FISHERIES TRAINING PROGRAMME
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Final Project 2010

A BIOECONOMIC ANALYSIS OF THE JAMAICAN INDUSTRIAL SPINY LOBSTER (*Panulirus argus*) FISHERY

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ABSTRACT

Static and dynamic models developed for the Jamaican spiny lobster (*Panulirus argus*) have highlighted a number of important characteristics. Among these is the fact that there is overexploitation in the fishery (if not overcapitalization) which has resulted in biomass, revenues and profits well short of either static or dynamic optima. The fishery is apparently on a dynamic path to the bioeconomic equilibrium where no profits are made in the fishery. This situation has developed largely due to an underdeveloped management regime, which has not been able to adequately control fishing effort or harvests, thus realize the biological and economic potential in the fishery. Despite this, there still remains potential for a much improved bioeconomic situation in the fishery. A property rights based fisheries management regime seems appropriate to address many of the problems facing this fishery.

Key words: Sustainable fishery, Spiny lobster, Optimal, Property rights.

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1 INTRODUCTION

The Spiny Lobster (*Panulirus argus*) is widely distributed throughout the west-central Atlantic, from North Carolina (USA) in the north to Rio de Janeiro in the south. Biologically, it is to a large extent a shared resource within this region due to a prolonged pelagic pre-adult phase, during which the larvae and pre-adults may drift far and wide before finally settling at the bottom. Clearly, this biological feature has important biological and economic implications for the lobster producing nations in the region (Chakalall and Cochrane 2007).

The spiny lobster fishery is an important source of income, employment and, to a lesser extent, food for many Jamaicans. However, historically detailed economic information and, by extension, assessments are not readily available. As a result it has generally difficult to determine financial profitability and economic viability of the fishery (Van Riel 2005).

In Jamaica, marine fisheries, apart from the Queen Conch (*Stombus gigas*) fishery which is managed through nation total allowable catch (NTAC) system, are characterized by a lack of individual property rights. Thus, the Jamaican industrial spiny lobster fishery, like most other fisheries, has fallen into the usual pitfalls of common property fisheries. These include, but are not limited to; depressed stocks, decreasing and fluctuating catch levels and low profitability. In order to mitigate or totally move away from these inevitable negative biological and economic outcomes, Jamaica may need to adopt a more bioeconomically efficient fisheries management regime in the lobster fishery.

The objective of this paper is to determine the most efficient utilization policy for the spiny lobster fishery in Jamaica, assess the potential benefits and determine an appropriate management regime that can achieve them. The results of this analysis will hopefully represent a step in the direction of developing the appropriate management regime for the spiny lobster fishery, particularly the improvement of property rights, and to maximize the utilization of the lobster stock.

2 JAMAICA AND ITS FISHERIES

Jamaica is an archipelagic state located approximately 145 km south of Cuba and 161 km west of Haiti consisting of a main island, several offshore cays, banks, rocks, and shoals. The main island is 236 km in length, between 35 and 82 km wide, has a total area of 10, 991 km², and a coastline of approximately 885 km (Kelly 2002). Jamaica's island shelf and nine proximal banks have a total area of approximately 4,170 km². The area of the exclusive economic zone (EEZ) is 274, 000 km², or approximately twenty-six (26) times the area of the main island (Van Reil 2005) (figure 1).

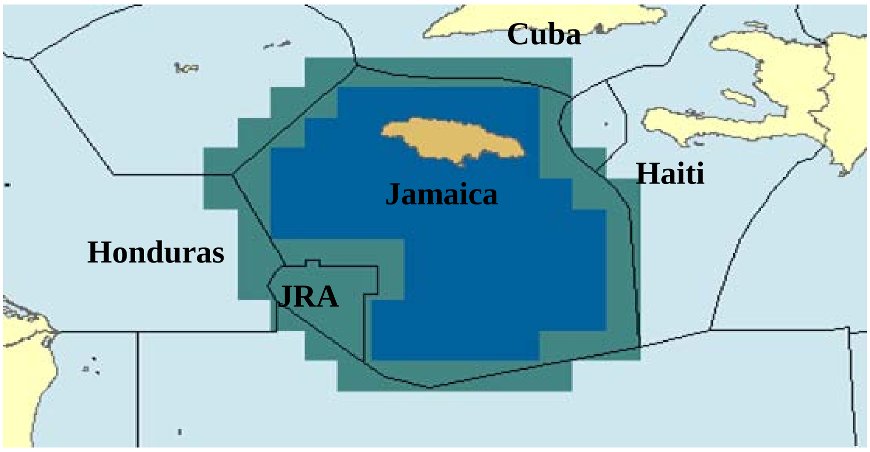

Figure 1. The approximate area of Jamaica's exclusive economic zone (EEZ). The Joint Regime Area (JRA) represents a maritime zone jointly managed by the governments of Jamaica and Columbia. (Picture modified from www.seaaroundus.org)

2.1 Government

Jamaica is a constitutional parliamentary democracy and a member of the British Commonwealth with a governance structure consisting of the executive, the legislative and the judiciary branches. The capital city Kingston is the headquarters for the main branches of government. The country is administratively divided into 14 Parishes, two of which are amalgamated into the Kingston and St. Andrew Cooperation (KSAC) (CIA 2010).
The executive is headed by Her Majesty Queen Elizabeth II (since 6 February 1952) who has the title Head of State and represented locally by a Governor General appointed by her on recommendation of the Prime Minister. The Prime Minister is the Head of Government and the leader of the majority in the House of Representatives, the members of which are elected by popular vote. The Cabinet is appointed by the Governor General on advice of the Prime Minister (CIA 2010).
The legislative arm of government consists of a bicameral parliament including a 21 member Senate and a 60 member House of Representatives. The main institutions of the Judiciary include the Supreme Court which is a body of judges appointed by the Governor General on the advice of the Prime Minister, and also the United Kingdom-based Privy Council which is the final appellate body. Jamaica is also a signatory to the Caribbean Court of Justice (CCJ) which is a regional judicial tribunal among Caribbean Community (CARICOM) states (CIA 2010).

2.2 Economy

Jamaica has a population just fewer than 3 million persons with a relatively high unemployment rate of around 10% annually (CIA 2010). Traditional economic sectors include; agriculture, mining and service-based industries such as tourism. Annual gross domestic product (GDP) figures averages just over US$20 billion (or approximately US$8 per capita). Agriculture (including Forestry and Fisheries) accounts for less than 10%, while the direct contribution fisheries is just about 0.25% of the total GDP which is approximately 4% of the agricultural GDP (Van Reil 2005). However, it has been estimated that the fisheries sector employs, directly and indirectly, some 200,000 people or roughly 7% of the population (Van Riel 2005). This suggests the widespread participation in and the importance of the fisheries for employment in Jamaica.

National fish consumption has fluctuated since the beginning of the 2000’s ranging from 16.3 kg per capita in 2001 to a low of 12.12 kg per capita in 2004, more recently in 2007 consumption was estimated at 14.7 kg per capita (STATIN 2010). Domestic marine production supplied roughly 30% of total fish consumption in 2007 (STATIN 2010).

In 2007 Jamaica exported an estimated 6,100 tons of fish products valued at approximately US$ 8.4 million (STATIN 2010; Fisheries Division pers. comm.). Aquaculture contributed approximately 60% of this value while Queen Conch and the spiny lobster, the two important marine export fisheries, accounting for the remainder (STATIN 2010; Fisheries Division pers. comm.). The economic contributions of the artisanal sector, which target mainly local householders and small retailers, have not been recently quantified.

The spiny lobster has increased in importance as an export product especially in the last 30 to 40 years. In 1962 the fishery contributed only 0.68% of total fish exports; however in 1995 spiny lobster exports had increased to 69% of total fish exports (Kelly 2002). In 2007, this percentage had fallen to approximately 15% (STATIN 2010; Fisheries Division pers. comm.). This decline may be attributed to the rise in aquaculture in the late 1990’s and 2000’s and not necessarily a fall in spiny lobster production.

2.3 Fishery Description

2.3.1 Jamaican Marine Fisheries

Jamaica’s marine fisheries sector can be broadly put into two categories; an artisanal sub-sector and an industrial sub-sector. The artisanal sub-sector consists of a multi-species and multi-gear fleet numbering approximately 20,000 registered fishers operating over 4,000 registered boats mainly open canoes of wood and fibreglass ranging from 8-10 m in length. The actual number of artisanal fishers and boats participating in the fishery may possibly be twice these above numbers. The primary fishing grounds of the artisanal fleet are the island shelf and the offshore banks, particularly the Pedro Bank, while the industrial fleet is only licenced to operate only on offshore banks particularly the Pedro Bank (figure 2).

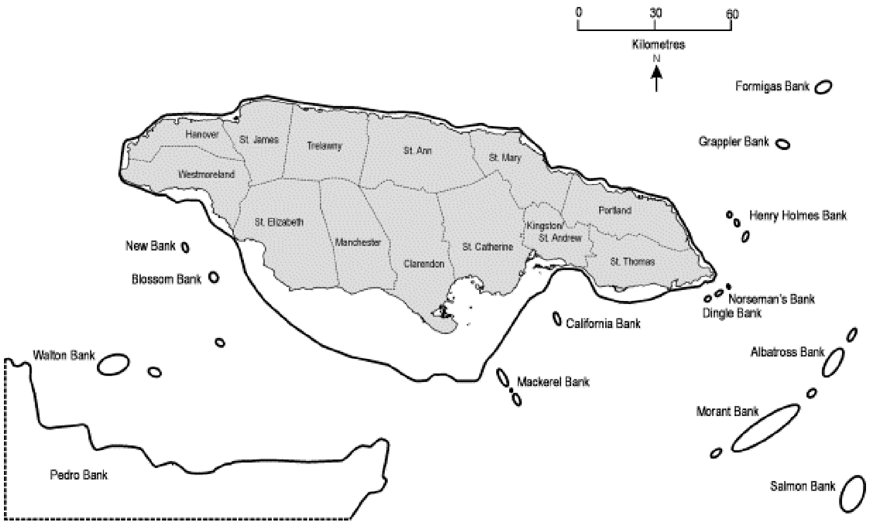

Figure 2. Jamaica's primary fishing grounds (adapted from Gustavson (2002)).

The industrial fleet is comparatively small consisting of approximately six decked vessels (Fisheries Division pers. comm; ECOST 2007).

The estimated marine harvest from the artisanal fleet is very large relative to the much smaller industrial fleet (table 1). Despite this, the industrial fleet’s contribution is arguably more valuable to the country’s economy as it earns valuable foreign exchange for the country each year.

Table 1: Production estimates (1000 kg) for the Jamaican marine fisheries sector 2001 to 2007 (STATIN 2010).

	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Artisanal	6,328	8,342	5,436	9,496	8,537	13,068	11,838
Industrial							
Queen Conch	946	946	504	550	640	650	640
Spiny Lobster	167	130	295	451	368	97	112

2.3.2 Spiny Lobster Fishery in the Region

The spiny lobster represents the most economically important fishery resource in the western central Atlantic region of the Caribbean (Erhardt *et al*. 2009). It provides employment to over 32,000 fishers across some 25 spiny lobster producing countries with significant annual earnings (Chavez 2007). Landings reached a high of about 32 to 37 thousand metric tonnes whole weight during the period 1987 to 1997 with an approximate landed value of US$300 million annually (Erhardt, et. al. 2009).

In terms of management, apart from the Florida (USA), Mexico, Cuba and possibly Belize as well which have relatively well-managed fisheries, the region’s spiny lobster fisheries are largely characterised by an open access, unregulated fisheries regime (Chakalall and Cochrane 2007; Erhardt *et al*. 2009); WECAFC 2007). In addition there is a high level of ‘artisanalization’ which makes monitoring and control increasingly difficult (Chakalall and

Cochrane 2007). Excessive exploitation in addition to environmental and ecological changes has seen a 55% fall in landings since the 2000's (Erhardt *et al.* 2009). The resource is therefore considered fully to over-exploited throughout most of the region with even some of the aforementioned well-managed fisheries experiencing decline (Chakalall and Cochrane 2007; WECAF 2007). Improved price due to high demand and decreasing supply has added the management problem by providing incentives for over-capitalization (Chakalall and Cochrane 2007).

The species' prolonged pelagic larval duration lasting up to 12 months (Erhardt *et al*. 2009; Marx and Herrnkind 1986) represent possibly its most significant biological characteristic for regional managers. The potential for wide dispersal of larvae via ocean currents presents a challenge in delimiting stock boundaries as well as to determine the origin of recruitment (Erhardt *et al*. 2009). This Pan-Caribbean theory of the spiny lobster population structure essentially regards the resource as shared throughout the region and has been suggested to be one of the reasons behind a poor catch-effort relationship throughout the region (Lyons 1980). The success of any management initiative will therefore depend heavily on cooperation and a coordinated regional approach (WECAFC 2007).

2.4.3 Jamaican Spiny Lobster Fishery

The Jamaican spiny lobster stock is concentrated mainly on the offshore banks and to a lesser extent on the island shelf, commercially viable quantities can be found particularly on the Pedro Bank, Morant Bank and Formingas Bank (figure 2) (Haughton and King 1992).

The spiny lobster represents Jamaica's second most important export fishery after the Queen Conch. Spiny lobster is considered a local delicacy and is also highly prized in the local tourism and export markets where it is sold primarily to the United States, Canada, Panama, Netherlands Antilles, Cayman Islands and Martinique (Kelly 2002) at prices ranging roughly between US$10 and US$25/kg (STATIN 2010) . Partly due to this fluctuating price earnings (as well as harvests) have also showed much variation over the years (figure 3).

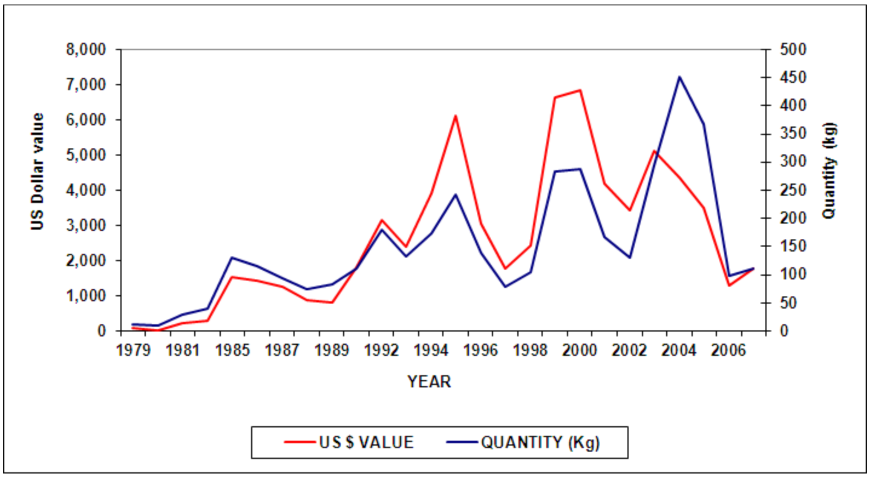

Figure 3. Jamaican spiny lobster export values and quantities for the period 1976 to 2007. (Figure modified from CRFM (2009))

The industrial lobster fleet consist of steel hulled decked vessels ranging from 15-35 m in length with inboard engines of up to 500 hp and crew sizes averaging 8-12 persons (Kelly 2002). The industrial fleet is based on the mainland and are specifically licensed to operate on offshore banks using Florida wooden traps (Figure 4). Each vessel transports about 1,000 traps with 500 in the water (soaked) at any given time (Kelly 2002). Often these vessels are a part of horizontally integrated companies who also own and operate processing plants where the catch is processed and packaged mainly as frozen lobster tails. Industrial lobster vessels often go out twice per month on fishing trips lasting roughly 14 days with catches averaging around 6,000 kg per trip. Landings for the industrial fleet usually peak in March corresponding with the end of the open season, and also in late September (Kelly 2002).

Figure 4. Florida-type lobster traps similar to these used in the Jamaican spiny lobster fishery. Source: www.lobstertrapart.com

The artisanal fleet, on the other hand consists of both non-mechanised and mechanised vessels with 40-60 hp outboard engines and crews of up to 3 fishers (Kelly 2002). There are two categories of artisanal lobster fishers; those operating from the mainland utilizing fishing grounds on the island shelf and those based on offshore banks. Both utilize diving methods (free lung, SCUBA and Hoocha), Antillean Z-traps (figure 5) which are common in the artisanal sub-sector, in addition to various nets. Those operating on offshore banks, particularly the Pedro Bank, are predominantly divers some of whom are based for large periods of the year on one of the small Pedro Cays. These artisans market their catch to ‘Packer Boats’ who subsequently distribute to customers on the mainland.

Figure 5. Antillean Z-trap used in the Jamaican fishery. (ECOST 2007)

Lobsters caught by artisanal fisheries are primarily sold directly to householders and small retailers. However, a small quantity is also sold directly or indirectly to the food industry or to processing plants (Murray-Martin 2010) at boat-side prices ranging from JA$ 200 to 250 per lb. or approximately US$ 5 - 6 per kg (Fisheries Division pers. Comm.).

2.4 Current Spiny Lobster Management

2.4.1 Legislation

There are three main pieces of legislation and associated regulations governing the fishing industry of Jamaica and setting the framework for fisheries management. These include the Morant and Pedro Cays Act (1907), The Fishing Industry Act (1975) and The Exclusive Economic Zone Act (1991). The Fishing Industry Act (1975), among other stipulations, provides a mandate for the Licensing Authority and also sets guidelines for general fisheries management and policy direction. Regarding the spiny lobster, the Act addresses size limits (minimum 76.2 mm carapace length), protection of lobsters with eggs (gravid females), conditions of licencing, as well as imposition of the closed season (April 1 to Jun 30).

The Exclusive Economic Zone Act (1991) establishes under law the limitations of Jamaica's EEZ (200 nautical miles) and also establishes the rights of both local and foreign interests within this zone under the United Nations Convention on the Law of the Sea. The Morant and Pedro Cays Act (1907) address the terms under which these offshore cays should be accessed, including the provision of a special written license for fishing activities.

There are also several other Acts of Parliament that either directly or indirectly address issues of fisheries management and/or establish the right of responsible agencies to enforce the provisions within them. These include; the Wildlife Protection Act (1945), the Natural Resources Conservation Authority Act (1991), and the Aquaculture, Inland, Marine Products and By-Products Act (1999).

2.7.2 Management and Enforcement

The Ministry of Agriculture and Fisheries, Fisheries Division is the main agency with responsibility for the management, research and policy direction of the fishing industry. Its capacity for effective enforcement is however limited due to staffing and funding constraints. As a result, the Division depends heavily on collaborated multi-agency approaches to fisheries management where partnerships with agencies such as; the marine police, military, other environment and planning agencies of government, as well as non-government organizations form the framework for management and enforcement. Despite these constraints however the Fisheries Division maintains an active programme including a licensing and registration system, limited monitoring of vessels and catch, in addition to biological monitoring and research.

Most management measures are geared toward the industrial fleet. These include a limited entry policy (Venema 2004) as well as specific licensing conditions which restrict fishing grounds to the offshore areas (particularly the Pedro Bank) and specifies the use of only the Florida lobster trap in addition to landing their catch no later than eight weeks after the commencement of each fishing trip. Licenses are also subject to regulations regarding the

capture of undersized (less than 74.2 mm carapace length), the prohibition of taking gravid female lobsters and adherence to the closed season (April 1 to June 30).
Enforcement activities by the Division include inspection of landings and lobster establishments to ensure compliance with the closed season and other regulations. Since 2009 in was made illegal for persons to possess lobster, whole or part, after 21 days of the commencement of the closed season.
Despite the existence of this framework, non-compliance remains high. This is partly due to weak linkages among the main arms of management, that is, biological restrictions, enforcement activities and judicial arrangements which are presently too weak to produce an adequate deterrent. Additional challenges include IUU (illegal unreported and unregulated) effort including poaching by foreigners.

3 BIOLOGY AND LIFE HISTORY OF SPINY LOBSTER

The spiny lobster (*Panulirus argus*) is a relatively shallow water species, preferring sheltered habitats, such as littoral fringes, particularly mangrove and seagrass beds which are inhabited mainly by the post larval and early juvenile stages (Chakalall and Cochrane 2007). Adults may be found in rocky areas and coral reefs down to at least 100 m (Munro 1974). They are distinguished by a rounded carapace with forward pointing spines, prominent rostral horns and long spiny antennae with varied body colours from shades of black, brown and purple of young juveniles to shades of red, brown, and light greys in adults (Marx and Herrnkind 1986).
The spiny lobster is sexually dimorphic with males tending to grow faster with larger and heavier carapace in addition to lighter and shorter tails (Munro 1974). Growth averages around 50 mm per year in the first year, but may fall dramatically to an approximate average of 25 mm per year (Murray-Martin 2010). Growth and moulting are largely dependent on local environmental conditions mainly temperature, as well as population density, and tend to occur more frequently in younger individuals (Travis 1954; Marx and Herrnkind 1986).
Individuals may live in excess of 12 years and grow to lengths of 500 mm total length and weigh up to 4.5 kg though lengths of 200 mm are more common (CFRAMP 2001). Juveniles are recruited to the fishery at lengths of 76.0 to 76.8 mm carapace length (CFRAMP 2001).
Females generally reach first sexual maturity at carapace lengths of 78 to 83 mm. Mating results in the male depositing a waxy spermatophoric mass on the sternum of the female (Marx and Herrnkind 1986). When the female is ready, eggs are passed over the spermatophore for fertilization to occur (Marx and Herrnkind 1986; CFRAMP 2001). After fertilization and incubation of about 4 weeks females move to deeper waters to spawn (Munro 1974). Spawning will peak generally during the period February to August; however some spawning occur all year round (Marx and Herrnkind 1986; Munro 1974), usually at temperatures approaching 24ºC (Lyons 1980).
There are five distinct life history phases of the spiny lobster (Marx and Herrnkind 1986). These include a planktonic phylosoma larva that may spend an estimated 6 – 12 months in the plankton developing through 11 (Lyons 1980) or 12 stages (Aiken 1984; Munro 1974). The larvae then metamorphose into a non-feeding, pelagic phase called pueruli (Marx and Herrnkind 1986) which make their way to coastal areas by night particularly during the first

quarter of the lunar phase (Lyons 1980; Marx and Herrnkind 1986). Shallow coastal areas are however not essential for completion of their life cycle as they may also settle on isolated offshore banks such as the Pedro Bank which has only 2.1% of its area being less than 10 m depth (Munro 1974).

After settlement advanced pueruli then acquire a reddish-brown pigment, and within days, moult into the first juvenile benthic phase. These then develop into late juveniles (>20 mm carapace length) and then adults (about 60 mm carapace length) who will tend to gradually and nomadically emigrate offshore to deeper sheltered areas (Marx and Herrnkind 1986) where they feed nocturnally mainly on bivalves, small crustaceans, and small fish (Munro 1974), and are preyed upon by skates, nurse sharks, octopus, snappers (Lutjanidae), dolphins and groupers (Serranidae) (Munro 1974).

4 FISHERIES AND BIOECONOMIC MODELS

The fisheries model used in this analysis of the Jamaican industrial lobster fishery is based primarily on a modified Schaefer-Gordon surplus production model. This model has been found to be adequate for many fisheries around the world. It is most common for studying lobster fisheries in the Caribbean despite it possibly being biologically unrealistic (Milon *et. al.* 1999). Given its robust assumptions and relative simplicity of this model (Clark 1985) and the limited data that is available, the use of this model seems appropriate for this study. This type of surplus production model has been used in Florida; one of the regions' most developed and extensively researched spiny lobster fisheries. Studies including the 1982 Fishery Management Plan by the Gulf of Mexico and South Atlantic Fishery Management Councils, Waters (1987) and Milon *et al.* (1999) who in an extensive bioeconomic examination and review of the commercial spiny lobster fishery in Florida stated that surplus production models were most useful for examining the effectiveness of effort management.

In addition, recent assessments and reviews of the Jamaican spiny lobster stock by CRFM (2007), CRFM (2009) and Martin-Murray (2010) have developed and/or examined reference points and management strategies based on the Schaefer surplus production model. The inherent biological characteristics of the spiny lobster, which exhibits a poor to weak stock-recruitment relationship, also render the use of a surplus production model as appropriate for this type of analysis (Milon *et al.* 1999).

4.1 The General Model

The general aggregated bioeconomic functions for the Jamaican spiny lobster fishery are:

(i) Biomass growth

$$\dot{x} = G(x) - y$$

where $G(x)$ is biomass growth as a function of biomass, y is the yield or harvest from fishing and $\dot{x} \equiv \frac{\partial x}{\partial t}$ represents the change in biomass over time.

(ii) Harvest function

$$y = Y(e, x)$$

where total harvest, y, is a function of fishing effort, e, and biomass, x.

(iii) Profit function

The profit function assumes a constant price p, which when multiplied by harvests will give the revenues (R) from the fishery. Profits (π) are therefore obtained by subtracting total costs (TC) which include; (i) costs associated with fishing effort and harvest and (ii) costs independent of fishing effort and harvest or fixed costs fk, from the marginal revenues (R) thus obtaining the following:

$$R = p \cdot Y(e, x)$$

$$TC = C(y, e) + fk$$

and therefore profits are:

$$\pi = p \cdot Y(e, x) - C(y, e).$$

4.2 Biomass Growth Function

Biological production of the Jamaican spiny lobster stock will be assumed to follow the Schaefer surplus production model as was developed by Martin-Murray (2010).

$$G(x) = rx\left(1 - \frac{x}{K}\right)$$

where x is population biomass, r is the intrinsic growth rate and K is the carrying capacity or virgin biomass. By adding harvest to the equation and the variable of time we obtain the effect of fishing on population dynamics:

(1)

$$\frac{\partial x}{\partial t} = rx_t\left(1 - \frac{x_t}{K}\right) - y_t$$

where y_t is the harvest at time t. We may write (1) more simply as:

$$\dot{x} = \alpha \cdot x - \beta \cdot x^2 - y_t$$

where $\alpha = r$ and $\beta = \frac{r}{K}$. The change in biomass in discrete time will be approximated by the following equation:

$$x_t - x_{t-1} = \alpha \cdot x_t - \beta \cdot x_t{}^2 - y_t$$

where the biomass at time, x_t ,minus the biomass at time x_{t-1} is equal to the biomass growth less the harvest.

The equilibrium (or sustainable) state of the biomass, defined by $\dot{x} = 0$, can therefore be represented by the expression:

$$y = x_t - x_{t-1} = \alpha \cdot x_t - \beta \cdot x_t{}^2 - y_t = 0$$

4.3 Harvest Function

The harvest from the fishery will be based on a modified Schaefer harvest equation:

(2)

$$y = q \cdot e \cdot x^{\delta}$$

where harvests, denoted y, is equal to the catchability coefficient q (a constant) times the fishing effort times the biomass to the power δ. In this case δ is a coefficient measure of schooling behaviour of the lobster stock $\delta \in [0, 1]$, $\delta=0$ indicates extreme schooling stock and $\delta=1$ represents perfectly dispersed stock.

Note that any one item of (2) may be obtained from knowledge of the others by the appropriate transformation of (1). Thus, e.g., the catchability coefficient q, can be obtained from:

$$q = \frac{y}{e \cdot x^{\delta}}$$

4.4 Economics

4.4.1 Costs

The total cost function is specified as:

$$TC = C(y, \mathbf{e}) + fk = \ a \cdot p \cdot y + b \cdot e + fk$$

where TC is the total cost, a is a measure of the crew share of revenues, p is the price of landings and b is the marginal cost of effort.

4.4.2 Profits

The profits from the fishery are defined as the total revenues ($R = p \cdot y$) less total costs (TC) defined above. We, therefore, obtain the profit function:

$$\pi = p \cdot (1 - a) \cdot y - fk - b \cdot e$$

or, by substituting in for y.

(3)

$$\pi = p \cdot (1 - a) \cdot q \cdot e \cdot x^{\delta} - fk - b \cdot e.$$

4.5 Fishery Reference Points and Optimisation

4.5.1 Static Reference Points

Static reference points for the maximum sustainable yield (MSY), maximum economic yield (MEY) and the bionomic equilibrium (BE) will be examined using the biological and economic model described above. Reference points are included for the stock biomass, harvest and effort levels as well as for revenues, costs and profits within the fishery (see appendix). The biological components of these reference points will be determined using the modified Schaefer-type functions given previously.

Biomass at MSY may be obtained using the formula:

$$X_{MSY} = \frac{\alpha}{2\beta}$$

while the associated harvest is obtained as follows:

$$Y_{MSY} = \frac{\alpha^2}{4\beta} = \frac{r}{4} \cdot K$$

The corresponding static equilibrium effort levels at MSY (E_{MSY}), or for any other equilibrium effort (E_{eq}) level for that matter, may then be estimated by combining the biomass growth and the harvest functions and solving for effort thus obtaining the expression:

(4)

$$E_{eq} = \frac{y}{q \cdot x^{\delta}} = \frac{\alpha - \beta \cdot x}{q \cdot x^{\delta - 1}} = \frac{\alpha \cdot x^{1-\delta} - \beta \cdot x^{2-\delta}}{q}$$

Equation (4) is extremely useful in any sustainable equilibrium calculations. Note that if δ=1, (4) reduces to a linear function of biomass.

The bionomic equilibrium (*BE*) is derived from the condition that $\dot{x} = 0$ and where,

$$\pi = R - TC = 0,$$

in other words, where total revenues and costs are equal. Using (3) from above this may be written as:

$$\pi = p \cdot (1 - a) \cdot q \cdot e \cdot x^{\delta} - b \cdot e - fk = 0$$

Clearly, substituting in for *e* in this equation yields and expression for the bionomic equilibrium biomass as:

(5)

$$p \cdot (1 - a) \cdot (\alpha \cdot x - \beta \cdot x^2) - b \cdot \left(\frac{\alpha \cdot x^{1-\delta} - \beta \cdot x^{2-\delta}}{q}\right) - fk = 0$$

This equation will in general have to be solved by numerical means. Once the X_{BE} has been found from (5), it is straight forward to find the corresponding effort level from (4) and subsequently the harvest.

The profit maximizing MEY biomass (X_{MEY}) static reference point may be obtained by maximizing the profit function (3) with respect to biomass, i.e.

$$\underset{x}{maximize} \quad p \cdot (1 - a) \cdot (\alpha \cdot x - \beta \cdot x^2) - b \cdot \left(\frac{\alpha \cdot x^{1-\delta} - \beta \cdot x^{2-\delta}}{q}\right) - fk = 0$$

The solution to this maximization problem will in general have to be found by numerical means.

4.5.2 Dynamic Reference Points

Though static reference points are useful their static nature diminishes their utility as fisheries management tools. This is especially true since it is unlikely that any fishery is in complete equilibrium at any given time (Seijo et al. 1998). Dynamic representations which take into consideration changes in biomass, effort, costs and benefits (profits) over time are much more realistic and therefore considered more effective in determining the optimal fisheries management policy.

Optimal equilibrium reference points (*) for a given discount rate were developed by combining biomass growth, harvest and profit functions to simulate the optimal discounted fishery over time. The basic optimal equilibrium biomass expression is (Arnason 1990, Clark and Munro 1975):

$$G_x(x) + \frac{C_e(e) \cdot Y_x(e, x)}{\pi_e(e, x)} = d$$

where *d* is the rate of discount and the functions are defined in 4.1 above. Substituting the Schaefer model discussed above we find:

(6)

$$\psi = (\alpha - 2 \cdot \beta \cdot x) + \left(\frac{b \cdot \delta \cdot (\alpha - \beta \cdot x)}{p \cdot (1 - a) \cdot q \cdot x^{\delta} - b} \right) = d$$

where d represents the discount rate.
From this equation the optimal sustainable biomass level, (X*) can be obtained by numerical means. Note that for a discount rate equal to zero, d=0, X*=X_{MEY} (Clark 1985).
The optimal equilibrium effort E* may then be obtained from expression (4) as:

$$E^{*}_{eq} = \frac{\alpha \cdot (X^{*})^{1-\delta} - \beta \cdot (X^{*})^{2-\delta}}{q}$$

Maximisation of the present value, PV is the usual objective of a dynamic fisheries policy. The present value of a future flow of benefits may be defined as the amount of benefits at years zero that is equally desirable to the future flow of benefits (Clark 1985). This is dependent on the rate of discount, d. A high discount rate will lead to a lower present value, while a low discount rate will lead to higher present values for net benefits in the same time period (Seijo *et al*. 1998). The present value of a flow of profits, π, in year t is expressed as:

$$PV_{\pi} = \frac{R_t - TC_t}{(1+d)^t} = \frac{\pi_t}{(1+d)^t}$$

The NPV of a flow of profits over a time interval [0, n] is obtained as:

$$NPV_{\pi} = \sum_{t=0}^{n} \frac{\pi_t}{(1+d)^t}$$

4.6 Data Sources

4.6.1 Biological Data

The data for the biological production of the Jamaican spiny lobster fishery including biomass, biomass growth, and harvest quantities for the period 1997 to 2007 are based on Martin-Murray (2010). The harvest quantities were then checked against annual export data from the Statistical Institute of Jamaica (STATIN 2010) which was used as an estimate of total harvest from the industrial fleet. This was deemed a fairly good proxy for the yield of industrial fishery since it is predominantly (90% of catches, Martin-Murray (2010)) geared toward export, while the artisanal fleet mainly targeted the small local market. Further, a similar method using local industry and export information was employed by Clerveaux *et al*. in WECAFC (2003) to estimate total yield in their bioeconomic report on the spiny lobster fishery of the Turks and Caicos Islands, another Caribbean fishery.

4.6.2 Effort Data

The associated effort (effort days) data for the fishery was developed by obtaining the number of licensed industrial boats per year (from the Fisheries Divisions' database). Then assuming each boat is adequately similar and does two fishing trips of 14 days per month during the nine month open season we obtain the effort in each year as:

$$Effort\ in\ year_i = days\ per\ trip \cdot trips\ in\ year_i \cdot number\ of\ boats\ in\ year_i$$

4.6.3 Economic Data

An economic perspective of the Jamaican industrial spiny lobster fishery, including estimates of marginal costs, revenues and profits, was developed with data obtained mainly through interviews with persons involved in the Jamaican industrial lobster fishery, including managers and fishers. Two fishers from separate lobster vessels were interviewed; this would represent roughly 1/3 of the six (6) licensed vessels for the 2007 season. Additional input and comparative information were obtained from both public and private data sources such as the Fisheries Division database, STATIN (2010) as well as current available literature.

4.7 Estimation of Parameters

4.7.1 Biological Parameters

Biological production parameters including the intrinsic growth rate (α) and carrying capacity (K) were estimated using linear regression of biomass versus the calculated biomass growth (see appendix). The parameter beta (β) obtained which is equivalent to the expression $\beta = \frac{r}{K}$, as explained previously in the biomass growth function, was then used to calculate K obtained from the expression $K = \frac{\alpha}{\beta}$. The values obtained for the biological parameters are given in table 2:

Table 2: Biological parameter estimates for the Jamaican spiny lobster stock.

Parameter	**Symbol**	**Value**
Intrinsic Growth rate/alpha	$r\ (\alpha)$	0.7987
Beta	β	0.0007
Carrying Capacity/ Virgin Biomass	K	1110.29

4.7.2 Harvest Function Parameters

The schooling parameter (δ) was taken to have the value 0.9 based on the known biology of the species which exhibit a very low schooling tendency. The catchability coefficient (q) was estimated by using the above harvest function:

$$\widehat{q_t} = \frac{y_t}{e_t \cdot x_t^{\delta}},$$

for available data on harvests, biomass and fishing effort each year (1997-2007) and taking an average (see appendix).

These parameter estimates are given in table 3:

Table 3: Harvest parameter estimates for the Jamaican industrial spiny lobster fishery.

Parameter	Symbol	Value
Catchability Coefficient	q	0.000301
Schooling Parameter	δ	0.9

4.7.3 Economic parameters

Total costs (TC) are defined as the sum of the fixed costs (fk) and variable costs as explained above. Fixed costs are those incurred independent of fishing activity and will include (i) capital costs consisting of (a) depreciation of vessel value and equipment and (b) the lost interest on the vessel and equipment value , (ii) average annual licensing and registration fees, (iii) average maintenance fees per year and (iv) management and overhead costs.
The estimate for the value of vessel and equipment is based on information given in interviews which produced a collective estimated value of US $86,881 calculated at the average 2007 exchange rate of JA $69.06/US$. An assumed annual depreciation rate of 5% and interest costs of 15% were also taken into consideration. Thus total annual capital costs are obtained from the summed depreciation and interest payments percentages (20%) multiplied by the value of the vessel and equipment (US $86,881) which is equal to US$ 17,376 per year.
Average annual registration and licensing fees are also based on interview information which placed this value at US $2,896 per year with maintenance costs averaging roughly US $11,584 per annum. Cost associated with management and overhead operational costs were estimated to be US $5,000. Thus, total fixed costs are estimated to be US $36,856 per year. A summary of the fixed costs can be seen in table 4.

Table 4: Average annual fixed costs estimates associated with the Jamaican spiny lobster industrial fishery.

Item	Value(US $)
Capital Costs (Depreciation 5%; Interest payments 15%)	**17,376**
Maintenance Fees	**11,584**
Licence and Registration Fees	**2,896**
Management and overhead	**5,000**
Total Fixed Costs	**36,856**

Variable costs are those costs associated with actual fishing activity. They are split into (i) variable costs related to fishing effort and (ii) variable costs dependent on landed value, primarily crew remuneration. For the former, we will include; the average cost of fuel per trip (14 days), the cost of food and supplies per trip for a crew of 10, as well as miscellaneous items.

The average fuel cost estimates are based on a voyage distance of approximately 320 km (roughly the distance to and from the Pedro Bank from the main landing sites in and around Kingston (ECOST 2007)), requiring approximately 1,450 gallons (5,489 litres) of diesel fuel calculated at the average 2004-2007 selling price of JA $39.30/litre (Petrojam 2010). Labour costs, according to fisher interviews, were paid as a 25% portion of the revenues from landings and were said to average between US $5,792 and US $8,688 per trip (implying revenues of up to US $34,752 per trip). Annual variable costs are calculated on the assumption that each vessel goes out twice per month during the 9 month spiny lobster open season (July 1 to March 30). Miscellaneous items totalled approximately US $2,500. A summary of the variable costs are given in table 5.

Table 5: Fishing effort dependent variable costs per trip and per year for the Jamaican industrial spiny lobster fishery.

Item	Unit price (US$)	Cost per trip (US$)	Annual Cost (US$)
Fuel	0.57/litre	3,124	56,232
Food and Supplies	311/person	3,113	56,034
Miscellaneous	-	2,500	45,000
Total Variable Costs	-	**8,737**	**157,266**

In the total cost equation, b, the marginal cost of effort (expressed in 1000 US $) was estimated by dividing the sum of variable costs, except labour, by the average days per trip (14). That is:

$$b = \frac{Variable\ Cost\ per\ trip}{days\ per\ trip} = \frac{8{,}737}{14} = US\ \$624.07$$

Finally, the labour costs were estimated as the fraction (a) of landed revenues. This fraction is close to 0.25 in the spiny lobster fishery of Jamaica. This gives us the total cost function per boat during the year as:

$$TC = 0.25 \cdot p \cdot y + 624.07 \cdot e + 36.856,$$

where $p{\cdot}y$ is the landed value and the last number is fixed costs.

At this point it should be recognized that the equations for both the sustainable and dynamic optima assume differentiability (can be differentiated) and therefore fixed costs will increase or decrease in a step-wise manner as vessels (or equivalent number of effort days) are added or removed from the fishery. As a practical matter, this cannot be applied mathematically without a smoothing of this step-wise adjustment by approximating a mid-point between each step. Since one aim of this analysis is to determine the optimal number of effort days (and associated number of vessels) for the fishery the above fixed costs will therefore become variable from a management point of view. To account for this reality, the marginal cost b was adjusted as follows to obtain the parameter bb. Recall that:

$$Costs = b \cdot e + fk \cdot No. of\ Vessels$$

where the number of vessels is determined by the expression:

$$No.Vessel = \frac{Effort\ Interval}{Annual\ effort\ days\ per\ vessel} = \frac{1.5}{252}$$

We therefore obtain:

$$Costs = b \cdot e + fk \cdot \frac{e}{252} = \left(b + \frac{fk}{252}\right) \cdot e = bb$$

The price p used to determine revenues were obtained from the average export price for the period 2003 to 2007 (STATIN 2010) (see appendix).
These economic parameters used in this study are summarized in table 6.

Table 6: Economic parameter estimates for the Jamaican industrial spiny lobster fishery.

Parameter	**Symbol**	**Value**	**Brief Description**
Price	p	13.16	US$/kg, based on 2003 to 2007 export data
Labour as share of revenues	a	0.25	Percent average given in interviews
Marginal cost per effort (fishing day)	b	0.624	Estimate of cost per trip in 1,000 US$
Adjusted cost per effort (fishing day)	bb	0.843	b + (fk/252)·1.5

In summary, based on the economic parameters and the harvesting function, the profit function may be expressed as:

$$\pi = 13.16 \cdot (1 - 0.25) \cdot (0.000301 \cdot x^{0.9} \cdot e) - 36{,}856 - (0.843 \cdot e)$$

5 STATIC ANALYSIS

Sustainability or equilibrium biomass solutions are important as they imply long-run stability in biological and economic terms. In other words, a sustainable fishery implies that for a certain level of biomass; growth and harvest are equal, thus the biological stock integrity as well as economic outcomes are maintained at more or less constant levels. Sustainability may occur at many levels of biomass. Of particular interest are the bionomic equilibrium, the maximum sustainable yield biomass and the maximum economic yield biomass

5.1 The Sustainable Fishery and its reference points

The following figure (6) is a diagrammatic summary of the sustainable fishery model with associated biomass, revenue, cost and profit curves in effort space:

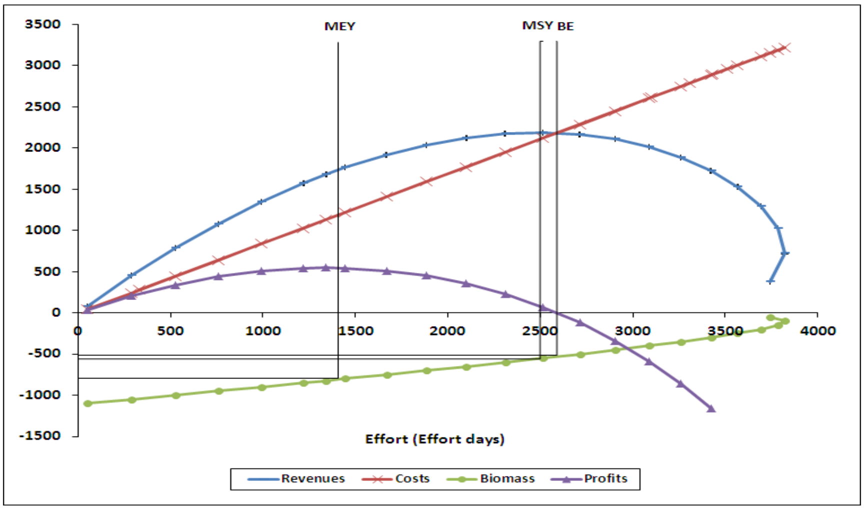

Figure 6. Sustainable fishery model for the Jamaican industrial spiny lobster fishery based on modified Gordon-Schaefer specifications. Illustrated are the sustainable revenues, costs, profits and biomass in fishing effort space comparing the MEY, MSY and BE reference points.

Note that the revenues curve represents net revenues, i.e. revenues after having subtracted the 25% crew share.

Equilibrium fisheries management reference points were calculated based on the empirical modified Schaefer-Gordon bioeconomic model described above. These reference points include the current (2007) condition as well as the calculated bioeconomic equilibrium (BE), maximum sustainable yield (MSY) and maximum economic yield (MEY) conditions. Table 7 presents a summary of these reference points for the Jamaican industrial spiny lobster fishery and the corresponding economic outcomes.

Table 7: Sustainable equilibrium and current (2007) fishery reference points for the Jamaican industrial spiny lobster fishery.

Reference point	Biomass (1000 kg)	Effort (effort days)	Number of Vessels	Harvest (1000 kg)	Revenues (US$ 1000)	Total Costs (US$ 1000)	Profits (US$ 1000)
2007	351	1,512	6	112	1,332	1,275	57
BE	531	2,590	10	221	2,184	2,184	0
MSY	555	2,494	10	222	2,188	2,103	85
MEY	823	1,342	5	170	1,679	1,132	547

The current (2007) fishery situation strongly indicates biological and economic overexploitation of this fishery. Most importantly, the current biomass level is far below what would be regarded as the optimal level. Fishing effort is slightly excessive and harvest levels considerably less than can be optimally sustained. Costs associated with excess effort have also dissipated potential profits from the fishery; in fact biomass and harvests are well below the respective X_{BE} and Y_{BE} levels however due a low level of effort the fishery seems to have achieved small profits close to the equilibrium MSY level.

The MEY option presents the best and most efficient sustainable outcome for the fishery. Here sustained profits could be yielded equivalent to roughly ten (10) times the current profit level, or over six (6) times the MSY profits level. This MEY condition would however require a positive adjustment and investments in the fishable biomass over a period of time to allow for an approximate doubling of current biomass levels. Fishing effort would also need to be adjusted possibly to include a substantial initial decrease then a subsequent increase to the E_{MEY} level.

Based on the cost estimates for the fishery both sustainable BE and MSY equilibrium options are placed very close to each other with only minor differences, most notable is the fact that there is small overall profit to be made using the MSY static option. This is important as it will have significant implications for any management strategy developed. Despite these facts the MSY option represents an almost doubling of current biomass, harvest and an increase in profit levels. In addition, the fact that the MSY solution lie so close the BE may call for caution as a MSY-policy would represent a considerable economic risk. The effect of such risks could be easily realised based on historical effort levels which shows effort levels hovering about the E_{MSY} and E_{BE} during the ten (10) year period 1997 to 2007 (figure 7).

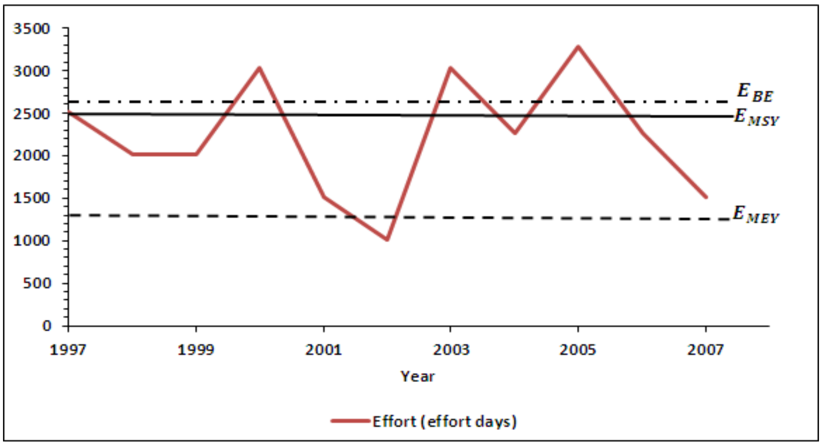

Figure 7. Calculated effort days per year (1997 to 2007) compared against the static effort reference points; E_{BE}, E_{MSY} and E_{MEY} for the Jamaican industrial spiny lobster fishery.

As can be seen from figure 7, the effort levels in this fishery have been highly variable. On average they have been slightly less than what corresponds to the bionomic equilibrium (so, there have been profits in the fishery)

6 DYNAMIC FISHERY

In order to provide some understanding of the dynamics of this fishery, it was simulated for a twenty (20) year management period from 2007 toward the long-run optimal solution and the net present value (NPV) of profits for varied discount rates compared for the period.

6.1 Equilibrium Dynamic Fishery

Figures 8 - 11 show the dynamic trajectories towards the long-run sustainable biomass reference points (BE, MSY and MEY) and the resulting outcomes in terms of biomass, harvest, revenue and profits. These figures illustrate a direct and immediate "jump" to the E_{MEY}, E_{MSY} and E_{BE} in the first managed year (2008) thus presenting a comparison of the long-run outcomes of each. Recall that a constant discount rate of zero assumes that the value of future benefits (profits) over time does not change.

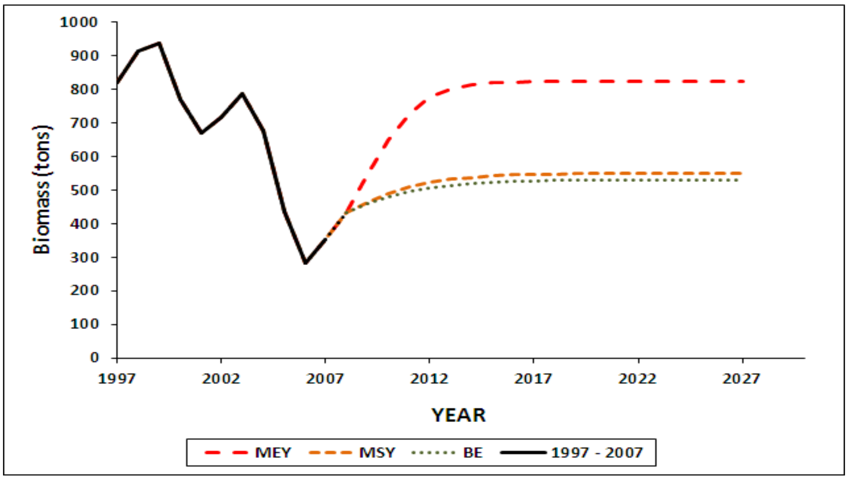

Figure 8. Estimated spiny lobster biomass for the period 1997 to 2007 and dynamic projections using the MEY, MSY and BE effort solutions for the fishery.

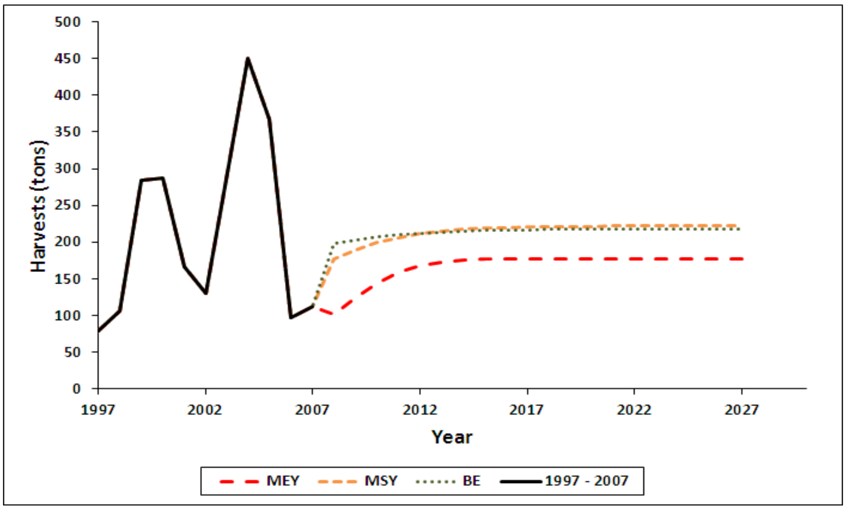

Figure 9. Spiny lobster harvests for the period 1997 to 2007 and dynamic harvest projections using the MEY, MSY and BE effort solutions for the fishery.

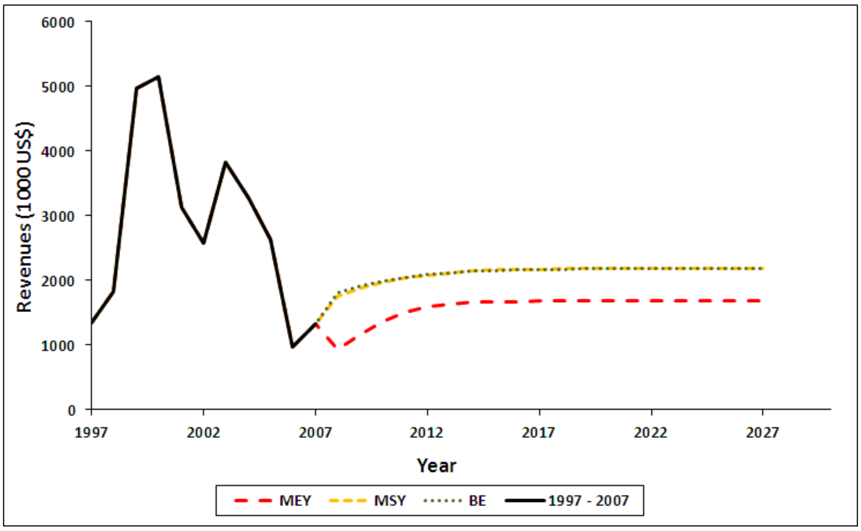

Figure 10. Estimated revenues from the Jamaican industrial spiny lobster fishery for the period 1997 to 2007 and dynamic revenue trajectories using the MEY, MSY and BE effort solutions.

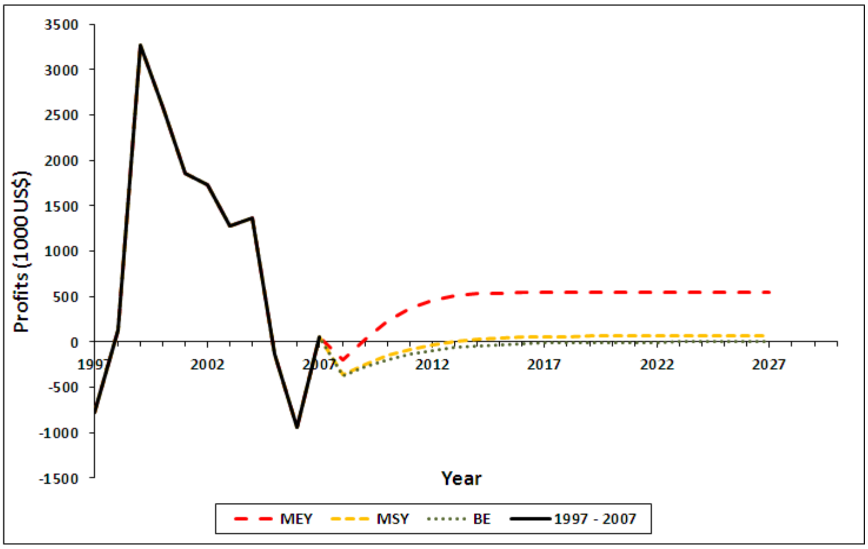

Figure 11. Estimated profits for the period 1997 to 2007 and dynamic profit trajectories for the MEY, MSY and BE solutions.

The above simulations (figures 8-11) show attainment of the steady state equilibrium within five (5) to ten (10) years. The differences between the dynamic and long run outcomes of heading toward the different steady state reference points are also illustrated particularly for the MSY and BE as against the MEY.

Biomass has shown a dramatic decline over the assessment period 1997 to 2007 leading to the current situation. This is strongly improved under all policies. Since the reference points for MSY and BE are similar their resulting revenues are also similar however due to differences in effort (and costs) profits show significant differences particularly MSY and BE against the MEY. This MEY solution will however vary once there is a positive discount rate.

6.2 Optimal Equilibrium Dynamics

The optimal MEY policy will vary depending on the rate of discount. To analyse and compare this effect, optimal bioeconomic reference points (*) for a range of discount rates were developed. Table 8 presents a summary of optimal bioeconomic outcomes for various discount rates:

Table 8: Optimal dynamic equilibrium solutions for various discount rates (*d*).

Discount Rate (*d*)	X^* (tons)	E^* (effort days)	E^* (No. Vessels)	Y^* (tons)	Revenues (1000 US$)	Costs (1000 US$)	Profits (1000 US$)
0.25	770	1,579	6	188	1,860	1,332	529
0.20	778	1,543	6	186	1,836	1,302	534
0.17[1]	785	1,512	6	184	1,813	2,103	537
0.10	800	1,445	6	179	1,762	1,219	543
0.05	810	1,400	6	175	1,727	1,181	546
0.00	823	1,342	6	170	1,679	1,132	547

The discount rate determines the future value of future benefits (in this case profit) from the fishery. The effect of increasing the discount rate is to encourage fishing effort *E** and harvests *Y** in addition to reducing the optimal biomass *X**. An increased discount rate reflects a higher return on investments which can make harvest more feasible, i.e. less investment in fish stocks.

6.2.1 Net Present Value of Optimal Equilibrium Projections

Further analyses of the optimal equilibrium dynamic reference points were done to determine and compare the cumulative value of each outcome with respect to various discount rates. For this analysis, the fishery was simulated for a twenty (20) year management period (similar to section 6.1) from 2007 to 2027 and the net present value (NPV) of profits for discount rates over the period calculated. The purpose was to (i) predict potential profits for the fishery and (ii) to help determine potential net benefits of any management action that may be implemented for the fishery (table 9).

Table 9: Net present value of profits (1000 US$) for a twenty (20) year optimal management simulation from 2007 at varied discount rates.

Discount Rate (*d*)	NPV of Profits (1000 US$)
0.20	1,187
0.17	1,562
0.10	2,930
0.05	4,927
0.00	8,852

[1] 2007 average inflation rate obtained from the Bank of Jamaica (2011).

NPV's for the period increased at a decreasing rate from low to higher rates of discounts. However, using the 2007 reference year as a guide, more likely NPV's for the period may be found at discount rates between 10% and 20%. Therefore NPV of profits for the simulation period could likely occur between US $2.9 million and US $1.2 million per year. It should be noted also that there are many variables not examined that may affect the optimal equilibrium overtime.

6.3 Adjustment Paths

6.3.1 Competitive Dynamics

One alternative to optimal management is, of course, no management at all. This essentially means allowing open access and for the fishery, as a system, to come to its own equilibrium, the bionomic equilibrium (BE). In this case the only inhibition will be the fisher's ability to make profits, or at least cover basic costs, which will eventually lead the fishery to the BE. In this case the fishery expands rapidly in the initial stages when biomass and profits are high, eventually, as biomass and profits are reduced effort will contract (Arnason 2008). This competitive cycle is repeated until fishing effort and biomass are such that (i) the fishery just breaks even and (ii) the biomass is in equilibrium. Figure 12 presents a possible competitive dynamic path for the Jamaican lobster fishery.

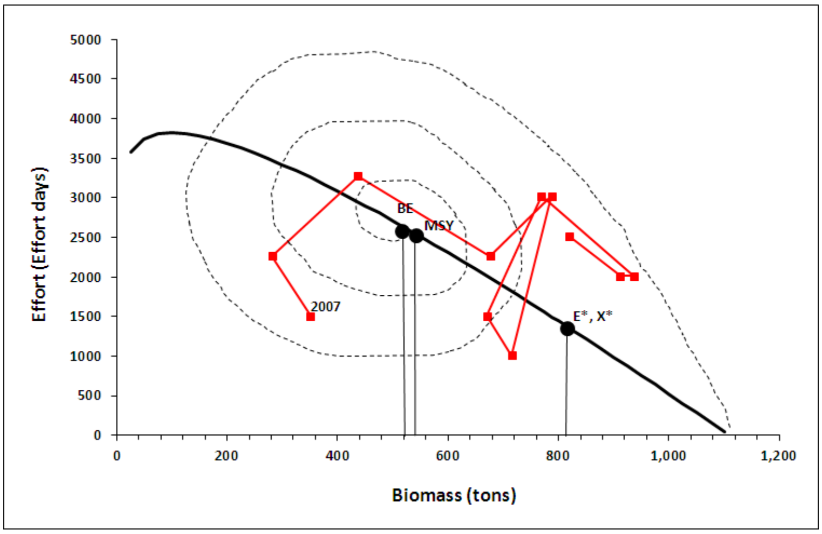

Figure 12. Possible competitive dynamic evolutionary path of the Jamaican industrial spiny lobster fishery from the initial exploitation stage. The assessment period 1997 to 2007 and the fishery reference points; BE, MSY and the optimal fishery (*E**, *X**) also given for comparative reference.

6.3.2 Optimal Adjustment Path

The optimal adjustment path toward the long-run optimal sustainable equilibrium will vary depending on the biological and harvest characteristics of the fishery (Arnason 2008). In this model where the cost of harvesting is assumed linear with respect to effort the "most rapid approach" or "bang-bang" approach is optimal (Clark and Munro 1975, Arnason 2008). This optimal policy suggests that there be large investment in the stock to allow for a rapid build-up to the X^*. This investment may include, among other measures, a partial or total reduction of fishing effort then a similar rapid increase to the E^* (figure 13).

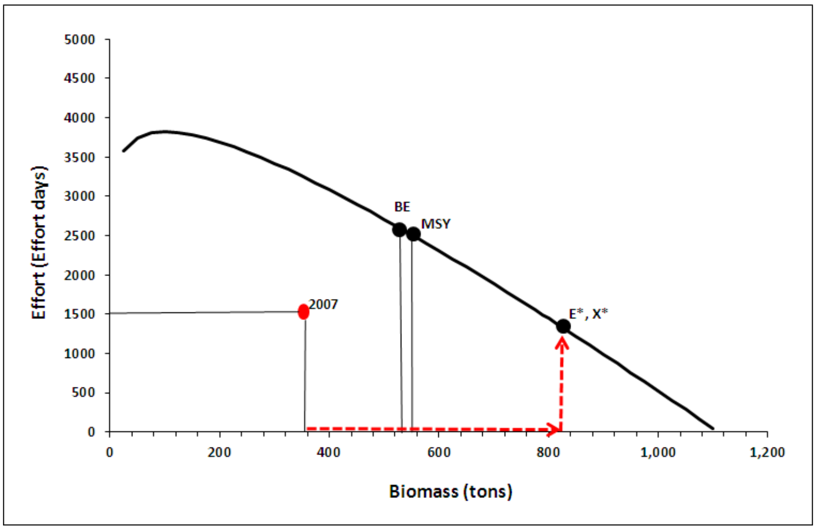

Figure 13. Most rapid optimal approach or "bang-bang" path toward the optimal sustainable equilibrium for the 2007 discount rate.

Though this approach represents an extreme (and possibly impractical) path to optimal sustainability the fundamental principle of this approach can still be appreciated from a management point of view.

7 DISCUSSION

7.1 Equilibrium Fishery and Undiscounted Dynamics

Both static (or sustainable) analysis and dynamic projections indicate overexploitation which has resulted in a dissipation of potential profits from the fishery. Over-capitalization does not seem to be occurring at present when both the number of effort days and vessels are considered. However, low biomass and high cost per unit catch have put the fishery in a marginally profitable state. This high cost of effort in spiny lobster fisheries is however not unique to Jamaica as Clerveaux et al. (2003) also pointed out that the high and variable cost of effort in the Turks and Caicos fishery, which they pondered, could have a part in their highly fluctuating harvests.

The fishery currently finds itself at a critical stage in terms of management with most bioeconomic criteria at levels below the BE. This current state may however represent an opportunity for management. According to the equilibrium MEY management solution, the fishery has a potential for sustained profits in excess of US $500,000 annually. This would however require an adjustment of biomass up to 800 tons in addition to dynamic adjustments in fishing effort.

Analysis of the period 1997 to 2007 have shown large, unsustainable peaks in harvests (288 tons in 2000 and 451 tons in 2004) due to excessive effort which has resulted in a sharp decline in biomass levels from a high of just over 900 tons in 1999 to a low of just less than 300 tons in 2006. Profits also peaked with these harvests but then fell sharply in the next year as biomass apparently declined.

Dynamic simulations have shown that significant improvement in the fishery could be realized over an approximate 10 year adjustment period toward the MEY optimal management solution. It was also shown that the MSY option not only yielded fair profits but represented a more improved fishery with twice the current biomass and harvests. Importantly as well it was shown that excessively high effort levels would eventually result in a trajectory towards BE. It should also be born in mind that as the fishery improves towards sustainability these projected outcomes are likely to change and therefore may represent further opportunity for improvement as the fishery evolves.

7.2 Optimal Dynamics

NPV analysis of profits for a simulated 20 year management period toward the long-run optima at varied discount rates obtained values ranging between US$ 8.9 million to US$ 1.2 million for discount rates from 0% to 20%. Using the 2007 discount rate as a reference however, a more likely range of values possibly lie between discount rates of 10% to 20% therefore obtaining the range US $2.9 to US $1.2 million.

These NPV's represent the value of pure profits from the fishery over the period and may also provide a benchmark from which an appropriate management strategy may develop, particularly with regards to the cost of management (or net benefit). It may be important to keep the net costs of any management initiative below the NPV for this or any management period in order to avoid a net loss to the Jamaican society.

Based on the model specifications the, "most rapid approach" or "bang-bang" adjustment path (Arnason 2008) is optimal. It may be recognized however that this policy may not be applicable in a strict sense to this or, indeed most other fisheries and may need to be modified for practical application. This policy however addresses the problems of the competitive dynamic path and other sub-optimal management objectives by contracting fishing effort in the short term, rebuilding the stock in the short to mid-term, and then adjusting fishing effort and harvests to their respective optima based on the available biomass.

7.3 Management Solution

The practical question then arises as to what type of fisheries management system may be best to achieve the optimal fishery in a dynamic and sustainable sense.

The fundamental problems of the Jamaican industrial lobster fishery are similar to those in many other fisheries around the world where negative forces are at work due to the common property nature of the resource (Seijo *et al*. 1998). Because, under argument, there is very little or no incentive for individual fishers to invest in the stock, the resource tends to be overexploited and fishing effort and fleets to be excessive. This result in a waste of valuable resources used to obtain competitive advantages in obtaining catches rather than achieving economic efficiency in the method of harvesting.

The solution to the fishery's problem lies in the development and implementation of a property rights-based fisheries management (PRBFM) system where, according to Hannesson (1993), the rights owner will have strong incentive to harvest as efficiently as possible and limit fishing effort to any level that will maximize his profits from the fishery. PRBFM's are used widely in fisheries management worldwide to varying extents and include, but are not limited to, sole ownerships, access licences, territorial user rights in fisheries (TURFS) and various forms of harvest quota systems (Arnason 1996). Of these PRBFM systems, individual quotas (IQ's) have proven to be most effective in solving the common property problem, particularly those that have been made transferable (Hannesson 1993).

PRBFM systems have been applied to similar fisheries throughout the region as well, including Florida, which has implemented the transferable trap certificate programme (TCP) since 1992 (Milon *et al*. 1999). This move was in part to reduce the number of traps and improve efficiency in the fishery. As a result, by the end of the decade the fishery was experiencing historical high harvest levels of around 3 million kg per year which was also achieved in the 1960's and 1970's but with less than one-ninth the fishing effort in addition to achieving improved profits (Milon *et al*. 1999).

There are however a number of conditions that must be developed for PRBFM to be successfully implemented. An effective property right is one which is secure in title, exclusive to the owner, durable in tenure, and preferably transferable to allow for a less efficient right holder to sell that right to a more efficient user (Arnason 1996). Improved property rights in the Jamaican lobster fishery would however also require strengthening of the lobster management regime to include; better monitoring, control and surveillance (MCS) systems as well as judicial arrangements issuing sanctions to violators.

Community management based on territorial user rights in fisheries (TURFS) is one option which could be fitted to the Jamaican context to promote efficiency in the utilization of the stock. Here exploitation rights could be given to a "community" or group of fishers who are then subject to an annual TAC. It would therefore be in the interest of individuals to come to some collective exploitation strategy which would maximise the net benefit of each (Hannesson 1993). A TURF system could also in theory suit the species since it exhibits a low degree of schooling and, apart from its larvae, the fishable stock remains more or less within a certain area.

This community based TURF system would confer relative advantages for assessment and enforcement activities as it would be a defined area within Jamaica's EEZ. Difficulties regarding this policy may however arise due to complexities in identifying and having the group of fishers agreeing on an equitable exploitation strategy. This could possibly present individual fishers with incentive to cheat if the arrangement seems unfair, or even if it is equitable may find it advantageous to take more than the agreed share (Hannesson 1993). Though there are benefits to TURF's they have been largely unsuccessfully implemented except in areas very near to shore (Arnason 1996) and thus may not be suit the Jamaican lobster fishery considering the main stock is some 180 km offshore (ECOST 2007).

A more ideal option would be an individual transferable quota (ITQ) system which has been successfully used to promote economic efficiency as well as biological conservation in some of the world's most developed fisheries including New Zealand, Iceland and the US and Canada (Arnason 1996). An ITQ system for the industrial fishery would confer a number of advantages for the industry. TAC's could be set at optimal levels and firms given transferable shares in this TAC. A share system would help to guard against biological uncertainties in the annual TAC especially considering the uncertainty regarding the stock-recruitment relationship (Erhardt et al. 2009). Economically, firms would be able to better plan their most efficient harvest strategy and rationalize investment in their expected quota share (Hannesson 1993). In addition, since a fisher would have legal rights to his share in the TAC he could also borrow against his quota or sell it to another fisher, all of which are not usually possible with fixed quotas. Jamaica could also draw on the valuable experience of formulating TAC's for Queen Conch fishery which has existed since 1993/94 fishing season (Aiken *et al*. 2006).

Aside from the obvious capital and financial challenges one would anticipate in the development of such a system, the most important issue would be the need for an effective MCS plan where the fisheries authority, or other responsible agencies, would have to enforce the property right otherwise the economic potential in the fishery will not be realized (Arnason 1996). This will require a firm institutional and legislative framework to support maintenance of the lobster stock and the quality of the property rights.

Additional requirements would include in-depth biological and economic programmes to (i) assess the stock and determine TAC's and (ii) to determine the fishery's relative position along the optimal adjustment path. Despite these challenges it appear certain that the fishery has the potential for substantial profits and therefore an investment in an optimal-oriented management system may be worthwhile. Jamaica could also look to solicit funds from global development partners such as the Global environment Facility (GEF) and the World Bank as well as other bodies having an interest in conserving biological resources and achieving economically efficient and sustainable development. For the biological aspect, a precautionary approach may however suffice and complement on-going biological research, at least in the short to medium term until a long-term biological strategy can be developed.

8 RECOMMENDATIONS

- Annual catch and effort levels should be set conservatively about or below the optimal until a long-run bioeconomic monitoring and assessment strategy can be developed.
- Develop legislative and institutional arrangements with a view toward the gradual implementation of an appropriate property rights-based fisheries management system for the lobster fishery.
- Develop and implement long-term programme for spiny lobster biological and economic research and securing of the national stock through improved MCS.
- Establish local and international partnerships regarding the development and implementation of property rights in the fishery.
- Develop and implement a long-term optimum adjustment policy for the fishery as follows:

1. Effort and harvest reduction.
2. Biomass enhancement toward optimum.
3. Optimally adjust effort and harvest.
4. Implement programme for maintaining optimal adjustment path.

ACKNOWLEDGEMENTS

I would like to extend sincere gratitude to the staff of the UNU-FTP namely; Dr. Tumi Tómasson, Þór Ásgeirsson and Sigríður Kr. Ingvarsdóttir, first of all for the opportunity to be part of this wonderful programme which has no doubt greatly enhanced my capacity as a professional, and secondly for a truly life changing experience in Iceland.

I would also like to thank my distinguished supervisor, Professor Ragnar Arnason whose excellent technical input and guidance throughout the duration of this project has ensured that the best possible output was produced.

Finally, I want to express my thanks to my family who have encouraged and supported me throughout, and my very good friends particularly those I have met in Iceland who have not only supported me during the writing of this paper but also ensured my experience in Iceland was one I will never forget. Thanks a million.

REFERENCES

Aiken, D.E. 1980. *Moulting and growth*. 91-147. In J.S. Cobb and B.F. Phillips, eds. The Biology and Management of Lobsters, Vol. 1. Academic Press, New York. [Accessed on December 14, 2010] http://www.sms.si.edu/irlspec/panuli_argus.htm

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

Aiken, K, Kong, A, Smikle, S, Appledoorn and Warner, G. 2006. *Managing Jamaica's Queen Conch Resources*. Ocean and Coastal Management. 49, 332–41

Arnason, R. 1990. *Minimum Information Management in Fisheries*. Canadian Journal of Economics. 23, 630-53.

Arnason, R. 1996. *Property Rights as an Organizational Framework in Fisheries: The Case of Six Fishing Nations*. In Crowley, B.L. (ed.) Taking Ownership; Property Rights and Fisheries Management on the Atlantic Coast. Halifax: Atlantic Institute for Market Studies. 99-144.

Arnason, R. 2008. *Basic Fisheries Economics* [Unpublished/manuscript]. A paper prepared for the Workshop on Policy and Planning for Coastal Fisheries Resources. University of South Pacific, Suva, Fiji, January 28 to February 8, 2008.

Bank of Jamaica (BoJ). 2011. [January 4, 2011] http://www.boj.org.jm/economic_data.php?report_id=84

Central Intelligence Agency (CIA) 2010. [December 12, 2010] https://www.cia.gov/library/publications/the-world-factbook/geos/jm.html

CFRAMP 2001. *A Regional Overview of Spiny Lobster (Panulirus argus) Resources in CARICOM/CARIFORUM Countries*. CFRAMP. [December 4, 2010] http://www.caricom-fisheries.com/LinkClick.aspx?fileticket=2Rg3zsjjELw%3D&tabid=85

Chakalall, B. and Cochrane, K. 2007. *Regional Cooperation for the Responsible Use of the Caribbean Spiny Lobster Resource*. Proceedings of the 60th Gulf and Caribbean Fisheries Institute. 60, 239-246.

Chavez, E.A. 2007. *Socio-economic Assessment for the Management of the Caribbean Spiny Lobster*. Proceedings of the 60th Gulf and Caribbean Fisheries Institute. 60, 193-196.

Clark, C.W. 1985. *Bioeconomic Modelling of Fisheries Management.* J. Wiley & Sons, New York. 17-19.

Clark, C.W. and Munro, G.R. 1975. *The Economics of Fishing and Modern Capital Theory: A Simplified Approach*. J. Environ. Mgmt. 2, 92-106.
CRFM. 2007. Report of Third Annual Scientific Meeting – Kingstown, St. Vincent & the Grenadines, 17-26 July 2007 - National Reports. *CRFM Fishery Report - 2007*. Volume 1, Suppl. 1. 62

Clerveaux, W., Puga, R. and Medley, P. *National Report on the Spiny Lobster Fishery of the Turks and Caicos Islands* In WECAFC 2003. *Report of the Second Workshop on the Management of the Caribbean Spiny Lobster Fisheries in the WECAFC Area Havana Cuba, 30 September – 4 October 2002*. FAO.

CRFM 2009. *Spiny Lobster Report- Jamaica*. Report of Fifth Annual Scientific Meeting – Kingstown, St. Vincent and the Grenadines, 09-18 June 2009 – Fishery Management Advisory Summaries. *CRFM Fishery Report* - 2009. Volume 2. 60p.

ECOST Project 2007. Case Study 2: Jamaica. Center for Marine Sciences (CMS). [January 2, 2011]
http://www.ird.fr/ecostproject/doku.php?id=case_study_2_jamaica_c_m_s_centre_for_marine_sciences

Ehrhardt, N., Puga, R., Butler IV, M. 2009. *The Caribbean spiny lobster, Panulirus argus, fisheries.* [December 25, 2010]
http://marineaffairsprogram.dal.ca/Files/Erhardt_The_Caribbean_spiny_lobster.doc

Fisheries Division, Ministry of Agriculture and Fisheries 2010. [Personal communication, December 2010]

Gulf of Mexico Fishery Management Council and South Atlantic Fishery Management Council. 1982. *Fishery Management Plan, Environmental Impact Statement, and Regulatory Impact Review for Spiny Lobsters in the Gulf of Mexico and South Atlantic.* [January 10, 2011] http://www.safmc.net/Portals/6/Library/FMP/SpinyLobster/SpinyLobFMP.pdf

Gustavson, K. 2002. *Economic production from the artisanal fisheries of Jamaica*, Fish. Res. 57 (2002), pp. 103–115.

Hannesson, R. 1993. *Bioeconomic Analysis of Fisheries*. Rome: Food and Agriculture Organisation of the United Nations (FAO). Fishing New Books. 1-131.

Haughton, M.O. and King, D.P.F. 1992. *Stock Assessment of the spiny lobster (Panulirus argus) in Jamaica*. Proceedings of the Gulf and Caribbean Fisheries Institute. 42,119-126. [December 1, 2010] http://procs.gcfi.org/pdf/gcfi_42-8.pdf

Kelly. R. 2002. *Report on the spiny lobster fishery in Jamaica* In Report of the Second Workshop on the Management of Caribbean Spiny Lobster Fisheries in the WECAFC Area Havana, Cuba, 30 September - 4 October 2002. FAO Fisheries Report/FAO Informe de Pesca. No. 715. Rome, Roma, FAO. 2003. 273. [November 26, 2010]
http://www.fao.org/docrep/006/y4931b/y4931b0e.htm

Lobster Trap Art 2011. [January 2011] http://www.lobstertrapart.com/framestory.html

Lyons, W.G. 1981. *Possible Sources of Florida's Spiny Lobster Population*. Proceedings of the Gulf and Caribbean Fisheries Institute. 33, 253-266. [November 20, 2010] http://procs.gcfi.org/pdf/gcfi_33-28.pdf

Martin-Murray, A. O. 2010. *The use of production models and length frequency data in stock assessments in Jamaican fisheries, building on the Caribbean spiny lobster observations* [Unpublished/manuscript]. United Nations University Fisheries Training Programme.

Marx, J.M., and W.F. Herrnkind. 1986. *Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (south Florida)—spiny lobster*. U.S. Fish Wildl. Serv. Biol. Rep 82(11.61). U.S. Army Corps of Engineers, TR EL-82-4. 21PP. [December 10, 2010] www.nwrc.usgs.gov/wdb/pub/species_profiles/82_11-061.pdf

Milon L. W, Larkin S.L and Ehrhardt N.M. 1999. Bioeconomic Models of the Florida Commercial Spiny Lobster Fishery. Florida Sea Grant Report Number 117. FLSGP-T-99-002. [December 24, 2010] http://nsgl.gso.uri.edu/flsgp/flsgpt99002.pdf

Munro, J.L. 1974. *The Biology, Ecology and Bionomics of the Spiny Lobsters (Palinuridae), Spinder Crabs (Majiidae) and other Crustacean Resources*. *In* Munro, J.L. ed. Caribbean Coral Reef Fishery Resources. ICLARM Studies and Reviews 7. International Center for Living Aquatic Resources Management, Manila, Philippines. 206-222. [December 1, 2010] http://books.google.is/books?id=yuGjAS0kwlgC&pg=PA72&lpg=PA72&dq=munro+j+l+1974&source=bl&ots=GXt6nFx3XP&sig=Kk8zgoQ0naOUPARNTfj5qYPjnOw&hl=en&ei=M3D2TMLcH46XOrjLyKoI&sa=X&oi=book_result&ct=result&resnum=3&ved=0CBoQ6AEwAg#v=onepage&q=munro%20j%20l%201974&f=false

PETROJAM Limited 2010. [December 2010] http://www.petrojam.com/index.php?q=archive_price_index_oct09b&page=10

Sea Around Us Project: Fisheries, Ecosystem and Biodiversity. [December, 2010] http://www.seaaroundus.org/eez/388.aspx

Seijo, J.C, Defeo, O. and Salas, S. (1998). *Fisheries bioeconomics: Theory, modelling and management*. FAO Fisheries, Technical paper 368. ISBN 92-5-104045-1. [November 27, 2010] http://www.fao.org/DOCREP/003/W6914E/W6914E00.HTM

Statistical Institute of Jamaica (STATIN) 2010. [Personal communication, December 2010]

Travis, D.F. 1954. *The Molting Cycle of the Spiny Lobster, panulirus argus latreille. I. Molting and growth in laboratory-maintained individuals.* Moulting and Growth in Laboratory Maintained Individuals. Biol. Bull., 107: 433-450. [December 14, 2010] http://www.biolbull.org/cgi/reprint/107/3/433.pdf

Van Riel, W. 2005. *Economic Study of Jamaican Fishery Industry*. FAO. Page 7

Waters, J. 1987. *Economic Source Document for Analysis of Limited Entry Alternatives for the Spiny Lobster Fishery in Florida*. Working Paper, National Marine Fisheries Service.

WECAFC 2007. *Report of the Fifth Workshop on the Management of the Caribbean Spiny Lobster. Merida, Yucatan, Mexico, 19-29 September 2006*. FAO Fisheries Report. No. 826. Rome, FAO. Page 99.

Venema, S.C. 2004. *Capture Fisheries and Aquaculture in Jamaica: A Sector Review.*

APPENDICES

Appendix I. Basic bioeconomic data and calculations for the period 1997 to 2007.

YEAR	Harvest (tons)	No. Licensed Vessel	Effort (Fishing Days)	Catch per unit effort	Biomass (tons)	Value (1000 US$)	Price (US$/kg)	Catchability *q*	Total Revenues (1000 US$) *R*	TC (1000 US$)	PROFITS (1000 US$)
1997	79	10	2,520	0.03	819	1,790	22.59	7.5E-05	1343	2126	-783
1998	106	8	2,016	0.05	912	2,448	23.16	1.1E-04	1836	1700	135
1999	284	8	2,016	0.14	936	6,626	23.31	3.0E-04	4970	1700	3269
2000	288	12	3,024	0.10	769	6,859	23.84	2.4E-04	5144	2551	2594
2001	167	6	1,512	0.11	670	4,182	25.08	3.2E-04	3137	1275	1861
2002	130	4	1,008	0.13	715	3,435	26.37	3.5E-04	2576	850	1726
2003	295	12	3,024	0.10	788	5,108	17.33	2.4E-04	3831	2551	1280
2004	451	9	2,268	0.20	676	4,368	9.69	5.6E-04	3276	1913	1363
2005	368	13	3,276	0.11	437	3,513	9.56	4.7E-04	2635	2763	-128
2006	97	9	2,268	0.04	281	1,294	13.30	2.7E-04	970	1913	-942
2007	112	6	1,512	0.07	351	1,776	15.92	3.8E-04	1332	1275	57

Appendix II: Sustainable Fisheries Model calculations.

Biomass	No. Vessels	Fishing Days	Harvest	Revenues	Costs	Profits	Negative Biomass
0	1	334	0	0	281	-281	0
50	15	3743	38	376	3157	-2780	-50
100	15	3822	73	717	3224	-2507	-100
150	15	3783	104	1023	3191	-2168	-150
200	15	3691	131	1293	3113	-1821	-200
250	14	3567	155	1527	3009	-1482	-250
300	14	3422	175	1726	2886	-1160	-300
350	13	3260	191	1889	2750	-861	-350
400	12	3087	204	2017	2604	-586	-400
450	12	2904	214	2110	2449	-339	-450
500	11	2712	220	2167	2288	-121	-500
550	10	2514	222	2188	2120	68	-550
600	9	2309	220	2174	1948	226	-600
650	8	2100	215	2124	1771	353	-650
700	7	1886	207	2039	1591	449	-700
750	7	1667	194	1919	1406	512	-750
800	6	1445	179	1762	1219	543	-800
850	5	1220	159	1571	1029	542	-850
900	4	991	136	1344	836	508	-900
950	3	760	110	1081	641	441	-950
1000	2	525	79	783	443	340	-1000
1050	1	289	46	449	243	206	-1050
1100	0	49	8	80	42	39	-1100

Appendix III: Dynamic biomass projection results.

YEAR	MEY Biomass (tons)	MSY Biomass (tons)	BE Biomass (tons)
1997	819	819	819
1998	912	912	912
1999	936	936	936
2000	769	769	769
2001	670	670	670
2002	715	715	715
2003	788	788	788
2004	676	676	676
2005	437	437	437
2006	281	281	281
2007	351	351	351
2008	431	431	431
2009	547	464	458
2010	651	489	479
2011	728	508	495
2012	776	522	506
2013	801	531	514
2014	813	538	520
2015	819	542	524
2016	821	545	526
2017	822	547	528
2018	823	548	529
2019	823	549	530
2020	823	549	530
2021	823	549	530
2022	823	550	531
2023	823	550	531
2024	823	550	531
2025	823	550	531
2026	823	550	531
2027	823	550	531

Appendix IV: Dynamic harvest projection results.

YEAR	MEY Harvests (tons)	MSY Harvests (tons)	BE Harvests (tons)
1997	79	79	79
1998	106	106	106
1999	284	284	284
2000	288	288	288
2001	167	167	167
2002	130	130	130
2003	295	295	295
2004	451	451	451
2005	368	368	368
2006	97	97	97
2007	112	112	112
2008	95	178	183
2009	118	190	194
2010	138	200	202
2011	152	207	208
2012	161	211	212
2013	166	215	215
2014	168	217	217
2015	169	219	218
2016	170	220	219
2017	170	220	220
2018	170	221	220
2019	170	221	221
2020	170	221	221
2021	170	221	221
2022	170	222	221
2023	170	222	221
2024	170	222	221
2025	170	222	221
2026	170	222	221
2027	170	222	221

Appendix V: Dynamic revenue projection results.

YEAR	MEY Revenues (1000 US$)	MSY Revenue s (1000 US$)	BE Revenue s (1000 US$)
1997	1343	1343	1343
1998	1836	1836	1836
1999	4970	4970	4970
2000	5144	5144	5144
2001	3137	3137	3137
2002	2576	2576	2576
2003	3831	3831	3831
2004	3276	3276	3276
2005	2635	2635	2635
2006	970	970	970
2007	1332	1332	1332
2008	938	1758	1811
2009	1162	1877	1913
2010	1359	1969	1992
2011	1504	2038	2051
2012	1592	2087	2093
2013	1639	2121	2123
2014	1661	2144	2143
2015	1671	2159	2157
2016	1675	2169	2166
2017	1677	2176	2172
2018	1678	2180	2176
2019	1679	2183	2179
2020	1679	2185	2180
2021	1679	2186	2182
2022	1679	2187	2182
2023	1679	2187	2183
2024	1679	2187	2183
2025	1679	2188	2184
2026	1679	2188	2184
2027	1679	2188	2184

Appendix VI: Dynamic profit projections Profits

YEAR	MEY Profits (1000 US$)	MSY Profits (1000 US$)	BE Profits (1000 US$)
1997	-783	-783	-783
1998	135	135	135
1999	3269	3269	3269
2000	2594	2594	2594
2001	1861	1861	1861
2002	1726	1726	1726
2003	1280	1280	1280
2004	1363	1363	1363
2005	-128	-128	-128
2006	-942	-942	-942
2007	57	57	57
2008	-194	-363	-374
2009	30	-244	-271
2010	227	-151	-192
2011	372	-82	-134
2012	460	-33	-91
2013	507	1	-62
2014	529	24	-42
2015	539	39	-28
2016	544	49	-19
2017	545	55	-13
2018	546	60	-9
2019	547	62	-6
2020	547	64	-4
2021	547	65	-3
2022	547	66	-2
2023	547	67	-2
2024	547	67	-1
2025	547	67	-1
2026	547	67	-1
2027	547	67	-1

Appendix VII: Optimal dynamic equilibrium calculation results.

X*	ψ	ψ-d	E*	Vessels*	Y*	R*	Costs*	Profits*
0	0.08	-0.02	0	0	0	0	0	0
25	0.01	-0.09	3575	14	20	193	3015	-2822
50	-0.05	-0.15	3743	15	38	376	3157	-2780
75	-0.12	-0.22	3806	15	56	551	3210	-2659
100	-0.19	-0.29	3822	15	73	717	3224	-2507
125	-0.26	-0.36	3812	15	89	874	3215	-2341
150	-0.33	-0.43	3783	15	104	1023	3191	-2168
175	-0.41	-0.51	3742	15	118	1162	3156	-1994
200	-0.50	-0.60	3691	15	131	1293	3113	-1821
225	-0.59	-0.69	3632	14	143	1414	3064	-1649
250	-0.69	-0.79	3567	14	155	1527	3009	-1482
275	-0.81	-0.91	3497	14	165	1631	2949	-1318
300	-0.94	-1.04	3422	14	175	1726	2886	-1160
325	-1.09	-1.19	3343	13	184	1812	2819	-1007
350	-1.28	-1.38	3260	13	191	1889	2750	-861
375	-1.51	-1.61	3175	13	198	1958	2678	-720
400	-1.82	-1.92	3087	12	204	2017	2604	-586
425	-2.25	-2.35	2996	12	210	2068	2527	-459
450	-2.93	-3.03	2904	12	214	2110	2449	-339
475	-4.19	-4.29	2809	11	217	2143	2369	-227
500	-7.39	-7.49	2712	11	220	2167	2288	-121
525	-36.45	-36.55	2614	10	221	2182	2205	-23
550	11.37	11.27	2514	10	222	2188	2120	68
575	4.65	4.55	2412	10	221	2185	2035	151
600	2.78	2.68	2309	9	220	2174	1948	226
625	1.89	1.79	2205	9	218	2153	1860	293
650	1.36	1.26	2100	8	215	2124	1771	353
675	1.00	0.90	1993	8	211	2086	1681	405
700	0.73	0.63	1886	7	207	2039	1591	449
725	0.53	0.43	1777	7	201	1983	1499	484
750	0.36	0.26	1667	7	194	1919	1406	512
775	0.22	0.12	1557	6	187	1845	1313	532
800	0.10	0.00	1445	6	179	1762	1219	543
825	-0.01	-0.11	1333	5	169	1671	1124	547
850	-0.10	-0.20	1220	5	159	1571	1029	542
875	-0.19	-0.29	1106	4	148	1462	933	529
900	-0.27	-0.37	991	4	136	1344	836	508
925	-0.35	-0.45	876	3	123	1217	739	478
950	-0.42	-0.52	760	3	110	1081	641	441
975	-0.48	-0.58	643	3	95	937	542	394
1000	-0.55	-0.65	525	2	79	783	443	340
1025	-0.61	-0.71	407	2	63	621	343	277
1050	-0.67	-0.77	289	1	46	449	243	206
1075	-0.72	-0.82	169	1	27	269	143	127
1100	-0.78	-0.88	49	0	8	80	42	39