive biology of the spiny lobster *Panulirus argus* (Latreille) and *P. guttatus* (Latrielle) at Bermuda. *Journal of Shellfish Research* 14(2): 371-381.

Food and Agricultural Organization of the United Nations (2001). *FAO Fisheries Report.* No. 619. FAO/Western Central Atlantic Fishery Commission Report on the FAO/DANIDA/CFRAMP/WECAFC Regional Workshops on the Assessment of the Caribbean Spiny Lobster (*Panulirus argus*). Belize City, 21 April - 2 May 1997 and Merida, Yucatan, 1-12 June 1998. Rome, FAO. 381pp.

Gittens, L.G. (2001). An assessment of recent (1996-2000) biological and socioeconomic characteristics of the Jamaican lobster (*Panulirus argus*) fishery, with implications for future management

Haddon, M. (2001). *Modelling and quantitative methods in fisheries*. Chapman & Hall/CRC: 406

Haughton, M.O. (1988). *Population biology of Panulirus argus in Jamaican waters*. M.Sc. thesis. University of Buckingham. 148 pp.

Haughton, M.O. and King, D.P.F. (1989). Stock Assessment of the spiny lobster (*Panulirus argus*) in Jamaica. *Proc. Gulf Carib. Fish. Inst* 42:119-126.

Little, E.J. (1972). Tagging of spiny lobsters (*Panulirus argus*) in the Florida Keys, 1967-1969. Florida Department of Natural Resources, Marine Research Laboratory [January 2010] < http://www.sms.si.edu/irlspec/panuli_argus.htm>

Lyons, W.G. (1980). The postlarval stage of scyllaridean lobsters. *Fisheries* 5:47-49.

Martinez, S., Monnereau, I. and Fanning, L. (2007). CLME Full Project Component 4: Spiny Lobster Pilot Project. CLME Project Implementation Unit. Centre for Resource Management and Environmental Studies (CERMES), University of the West Indies, Barbados [February 2010] <http://www.cavehill.uwi.edu/cermes/clme_eng.html>

Marx, J.M. and Herrnkind, W.F. (1986). Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (south Florida): spiny lobster. Florida State University, Tallahassee (USA). Deptartment of Biological Science, Technical Report TR-EL-82-4/82-11-61 [January 2010] <http://www.nwrc.usgs.gov/wdb/pub/species_profiles/82_11-061.pdf>

Olsen, D.A. and Koblick, I.G. (1975). Population dynamics, ecology, and behaviour of spiny lobster, *Panulirus argus*, of St. John, U.S. Virgin Islands: growth and mortality. Results of the Tektite program, Vol. 2. Nat. Hist. Mus. Los Ang. Cty. Sci. Bull. 20: 17-21. [January 2010] < http://www.sms.si.edu/irlspec/panuli_argus.htm>

Quinn, T.J. and Deriso. R.B. (1999). *Quantitative fish dynamics*. New York: Oxford University Press, 542 pp.

Sterrer, W. (1992). *Bermuda's Marine Life.* Flatts: Bermuda Zoological Society.

Munro, J.L. (1983). Caribbean coral reef fishery resources. *ICLARM Studies and Reviews* 7, Manila, Philippines. *In* Houlihan, C. and Wood J. Marine Invertebrates of Bermuda. Caribbean Spiny Lobster (*Panulirus argus*) [January 2010] <http://www.thecephalopodpage.org/MarineInvertebrateZoology/Panulirusargus.html>

Waugh, G.T. (1981). Management of juvenile spiny lobster (*Panulirus argus*) based on estimated biological parameters from Grand Bahama Island, Bahamas. *Proc. Gulf Caribb. Fish. Inst*. 33:271-289.

Williams, A.B. (1984). Shrimps, Lobsters, and Crabs of the Atlantic Coast of the Eastern United States. Maine to Florida. Smithsonian Institution Press, Washington, D.C. [January 2010] < http://www.sms.si.edu/irlspec/panuli_argus.htm>

Witherell, D. and Ianelli, J. (1997). A guide to stock assessment of Bering Sea and Aleutian Islands. Groundfish North Pacific Fishery Management Council. Anchorage, Alaska. [November 2009**] <**http://www.fakr.noaa.gov/npfmc/summary_reports/bsstock.htm>

Young, G.R. (1992). Studies on settlement and growth of post larval, spiny lobster (*Panulirus argus*) from Bowden Harbour, Jamaica. M.Phil. Thesis. The University of the West Indies.

ACKNOWLEDGMENTS

Special thanks to the wonderful staff of the UNU Fisheries Training Programme - Dr. Tumi Tomasson, Director, Mr. Þor Ásgeirsson, Deputy Director, and Ms. Sigríður Ingvarsdóttir, Programme Officer for their constant concern, support and encouragement for my colleagues and I during this period in Iceland.

Sincere gratitude to my supervisor Guðmundur Þórðarson for his guidance throughout the scope of the project. I am also very grateful to Professor Gunnar Stefánsson and Dr. Einar Hjörleifsson for all the knowledge transmitted during the stock assessment specialist course.

My endless gratitude and love to my husband Eric, family members and dear friends from both the Miracle Open Bible Church (Jamaica) and the International Church of Filadelfia (Iceland) for all the support through words of encouragement and prayers especially during the most challenging times of my stay in Iceland.

Finally, thanks very much to the UNU Fisheries Training Programme for allowing me to participate in this life-changing programme.

APPENDIX

APPENDIX I: Estimated CPUE indices based on similar gear types

Combination of like gears (fishing techniques) from the reported catch and effort data used to estimate total CPUE (shown) for the Jamaica spiny lobster fishery (See section 3.4.1 for details).

Year	dive+hookah+scuba				gnet+sprat+trammel (Gill, sprat and trammel net)				Ztfp (Z-traps, fish pots)				TOTAL Catch (kg)
	Catch (kg)	Effort (Fishing Days)	cpue (kg/ fishing day)	% catch	Catch (kg)	Effort (Fishing Days)	cpue (kg/ fishing day)	% catch	Catch (kg)	Effort (Fishing Days)	cpue (kg/ fishing day)	% catch	
1996	4.07	2	2.03	100.0	0.00	0		0.0	0.00	0		0.0	4.07
1997	2821.30	23	122.67	97.7	10.47	1	10.47	0.4	55.13	2	27.56	1.9	2886.89
1998	1755.73	41	42.82	57.7	1287.61	17	75.74	42.3	0.00	0		0.0	3043.34
1999	998.20	21	47.53	49.2	1030.84	9	114.54	50.8	0.00	0		0.0	2029.04
2000	751.91	19	39.57	21.8	2539.06	28	90.68	73.6	160.97	1	160.97	4.7	3451.93
2001	524.49	4	131.12	29.7	1243.62	22	56.53	70.3	0.00	0		0.0	1768.10
2002	0.00	0		0.0	1638.32	9	182.04	100.0	0.00	0		0.0	1638.32
2003													
2004													
2005	143.91	3	47.97	12.1	1042.54	21	49.64	87.9	0.00	0		0.0	1186.46
2006	383.13	30	12.77	38.1	621.19	46	13.50	61.8	1.59	3	0.53	0.2	1005.91
2007	849.02	53	16.02	56.9	635.49	57	11.15	42.6	8.39	2	4.20	0.6	1492.90
2008	147.19	13	11.32	60.9	94.57	16	5.91	39.1	0.00	0		0.0	241.77

Raised catch and effort of Jamaica spiny lobster across the combination of like gears (fishing techniques) based on CPUE and percentage composition of catch from reported landings and total export data.

Year	**dive+hookah+scuba**				**gnet+sprat+trammel**				**ztfp**				TOTAL Catch (kg)	TOTAL Effort (fishing days)
	Catch (kg)	Effort (fishing days)	CPUE (kg/ fishing day)	% catch	Catch (kg)	Effort (fishing days)	CPUE (kg/ fishing day)	% catch	Catch (kg)	Effort (fishing days)	CPUE (kg/ fishing day)	% catch		
1996														
1997	77455.17	631	122.67	97.7	287.44	27	10.47	0.4	1513.39	55	27.56	1.9	79256.0	714
1998	60979.32	1424	42.82	57.7	44720.68	590	75.74	42.3	0.00	0	0.00	0.0	105700.0	2014
1999	139829.86	2942	47.53	49.2	144401.14	1261	114.54	50.8	0.00	0	0.00	0.0	284231.0	4202
2000	62683.24	1584	39.57	21.8	211670.77	2334	90.68	73.6	13418.99	83	160.97	4.7	287773.0	4002
2001	49469.91	377	131.12	29.7	117299.09	2075	56.53	70.3	0.00	0	0.00	0.0	166769.0	2452
2002				0.0	130238.00	715	182.04	100.0				0.0	130238.0	715
2003														
2004														
2005	44588.78	930	47.97	12.1	323015.22	6507	49.64	87.9	0.00	0	0.00	0.0	367604.0	7436
2006	37068.47	2903	12.77	38.1	60101.89	4451	13.50	61.8	153.64	290	0.53	0.2	97324.0	7643
2007	63430.56	3960	16.02	56.9	47477.55	4258	11.15	42.6	626.89	149	4.20	0.6	111535.0	8368
2008	0.00	0	11.32	60.9	0.00	0	5.91	39.1	0.00	0	0.00	0.0	0.0	0

APPENDIX II. Results of fitting the Schaefer surplus-production model from observed catch, effort and CPUE indices for the Jamaica spiny lobster.

Year	Effort (Fishing Days)	Catch (Ton)	Observed CPUE	Expected CPUE	Bt (Ton)	Bmid (Ton)	ObsCPUE* Bmid (Ton)	Bmid^2 (Ton)	error^2	Expected catch (Ton)	F	F/F_{MSY}	B/B_{MSY}	C/C_{MSY}	%B0
1979		12.54		0.13	1109	1103					0.011	0.028	2.000	0.056	
1980		9.23		0.12	1097	1097					0.008	0.021	1.977	0.042	100.0
1981		28.52		0.12	1098	1088					0.026	0.066	1.979	0.129	98.9
1982		31.17		0.12	1078	1075					0.029	0.073	1.944	0.140	98.9
1983		36.48		0.12	1071	1068					0.034	0.085	1.931	0.164	97.2
1984		39.14		0.12	1064	1062					0.037	0.092	1.919	0.176	96.6
1985		131.41		0.11	1060	1013					0.130	0.324	1.911	0.592	95.9
1986		116.50		0.11	966	958					0.122	0.304	1.742	0.525	95.5
1987		94.58		0.11	950	957					0.099	0.247	1.712	0.426	87.1
1988		74.43		0.11	964	978					0.076	0.190	1.739	0.335	85.6
1989		83.72		0.11	991	991					0.084	0.211	1.786	0.377	86.9
1990		97.82		0.11	992	985					0.099	0.248	1.788	0.441	89.3
1991		111.93		0.11	978	968					0.116	0.289	1.763	0.504	89.4
1992		179.18		0.10	959	921					0.194	0.486	1.728	0.808	88.2
1993		132.30		0.10	884	890					0.149	0.372	1.593	0.596	86.4
1994		173.71		0.10	895	878					0.198	0.495	1.614	0.783	79.7
1995		243.00		0.09	860	816					0.298	0.745	1.550	1.095	80.7
1996		140.18		0.09	772	796					0.176	0.441	1.391	0.632	77.5
1997	714	79.26	0.11	0.10	819	865	96.10	749028	0.0002	70.02	0.092	0.229	1.477	0.357	69.5
1998	2014	105.70	0.05	0.10	912	924	48.47	853262	0.0027	210.91	0.114	0.286	1.643	0.476	73.9
1999	4202	284.23	0.07	0.10	936	852	57.65	726519	0.0008	406.00	0.333	0.834	1.687	1.281	82.2
2000	4002	287.77	0.07	0.08	769	719	51.73	517447	0.0001	326.26	0.400	1.000	1.386	1.297	84.4
2001	2452	166.77	0.07	0.08	670	693	47.10	479771	0.0001	192.53	0.241	0.602	1.208	0.752	69.3
2002	715	130.24	0.18	0.09	715	752	136.88	565429	0.0094	60.98	0.173	0.433	1.290	0.587	60.4
2003		294.69		0.08	788	732					0.402	1.006	1.421	1.328	64.5
2004		450.81		0.06	676	556					0.810	2.025	1.219	2.032	71.1
2005	7436	367.60	0.05	0.04	437	359	17.74	128753	0.0001	302.43	1.024	2.561	0.787	1.657	61.0
2006	7643	97.32	0.01	0.04	281	316	4.03	99984	0.0005	273.94	0.308	0.769	0.506	0.439	39.4
2007	8368	111.54	0.01	0.04	351	351					0.317	0.793	0.634	0.503	25.3

APPENDIX IIIa: Output from length-based Thompson and Bell analysis, Jamaica male spiny lobster

L1 (mm)	L2 (mm)	Lmean	X	Wi (kg)	W_{mean} (kg)	Selectivity	F	Z	N	N_{mean}	C_{num}	Y(ton)	Bi(ton)	Revenue ($)
45	50	47.5	1.0272	0.0902	0.1047	0.0020	0.003351	0.3434	394997.05	60620.29	203.14	0.02	35.62	276.51
50	55	52.5	1.0282	0.1207	0.1381	0.0209	0.035536	0.3755	374183.02	59372.74	2109.89	0.29	45.15	3787.30
55	60	57.5	1.0293	0.1570	0.1776	0.0579	0.098426	0.4384	351886.40	57646.49	5673.91	1.01	55.25	13096.45
60	65	62.5	1.0305	0.1997	0.2236	0.1771	0.300793	0.6408	326612.68	54645.08	16436.84	3.67	65.23	47772.75
65	70	67.5	1.0318	0.2492	0.2766	0.2911	0.494441	0.8344	291596.52	49884.28	24664.83	6.82	72.66	88679.54
70	75	72.5	1.0333	0.3058	0.3370	0.5125	0.870629	1.2106	249971.03	43047.64	37478.53	12.63	76.44	164174.77
75	80	77.5	1.0349	0.3701	0.4052	1.0610	1.802352	2.1424	197856.30	32697.78	58932.89	23.88	73.22	310411.13
80	85	82.5	1.0366	0.4423	0.4816	1.4530	2.468316	2.8083	127806.16	20744.97	51205.15	24.66	56.53	320584.11
85	90	87.5	1.0385	0.5230	0.5667	1.7391	2.954389	3.2944	69547.72	11254.33	33249.68	18.84	36.38	244933.06
90	95	92.5	1.0406	0.6125	0.6607	1.4977	2.544214	2.8842	32471.57	5655.06	14387.69	9.51	19.89	123582.34
95	100	97.5	1.0430	0.7113	0.7642	1.5468	2.627563	2.9676	16161.16	2908.73	7642.86	5.84	11.49	75930.15
100	105	102.5	1.0456	0.8196	0.8775	1.7126	2.909351	3.2494	7529.33	1376.01	4003.28	3.51	6.17	45667.45
105	110	107.5	1.0486	0.9379	1.0010	1.0624	1.80484	2.1448	3058.21	653.65	1179.73	1.18	2.87	15351.26
110	115	112.5	1.0520	1.0666	1.1350	1.8024	3.061772	3.4018	1656.24	325.09	995.36	1.13	1.77	14686.43
115	120	117.5	1.0560	1.2061	1.2799	1.2091	2.053987	2.3940	550.35	126.52	259.86	0.33	0.66	4323.90
120	125	122.5	1.0605	1.3566	1.4362	0.7704	1.308664	1.6487	247.47	66.19	86.62	0.12	0.34	1617.25
125	130	127.5	1.0660	1.5187	1.6041	1.5438	2.622509	2.9625	138.34	33.03	86.62	0.14	0.21	1806.34
130	135	132.5	1.0724	1.6926	1.7841	1.5403	2.616522	2.9565	40.49	13.70	35.84	0.06	0.07	831.15

APPENDIX IIIb: Output from length-based Thompson and Bell analysis, Jamaica female spiny lobster

L1 (mm)	L2 (mm)	Lmean	X	Wi (kg)	W_{mean} (kg)	Selectivity	F	Z	N	N_{mean}	C_{num}	Y(ton)	Bi(ton)	Revenue ($)
50	55	52.5	1.0372	0.1207	0.1381	0.0211	0.03502	0.3750	326978.62	67498.53	2363.81	0.33	29.49	4243.09
55	60	57.5	1.0391	0.1570	0.1776	0.0781	0.129939	0.4699	301665.30	64559.41	8388.78	1.49	36.40	19362.90
60	65	62.5	1.0412	0.1997	0.2236	0.1603	0.266498	0.6065	271326.32	59995.23	15988.63	3.57	42.61	46470.05
65	70	67.5	1.0435	0.2492	0.2766	0.2697	0.448404	0.7884	234939.32	53449.06	23966.75	6.63	46.92	86169.68
70	75	72.5	1.0461	0.3058	0.3370	0.6301	1.047736	1.3877	192799.88	43013.14	45066.44	15.19	48.04	197413.62
75	80	77.5	1.0490	0.3701	0.4052	1.2446	2.069337	2.4093	133108.97	27811.08	57550.51	23.32	40.71	303129.83
80	85	82.5	1.0523	0.4423	0.4816	1.5282	2.540997	2.8810	66102.70	13743.45	34922.05	16.82	24.46	218639.22
85	90	87.5	1.0561	0.5230	0.5667	1.4459	2.404108	2.7441	26507.88	5862.17	14093.28	7.99	11.73	103817.87
90	95	92.5	1.0605	0.6125	0.6607	1.2736	2.1176	2.4576	10421.46	2506.95	5308.72	3.51	5.45	45598.97
95	100	97.5	1.0656	0.7113	0.7642	1.1329	1.88362	2.2236	4260.38	1115.56	2101.30	1.61	2.61	20875.94
100	105	102.5	1.0717	0.8196	0.8775	1.2861	2.138343	2.4783	1779.79	476.68	1019.32	0.89	1.27	11627.84
105	110	107.5	1.0791	0.9379	1.0010	2.0891	3.473476	3.8135	598.40	142.12	493.65	0.49	0.49	6423.66
110	115	112.5	1.0881	1.0666	1.1350	1.8404	3.06	3.4000	56.43	16.60	50.78	0.06	0.05	749.31

APPENDIX IIIc: Results of the length-based Thompson and Bell analysis, Jamaica spiny lobster

F-factor	Total Yield (tons)	Total Mean biomass (tons)	B/B0 %
0	0	2363	100.0
0.01	13	2334	98.8
0.1	93	2102	89.0
0.2	140	1889	80.0
0.3	168	1715	72.6
0.4	184	1572	66.5
0.5	194	1452	61.5
0.6	200	1352	57.2
0.7	204	1267	53.6
0.8	205	1195	50.6
0.9	205	1133	48.0
1	205	1080	45.7
1.1	204	1033	43.7
1.2	203	993	42.0
1.3	201	957	40.5
1.4	200	925	39.2
1.5	198	897	38.0
1.6	196	872	36.9
1.7	195	849	35.9
1.8	193	828	35.0
1.9	192	809	34.2
2	190	792	33.5
2.1	189	776	32.8