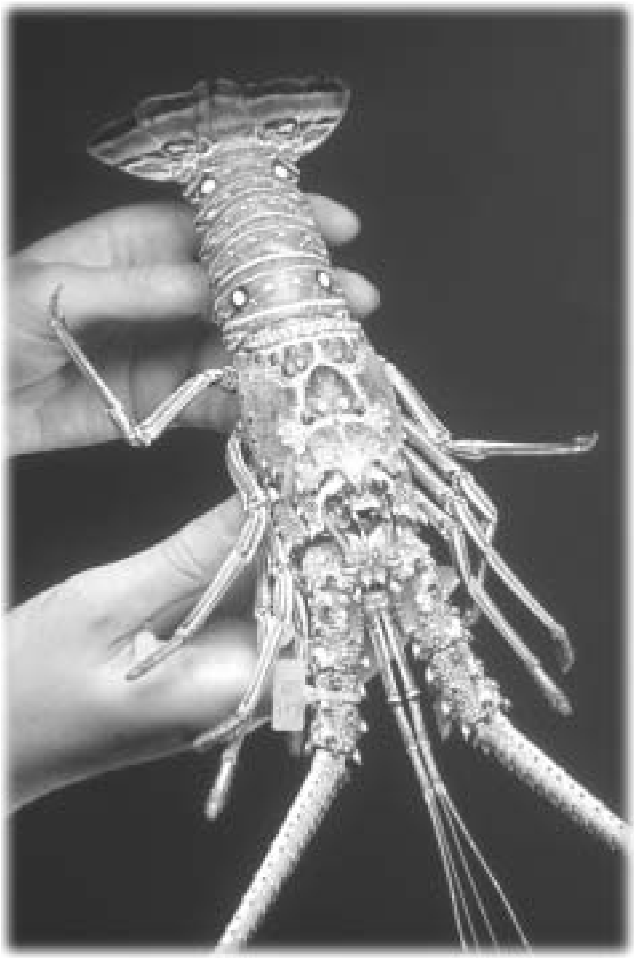
The Performance of

Florida's Spiny Lobster Trap Certificate Program



by
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Bioeconomic Models of the Florida Commercial Spiny Lobster Fishery

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Opinions expressed in this report should not be interpreted as the official position of the Florida Sea Grant College Program, the Florida Marine Fisheries Commission, or the Florida Department of Environmental Protection. The authors bear sole responsibility for any errors.

EXECUTIVE SUMMARY

The commercial spiny lobster (*Panulirus argus*) fishery in Florida has been dominated by the use of traps since the 1960s. Between 1960 and 1990 the number of traps in the fishery increased nine-fold (from approximately 100,000 to more than 900,000) while commercial landings remained relatively stable between five and eight million pounds. Even though the significant increase in trap numbers did not appear to have a corresponding effect on landings (that would provide for obvious concern for the health of the stock), it did raise several other concerns that were cited by the Florida Legislature:

> Due to rapid growth, the spiny lobster fishery is experiencing increased congestion and conflict on the water, excessive mortality of undersized lobsters, a declining yield per trap, and public concern over petroleum and debris pollution from existing traps (Florida Statute 370.142(1)).

The number of traps in the fishery was regulated in 1992 when a transferable trap certificate program (TCP) was implemented. Under the TCP, qualified commercial fishers were issued certificates (based on historical participation in the fishery) that entitled the owner to fish a specified number of traps. Each year, fishers receive one tag for each certificate owned (provided all fees are paid) and certificates can be sold to other fishers. The total number of certificates owned by each individual, however, has been periodically reduced by the Florida Marine Fisheries Commission (FMFC) in accordance with the goal of the program: "… to stabilize the fishery by reducing the total number of traps, which should increase the yield per trap and therefore maintain or increase overall catch levels" (Florida Statute 370.142(1)). The total number of certificates to be eliminated (i.e., final trap numbers) has never been specified by the Legislature or the FMFC.

The objectives of this analysis were to determine the total number of traps that would maximize the net economic benefits in the fishery and to test the general hypothesis that previous regulatory actions have achieved a sustainable, economically optimal number of traps in the fishery. This analysis addresses the limitations of prior bioeconomic studies of the fishery and provides new information on the economic performance of commercial firms in the fishery. The following conclusions resulted from the bioeconomic analysis:

- The maximum economic yield (MEY) was determined by equating the marginal benefit per trap (the value of the annual yield per trap) with its marginal cost (including trip and capital costs and labor expenses). This optimum represents the most economically efficient solution that provides the highest profits per trap. But, it does not consider social and equity issues associated with effort re-allocation to other fisheries, employment concerns, and community dependence on the industry. The

MEY solutions provide a benchmark to assess other relevant concerns about the fishery.

- Traditional surplus production models that have been used to model other lobster fisheries – namely the Schaefer, Fox, and Schnute – do not adequately represent the biological dynamics of the spiny lobster fishery in Florida.
- Regardless of the biological model specification, marginal benefits from reducing the total number of traps will not increase until the number of certificates is reduced below 400,000.
- The estimated marginal cost per trap, which is the cost associated with adding an additional trap to the fishery (not the cost of each trap), depends on the assumed method of labor payment and time horizon. These costs were not found to vary by vessel size (i.e., length or number of traps fished) or degree of participation in other fisheries. In addition, the marginal cost was independent of the total number of traps in the fishery.
- The short-run (single year) MEY solutions indicate that from approximately 160,000 to 260,000 traps would maximize profits per trap. When future years are considered, the optimal number of traps increases approximately 10 percent.
- Estimated prices for trap certificates at MEY levels of effort are significantly higher than currently reported certificate prices.

In summary, previous certificate reductions under the Florida spiny lobster TCP have made progress toward the goal for the program established by the Florida Legislature. From the 1991-92 to 1998-99 seasons, total effort has declined to approximately 544,000 traps and the average yield per trap has increased. This bioeconomic analysis reveals that additional reductions would continue to improve the economic efficiency of the fishery. Also, other revisions in the TCP are needed to increase the effectiveness of the program; these are summarized in the companion report titled “The Performance of Florida’s Spiny Lobster Trap Certificate Program” (Milon et al. 1998).

It should be noted that the optimal-MEY solutions derived from the bioeconomic analysis represent the number of traps in the fishery that would provide the maximum economic benefits to the certificate (trap) owners as a whole. The MEY optimums do not consider equity issues or social costs stemming from the re-allocation of effort to other fisheries or loss of jobs that might result from reductions in the total number of traps in the fishery. The analysis did not consider allocation between the trap fishery and other commercial harvesting or recreational harvesting. These equity and allocation issues should be addressed in any determination of the most desirable number of traps in the fishery.

Bioeconomic Models of the Florida Commercial Spiny Lobster Fishery

1. INTRODUCTION

1.1. The Fishery

Florida's spiny lobster (*Panulirus argus*) fishery is one of the State's most important fisheries with annual dockside landings valued between $25 million and $30 million over the past five years (National Marine Fisheries Service 1994, 1998). Florida accounts for the vast majority (from 85 to 90 percent) of spiny lobster landings in the United States, but these landings represent less than 10 percent of total U.S. supply (National Marine Fisheries Service 1994, 1998). Due to the high economic value, spiny lobster has been an attractive target for both commercial and recreational harvesters. From 1960 to the late 1980s, the number of traps (the dominant gear in the commercial fishery) expanded from less than 100,000 to more than 900,000 (Harper 1995). Despite the nine-fold increase in the number of traps, total commercial landings varied little, ranging between 5 and 8 million pounds per year (Harper 1995). Similarly, recreational effort has increased and the corresponding landings presently account for approximately 20 percent of the total spiny lobster harvest (Hunt et al. 1998).

The State of Florida Marine Fisheries Commission (FMFC) manages the Florida spiny lobster fishery within Florida's territorial waters (3 nautical miles into Atlantic, 9 nautical miles into the Gulf of Mexico). Under agreement with the Gulf of Mexico and South Atlantic Fishery Management Councils, the State of Florida is also responsible for managing the spiny lobster fishery in the Exclusive Economic Zone (9-200 nautical miles). Fishery management regulations mostly correspond to those of the State of Florida and are contained in the laws and regulations of the State. The majority of these regulations are designed to protect the reproductive capabilities of the stock. These include a closed season from April to July (to protect egg-bearing females during peak summer spawning months), a minimum landed carapace of 70 mm (size at first maturity), and prohibition on landings of egg-bearing females.

Several other regulations govern commercial harvesting practices, including the construction (e.g., size and materials) and identification (e.g., tags and buoys) of traps (Florida Administrative Code, Chapter 46-24). In 1988, an attempt was made to limit total commercial effort by establishing with a 3-year moratorium on the issue of new permits (Florida Administrative Code). Then, in 1992, a trap reduction program was implemented (Florida Statute 370.142). Under the Florida Spiny Lobster Trap Certificate

Program, the number of transferable certificates, each allowing the use of a single trap, would be periodically reduced. It was believed that a reduction in the number of traps would reduce unnecessary gear competition and over capitalization. Aside from reducing costs, such reductions were also expected to increase catch rates, decrease conflicts on the water, and reduce environmental damage. For further details on the Program, interested readers are referred to the companion report “The Performance of Florida’s Spiny Lobster Trap Certificate Program” (Milon et al. 1998).

1.2. The Problem

Despite several studies indicating excess effort (trap numbers) in the Florida spiny lobster fishery during the late 1970s and early 1980s (Williams 1976; Williams and Prochaska 1977; Prochaska and Cato 1980; and Keithly 1981), the fishery continued to operate without entry restrictions. As a result, the total number of traps used in the commercial fishery continued to increase. By 1991, widespread recognition of the excess effort problem, accompanied by conflicts on the water, led the Florida Legislature to establish the trap certificate program (Florida Statutes, Chapter 370.142). The objective was to “…reduce the number of traps used in the fishery to the lowest amount that will maintain or increase overall catch levels, promote economic efficiency in the fishery, and conserve natural resources.” Under the trap certificate program (TCP), 724,232 certificates (traps) were allocated for the 1992-93 season. Additional certificate allocations from appeals totaled 100,947 certificates. The legislation delegated authority to manage the TCP to the Florida Marine Fisheries Commission. The Commission is allowed to develop an annual schedule to further limit the number of traps with the proviso that the reductions cannot exceed 10 percent per year. In addition, the legislation authorized trap certificate transfers on a fair market basis, an approach advocated by economists (Neher et al. 1989). This program established one of the first effort reduction strategies in the United States based on economic principles of scarce resource allocation.

The Commission subsequently authorized annual trap reductions that reduced the total number to approximately 544,000 in the 1998-99 season (Florida Department of Environmental Protection). In total, 34 percent of the approximately 825,000 certificates originally issued have been eliminated. The next reduction, which would eliminate 55,000 traps, is planned for the 2000-01 season. No final target for the number of traps in the fishery has been established by the FMFC.

1.3. Need for Additional Research

This analysis addresses the need for updated estimates of the total number of traps that would maximize net economic benefits in the industry. Three factors suggest that new estimates of the efficient number of traps may be different from estimates in studies conducted in the 1970s and 1980s (prior to implementation of the TCP). First, the production models used in the early bioeconomic studies performed poorly due to the availability of only a short data series (Prochaska and Cato 1980; Keithly 1981; and Waters 1987), and these models may not be appropriate for the fishery (Ehrhardt 1996). Second, fishing cost data collected during the 1970s and used to derive point estimates of the marginal cost per trap were based on simple and/or incomplete cost definitions. For example, the share of income from lobster was used to approximate capital costs and/or the total cost estimate excluded labor. Third, several researchers estimated both the optimal number of traps per vessel *and* the total number of vessels to arrive at an estimate of the optimal total number of traps in the fishery. The main problem with this approach is that the specification of the production functions lacked a biological foundation since they were driven by the need to include (nonlinearly) traps and vessels as explanatory variables. In addition, several studies assumed differences in the cost per trap based on vessel length. However, costs were not shown to differ statistically between vessel classes.

The specification of the biological production model is one of the most important modeling decisions. Surplus production models used in fishery stock assessments and bioeconomic analyses may utilize parabolic, exponential, or generalized specifications (Schaefer 1957; Fox 1970; and Pella and Tomlinson 1969, respectively) depending on the population generation model adopted. Each model assumes instantaneous, density-dependent responses to changes in fishing effort. Thus, the effect of exploitation on the stock is usually depicted as a global (pooled) effect on surplus production through instantaneous changes in recruitment as well as parent stock compositions. Surplus production models are further characterized by defining a maximum sustainable yield (MSY) at a given level of fishing effort, below or above which production is suboptimal from a biological standpoint. Surplus production models also assume that catchability is constant – that is, the fraction of the stock caught per unit of effort is independent of stock size – and it does not interact with different levels of fishing effort.

Prior bioeconomic studies of the Florida spiny lobster fishery assumed reciprocal (Williams 1976; Williams and Prochaska 1977; Prochaska and Cato 1980) and quadratic (Keithly 1981) specifications of the biological production function. Recently, however, doubts have been raised about the applicability of surplus production models for lobster fisheries. Townsend (1986), in his critique of Bell's (1972) and Smith's (1980) predictions of a collapse in the American lobster (*Homarus Americanus*) fishery, argued surplus production models were not appropriate because they do not account for exogeneous recruitment and minimum size restrictions. On the other hand, Clarke, Yoshimoto, and Pooley's (1992) analysis of the Northwestern Hawaiian Islands spiny and slipper lobster fishery (*Panulirus marginatus* and *Scyllarides squammosus*, respectively) indicated relatively good statistical fit for several alternative surplus production model specifications. However, the models suggested different MSY and MEY solutions and there was relatively little basis to prefer any one model.

In the Florida lobster fishery, annual commercial landings in the spiny lobster fishery have averaged slightly more than six million pounds for the last 25 years with significant inter-annual variability due to changes in recruitment (Hunt et al. 1998; Ehrhardt 1994; Hunt 1994). During this same period, fishing effort (traps and vessels) increased dramatically with little apparent effect on the total landings (Milon et al. 1998). The lack of an apparent stock-recruit relationship is supported by the absence of recruitment overfishing in spite of the high levels of fishing mortality observed in the fishery (Ehrhardt 1994; Hunt 1994). This condition may be the consequence of a Pan-Caribbean origin of spiny lobster larvae in Florida (Lyons 1981). Ehrhardt (1994) found a significant positive correlation between spiny lobster abundance trends in Central America and Florida, which would support (at least in part) the Pan-Caribbean origin hypothesis. This hypothesis is also plausible because of the dynamics of ocean currents prevailing in the Eastern Caribbean and the protracted life history of spiny lobster larvae (larvae may drift in ocean currents up to 6 months) (Silberman, Sarver, and Walsh 1994). The fundamental independence of spiny lobster recruitment from local spawning stocks is also suggested by the high incidence of recruits on annual landings in the Florida fishery. In effect, annual variability in landings is related to variability in annual recruitment (Powers and Bannerot 1984). Consequently, the characteristics of the stock may not be adequately accounted for with a traditional surplus production model.

Another significant reason to reconsider prior bioeconomic studies of the Florida spiny lobster fishery is that these studies derived estimates of per trap costs on species-specific cost equations. In addition, the cost data were from relatively small samples of less than 30 firms. The authors of these prior studies acknowledged that vessels participated in other fisheries (e.g., Keithly 1981), but this factor was not addressed specifically in the bioeconomic model. Recent research on other fisheries has shown that management strategies based solely on a single-species approach may not be appropriate if the fishery is dominated by multiproduct firms (Squires 1987; Kirkley and Strand 1988; Thunberg, Bresnyan, and Adams 1995). A recent study using interviews with current participants in the Florida spiny lobster fishery indicated that many fishermen fish for other species during the year (Milon et al. 1997). This occurs because the spiny lobster harvest season includes only part of the year (August to March) and other economically valuable species also have limited harvest seasons (e.g., king mackerel).

1.4. Objectives and Outline of Analysis

This research addresses the limitations of prior bioeconomic studies of the commercial spiny lobster fishery in Florida and provides new information on the economic performance of commercial firms in the fishery. This information can be used by the Florida Marine Fisheries Commission and others to assess the effects of trap reductions enacted to date and to determine whether additional trap reductions would be consistent with the objectives of the TCP. Specifically, this research will test the general hypothesis that existing regulatory actions under Florida's spiny lobster TCP have achieved a sustainable, economically optimal number of traps in the fishery. The objectives of this report are:

Objective 1. To overview the methodology for determining the optimal level of effort in a fishery.

> Rationale: The "optimal" allocation of scarce resources in society can be determined within a bioeconomic framework. This framework allows for straight-forward comparison of the open-access equilibrium (OAE), maximum sustainable yield (MSY), and maximum economic yield (MEY) solutions. The MEY solution is economically efficient and, therefore, considered the optimal solution in this study (Chapter 2).

Objective 2. To develop alternative biological production models to estimate expected yield for the Florida spiny lobster fishery.

> Rationale: Following a review and estimation of traditional surplus production models, new models for the spiny lobster fishery will be developed and estimated. The new models will consider the dynamic behavior of catchability (i.e., as a function of fishing effort) and will also incorporate stock-independent recruitment trends on yield. By incorporating recruitment variability and the dynamics of catchability into biomass generation, the new production models may more accurately represent the spiny lobster fishery in Florida (Chapter 3).

Objective 3. To estimate cost functions – single and multiproduct – for a sample of firms (i.e., vessels) in the spiny lobster fishery.

> Rationale: Ideally bioeconomic models should reflect the long-run opportunity costs of harvesting (Anderson 1996). Cost functions based only on single species harvesting cannot account for joint costs in a multiproduct cost framework that is necessary to determine the long-run efficient level of effort (i.e., number of traps as regulated by the TCP). Differences in marginal costs may imply different MEY solutions for the fishery (Chapter 4).

Objective 4. To integrate the surplus production and cost functions into a bioeconomic model for the Florida spiny lobster fishery.

> Rationale: The virtue of bioeconomic models is the integration of biological and economic objectives in a single framework. An updated bioeconomic model of the fishery is necessary to evaluate the effects of trap reductions to-date and to estimate the number of traps necessary to achieve specific management objectives. Estimates of "optimal" effort levels (total certificate numbers) will be affected by the specific decisions regarding, and/or the variability of coefficients in, the underlying production and cost models (Chapter 5).

2. AN OVERVIEW OF BIOECONOMIC THEORY

Bioeconomic theory for a commercial fishery posits that the socially optimal level of effort and corresponding harvest is determined by both the biological dynamics of the stock and the economics of the industry (i.e., harvesting costs and market price for the product). This is because society is interested in stock conservation *and* the profitability of the industry. Without entry or effort restrictions, harvest continues to the breakeven point – an effort level where total revenues just cover total costs – which is known as the open-access equilibrium (OAE). This unregulated equilibrium, however, is socially inefficient (sub-optimal) because effort is too high (Gordon 1954). Typically, open-access harvesting also produces a lower level of catch as compared to the maximum sustainable yield (MSY). In addition, the same level of catch can usually be landed at a lower cost. From society's point of view, the maximum economic yield (MEY) is the optimal solution since it equates the marginal revenue of an additional unit of effort – for example, the entry of another vessel or addition of another trap – with its marginal cost (which reflects the opportunity cost of the investment).

The equilibrium solution for a given fishery – either the OAE, MSY, or MEY – will depend on the objective of management. In this chapter, each equilibria is described and compared using a traditional modeling approach that provides the framework for analyzing Florida's spiny lobster fishery in the following chapters. The effect of a positive discount rate, which is an indicator of the value of future profits (rents), is also considered. The material in this chapter is designed as a basic overview of the general concepts; for further detail and special cases interested readers should see: Anderson (1986); Gordon (1954); Hannesson (1993); Hartwick and Olewiler (1998); and McHugh (1984).

2.1. The Long-run Biological Production Function

The long-run biological production function, also known as the sustainable yield curve, represents the relationship between fishing effort and the quantity of fish caught. In particular, this function shows the catch that will be forthcoming from any given level of effort once the equilibrium population size for that level of effort has been achieved. This production function, which is critical to determine the equilibrium catch and effort level, will depend on the reproductive biology of the stock.

In a long-term equilibrium for a single stock, the amount of fish caught (yield) is exactly equal to the surplus growth of the stock. This implies that the stock will remain steady at some level. Hence the surplus growth is said to represent the "sustainable yield" from the stock. In particular, the catch obtained from a level of effort and its corresponding equilibrium population is called a sustainable yield. It is sustainable because population size will not be affected by fishing since catch is replaced by the natural growth of the stock. Therefore, the same level of effort will yield the same catch in the next period. The maximum surplus growth is referred to the maximum sustainable yield (MSY).

A simple biological theory of population dynamics is the Schaefer logistic model where stock growth is a function of the biomass (in weight). This density-dependent model assumes that the equilibrium yield curve is logistic, as in the following specification:

$$C = \alpha E - \beta E^2 \qquad [2\text{-}1]$$

where catch (C) is a nonlinear function of effort (E) and the positive parameters α and β can be estimated using historic annual data. In the Florida spiny lobster fishery, for example, reported landings in pounds and the corresponding total number of traps could be used for the catch and effort data, respectively. The Schaefer sustainable yield curve is shown graphically in Figure 2-1.

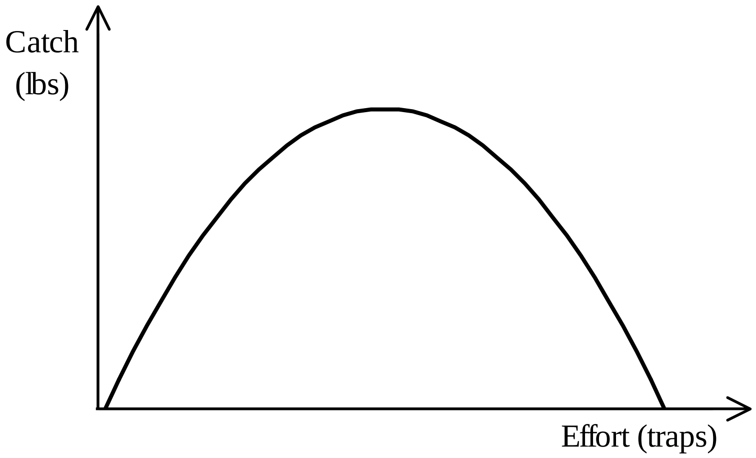

Figure 2-1. The Schaefer (Logistic) Sustainable Yield Curve

This density-dependent model assumes that the equilibrium yield curve is bell-shaped. At first, catch increases with fishing effort. Competition between units of effort (vessels, traps, fishing lines, etc.), however, eventually begins to negatively affect catch-per-unit-effort (CPUE); each additional unit of effort is landing less catch. If effort continues to increase past the MSY level, total catch declines.

2.2. Static Optimum

The conditions that are used to determine the “optimal” equilibrium solution – the appropriate levels of catch and effort – in a static model will depend on the goals of management. Three such conditions (objectives) are frequently analyzed: (1) to maximize the sustainable yield, (2) to allow the open-access (unregulated) equilibrium, or (3) to maximize the economic yield. Aside from the production function described in the previous section, the latter two objectives require economic information on fishing costs (opportunity costs associated with all inputs)[1] and the product market (value of output).

2.2.1. Management Objective: Maximize the Sustainable Yield (MSY)

The maximum sustainable yield is easily found with the Schaefer logistic model by setting the first derivative of the catch equation with respect to effort – the slope of the production function – equal to zero. Mathematically, the MSY for the Schaefer model is:

$$\frac{dC}{dE} = 0 \quad \Rightarrow \quad \alpha - 2\beta E = 0 \quad \Rightarrow \quad E^{MSY} = \frac{\alpha}{2\beta} \quad \Rightarrow \quad C^{MSY} = \frac{\alpha^2}{4\beta}$$

where C^{MSY} is the highest catch that can be produced on a sustained basis which results from the use of E^{MSY} effort units (e.g., traps).[2] The MSY solution is shown in Figure 2-2.

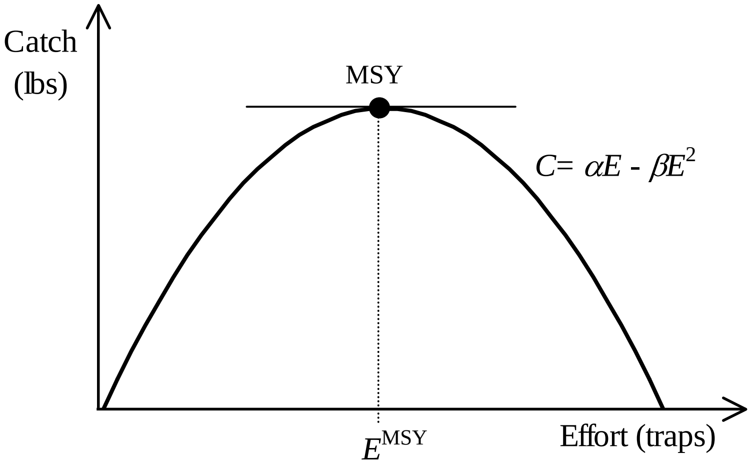

Figure 2-2. The Maximum Sustainable Yield (MSY) Solution

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[1] Opportunity costs represent the value of the input should it be used for another purpose. For example, the opportunity cost of labor is the wage rate or salary each crew member would receive if he/she were working another job. The minimum opportunity cost of labor equals the minimum wage rate specified by law. The opportunity cost of the vessel would equal the value of the vessel for use in another fishery or, for example, as a transport or recreational fishing vessel (i.e., charter operation).

[2] The Schaefer model is used to illustrate the alternative optimum solutions since it is the most recognized and studied fisheries model. Its use in this theoretical exercise does not imply it is the best model for the spiny lobster fishery in Florida.

2.2.2. Management Objective: Allow the Open-Access Equilibrium (OAE)

Open-access represents a lack of property rights to restrict harvesters from a fishery. No fisher can prevent another from using or exploiting the resource. A common-property open access fishery is completely nonexclusive because entry will occur as long as profits can be made. Without entry or effort restrictions, the industry will be in equilibrium where total revenue equals total cost (i.e., zero profits).

Using the Schaefer catch-effort sustainable yield curve depicted in Figure 2-1, the total revenue curve is given by multiplying each point on the sustainable yield curve by price (p), which is assumed constant for simplicity. This produces a sustainable total revenue curve with the same general shape as the sustainable yield curve. Since increasing effort will increase costs, it is reasonable to assume (for simplicity) that each additional unit of effort incurs an equal increase in cost (w). Assuming that costs increase in direct proportion to effort gives rise to a linear total cost function ($TC = wE$). Using the open-access management objective, total revenues (TR) are set equal to total costs to find the optimal level of effort for a common property fishery. Mathematically, the OAE solution is found as follows:

$$TR = TC \quad \Rightarrow \quad p(\alpha E - \beta E^2) = wE \quad \Rightarrow \quad E^{OAE} = \frac{p\alpha - w}{p\beta}$$

where the open-access harvest level is found by substitution: $C^{\mathrm{OAE}} = \alpha E^{\mathrm{OAE}} - \beta(E^{\mathrm{OAE}})^2$. Note that either a higher price or higher cost of effort would entail the use of fewer units of effort at the OAE solution. The open-access equilibrium (OAE) solution is shown in Figure 2-3.

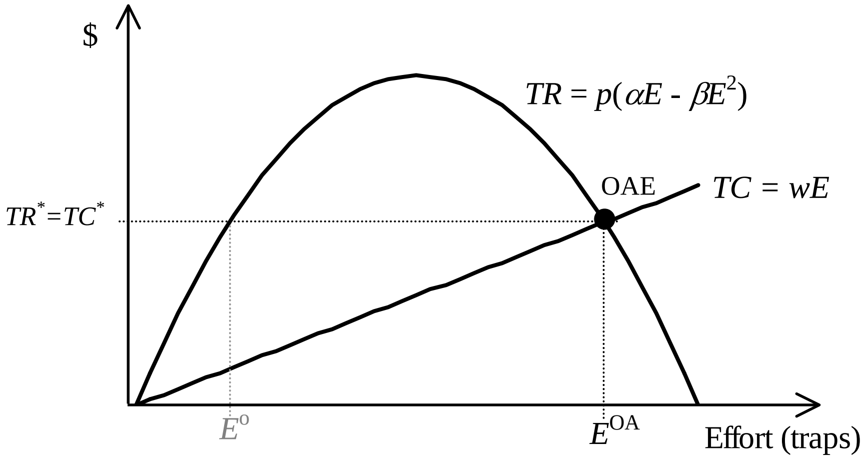

Figure 2-3. The Open Access Equilibrium (OAE) Solution

The OAE is a bioeconomic equilibrium in that the level of effort and catch will not change unless any of the underlying components of the model changes (e.g., market price, fishing costs, and/or carrying capacity of the stock).[3] However, the resources used in open access cannot achieve an efficient allocation – and thereby maximize rents (profits) – since, as in the example shown, the same level of catch can be achieved at a lower cost with a lower level of effort (E^o in Figure 2-3).

2.2.3. Management Objective: Maximize the Economic Yield (MEY)

Economic yield is the total rent (revenues less costs) generated by the fishery:

$$\pi(E) = p(\alpha E - \beta E^2) - wE \qquad [2\text{-}2]$$

Since rent is the difference between the value of a good produced from using a natural resource and the costs associated with turning that natural resource into the good, rent is considered an economic "surplus" (Hartwick and Olewiler 1998). Rent represents the economic value of harvesting the resource since the cost of the factor inputs – including the value of the labor, capital, materials, and energy inputs used to convert the resource into the product – have been netted out. However, this rent excludes the value of any externalities associated with the industry or the product.[4]

The sustainable rent is maximized where the distance between the cost and revenue curve is the greatest. This equilibrium is found by equating the marginal revenue (MR) to marginal cost (MC), that is, by equating the slopes of the total revenue and total cost curves. Mathematically, the MEY solution is found as follows:

$$MR = MC \quad \Rightarrow \quad \frac{dTR}{dE} = \frac{dTC}{dE} \quad \Rightarrow \quad p(\alpha - 2\beta E) = w \quad \Rightarrow \quad E^{MEY} = \frac{p\alpha - w}{2p\beta}$$

where the corresponding catch is found through substitution, $C^{\mathrm{MEY}} = \alpha E^{\mathrm{MEY}} - \beta(E^{\mathrm{MEY}})^2$. The MEY solution is shown graphically in Figure 2-4.

As shown in Figure 2-4, TR^{MEY} minus TC^{MEY} represents the maximum rent per unit effort in the fishery. Given the Schaefer sustainable yield relationship and constant cost per unit of effort, the optimal effort level is less than needed to take the MSY. The economic optimum provides more conservation than fishing based on maximizing the sustainable yield.

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[3] We thank an anonymous reviewer for alerting us to the importance of the relationship between the carrying capacity of the stock and the sustainable yield curve for the equilibrium solution.

[4] An anonymous reviewer also notes the possibility of externalities reducing the value of the resource. In this case, the pollution caused by fishing vessels and gear (e.g., oiled traps) could reduce the estimated value of harvesting the resource.

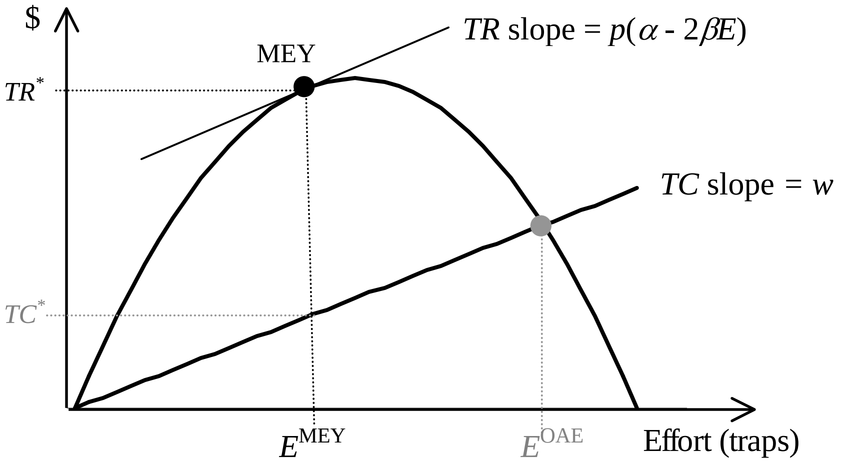

Figure 2-4. The Maximum Economic Yield (MEY) Solution

2.3. Dynamic Optimum

The static MEY equilibrium provides the maximum sustained annual rents from the fishery. However, this optimal solution does not consider intertemporal differences in the value of money. The static MEY solution is optimal in the long run if a dollar today is equal to a dollar in the future (i.e., the discount rate is zero). With a non-zero discount rate, however, society faces an intertemporal trade-off. For example, with a positive rate of interest, a unit of money today is worth more than the same unit in the future (one dollar today is worth more than one dollar received in the future). This is because over time the initial investment earns interest (one dollar today is equivalent to one dollar plus interest received in the future). The same principle applies to harvesting decisions. If more fish are harvested today, the income gained can be invested and will be worth more in the future. However, if more fish are harvested today, costs will be higher and the stock size will be reduced, which has future biological and economic consequences.

Assuming the goal of resource management is to maximize benefits while sustaining the stock, the appropriate modeling objective is to find the economically optimal level of effort (the MEY solution). This is accomplished by maximizing the net present value (sum of discounted rents) of harvest based on the sustainable yield curve. This long-run solution will consider the additional cost – referred to as the “marginal user cost” – of increasing effort (harvests) in the current period. The marginal user cost is the present value of decreased future harvests. With a positive discount rate, the optimum level of effort would be between E^{MEY} and E^{OAE}.

The effect of a positive discount rate on the equilibrium solution – catch, effort, and profit – can be examined as follows. First, note that if effort is expanded beyond the

MEY level – the level that maximizes the sustained annual rent – the immediate gain would equal (approximately) the value of the catch per trap multiplied by the assumed ‘small’ increase in effort. This short-run gain is accompanied, however, by the present value of the long-term loss (of increasing current period effort), which equals the loss in sustained profit caused by the small increase in effort divided by the discount rate (δ). Adding the short- and long-run effects, and observing that in equilibrium they must net to zero (i.e., the present and future marginal net returns must equal), the following implicit equation for the MEY-optimal level of effort in the long-run is derived:

$$\left\{ p\frac{C}{E} - w + \frac{(p\,{}^{dC}\!/_{dE} - w)}{\delta} \right\} \Delta E = 0 \qquad [2\text{-}3]$$

Equating intertemporal profits ensures an MEY-optimal solution over time. For example, with the Schaefer specification, the solution is:

$$p(\alpha - \beta E) - w + \frac{[p(\alpha - 2\beta E) - w]}{\delta} = 0 \quad \Rightarrow \quad E^{MEY} = \frac{(p\alpha - w)(1+\delta)}{2p\beta(1+0.5\delta)}$$

Since $(1 + \delta) > (1 + 0.5\delta)$, assuming a positive discount rate, long-run MEY-optimal effort occurs at a higher level of effort than with the static MEY. In other words, discounting future rents makes an increasing rate of exploitation more attractive. In the limit ($\delta \to \infty$), optimal effort would be the same as at the static open-access equilibrium, E^{OAE}.

2.4. Bioeconomic Models and the Florida Spiny Lobster Fishery

The most important principle of bioeconomic modeling is the equivalence of marginal costs and revenues at the efficient (MEY-optimal) level of effort. In both the static and dynamic bioeconomic models, the MEY solution is critically dependent on the biological production function because the stock dynamics combined with the market price of the harvested product determine the marginal revenue function.

The production model used to illustrate alternative management solutions in Figure 2-4 – a Schaefer logistic catch-effort relationship – assumed a population dynamics function where the annual (sustainable) harvest is dependent on the previous years’ population. If the annual harvest is not significantly dependent on the historical stock size – such as the case with shrimp in the Gulf of Mexico (Anderson 1986) – the Schaefer specification may not be appropriate. In fact, Florida spiny lobster (*Panulirus argus*) were often referred to as giant shrimp, prawn, crayfish, or crawfish in the 19th century (Moe 1991). William Gerard De Brahms, Surveyor General of the British Colony of East Florida wrote in 1772:

> A species of prawns, (shrimps) growing to a weight of five pounds apiece, live in great numbers in the holes of coral rocks, on the mangrove islands: these shrimps are by West-Indians improperly called lobsters, although they have not the two claws, as lobsters: they are beautifully spotted with red, yellow, blue, green, grey, and a little black; but they all change into one red colour by boiling…. (Moe 1991, p. 377).

De Brahms was, however, actually talking about spiny lobster. Researchers have since found that recruitment in Florida is dependent, at least in part, on spawning stock in the Caribbean (Ehrhardt 1996). Consequently, as with shrimps, the traditional Schaefer specification may not be appropriate for this fishery. The density-dependent type of biological function is, however, the most widely used despite its obvious limitations because of the minimal data requirements and mathematical simplicity (Garcia 1988). In addition, the specification is useful even if it is no more than an empirical descriptor of the catch-effort trajectory (Garcia 1988). According to Clark (1985), "although the Schaefer model may be biologically unrealistic (for prawns) its cautious use as a basis for general economic analysis seems justified because its principles are in fact quite robust."

The implications of an alternative biological production relationship for bioeconomic analysis can be seen with the aid of Figure 2-5. In this case, catch and corresponding total revenue reach a plateau after which additional units of effort do not increase total revenues. Also, total revenues do not decrease (as with a Schaefer-type model used in Figure 2-4) indicating that the sustainable yield is not dependent on the existing stock. This may occur if recruitment is exogenous (and other spawning stocks remain healthy) and/or if regulations such as closed seasons, protection of gravid females, and minimum sizes are sufficient to maintain recruitment. The fact that additional effort does not decrease yields and total revenues does not imply, however, that open-access is a socially desirable management strategy.

As illustrated in Figure 2-5, effort at the open-access equilibrium (E^{OAE}) is greater than effort at the maximum economic yield (E^{MEY}). Since total revenues are the same at either E^{MEY} or E^{OAE}, society is not making the best use of its scarce resources by employing effort up to the point E^{OAE}. In addition, this excess effort dissipates rents that would be earned from the fishery at E^{MEY}. Thus, even if the biological relationship indicates that additional units of effort do not threaten the sustainability of the stock, the bioeconomic framework shows that it is necessary for management to limit the amount of effort in the fishery to achieve an efficient allocation of resources.

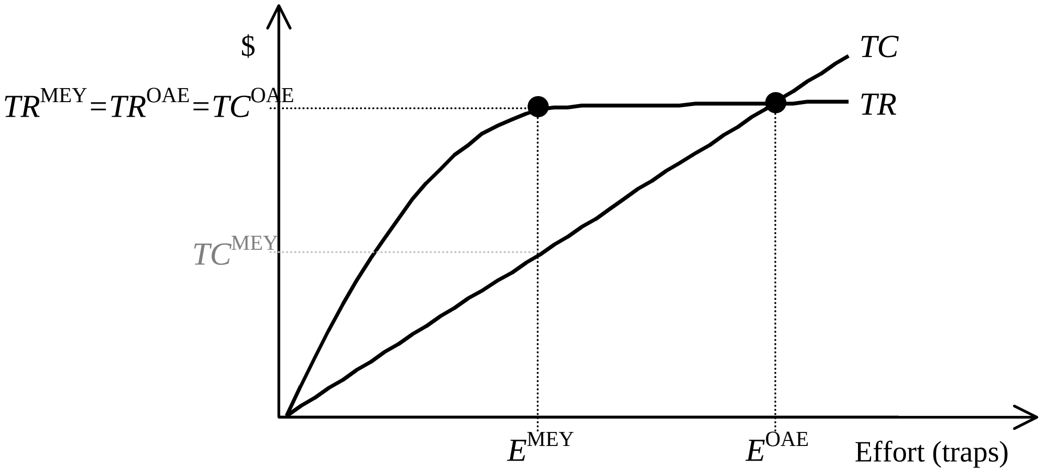

Figure 2-5. Maximum Economic Yield (MEY) with an Alternative Biological Production Function

3. BIOLOGICAL MODELS OF THE FLORIDA SPINY LOBSTER FISHERY

Three general classes of models are used as the biological basis for fisheries management decisions: (1) spawner-recruit, (2) dynamic pool, and (3) surplus production models (Sissenwine, Fogarty, and Overholtz 1988). Spawner-recruit models describe the relationship between generations using compensatory mortality during the early life stages. Dynamic pool models, also known as yield per recruit models, describe changes in biomass following recruitment using age-specific growth and mortality rates. Dynamic pool models are used to examine the effect of varying the fishing mortality rate or age at first capture. Traditional surplus production models describe the aggregate effects of natural mortality, growth, and recruitment in a single compensatory function.

According to Sissenwine, Fogarty, and Overholtz (1988), changes in equilibrium yield from variation in fishing effort are best examined using surplus production models. Given the primary objective of this study is to examine whether the spiny lobster TCP has reduced effort to the “optimal” level, the use of a surplus production model is appropriate. In addition, according to Menzies and Kerrigan (1980), production models are appropriate when the relationship between the local stock size and future recruitment is weak or unknown, as with spiny lobster in Florida (Ehrhardt 1994). Further, according to Yoshimoto and Clarke (1993), the production model approach is one of the simplest and, given the relatively modest data requirements, it is particularly useful as a first approximation (Clarke, Yoshimoto, and Pooley 1992). Surplus production models were also used in previous bioeconomic modeling of this fishery (Prochaska and Cato 1980; Waters 1987), including the 1981 Fishery Management Plan (Gulf of Mexico and South Atlantic Fishery Management Councils) and in other lobster studies (Evans and Evans 1995; Clarke, Yoshimoto, and Pooley 1992; Coppola and Pascoe 1998).

In this chapter, several production models for the Florida spiny lobster fishery will be defined and empirically estimated. Alternative production functions will be used to compare the effects of different modeling assumptions on the resulting catch-effort equation that is used to determine the bioeconomic MEY optima described in Chapter 2.

3.1. Overview of Spiny Lobster Biological Models

The development of an explicit surplus production model begins with a biological function for the growth rate of a population:

$$\frac{dX}{dt} = f(r, K, X, C) \qquad [3\text{-}1]$$

whereby the growth rate of the population (*dX/dt*) depends on the intrinsic growth rate (*r*), the maximum stock level (*K*), the population (*X*), and the catch rate (*C*). Fishing effort enters the model through the catch rate equation. Usually the catch rate is a function of fishing effort (*E*), the catchability coefficient (*q*), and the population (*X*). By assuming a functional form for the population growth rate and the catch rate, the biological parameters (*q*, *r*, *K*, and *X*) can be estimated using only historical catch and effort data. Substitution of the estimated parameters into the catch equation produces an explicit catch-effort equation that can be used to determine the MEY-optimal effort and corresponding catch in the fishery.

The Schaefer model is the most common and well-studied surplus production model for lobster (Bell 1972; Townsend 1986; Clarke, Yoshimoto, and Pooley 1992). Assuming a logistic growth rate:

$$\frac{dX}{dt} = rX\left(1 - \frac{X}{K}\right) - C \qquad [3\text{-}2]$$

the growth rate to biomass relationship is parabolic. The current population, *X*, is found using an explicit equation for the catch rate:

$$C = qEX \qquad [3\text{-}3]$$

In equation [3-3], each unit of effort (traps, boats, trips, etc.) earns constant returns (i.e., catch equals a fraction of the harvestable stock). Since catch is proportional to effort, the marginal productivity of additional effort is constant. Substituting catch into the population growth rate equation, equation [3-2] can be transformed using a finite difference approximation into the equation (Schaefer 1957):

$$\frac{1}{2U}\frac{\Delta U}{\Delta t} = r - \frac{r}{qK}U - qE \qquad [3\text{-}4]$$

where *U* is defined as *C/E*, the instantaneous catch per unit effort (CPUE). Using regression techniques, equation [3-4] can be estimated as:

$$\frac{1}{2U_t}\frac{\Delta U_t}{\Delta t} = c_1 + c_2 U_t + c_3 E_t \qquad [3\text{-}5]$$

The estimated coefficients from equation [3-5] provide the biological parameter values for equation [3-4] according to the formulas: $r = c_1$, $q = -c_3$, and $K = -r/(qc_2)$ (Fox 1970). Assuming a static equilibrium ($dX/dt = 0$), an empirical equation relating catch and effort for the Schaefer model is obtained:

$$C = qKE\left(1 - \frac{qE}{r}\right) \qquad [3\text{-}6]$$

For correspondence with the sustainable solutions in Chapter 2, let $\alpha = qK$ and $\beta = q^2K/r$.

3.1.1. Previous Production Model Specifications

Little quantitative information exists on the cyclical dynamics of the spiny lobster population in Florida (Ehrhardt 1994; Hunt 1994; Muller et al. 1997). Therefore, estimation of biological parameters is restricted to the use of catch and effort data (landings in weight and total number of traps, respectively).[5] Fortunately, recent efforts to model similar lobster species have provided several alternatives and modifications to the traditional Schaefer model (Clarke, Yoshimoto, and Pooley 1992; Yoshimoto and Clarke 1993; Townsend 1986). These alternatives produce different catch-effort equations that have been successfully applied to the American and Northwestern Hawaiian Islands lobster stocks and lobster fisheries in New England, New Zealand, Tasmania, and Western Australia.

The alternative catch-effort equations are the result of assuming a different (1) functional form for the growth rate, (2) functional form for the catch rate, and/or (3) approximation technique. Recent research by Clarke, Yoshimoto, and Pooley (1992) and, more recently, Yoshimoto and Clarke (1993), utilized three different forms of the growth relationship for lobster – that is, the change in stock size over time – including the logistic, Gompertz, and logarithmic. General representations of the resulting catch-effort functions are presented in Figure 3-1 for comparison.

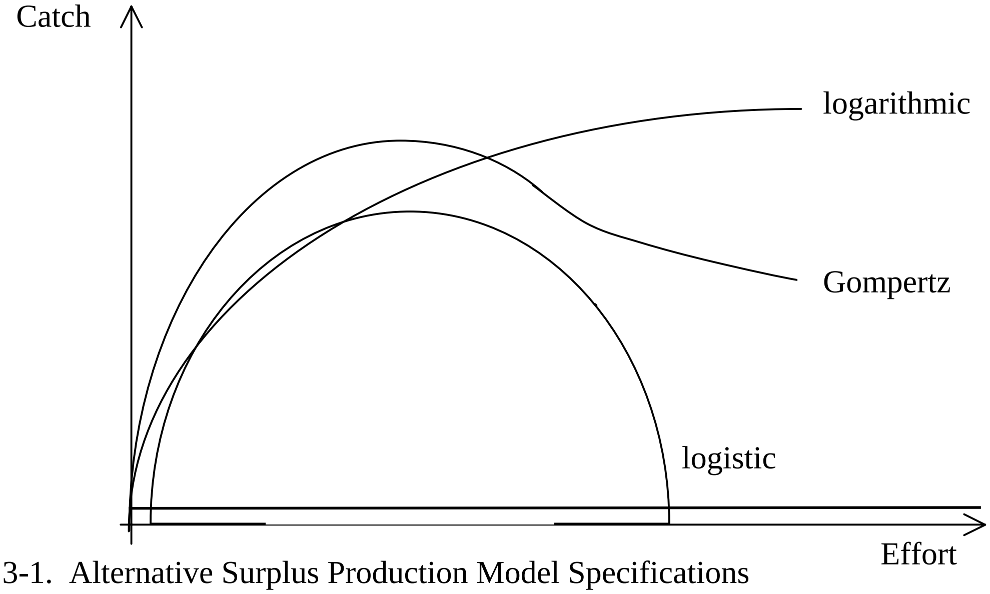

Figure 3-1. Alternative Surplus Production Model Specifications

Figure 3-1 illustrates the differences in catch predictions that occur at higher levels of effort with each form. The symmetric shape of the logistic (parabolic) curve, such as used in the Schaefer model, implies that at high effort levels the fishery collapses. Conversely, the logarithmic model assumes that at higher effort levels catch continues to increase but at a decreasing rate. With the Gompertz functional form there is an MEY-

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[5] Slat traps have been the dominant commercial gear type and, thus, the only gear type on which data has been collected since the 1950s (Labisky, Gregory, and Conti 1980). Consequently, several studies have used the total number of traps in the fishery to represent effort (Prochaska and Cato 1980, Waters 1987). Since the TCP directly regulates the total number of traps in the fishery, this variable is considered most appropriate for policy analysis.

optimal level of effort that maximizes catch but the fishery does not collapse at higher effort levels.

Aside from alternative functional forms for the growth equation, there are also alternative approximation techniques to derive the biological parameter values. Instead of finite differencing, as in the Schaefer model, iteration or integration techniques (using a Taylor series approximation) can be utilized. Clarke, Yoshimoto, and Pooley (1992) used alternative catch-effort relationships and approximation techniques to generate and estimate four models in addition to the traditional Schaefer specification. Figure 3-2 shows the assumptions used in deriving each of the estimated surplus production models, namely: Threshold, Fox, CY&P, Schaefer, and Schnute models.

The Threshold model is the only model that utilizes the logarithmic specification where catch reaches a maximum asymptotically. This specification has been used for species that are exploited seasonally or are characterized by partial exploitation (i.e., only a portion of the stock is subject to fishing pressure) (Clarke, Yoshimoto, and Pooley 1992). This specification may be appropriate for spiny lobster in Florida since (1) harvest is not allowed April through July, (2) minimum size regulations are enforced, and (3) local recruitment may result from a parent stock that is not exploited in Florida.

The Threshold model can be estimated as:

$$\ln(C_{\max} - C_t) = c_1 + c_3 E_t \tag{3-7}$$

where $C_{\max}$ is the maximum (or threshold) level of catch. This variable is initially assumed to equal the highest observed catch. The initial value is then changed iteratively until the estimated coefficients maximize the explanatory power of the model (i.e., the R^2 value) (Clarke, Yoshimoto, and Pooley 1992). Since this model is based on the threshold catch level, it implicitly represents, for example, the growth and natural mortality rate of the stock (which do not need to be specified). The estimated coefficients from equation [3-7] are used to determine estimates of the MEY-optimal catchability coefficient (q^*) and maximum stock level ($\exp(c_1)$).

All of the Gompertz and logistic models estimate an intercept term (c_1) and two coefficients (c_2 and c_3) for the CPUE and effort variables, respectively. Even though the explanatory variables and the formulas for deriving the underlying parameters vary by specification, equations for the Fox, CY&P, and Schnute models are similar to the Schaefer specification of equation [3-5].

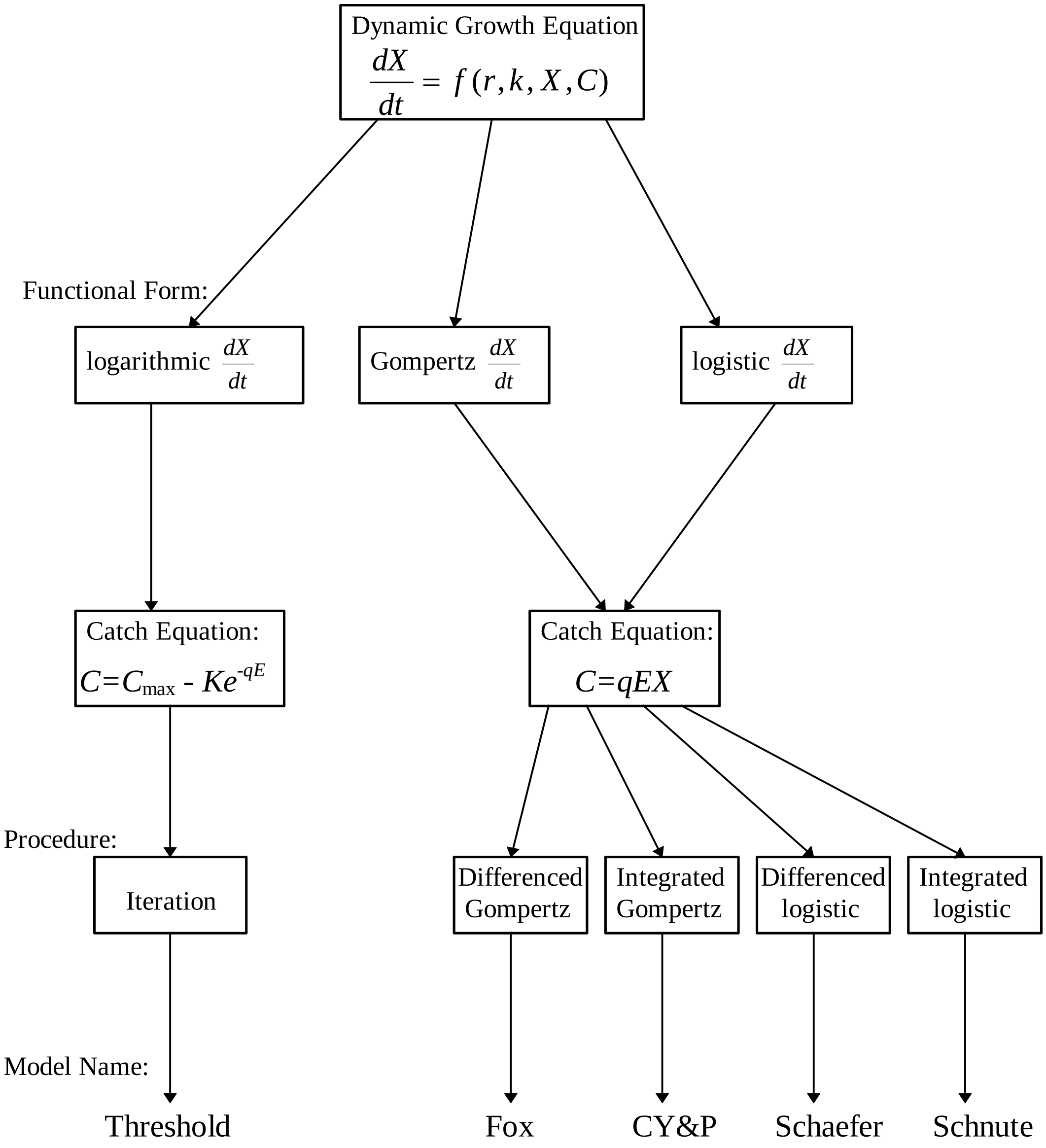

Figure 3-2. Development of the Surplus Production Models used in Clarke, Yoshimoto, and Pooley (1992)

The formulas that convert the estimated coefficients into the biological parameters for each model are summarized in Table 3-1. These formulas are used to derive the empirical, static equilibrium equations relating catch and effort as follows:

Schaefer and Schnute: $$C = q^*K^*E\left(1-\frac{q^*}{r^*}E\right) \qquad [3\text{-}8]$$

Fox and CY&P: $$C = q^* K^* E e^{\frac{-q^*}{r^*}E}$$ [3-9]

Threshold: $$C = C_{\max} - e^{(\ln K - q^* E)}$$ [3-10]

Table 3-1. Formulas for Biological Parameters of the Surplus Production Models

Model	intrinsic growth rate $r*$	catchability coefficient $q*$	maximum stock level $K*$
Schaefer	c_1	$-c_3$	$-r^*/(q^* c_2)$
Fox	$-c_2$	$-c_3$	$e^{c1/r*}/q^*$
Schnute	c_1	$-c_3$	$-r^*/(q^* c_2)$
CY&P	$2(1-c_2)/(1+c_2)$	$-c_3(2+r^*)$	$e^{c1(2+r*)/(2r*)}/q^*$
Threshold[a]	NA	$-c_3$	$\exp(c_1)$

[a] NA indicates the parameter is not applicable to the Threshold model. Following Clarke, Yoshimoto, and Pooley (1992), the q^* and K^* parameters are loosely interpreted as in the other models, but this interpretation has not been verified.

Each production model in Figure 3-2 and Table 3-1 provides a point estimate of the catchability coefficient ($q*$). Alternatively, the modified DeLury approach developed by Chien and Condrey (1985) can be used to obtain an equation whereby the catchability parameter is a function of effort and natural mortality (m):

$$q = -\frac{1}{E}(m + \log(1 - q'E))$$ [3-11]

where q' is the estimated coefficient on the cumulative catch variable from a linear regression of CPUE (U) on cumulative catch:

$$U_t = \alpha - q' Z_t$$ [3-12]

and cumulative catch Z_t is the total catch to the start of the intra-season period t (e.g., months) plus one-half the catch during period t:

$$Z_t = \sum_{i=1}^{T-1} C_t + 0.5 C_T$$ [3-13]

and T represents the last period.[6] This effort-dependent endogenous specification is desirable for spiny lobster because it implies that increasing effort can reduce catchability (Ehrhardt 1994; Puga et al. 1996).

Effort-dependent catchability – which allows an increase in effort to reduce catch rates within each season – assumes that: (1) once spiny lobsters recruit to the fishery, a closed population is available, and (2) constant fishing effort occurs during the fishing season. The first assumption may not be appropriate for the Florida spiny lobster fishery since recruitment trends vary during November and December of every season. The second assumption, of constant effort, is also debatable since poor weather during the winter months and the availability of other valuable species (e.g., stone crabs and mackerels) may reduce time spent fishing for lobster in the latter part of the season (Forcucci, Butler, and Hunt 1994). Since intra-season recruitment is limited in duration, adverse weather conditions affect all fisheries, and relative abundance indices and market prices are uncertain, we maintain the assumptions are adequate to derive effort-dependent catchabilities for use in constructing a new production model for the Florida fishery.

3.1.2. New Production Model Specifications for Spiny Lobster

The successful application of existing surplus production models to the spiny lobster (*Panulirus argus*) fishery in Florida is contingent upon the stock exhibiting similar characteristics. However, the Florida fishery may be significantly dependent upon larval production from other sources such as the Nicaraguan-Honduran population (Ehrhardt 1994). If the local stock originates from a single gene pool in the Caribbean Sea, then catch and effort in the Florida fishery are largely independent of the size of the parent stock. Although the Threshold model reflects, to some extent, this characteristic, two new production models can be developed specifically for the Florida spiny lobster fishery.

3.1.2.a. Effort-Corrected (E-C) Schaefer Model

This model hypothesizes that at higher trap densities – expressed by a larger number of traps used in the fishery – the catchability coefficient (q) will be lower. In particular, the effects of trap density are incorporated into a traditional Schaefer production model by specifying catchability as a function of effort. The inverse relationship between trap density and catchability is a consequence of interactions among traps competing for a fixed seasonal level of local resource availability.

The development of the E-C Schaefer model begins with an estimation of seasonal (intraseason) catchability. Using Chien and Condrey's (1985) procedure, equation [3-11] is estimated for each season using monthly data. The seasonal

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[6] Note that q is derived from the underlying conventional population dynamics equation: $N_{t+1}=N_t e^{-(qE+m)}$ where N is the population, qE is fishing mortality, and t represents time (Chien and Condrey 1985).

relationship between the catchability coefficient (q) and effort (E) provides the basis for hypothesizing a mathematical relationship between q and E. We assume that catchability is determined nonlinearly by effort, a "trap efficiency parameter" (b), and at catchability when effort is zero (i.e., $E = E_t = 0$ from equation [3-11]). Using the negative exponential relationship:

$$q_t = q_t(0)e^{-bE_t} \qquad [3\text{-}14]$$

a "relative trap efficiency factor" (*RTEF*) can be defined. *RTEF* equals the ratio of the catchability coefficient – as calculated using the Chien and Condrey procedure – to the catchability coefficient when fishing effort is zero ($E_t = 0$):

$$\frac{q_t}{q_t(0)} = e^{-bE_t} \qquad [3\text{-}15]$$

This *RTEF* is then used to standardize nominal (observed) seasonal fishing effort, which is measured as the total number of traps in the fishery (E_t). Specifically, the effective seasonal standardized fishing effort units, E_t^s, are expressed as:

$$E_t^s = E_t e^{-bE_t} \qquad [3\text{-}16]$$

The effective seasonal standardized fishing effort in number of traps and seasonal landings in whole weight can then be used in a parabolic (Schaefer) equilibrium surplus production model:

$$C_t = \beta E_t^s - \gamma(E_t^s)^2 \qquad [3\text{-}17]$$

Regression techniques provide estimates of parameters β and γ.

Given that bioeconomic evaluation of catch and effort reflects costs and revenues based on the non-standardized number of traps, equation [3-17] is transformed into a catch-effort equation using nominal effort (equation [3-16]) as:

$$C_t = \beta E_t e^{-bE_t} - \gamma E_t^2 e^{-2bE_t} \qquad [3\text{-}18]$$

In comparing the E-C Schaefer model in equation [3-18] to the standard Schaefer model in equation [3-8], we find that the *RTEF* replaces the traditional catchability coefficient (q^*). Similarly, β replaces K^* and γ replaces $(q^*K^*)/r^*$ where q^*, r^*, and K^* are the equilibrium levels of catchability, intrinsic growth rate, and stock size, respectively.

3.1.2.b. Biomass Utilization (BU) Model

The second new model is similar to, but conceptually different from, the Threshold model of equation [3-10]. Unlike the Threshold model, the catch-effort equation derived from the new model – referred to as the “Biomass Utilization” model – assumes that catch is only a function of two parameters, $C_{\max}$ and q:

$$C = C_{\max}(1 - e^{-qE}) \tag{3-19}$$

In this model the catchability coefficient is a shape parameter that describes the rate at which the yield curve approaches the asymptotic $C_{\max}$ as fishing effort increases. This parameter reflects the dynamics of trap density on yield. Catch is estimated as the difference between the asymptotic catch minus the potential catch that survives fishing effort.

The Threshold and Biomass Utilization models have the unique aspect that catch is a function of available catchable biomass without taking into consideration population regeneration. Given that recruitment to the Florida fishery may be from different sources than the local parent stock (Ehrhardt 1994; Silberman, Sarver, and Walsh 1994), these models hold particular promise for the Florida spiny lobster fishery.

3.2. Catch and Effort Data for the Florida Spiny Lobster Fishery

Total commercial landings and trap numbers by season (August through March) for Florida’s East and West Coasts – from 1960 to 1984 – were obtained from the National Marine Fisheries Service (Harper 1995). In 1985, the data collection activities were transferred to the Florida Department of Environmental Protection (FDEP). Pounds landed is the whole weight purchased by licensed wholesale dealers and is assumed to equal total commercial catch (C). These landings exclude harvests by the recreational sector. Fishing effort (E) is the total number of traps operated by commercial fishermen. It is implicitly (and conservatively) assumed that fishing practices (e.g., type of gear used) have not changed over time and do not differ among fishers.[7]

The catch and effort data have been collected by coast. This is important since fishing activity in the Bahamas from 1964 through 1975 was reported on Florida’s East Coast (Labisky, Gregory, and Conti 1985; Harper 1995). Until 1975, when the Bahamian fishing grounds were closed, landings and traps reported on the East Coast each averaged 41 percent of the state totals (Bahamian fishing activity averaged 35 percent of the East Coast total). For comparison, following closure of the Bahamian fishing grounds, landings and traps reported on Florida’s East Coast fell to 13 and 7 percent – from 41 and 35 percent – respectively (from 1976 through 1995). Even though landings and trap use

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[7] This assumption is considered valid given that trap size and construction have not changed significantly over time due to regulations. Fishing seasons have become somewhat compressed over the years, however, this is partially explained by the increase in vessels and traps (see Figures 2-2 and 2-1, Milon et al. 1998). Changes in fishing technology would be expected to increase the rate of harvest. This change is accounted for in the cost information and the effort-dependent catchabilities, but does not affect resource availability. However, it has increased conflicts on the water which can reduce harvest efficiency.

reported for Florida's East Coast has always accounted for a minority of statewide totals, it is necessary to remove the Bahamian fishery from the nominal data to obtain unbiased estimates of the production relationship.

Two assumptions were adopted to correct the East Coast data series from 1964-75. The first assumption was that growth of East Coast effort (increase in trap numbers) was at a constant rate during the period. This assumption was plausible given the distinct trend in traps observed during this period (Appendix A, Figure A-1). The growth rate of 1.5 was determined by the slope of a line connecting the number of traps in 1963 and 1976 (Appendix A, Figure A-2). The second assumption was that CPUE in the East Coast fishery from 1964 to 1975 was similar to the CPUE trend observed in the West Coast fishery. This is because the standardized CPUE for each fishery, which is the observed CPUE minus the mean standard deviation for each coast, followed similar trends from 1960 to 1963 and from 1977 through 1980 (Appendix A, Figure A-3). During the period of the international fishery in the Bahamas fishery, however, large departures between Florida's East and West Coast abundance indexes (i.e., standardized CPUE series) were observed. The similarities in CPUE trends immediately prior to and after the Bahamas fishery, and the significantly different seasonal CPUE differences observed in the 1964-1975 period, should be related to differences in abundance and fishing efficiencies and practices in the Bahamas fisheries.

To correct East Coast landings, annual landings were estimated as the product of the adjusted seasonal number of traps in the East Coast times the seasonal CPUE in the West Coast fishery. The corrected East Coast landings (Appendix A, Figure A-4) were added to nominal data for the West Coast fishery to generate a "corrected" time series for the whole fishery. To compare the nominal (reported) and corrected data series, the corrected catch and effort data (referred to as the Florida data) are graphed as deviations from the nominal data (referred to as Florida and Bahamas data) in Figure 3-3. In the early 1960s, annual landings averaged approximately 3 million pounds. Since 1975, however, landings have ranged from 4.3 to 7.8 million pounds, with no apparent trend. Total effort increased significantly from 1960 to 1992 when the TCP was implemented. Since 1992, however, the number of traps has been reduced to approximately 544,000. Note that in order to estimate the effects of reducing trap numbers, it is important to include catch-effort data from seasons when trap numbers were low (i.e., the 1960s and 1970s). Without data on a relatively wide range of effort, it would be impossible to predict the effects of the TCP and future trap reductions.

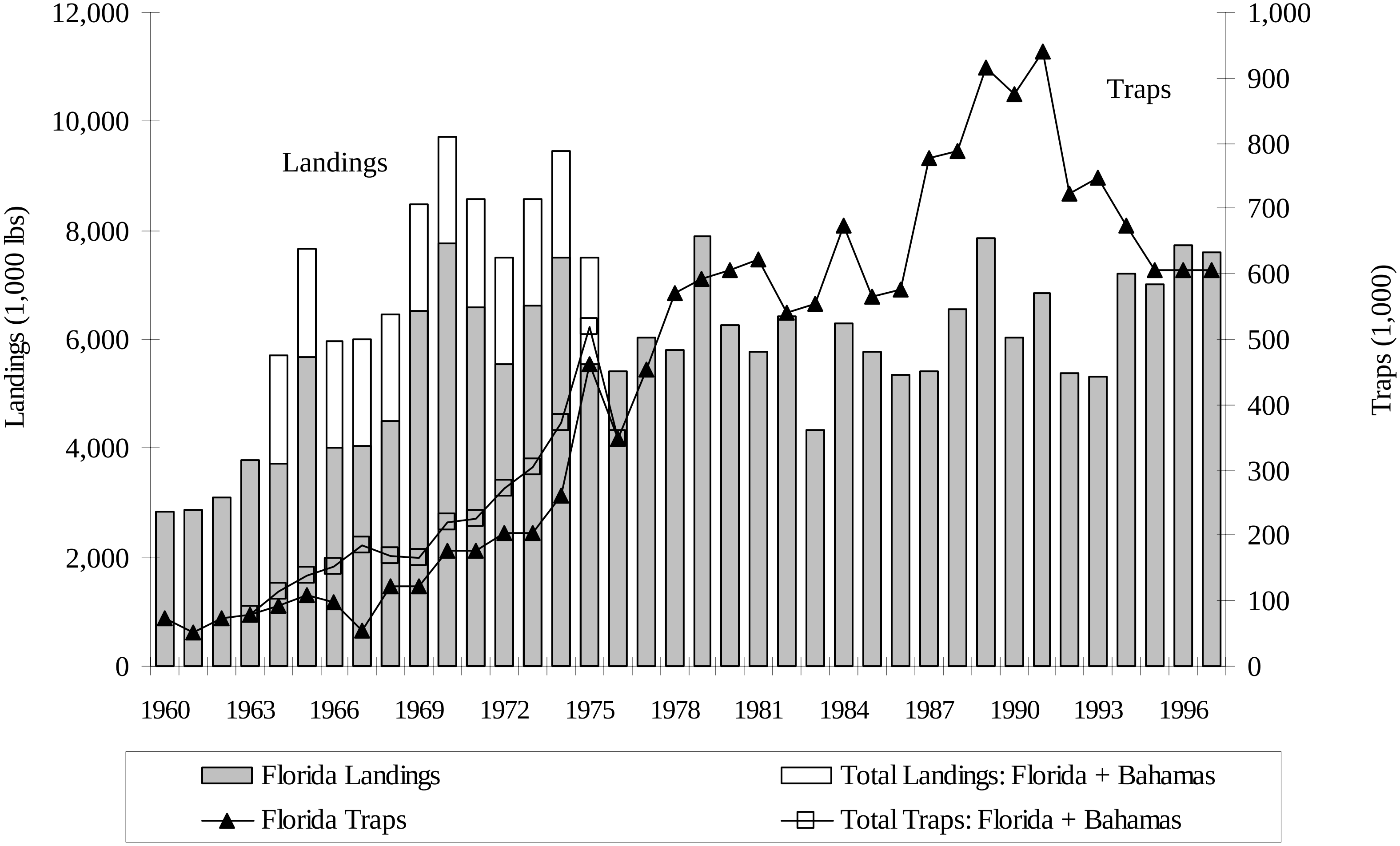

Figure 3-3. Reported Total Landings and Traps during 1960-97 with Correction for Bahamian Fishing during 1964-75

The catch-effort relationship from 1960 to 1997 from Figure 3-3 is presented with the catch-per-unit-effort (CPUE) series in Figure 3-4. When ordered by the number of traps fished, landings (*C*) and CPUE (*U*) appear stable at effort levels above 200,000 and 400,000 traps, respectively.

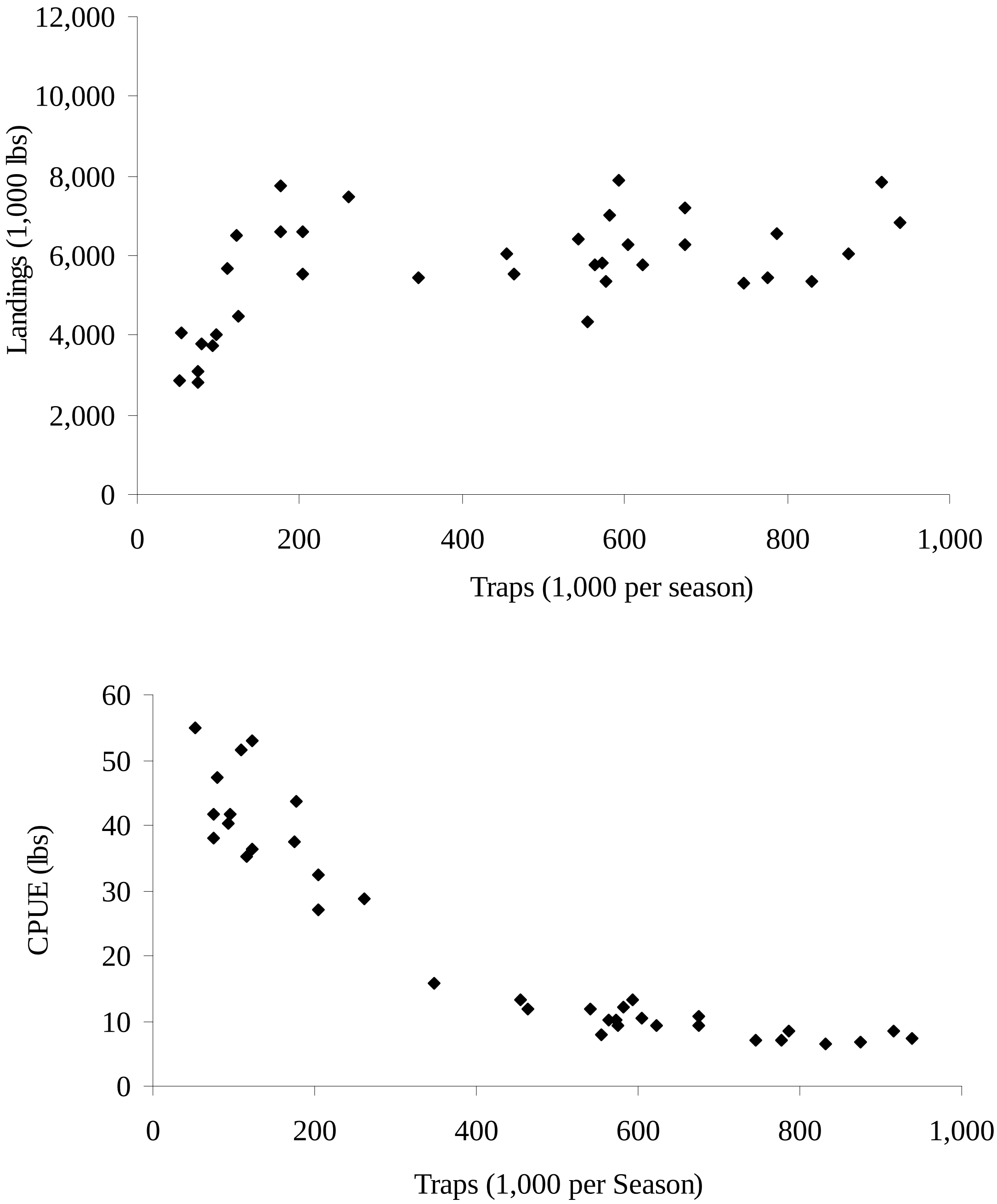

Figure 3-4. Florida Spiny Lobster Landings and CPUE by Trap Numbers

The nominal and corrected data series are provided in Appendix B. In summary, eliminating landings and traps used in the Bahamas reduced the peak landings from nearly 12 million pounds to less than 8 million pounds. The CPUE trend was largely unaffected since the landings and traps were reduced in roughly equal proportions.

3.3. Estimation Results

3.3.1. Previous Production Models

The five surplus production models specified in Figure 3-2 were estimated using the corrected (Florida only) data. Results are presented in Table 3-2. All equations were estimated using either ordinary least squares (OLS) or maximum likelihood estimation (MLE) techniques (SAS Institute Inc.). OLS was used if autocorrelation was not a problem based on the Durbin-Watson (DW) test. For the remaining models, the significance of the estimated autoregressive parameters was used to determine the appropriate number of lags (Greene 1997).

Table 3-2 shows the Schaefer, Fox, and Schnute models (Models 1– 3) do not adequately describe the fishery. None of the explanatory variables were significant, all signs were incorrect, and low R^2 statistics indicated poor explanatory power. The first CY&P model (Model 4a) fit the data well (having a high R^2 and statistically significant F value of 166.7) and, unlike the previous models, did not show signs of autocorrelation. However, since this equation contained a lagged dependent variable as a regressor (which can render the OLS estimation approach inappropriate), it was replaced by an instrumental variable in the second model (Model 4b).[8] The substitution did not substantially increase the explanatory power of the model. Moreover, the instrumental variable was insignificant (most likely due to the small sample size). The R^2 in the Threshold models (Models 5a, 5b, and 5c) increased until the assumed maximum catch level was approximately 35 percent above the highest reported catch level (16 million pounds). Since the individual parameters were statistically significant in each Threshold model, and the R^2 did not increase substantially by increasing the maximum catch above 12 million pounds, Model 5b is deemed the most representative of the Threshold models.

Given the poor results of the Schaefer, Fox, and Schnute equations, biological parameters were not derived for these models; biological parameters were only calculated for the “best” CY&P and Threshold equations (Models 4a and 5b) in Table 3-3. Overall, the models estimated roughly identical catchabilities (q^*). The CY&P model estimated the maximum stock level (K^*) at 15.3 million pounds as compared to the 7.3 million pound minimum level predicted by the Threshold model.

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[8] The lagged dependent variable, $\ln U_t$, was regressed against the remaining independent variables and its lag. The resulting predicted variable (designated by the ^ symbol) replaced the original in the MLE estimation.

Table 3-2. Estimated Surplus Production Models using Florida (Bahamas-Corrected) Landings and Traps

		Model Statistics[b]			
Model	Estimated Equation[a]	method	R^2	df	DW
(1) Schaefer	$\Delta U_t/2U_t = -0.326 + 0.0056\ U_t + 0.00035\ E_t$ (0.214) (0.0045) (0.00026)	MLE	0.09	30	1.86
(2) Fox	$\Delta U_t/2U_t = -0.617 + 0.139 \ln U_t + 0.00040\ E_t$ (0.563) (0.142) (0.00037)	MLE	0.07	30	1.86
(3) Schnute	$\ln(U_{t+1}/U_t) = -0.348 + 0.0062\ (U_{t+1}+U_t)/2 + 0.00039\ (E_{t+1}+E_t)/2$ (0.279) (0.006) (0.00033)	MLE	0.14	31	2.06
(4a) CY&P	$\ln U_{t+1} = 2.718 + 0.302 \ln U_t - 0.00086\ (E_{t+1} + E_t)$ (0.72)*** (0.181)* (0.00024)***	OLS	0.91	32	N/A
(4b) CY&P	$\ln U_{t+1} = 5.705 - 0.462\ \widehat{\ln U_t} - 0.00178\ (E_{t+1} + E_t)$ (1.27)*** (0.322) (0.00041)***	MLE	0.92	29	2.00
(5a) Threshold	$\ln(8{,}000 - C_t) = 7.997 - 0.00116\ E_t$ (0.296)*** (0.00057)**	MLE	0.14	33	1.95
(5b) Threshold	$\ln(12{,}000 - C_t) = 8.899 - 0.000380\ E_t$ (0.086)*** (0.00016)**	MLE	0.34	33	1.93
(5c) Threshold	$\ln(16{,}000 - C_t) = 9.340 - 0.000238\ E_t$ (0.053)*** (0.000101)***	MLE	0.38	33	1.93

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[a] U_t is catch per unit effort (C_t/E_t) where catch (pounds landed) and effort (number of traps) are measured in thousands. Standard errors appear in parentheses below the estimated parameter. Single, double, and triple asterisks indicate significance at the 10, 5, and 1 percent levels, respectively.

[b] Equations were estimated using MLE corrected for first-degree autocorrelation or OLS. The degrees of freedom (df) and Durbin-Watson (DW) statistics are also presented.

Table 3-3. Biological Parameters Calculated from Selected Production Models

Model[a]	growth rate (r^*)	catchability coefficient (q^*)	stock level (K^*)
(4a) CY&P	1.337	0.00000340	15,332,395
(5b) Threshold	N/A	0.00000379	7,324,438

[a] From equations when estimated in original units. Threshold q^* and K^* values are interpreted differently, as lower bound values (see also Footnote 1).

Since the results in Tables 3-2 and 3-3 were generated from the corrected (unofficial) data series, it was necessary to determine the extent that biased East Coast data from 1964 through 1975 had on the resulting production models and catch-effort equations. First, the models were re-estimated with corrected landings and nominal traps. Second, the models were re-estimated with the nominal data (landings and traps). Third, the CY&P model – the model with the highest R^2 and most significant variables – was re-estimated with dummy and interaction variables that represent the suspect years (D=1 if season began in years 1964-1975, D=0 otherwise). The CY&P model was also estimated using only data from the West Coast, the region unaffected by fishing in the Bahamas. These modeling results are summarized in Appendix C. Given the relatively small effect of Bahamian fishing activity in terms of the number of years and percent of total activity (landings and traps), the use of a corrected data series did not significantly alter the results. For accuracy, however, the bioeconomic analysis reported here uses the results from the corrected data from Tables 3-2 and 3-3.

3.3.2. New Production Models

The E-C Schaefer model – as described in Section 3.1.2.a – utilized an endogenous catchability coefficient whereby the coefficient was assumed to depend on the level of effort in the fishery. Such a specification requires seasonal (intra-season) data. Estimates of the catchability coefficient (q) by month from CPUE in numbers caught per trap and catch in numbers were only available for the 1985 to 1996 fishing seasons. To estimate q-values associated with numbers caught per trap for the earlier years it was necessary to use the available CPUE and catch statistics from catch in weight. The q-estimates should not be different, if seasonal growth has not interfered with seasonal stock depletion. Before this assumption was adopted, q estimates from 1985 to 1996 using data in numbers and weight were estimated and statistically compared (Appendix A, Figure A-5). The slope of a regression line forced through the origin is 1.016 with a correlation coefficient of 0.944. The 95 percent confidence interval for the slope is 0.981 to 1.053. Since this interval contains the theoretical slope of 1.0, the catchability estimates (using numbers and weight) are considered similar in this fishery. Consequently, the q estimates from the weight data were used for q estimates in numbers in the years when the latter figures were unavailable.

The annual catchability estimates derived for each of the 1960-63, 76-77, and 85-96 seasons (18 in total) ranged from 1.4E-06 to 6.3E-08 and generally decreased over time with increased trap numbers. Catchability coefficients were not estimated for the seasons corresponding to the years of the Bahamas fishery (1964-76) because landings and traps for those seasons could not be corrected by monthly data. Also, *q*-estimates were not estimated for the period 1978 to 1984 because recruitment affected the CPUE trends in those seasons. The values of *q* were estimated using the procedure outlined in equations [3-11] through [3-13] with a constant natural mortality rate (*m*) of 0.029 per month (Ehrhardt 1996). Separate equations were estimated for each year (i.e., eight observations per year). The R^2 statistics ranged from 0.55 to 0.98, with the majority (61 percent) falling in the 0.93 to 0.98 range. Relatively high R^2 values result from the use of aggregate monthly data (removing daily fluctuations increased the fit of the model).

As observed in Figure 3-5, catchability is characterized by a sharp decrease at effort levels between approximately 100,000 to 400,000 traps. Note, however, the lack of data points corresponding to this range. The decreasing trend is modeled by a negative exponential function as specified in equation [3-14]. Estimates for the parameters $q_t(0)$ and *b*, using the corrected data depicted in Figure 3-3, are 1.702903 and 0.000001807, respectively. These parameters were estimated using least-squares regression. The equation was significant ($F_{1,16}$=136.7) and the R^2 was 0.89.

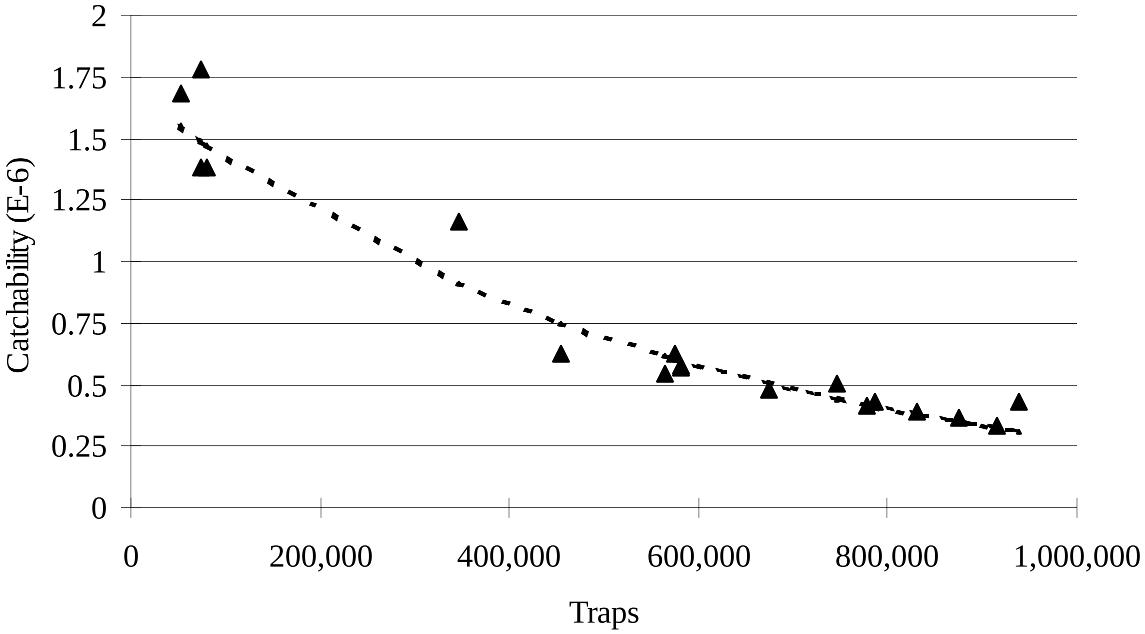

Figure 3-5. Catchability by Weight at Increasing Effort Levels

The *RTEF* calculated using equation [3-15] was used to estimate a seasonal efficiency factor for the fishery. Nominal trap numbers were standardized relative to the efficiency factor using equation [3-16]. Comparison of the catch (in weight) per unit of nominal effort (traps) and the standardized CPUE series (Appendix A, Figure A-6) reveals a lower abundance in each year from the mid-1970s to the mid-1980s and higher levels of abundance in the 1960s, early 1970s, and 1990s. This trend is not depicted by the CPUE based on nominal traps since the trap efficiency fell well below their expected values. Both the observed and standardized CPUE series fell significantly in 1974 (Figure A-6). Although the standardized series was higher than the observed, the standardized series did not vary as much. All data are summarized in Appendix B.

A least-squares regression of the E-C Schaefer model (equation 3-17) was used to fit the model to the standardized CPUE and effort (pounds landed per trap and number of traps, respectively) data. The regression was statistically significant ($F_{1,34} = 69.9$) at the five-percent level and produced the following significant parameter estimates:

$$\beta = 67.71346 \text{ and } \gamma = -0.000181$$

These parameters were used with the estimate of b ($b = 1.807\text{E-}06$) in the nominal effort specification (equation [3-18]).

The Biomass Utilization (BU) model was fitted using a non-linear least squares procedure to the catch and nominal effort data in Figure 3-3. The model fit the data well as the F-value was significant ($F_{1,34} = 71.09$) and the corrected correlation coefficient equaled 0.584 ($R^2 = 0.34$). The following parameter estimates were obtained from this model: $C_{\max} = 6{,}180{,}829.52$ pounds and $q = -0.000012976$.

3.4. Estimated Catch-Effort Equations for the Florida Spiny Lobster Fishery

Catch-effort equations relating total traps to total landings were constructed for the CY&P, Threshold, and new surplus production models using the biological parameters from Table 3-3. The CY&P and Threshold models were chosen for their relatively high explanatory power and number of significant variables. The new models (BU and E-C Schaefer) were included since they represent a unique application to the fishery. The four equations are presented in Table 3-4, namely: the CY&P (Model 4a), Threshold (Model 5b), Biomass Utilization (BU), and Effort-Corrected (E-C) Schaefer. The retention and use of several models is desired in this analysis in order to determine the sensitivity of the bioeconomic solution to the production model specification.

Table 3-4. Catch-Effort Equations for the Florida Spiny Lobster Fishery

Model	Catch-Effort Equation[a]
(4a) CY&P	$C = 49.03Ee^{-0.00000246E}$
(5b) Threshold	$C = 12{,}000{,}000 - e^{(15.81-0.000000379E)}$
Effort-Corrected Schaefer	$C = 67.71Ee^{-0.000001807E} - 0.000181E^{2}e^{-0.000003614E}$
Biomass Utilization	$C = 6{,}180{,}830(1 - e^{-0.000013E})$

[a] Catch (C) represents annual landings in pounds. Effort (E) is the total traps (certificates) in the fishery.

Figure 3-6 compares the relationship between the number of traps in the fishery and the pounds landed for each equation in Table 3-4. The CY&P model predicts landings peak at approximately 400,000 traps. This equation also produced higher landings for the mid-range of effort (between 200,000 and 650,000 traps). The Threshold, E-C Schaefer, and BU models produced more conservative catch-effort relationships. The Threshold model produced steadily increasing landings, which suggests a linear catch-effort relationship. The E-C Schaefer and BU predict landings increasing at a decreasing rate until approximately 400,000 traps, after which landings remain constant as the number of traps increase. Unlike the CY&P specification, these models predict non-decreasing catch with continual increases in effort.

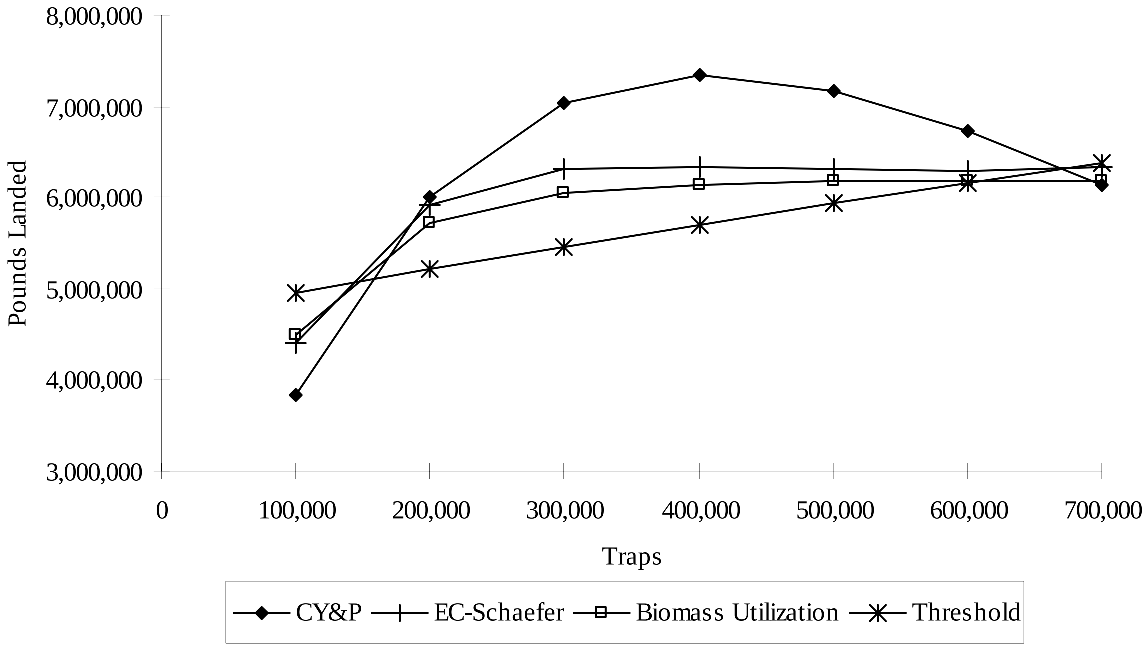

Figure 3-6. Catch-Effort Relationships for Equations in Table 3-4

Comparisons of the predicted catch-effort relationships (Figure 3-6) with the corrected data (Figure 3-3) were used to eliminate some production models from further analysis. First, the continuously increasing catch (landings) predicted by the Threshold models is not conducive to a bioeconomic relationship in which increasing effort (traps) reduces the catch rate. Consequently, the Threshold model is not considered further. The new models – E-C Schaefer and BU – are also nearly identical; both models capture the flat top characteristic of the Florida spiny lobster catch and effort data. In addition, comparison of the residuals supports the conclusion that both fit the data almost identically (Appendix A, Figure A-7). The BU model is considered preferable under the assumption that Florida lobster stocks may have a significant contribution of larvae of Pan-Caribbean origin. The CY&P model, which most accurately fit the data, predicts that increasing trap numbers would eventually reduce total landings. Since landings peaked in 1979 at nearly 7.9 million pounds from the use of 593,000 traps, this model is also considered representative. The forecast errors predicted from comparing the corrected landings with the landings predicted from the BU and CY&P models using the corrected traps data are presented in Figure 3-7. In general, the BU produced smaller errors due to the conservative catch estimates.

Aside from the catch-effort relationship, we were also interested in the marginal productivity of each trap, dC/dE (Chapter 2). This relationship is important since the economically optimal number of traps is determined by equating the marginal revenue (i.e., marginal productivity per trap times price) with the marginal cost per trap. Figure 3-8 illustrates the differences in marginal productivity with the preferred biological production models for purposes of determining the MEY-optimal number of traps in the fishery. The CY&P model predicts the largest increase in total landings up to 400,000 traps; past 400,000 traps, the addition of another trap is predicted to decrease total landings due to crowding effects.[9] Conversely, the marginal productivity for the BU model predicts that total catch will be unaffected by the addition of traps beyond 400,000.

3.5. Summary of the Biological Production Model Results

The Schaefer, Fox, and Schnute specifications yielded poor results. The Threshold model provided reasonable lower bound estimates for both the catchability coefficient and the stock level, but the marginal productivity was near zero at all effort levels. Given the historical data of Figure 3-3, the prediction is unrealistic and the model is considered inappropriate for this fishery.

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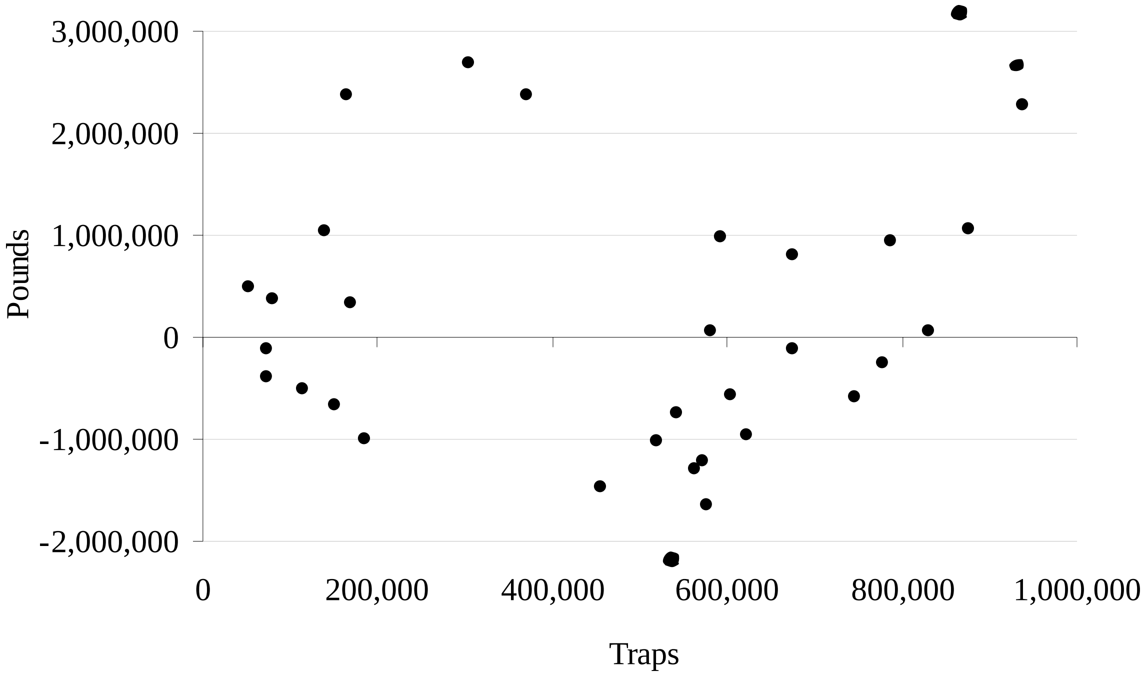
[9] A negative marginal productivity implies that an adding another trap, while all other inputs are maintained at their same level, will lower total catch. This is typically referred to as the “crowding effect” whereby the number of traps are increased to such an extent that it reduces the efficiency of the previous traps and results in an actual decline in output (i.e., similar to the trap-density effect built into the EC-Schaefer model). Note that the BU model implicitly includes this effect.

(*a*) CY&P Forecast Errors



(*b*) Biomass Utilization (BU) Forecast Errors

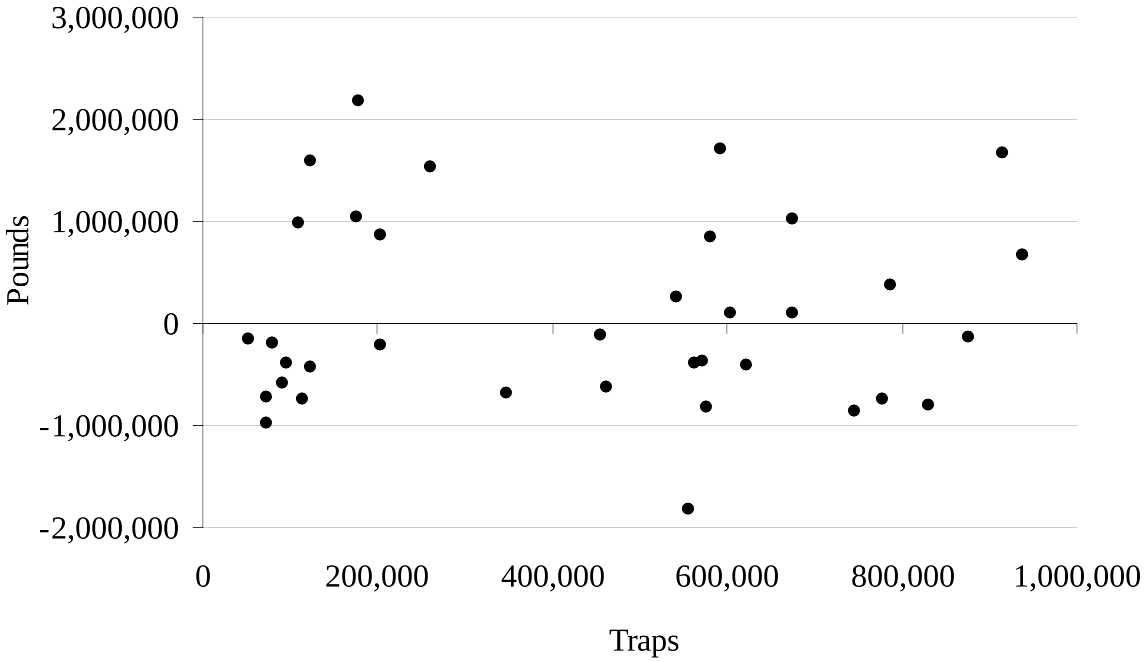


Figure 3-7. Forecast Errors at Observed Trap Numbers for the CY&P and BU Models

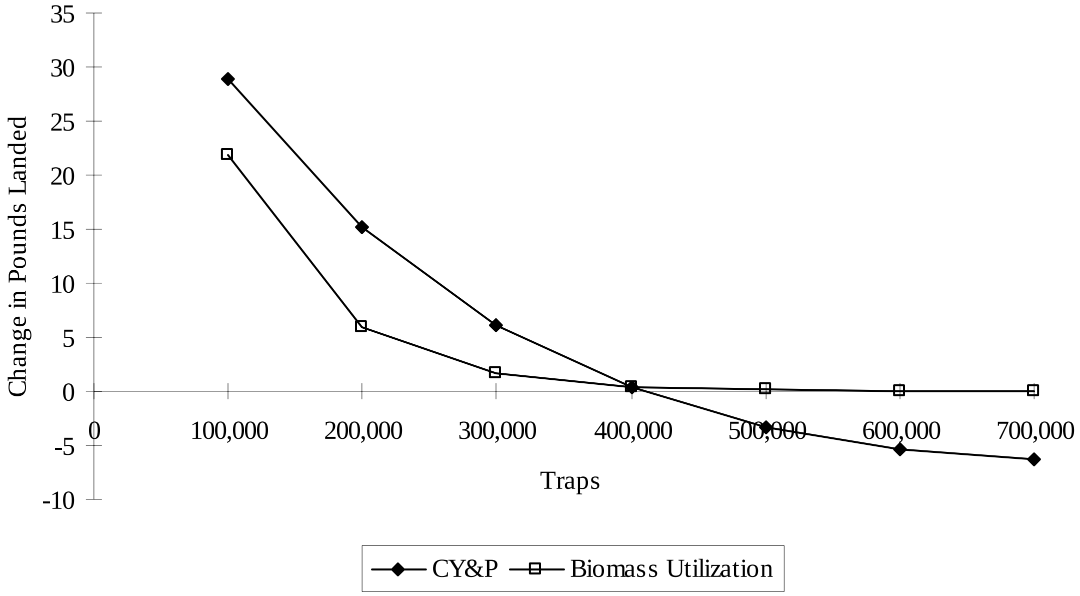


Figure 3-8. Marginal Productivity for Alternative Biological Production Models

The CY&P model, which was robust to the inclusion of Bahamian fishing activity (Appendix C), appears to be appropriate for the spiny lobster fishery in Florida. The calculated biological parameters had the correct sign and the magnitudes appear reasonable. In addition, the marginal productivity curve exhibited the same trend as observed in the historical and corrected CPUE data of Figure 3-4. The decreasing marginal productivity indicates that total catch increases with the addition of traps until 400,000 traps are in the fishery, at which point adding additional traps will decreases total landings due to crowding effects.

The BU model, which was developed specifically for this fishery, explicitly incorporated trap density into the estimation of the surplus production function. This model predicted modest increases in catch up to approximately 400,000 traps, at which point additional traps do not increase catch. This trend in decreasing marginal productivity, similar to the CY&P model, also corresponds with the observed characteristics of the fishery. Although the CY&P and BU models predict similar trends in marginal productivity, the difference may be substantial for predicting MEY-optimal trap numbers. These predictions are the topic of Chapter 5.

4. COST OF PRODUCTION MODELS

The determination of a bioeconomic optima requires – in addition to a marginal revenue curve (i.e., lobster price times a marginal productivity curve in Figure 3-8) – an estimate of the marginal cost per trap. In this study, the marginal cost will represent the opportunity cost of adding an additional trap to the fishery. In addition to annual fishing costs, the marginal cost will depend on the time horizon, whether the fishery is over-capitalized, and whether the fishing vessels are involved in other fisheries. We will also examine costs by vessel length. Differences in marginal costs are important, perhaps critical, since each estimate implies a different MEY solution.

4.1. Definition of Variable and Fixed Costs

Variable costs are incurred from fishing and include trip costs (e.g., fuel, bait, groceries, ice, supplies, and wages), equipment leasing and repair, and maintenance expenses. Fixed costs are incurred independent of fishing activity and include administration, interest payments, vessel insurance, docking fees, depreciation (vessels and gear), registration costs, and licensing fees. Total costs equal the sum of fixed and variable expenses.

Previous fishery studies have used the average *variable* cost as a proxy for the marginal cost when capacity in the fishery is large relative to the harvests (Campbell, Hand, and Smith 1993). This is because when a fishery is “over-capitalized,” effort can be increased at a constant unit cost. And, since additional capital investment is not being considered, fixed costs are irrelevant to decision making (Conrad and Clark 1987). Alternatively, the average *total* cost has been used as a marginal cost proxy under the assumption that, in the long-run, all costs are dependent on effort (Christensen and Vestergaard 1993). Such an assumption would be appropriate, for example, when a sustainable yield curve is being used (e.g., the equilibrium catch-effort relationship estimated in Chapter 3).

Although using average cost estimates as a proxy for the marginal cost is justifiable in some cases, and relatively straightforward, estimating the marginal cost directly using data from a sample of vessels is preferred. Given the complexity and variation between fisheries, there are several options for obtaining such estimates. The two basic approaches are to estimate: (1) a single-species function, or (2) a multispecies function that accounts for participation in more than one fishery in a given year. The single and multiproduct specifications are discussed in more detail below, followed by a description of a survey administered in 1997 of spiny lobster fishers in Monroe County. Data from this survey were used to develop cost functions for the fishery.

4.2. Single- vs. Multi-product Cost Models

Single-product cost equations produce an estimate for the marginal cost per unit of effort using data for a single fishery, in this case the spiny lobster fishery. Including all the fixed costs in the total cost measure – such as the total value of the vessel – implies that spiny lobster is the primary target. In other words, the owner plans to cover all fixed costs with lobster revenues. If this is the case, the decision to include secondary fisheries depends only on whether the revenues from the secondary fisheries can cover the variable costs associated with their harvest (Prochaska and Landrum 1981).

For example, a single-product cost model of the Florida spiny lobster fishery was estimated by Prochaska and Cato (1981). The total annual cost of participating in the lobster industry for firm i (TC_i) was regressed against the number of traps the firm operated (E_i):

$$TC_i = \alpha + \beta E_i \qquad [4\text{-}1]$$

Equation [4-1] provides an estimate of the annual fixed cost for lobster fishing (α) – for each vessel – and the corresponding marginal cost per trap (β). Note that the marginal cost will not equal the average cost since the average is given by TC_i/E_i.

If the cost curve is linear, as in equation [4-1], cost for the fishery increases in direct proportion to effort. That is, each additional trap, when operated in the most efficient manner, can be added to the fishery at the same cost as the previous one (Anderson 1986). A linear cost curve also implies that traps are homogeneous.

An alternative specification for the cost equation assumes that all costs are dependent on effort:

$$TC_i = \beta E_i \qquad [4\text{-}2]$$

that is, the total cost is essentially variable since it depends on the number of traps fished, which is a variable input. Equation [4-2] is the appropriate specification for a long-run analysis. Such a specification also corresponds to the use of a sustainable yield function (e.g., the catch-effort relationship) to determine revenues. This specification implies that extra effort is from new traps, not increased effort from existing traps. Equation [4-2] estimates the minimum point on the long-run average cost curve if all markets are competitive (Clarke, Yoshimoto, and Pooley 1992).

Bioeconomic models should, however, consider the long-run opportunity costs of all harvesting activities. Cost functions based only on harvesting a single species – such as equations [4-1] and [4-2] – cannot account for joint costs when more than one primary harvesting activity exists. If firms participate in multiple fisheries, with the intent to use revenues from each to cover fixed costs, a multiproduct cost framework is necessary to determine the long-run efficient level of effort. In addition, the use of a multiproduct cost function may be especially appropriate in fisheries due to the inherent variability in fish stocks, which increases and changes the reliance on any one fishery. Variability in market prices also increases the need for full utilization of fixed capital investment.

Following previous cost studies for other fisheries (Squires 1987; Kirkley and Strand 1988; Thunberg, Bresnyan, and Adams 1995), commercial operations for multiple species can be represented by a general multi-product revenue function:

$$R_i = f\,(p_j, VC_{i,j}, K_i) \quad \forall\, j \text{ species.} \qquad [4\text{-}3]$$

Firm *i*'s revenue (R_i) is a function of the ex-vessel price of the j^{th} species (p_j), the variable cost associated with harvesting the j^{th} species ($VC_{i,j}$), and a composite capital good (K_i). Firms that harvest only spiny lobster – such as represented by the cost specifications in equations [4-1] and [4-2] – are a special case of this more general framework.

The choice of a specific functional form for the revenue function in equation [4-3] depends on a number of criteria, including the flexibility of the form to adapt to different output configurations. A likely choice for this application is the normalized quadratic function, which allows for zero output for any particular species (Lau 1978). The ability to include harvesters with zero output for some species is a desirable characteristic for this problem because not all firms participate in the same fisheries. The normalized quadratic revenue function also embodies information on the shadow cost (or implicit price) structure of a multiproduct firm that can be used to derive an estimate of the marginal cost for each unit of effort (Lau 1978; Squires and Kirkley 1991).

4.3. Landings and Cost Survey Description and Data Summary

A survey was conducted for this project during the summer and fall of 1997 to obtain data to estimate cost models for the fishery. A stratified sample was selected from the (approximately) 2,900 Florida Saltwater Product License (SPL) holders in Monroe County, which includes the Florida Keys. Monroe County accounts for approximately 90 percent of total spiny lobster landings in Florida (Hunt 1994). The SPL data file is part of a computerized data system that also provides information on the restricted species a license holder is allowed to harvest – for example, lobster and stone crabs – and the number of traps used to fish for these species. Of the total SPL holders in Monroe County, approximately 60 percent possessed certificates for lobster traps.

Our survey used a sample of 53 fishers who operated a single vessel with at least 100 spiny lobster traps in 1996. This sample represents approximately nine percent of all owners with at least 100 certificates during the 1995-96 season (Florida Department of Environmental Protection; Milon et al. 1998). The socioeconomic information for the sample – including age of the respondent, years of experience, homeport, economic dependence on fishing, whether nets are used, whether interest payments are made, and relative quantities of species landed – is summarized in Table 4-1.

Table 4-1. Socioeconomic Profile of Monroe County Commercial Fishermen in the Sample

Characteristic	Percent of Total Sample (*n*=53)
Age of Fishers	
18 to 30 years	6 %
31 to 40 years	28 %
41 to 50 years	32 %
51 to 60 years	26 %
Over 60 years	7 %
Years Fishing in Monroe County (i.e., Florida Keys)	
1 to 5 years	4 %
6 to 10 years	2 %
11 to 20 years	49 %
More than 20 years	45 %
Port Where Vessel Docked	
Lower Keys (e.g., Summerland, Big Pine, Key West)	41.5 %
Middle Keys (e.g., Marathon, Islamorada)	34.0 %
Upper Keys (e.g., Long, Key Largo, Tavernier)	24.5 %
Percent of Income from Fishing (Reported Values)	
25 % (part-time fishermen)	2 %
50 % (part-time fishermen)	2 %
90 % (full-time fishermen)	2 %
100 % (full-time fishermen)	94 %
Percentage of Fishers with Nets	23 %
Percentage of Fishers with an Interest Payment	2 %
Percentage of Fishers Reporting Landings	
Spiny Lobster	100 %
Stone Crab	77 %
King Mackerel	35 %
Snappers and/or Groupers	17 %
Other (blue crab, inshore pelagics, other offshore)	17 %

The respondents (referred to as fishermen, vessels, or firms throughout the analysis) were stratified across regions based on the location of the docked vessel and by the number of lobster traps fished in 1996. The number of traps fished by any one vessel averaged 1,279, but ranged from 113 to 2,570 (Figure 4-1):

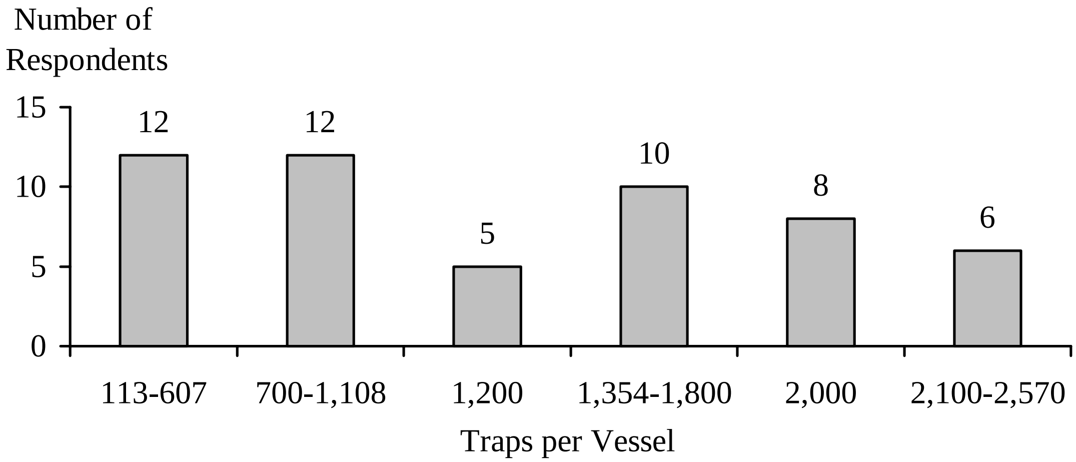


Figure 4-1. Distribution of Number of Spiny Lobster Traps Fished by Survey Respondents in 1996

Since each respondent fished at least 113 traps in the 1996-97 season, each landed spiny lobster. The majority of respondents (77 percent) also landed stone crab and more than one-third landed king mackerel (Table 4-1). Of the 53 respondents, 50 were full-time fishermen who received at least 90 percent of their total annual income from fishing. Other demographic information included years of fishing experience and age. Only three respondents reported fishing for 10 years or less. Age was distributed normally around the 41-50 year range (Figure 4-2):

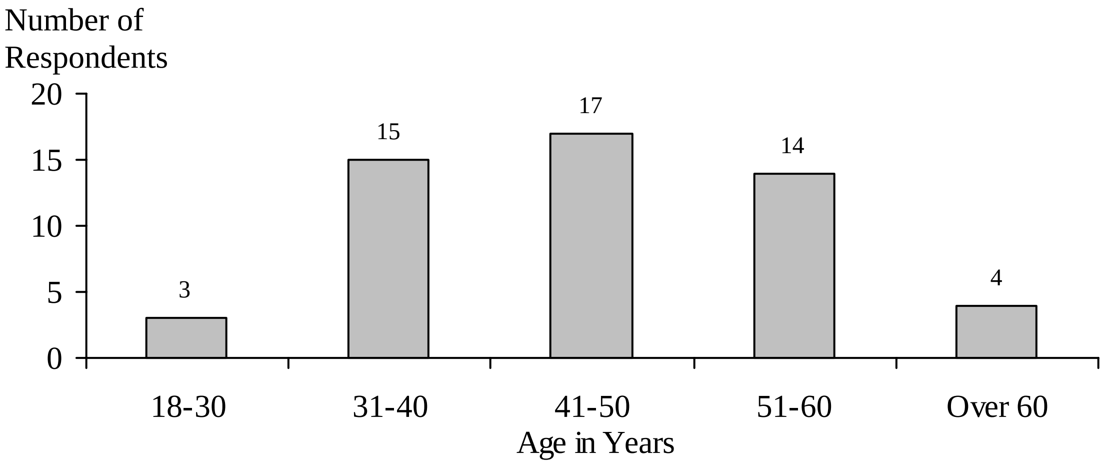


Figure 4-2. Age Distribution of Survey Respondents in 1996

Economic information included data on total fishing activity in 1996. Landings were grouped into five categories (j = 1, 2,… 5): spiny lobster, stone crab, king mackerel, snappers/groupers, and other. Landings were reported in pounds ($Q_{i,j}$). Output prices were available separately through the Florida Trip Ticket Information System (Florida

Department of Environmental Protection). Using the average price per pound in 1996 (p_j), the total revenue of each vessel was approximated as:

$$TR_{i,j} = Q_{i,j}p_j \, . \qquad [4\text{-}4]$$

For the crab, snapper/grouper, and other categories, price is a weighted average based on the total quantity of the individual species and/or size categories landed. Since Florida accounts for less than 10 percent of the total spiny lobster supply in the United States (NMFS 1998), Monroe County fishermen were assumed to be price-takers. Market prices are summarized with annual landings per vessel (from the sample) in Table 4-2.

Table 4-2. Average Prices and Reported Annual Landings per Vessel by Species in 1996

Species	Ex-vessel Price[a] ($ per lb)	Annual Reported Landings per Vessel (pounds) Average	Standard Deviation	Minimum	Maximum
Spiny Lobster	$3.79	19,726	13,495	1,200	55,000
Stone Crab	$6.60	4,957	6,270	0	28,000
King Mackerel	$1.24	4,262	12,115	0	50,000
Snapper/Grouper	$1.95	721	2,073	0	12,000
Other	$1.04	3,208	11,935	0	80,000

[a] Florida Marine Fisheries Information System, reported dated 4/14/97 (FDEP). Prices for species groups based on a weighted average of pounds landed of each species and/or size category included.

Total annual costs for each vessel (*TC*) consist of total fixed and variable costs (*FC* and *VC*, respectively) associated with the harvest of each species:

$$TC_{i,j,l} = FC_{i,j} + VC_{i,j,l} \qquad [4\text{-}5]$$

where:

i = firms (I = 53)
j = species (J = 5: spiny lobster, stone crab, king mackerel, snapper/grouper, other)
l = labor cost calculation (L = 3: *zero*, minimum *wage*, *share* of total revenues).

Fixed costs include the average annual value of depreciation (*DEPR*), total loan payment (*LOAN*), and docking fees (*DOCK*):

$$FC_{i,j} = DEPR^{\text{vessel}}_{i} + DEPR^{\text{gear}}_{i,j} + LOAN_i + DOCK_i. \qquad [4\text{-}6]$$

Vessel depreciation was calculated using the straight-line method, assuming an 18-year class life, as described in the U.S. Tax Guide Publication 946 (Internal Revenue Service).[10] Gear depreciation included the cost of lost traps and nets. The reported life of lobster traps was used to calculate the average annual lost value of the asset for each

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[10] Annual depreciation equals the tax rate (one divided by years remaining in the recovery period, which is assumed to equal the class life) multiplied by the basis, which is assumed to equal the cost of the vessel.

vessel. Information on stone crab trap life was not included in the survey; the average lobster trap life (3.86 years) was used as a proxy. Information on the life of nets was also missing; they were assumed to last 13.5 years based on an average life of 12 to 15 years (D. Gregory, personal communication). Only one respondent reported a loan (interest) payment, which corresponds to previous studies that found the majority of vessels in Monroe County are owned outright (Milon et al. 1997). Docking fees were reported by the majority of respondents. Zero docking fees indicated the vessel used a private dock or one belonging to a fish house (M. Shivlani, personal communication). The reported fixed costs are summarized in Table 4-3.

Table 4-3. Average Annual Fixed Costs by Monroe County Fishermen in the 1996 Survey

	Average (*n*=53)	Standard Deviation	Minimum	Maximum
Vessel Depreciation (cost/18 years)	$ 4,890	3,803	556	16,667
Gear Depreciation:				
Spiny Lobster Traps (cost/reported life in years)	$ 7,353	5,005	452	24,094
Stone Crab Traps (cost/3.86 years)	$ 6,485	10,429	0	41,969
Nets (cost/13.5 years)	$ 958	2,751	0	12,593
Loan Payment	$ 362	2,637	0	19,200
Docking Fee	$ 1,190	1,632	0	6,600
TOTAL ANNUAL *FC*	$13,795	9,431	1,796	55,311

Variable costs for supplies (*SUPPLIES*) and labor (*LABOR*) are distinguished by species. Total variable costs (*VC*) also include annual miscellaneous expenses (*MISC*) for maintenance, repairs, gear leasing, and trap certificate fees:

$$VC_{i,j,l} = SUPPLIES_{i,j} + LABOR_{i,j,l} + MISC_{i,j}\,, \qquad [4\text{-}7]$$

where:

$$SUPPLIES_{i,j} = \sum_{s} c_{s,i,j} X^{T}_{i,j} \qquad [4\text{-}8]$$

s = trip supplies (S = 6: fuel and oil, bait, ice, food and supplies, other, spotter plane)
c = cost per typical trip for supply s, by firm i, targeting species j
X^T = number of trips taken in 1996 by firm i targeting species j.

The information on annual supply costs obtained from the 53 respondents for 1996 is summarized in Table 4-4. The wide variation in variable costs between vessels is explained by differences in the level of participation in each fishery (i.e., the number and length of trips) and/or the size and age of the vessel and gear.

Table 4-4. Average Annual Supply Costs by Monroe County Fisherman in the 1996 Survey

Trip Supplies (*SUPPLIES*$_{i,j}$)	Average (*n*=53)	Standard Deviation	Minimum	Maximum
j = spiny lobster				
Fuel and Oil	$5,747	4,538	440	19,200
Ice	$ 193	753	0	4,000
Bait	$3,124	4,522	0	16,800
Food & Supplies	$2,027	1,841	150	8,000
Other	$ 175	718	0	4,000
j = stone crab				
Fuel and Oil	$4,383	5,646	0	28,800
Ice	$ 0	0	0	0
Bait	$7,032	9,493	0	36,800
Food & Supplies	$ 943	1,305	0	5,600
Other	$ 58	248	0	1,200
j = king mackerel				
Fuel and Oil	$ 295	734	0	3,750
Ice	$ 91	250	0	1,500
Bait	$ 70	494	0	3,600
Food & Supplies	$ 188	737	0	5,000
Other	$ 90	381	0	2,500
Spotter Plane	$ 477	1,501	0	6,200
j = snappers/groupers				
Fuel and Oil	$ 235	692	0	3,900
Ice	$ 223	826	0	5,440
Bait	$ 260	988	0	6,000
Food & Supplies	$ 128	538	0	3,750
Other	$ 22	109	0	750
j = other				
Fuel and Oil	$ 276	792	0	3,600
Ice	$ 12	66	0	450
Bait	$ 149	694	0	4,600
Food & Supplies	$ 140	432	0	2,500
Other	$ 11	58	0	300

The average annual supply costs in Table 4-4 were derived from the average reported trip cost (*c*) and the number of trips reported during the season (X^T), for each species by each vessel, as defined in equation [4-8]. Table 4-5 provides a summary of the input variables (X^f), including the average reported number of trips ($f = T$), hours worked per day ($f = H$), days per trip ($f = D$), and number of crew ($f = C$).

Table 4-5. Average Number of Trips, Hours per Trip, Days per Trip, and Crew by Species for Monroe County Fishermen in the 1996 Survey

Variable ($X^f_{i,j}$)	Spiny Lobster (*n*=53)	Stone Crab (*n* =44)	King Mackerel (*n* =12)	Snapper/ Grouper (*n* =9)	Other (*n* =9)
$X^T_{i,j}$ (*T*rips)	91.17	70.51	8.33	12.56	15.00
	(45.58)	(45.41)	(6.44)	(11.92)	(13.50)
$X^H_{i,j}$ (*H*ours)[a]	10.42	8.00	8.00	8.00	8.00
	(2.04)	(N/A)	(N/A)	(N/A)	(N/A)
$X^D_{i,j}$ (*D*ays)	1.42	1.02	1.05	3.56	1.39
	(1.38)	(0.16)	(0.17)	(3.50)	(0.70)
$X^C_{i,j}$ (*C*rew)	2.26	2.33	3.09	2.44	3.00
	(0.92)	(1.00)	(1.04)	(0.88)	(0.87)

Note: Spiny lobster was the only fishery participated in by all respondents (*n*=53). Input information for the remaining fisheries was only available on a subset of respondents (*n*<53). Zeros were excluded to facilitate input comparisons between fisheries (not comparisons of annual vessel activity).

[a] Respondents were not asked about typical trip length for the non-lobster trips. An 8-hour workday is assumed for those species.

The survey did not directly elicit labor costs for two reasons. First, early field trials indicated that a variety of compensation methods were used: hourly wages, fixed daily sums, and shares of total revenues. This was further complicated by the fact that the crew and captain may each be compensated under a different method. Second, labor payments were considered a sensitive issue that many captains did not wish to reveal. Therefore, for this analysis, two approaches were used to estimate labor expenses: (1) a minimum hourly wage for captain and crew, and (2) shares of total revenue.

The input variables summarized in Table 4-5 were used to calculate per trip and annual labor expenses when the captain and crew are paid minimum wage:

$$LABOR_{i,j,l=wage} = w\prod_f X^f_{i,j} \qquad [4\text{-}9]$$

$$= w(X^T_{i,j}X^H_{i,j}X^D_{i,j}X^C_{i,j})$$

where:

w = national minimum hourly wage ($5.15 in 1996)

$\prod_f X^f_{i,j}$ = total hours worked by all crew and captain in 1997.

Basing labor costs on the minimum wage provides an estimate of the minimum opportunity cost associated with work hours expended in the fishery. Using the minimum opportunity cost is an important benchmark for evaluating management plans since it results in the estimation of maximum rents generated from the fishery. Excluding labor costs would not allow for estimation of rents (which the state is allowed to redistribute) and overestimate returns to the fishery (above the maximum from using the minimum wage), which could bias the evaluation of alternative management plans. For comparison with previous studies of this fishery, and to correspond with traditional payment systems in this fishery (Prochaska and Landrum 1981), labor expenses were also calculated as a share of total revenues (TR):

$$LABOR_{i,j,l=share} = \left[\frac{TR_{i,j}}{(X^{C}_{i,j} + 1)} \right] \cdot (X^{C}_{i,j} - 1) \qquad [4\text{-}10]$$

Since the crew (X^C) includes the captain, revenue is first divided among all personnel plus one for the vessel. Shares for labor are then paid only to the hired crew (X^C minus the captain).[11] For king mackerel (*km*), 10 percent of revenues may go to a spotter plane before the share is calculated (M. Shivlani, personal communication). Labor cost as calculated in equation [4-10] includes the share of industry rents that go to the crew; hence, this payment method would likely produce an upper bound on labor costs (i.e., lower bound of rents generated from the fishery). The average annual minimum wage and equal share labor costs for each vessel and by fishery are summarized in Table 4-6.

Table 4-6. Average Annual Labor Expenses by Species for Monroe County Fishermen in the 1996 Survey

$LABOR_{i,j,l}$	Spiny Lobster	Stone Crab	King Mackerel	Snapper/ Grouper	Other
l = wage	\$12,950 (8,736)	\$5,194 (6,087)	\$270 (772)	\$414 (1,377)	\$343 (968)
l = share	\$31,851 (29,386)	\$14,858 (24,461)	\$2,661 (7,846)	\$535 (1,618)	\$1,788 (7,269)

Notes: Standard deviations in parenthesis. For all species except spiny lobster, the minimum labor cost was zero due to non-participation by some firms (*n*=53).

For each species, labor costs calculated as a share of total revenues exceeded the minimum wage calculation. Therefore, estimated rents from the total share and minimum wage cost estimates will provide the minimum (most conservative) and maximum (most liberal) solutions, respectively.

Miscellaneous expenses, the last component of variable costs (*MISC* in equation 4-7), were estimated as:

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[11] This share method differs from that used in the earlier study by Prochaska and Landrum (1981).

$$MISC_{i,j} = \sum_{g} Z_{g,i,j} \qquad [4\text{-}11]$$

where:
Z = miscellaneous expense variable (total annual cost)
g = expense (G = 4: *V*essel maintenance, *G*ear maintenance, certificate *F*ees, and certificate *L*easing).

Miscellaneous expenses include maintenance and repair of the vessel and fishing gear (nets and traps). For spiny lobster, the cost associated with certificate ownership (an annual \$0.75 per certificate fee) and/or leasing – either a payment to lease in additional certificates or receipt for leasing to another – for the season was also included. These annual variable costs are summarized in Table 4-7.

Table 4-7. Average Annual Miscellaneous Variable Costs by Monroe County Fishermen in the 1996 Survey

Miscellaneous Costs ($MISC_{i,j}$)	Average (n=53)	Standard Deviation	Minimum	Maximum
Net and Trap Maintenance ($Z_{G,i,j}$)	\$9,244	10,506	1,200	55,000
Vessel Maintenance ($Z_{V,i}$)	\$9,811	9,078	0	45,000
Certificate Fee ($Z_{F,i,j}$)	\$ 946	529	85	1,928
Certificate Leasing ($Z_{L,i,j}$)	\$ 758	3,970	-20,845	10,000

The total annual cost per firm, equal to the sum of average costs reported in Tables 4-4 through 4-7, are reported in Table 4-8. For comparison, the average costs reported by Prochaska and Landrum (1981) for spiny lobster vessels in 1978-79 are also presented. The costs are not directly comparable due to differences in the information collected. For example, since the TCP did not exist in the 1978-79 season, no expense for leasing certificates was reported. Other costs not reported in the 1978-79 survey include food expenses and trap depreciation. However, Prochaska and Landrum (1981) did include, as a variable cost, the total cost to construct 466 new traps – approximately 43 percent of the average owned – to account for traps lost during the year.[12] In addition, Prochaska and Landrum (1981) prorated some fixed cost estimates to derive the portion specific to lobster fishing. In the 1996-97 survey, trap depreciation was included as a fixed cost but did not include a cost for lost traps. In addition, the 1997 survey did not ask for licensing, registration, or insurance expenses since these costs are roughly equal among participants. In addition, these costs do not represent a significant portion of fixed costs. For example, the inflation-adjusted estimate of these expenses from Prochaska and

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[12] The construction cost per trap equaled \$9.89 and included only the cost of materials since fishermen constructed their own traps (Prochaska and Landrum 1981, p. 11).

Landrum (1981) equals just $310 (six percent) of total fixed costs. For comparison, a resident Saltwater Products License is $50 for an individual or $100 for a vessel (Florida Statute 370.06), a relatively small figure compared to the 1996-97 average fixed cost of $13,795. In summary, the estimated 1996-97 costs (1) overestimate the fixed expenses to the extent the average vessel participated in other fisheries, and (2) underestimate fixed expenses (which may be spread across several fisheries) associated with insurance and permits. These differences may not be important, however, since a change in the fixed cost would not affect the marginal cost (which is used to determine the economically optimal number of traps).

Using the 1996-97 survey data, both single and multiproduct costs functions were estimated. The single-species lobster fishery marginal costs were first compared to the inflation-adjusted marginal costs estimated by Prochaska and Cato (1980). In addition, average costs were developed for the purpose of comparing the 1996-97 results with costs from the 1978-79 data used in separate studies by Keithly (1981) and Waters (1987). Since previous studies of the Florida spiny lobster fishery calculated and utilized costs based on vessel length (Prochaska and Landrum 1981; Keithly 1981; Waters 1987), the single-species cost functions were also used to test for cost differences by vessel length and number of traps fished. We also estimated a non-linear cost function.

4.4. Cost Function Estimation Results

4.4.1. Single Product Cost Functions

Regression results for the two single-product cost models (equations 4-1 and 4-2) with the 1996-97 survey data are presented in Table 4-9. Each model was estimated using one of three measures of labor cost. Either the crew is assumed paid an equal share of gross revenues, the captain and crew are all paid minimum wage, or labor costs were assumed to be zero. The latter is included to evaluate the effects of the labor cost estimates on the overall explanatory power of the models. For comparison, Table 4-9 also contains the corresponding average costs from the raw data.

Table 4-8. Average Annual Revenues and Costs for Monroe County Spiny Lobster Fishermen, 1996-97 and 1978-79 Seasons

Item	1996-97 Survey Data	Prochaska and Landrum (1981) Original 1978-79	 Updated 1978-79[a]
Revenue (lobster)	$74,763	$40,912	$67,822
Costs:			
Fuel and Oil	5,747	3,559	6,278
Bait	3,124	3,297	5,816
Ice	193	131	231
Supplies	NC	398	702
Food and Supplies	2,027	NC	NC
Other	175	NC	NC
Certificate Fees	946	NA	NA
Certificate Leases	758	NA	NA
Repair - Vessel	9,811	875[b]	1,544[b]
Repair - Traps	3,396	1,857	3,276
Traps (materials for 466)	NC	4,610	8,132
Labor	12,950 - 31,851	8,339	14,710
Total Variable Costs:	$39,127 - 58,028	$23,063	$40,683
Vessel Depreciation	2,934	2,791[b]	4,923[b]
Dockage	1,190	2	4
License, Ins., and Regist.	NC	176	310
Trap Depreciation	7,353	NC	NC
Interest Payment	362	NC	NC
Total Fixed Costs:	$13,795	$ 2,969	$ 5,237
Total Costs	$52,922 - 71,823	$26,032	$45,920
Net Revenue per Firm	$ 2,940 - 21,841	$14,880	$21,902

Notes: NA = Not Applicable. NC = Not Collected.

[a] Revenues converted to 1996 dollars using the average pounds landed in 1978-79 multiplied by the 1996-97 average price. Costs converted using the average Producer Price Index for All Commodities.

[b] The cost was prorated (reduced) according to the time spent lobster fishing relative to other fisheries.

Table 4-9. Alternative Single-Species Average and Marginal Cost Estimates

	Labor Cost		
Single-Species Costs	Equal Share	Minimum Wage	No Labor
Model Specification			
Short-run Equation [4-1]:			
$TC = \alpha + \beta EFFORT$	$\hat{\beta}$ = \$53.34	$\hat{\beta}$ = \$29.73	$\hat{\beta}$ = \$21.04
	(5.95)	(4.18)	(3.30)
R^2 Statistic	0.61	0.50	0.44
Long-run Equation [4-2]:			
$TC = \beta EFFORT$	$\hat{\beta}$ = \$55.54	$\hat{\beta}$ = \$38.81	$\hat{\beta}$ = \$29.00
	(2.77)	(2.06)	(1.65)
R^2 Statistic	0.89	0.87	0.86
Average Costs			
Average *VC* per Trap	\$44.76	\$34.68	\$24.21
Average *TC* per Trap	\$56.52	\$46.44	\$35.97

Notes: The standard error of the marginal cost coefficient is reported in the parentheses. Fixed costs were estimated at \$3,618 (std. error = 8,616), \$14,901 (std. error = 6,602), and \$13,062 (std. error = 4,782) in the equal share, minimum wage, and no labor cost models, respectively. The equations without an intercept term [4-2] technically do not have a valid R^2 measure (Greene 1997); the number is shown only to compare models.

Each estimated parameter (i.e., marginal cost estimate) was statistically significant at the 1 percent level and the estimated marginal cost ranged from approximately \$21 per trap in the no labor cost model to \$56 per trap in the equal shares cost model. When labor costs were calculated as shares, the marginal cost was relatively unaffected by including an estimate of fixed costs. The cost estimates of both "no labor" equations had the lowest R^2 statistic indicating that the labor cost component was a statistically important component of the overall cost equation.

For comparison, the inflation-adjusted *marginal* cost estimate from Prochaska and Cato (1980) would be \$30.90 per trap.[13] Using an identical model specification as Prochaska and Cato (1980), Table 4-9 shows the minimum wage model estimates the marginal cost at \$29.73 per trap.

The average variable cost per trap, when labor costs are excluded, was \$24.21 for the 1996-97 season. For comparison, the inflation-adjusted average variable cost

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[13] The estimate of \$11.55 was converted to 1996-97 dollars using the Producer Price Index for all Commodities averaged across the August through March season. The original estimate of \$11.55 was, most likely, derived from total cost data that included crew wages based on a \$7 hourly rate – the rate quoted in the data source, i.e., Prochaska and Williams (1976) – but this cannot be verified.

estimates from Keithly (1981), which were also used by Waters (1987), would range from \$19.30 to \$29.02 per trap depending on vessel length. According to Keithly (1981), labor costs were excluded “because the crew generally received a percentage of revenue for their work which was not directly related to costs or the level of inputs used by the firm” (p. 73). Using the original Prochaska and Landrum (1981) data, and assuming labor costs equaled 20 percent of gross revenues, the inflation-adjusted average total cost per trap is \$42.32.[14] Since a 20 percent total *crew* share is considerably less than the equal shares assumed received by each crewmember, the captain, and the owner in the 1996-97 study, the inflation-adjusted 1978-79 figure is 25 percent lower than the 1996-97 estimate of \$56.52. It is also 9 percent lower than the minimum wage estimate of \$46.44, but 18 percent higher than the estimate which excluded labor costs (\$35.97 per trap). Regardless of the differences between the average and marginal estimates in Table 4-8, using the average variable cost per trap as a proxy for the marginal cost in a bioeconomic model could produce misleading results since the measures are theoretically different.

4.4.1.a. Tests for Cost Differences in the Lobster Fishery by Vessel Length

Prochaska and Landrum (1981) also calculated costs (total and average) by vessel length, which were found to differ significantly using the Analysis of Variance (ANOVA) technique. Consequently, it is plausible that the marginal cost per trap, and perhaps the annual fixed cost, might also depend on vessel length. Re-specifying the cost functions in equations [4-1] and [4-2] to include a dummy variable, which distinguishes each vessel as “short” (20 to 35 feet) or “long” (35 to 55 feet), is a way to estimate differences in annual fixed costs due to vessel length. This method is desirable in this study since it preserves the degrees of freedom. In addition, if the dummy variable is multiplied by the number of traps, differences in marginal trap costs by vessel length can also be identified. Including both the intercept dummy and dummy-effort interaction variables, cost equation [4-1] is re-specified:

$$TC_i = \alpha + \beta E_i + \delta D_i + \gamma (D_i E_i) \qquad [4\text{-}12]$$

where $D = 0$ for short vessels and $D = 1$ for long vessels. The δ parameter will shift the intercept (i.e., annual fixed cost α). The γ parameter will shift the slope (i.e., marginal cost per trap β). In other words, the total cost equation for short vessels remains unchanged (equal to equation [4-1]), while the total cost equation for long vessels becomes $TC = (\alpha+\delta) + (\beta+\gamma)E$. Equation [4-2], which does not estimate a fixed cost component, is also re-specified:

$$TC_i = \beta E_i + \gamma (D_i E_i) \qquad [4\text{-}13]$$

Again, the total cost equation for short vessels remains unchanged (equal to [4-2]), while the total cost equation for long vessels becomes $TC = (\beta+\gamma)E$. The empirical results for

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[14] The labor cost calculation was not explained in sufficient detail to compare methods, however, the total crew costs equaled approximately 20 percent of the gross revenues and this cost was repeatedly referred to as a “share” (Prochaska and Landrum 1981; Keithly 1981, p. 106).

each model, using alternative assumptions regarding the labor cost, are presented in Table 4-10 for comparison with the "length-pooled" results of Table 4-9.

The inclusion of dummy variables to obtain separate estimates of fixed and variable costs by vessel length improved the overall explanatory power of each model. The variable cost models (equations 4-1 and 4-12), which estimate fixed and marginal costs, explained less of the variation in total annual costs than did the total cost models (equations 4-2 and 4-13), which estimate only marginal costs. This was also observed with the pooled models presented in Table 4-9.

Fixed annual costs differed significantly by vessel length. The annual fixed cost for short vessels (20-35 feet) was $10,319 without labor costs and $11,036 when labor was paid a minimum wage. These estimates are 21 to 26 percent below the pooled estimates (Table 4-9). The fixed cost estimate for short vessels paying an equal share to the crew was insignificant, most likely these vessels were owner-operated. Longer vessels, from 36 to 55 feet in length, incurred additional fixed expenses ranging from $32,907 (when labor costs were excluded) to $52,513 (when the crew was paid an equal share of revenues), both of which are significantly higher than the pooled estimates (approximately $13,000 and $15,000).

All marginal cost estimates for vessels in the short class (20-35 feet in length) were significant at the 1 percent level. The estimates, however, ranged from $16.90 (without labor) to $44.48 (when the crew was paid an equal share). This upper bound estimate was extremely robust to the model specification, dropping only $0.28 (less than 1 percent) per trap. For the longer vessels, ranging from 36 to 55 feet, only one estimated marginal cost was significant. The equal share model without an intercept estimated the marginal cost per trap for longer vessels to be $15.40 higher than the marginal cost for short vessels, or $59.98 per trap. On the other hand, the models with an intercept estimated that the marginal cost per trap for longer vessels was lower by approximately $10 to $13. But, these marginal cost adjustments were not statistically significant.

Overall the models indicate that when the crew was paid an equal share of revenues, the marginal cost per trap for short vessels was just over $44, which is approximately 18 to 20 percent below the pooled estimates of $53.34 and $55.54 presented in Table 4-9. Conversely, the $59.98 per trap marginal cost for long vessels was 7 percent greater than the corresponding pooled estimate of $55.54. If labor was paid the minimum wage, the pooled marginal cost estimate would overestimate the cost per

Table 4-10. Alternative Single-species Estimates of Fixed and Marginal Cost by Vessel Size

	Short-run Equation [4-12] $TC = \alpha + \beta E + \delta D + \gamma(D \cdot E)$			Long-run Equation [4-13] $TC = \beta E + \gamma(D \cdot E)$		
	Equal Share	Minimum Wage	No Labor	Equal Share	Minimum Wage	No Labor
Estimated Coefficients:						
Annual Fixed Cost, Short Vessels ($\hat{\alpha}$)	$\$\ 359$ (8,991)	$\$11{,}036^{*}$ (6,341)	$\$10{,}319^{**}$ (4,919)	NE	NE	NE
Marginal Cost per Trap, Short Vessels ($\hat{\beta}$)	$\$44.20^{***}$ (8.35)	$\$25.44^{***}$ (5.89)	$\$16.90^{***}$ (4.57)	$\$44.48^{***}$ (4.96)	$\$33.97^{***}$ (3.84)	$\$24.87^{***}$ (3.06)
Fixed Cost Adjustment, Long Vessels ($\hat{\delta}$)	$\$52{,}513^{***}$ (19,534)	$\$41{,}415^{***}$ (13,777)	$\$32{,}907^{***}$ (10,687)	NE	NE	NE
Marginal Cost Adjustment, Long Vessels ($\hat{\gamma}$)	$-\ \$13.14$ (12.94)	$-\ \$13.33$ (9.13)	$-\ \$\ 9.84$ (7.08)	$\$15.40^{***}$ (5.85)	$\$\ 6.73$ (4.53)	$\$\ 5.74$ (3.61)
Equation Statistics:						
R^2 Statistic	0.71	0.63	0.60	0.90	0.88	0.86

Notes: Parentheses contain the standard errors. NE indicates the parameter was not estimated. Single, double, and triple asterisks indicate significance at the 10, 5, and 1 percent levels, respectively. *D*=0 if vessel 20-35 feet (*n*=26), *D*=1 if vessel 36-55 feet (*n*=27).

trap for short vessels. In particular, the marginal cost fell from 12 to 14 percent per trap (depending on the model) when dummy variables were used to distinguish vessel length. A similar result was found if labor costs were excluded: the marginal cost estimate fell from 14 to 20 percent, depending on the model. Changes in the marginal cost for long vessels were not significant if labor was paid the minimum wage or if labor costs were excluded. In addition, the results were conflicting, one model predicted an increase while the other predicted a decrease in the marginal cost per trap for long vessels.

The significance of fixed and marginal cost estimates by vessel length in Table 4-10 suggests there are economies of scale in the commercial spiny lobster trap fishery. However, the inconsistent model results do not support the selection of a specific 'MEY-optimal size' for vessels in the fishery.

4.4.1.b. Tests for Cost Differences in the Lobster Fishery by Number of Traps Fished

To test for differences in fixed and marginal costs per trap by the number of traps fished, the dummy variable was redefined using the distribution of traps in Figure 4-1:

$D = 0$ if traps fished by a vessel ranged from 113 to 1,200,

$D = 1$ if traps fished by a vessel ranged from 1,354 to 2,570.

Twenty-four vessels fished 113 to 1,108 traps, five fished 1,200 traps, and the remaining 24 fished 1,354 to 2,570. Vessels fishing 1,200 traps were grouped with the vessels fishing fewer traps since 1,200 is (1) closer to 1,108 than to 1,354 and (2) closer to the mean of the group with fewer traps. The new dummy variable was used in equations [4-12] and [4-13]; results are presented in Table 4-11.

The estimated marginal cost per trap for vessels fishing fewer traps (from 113 to 1,200) ranged from approximately \$38 to \$67. These estimates were significantly higher than those estimated for "short" vessels (Table 4-10). In addition, the marginal costs for vessels fishing fewer than 1,200 traps were higher in the equations with fixed costs (opposite of the vessel length results), perhaps since these costs were the only significant parameter in each equation. The estimated marginal costs per trap for vessels fishing 1,354 to 2,570 traps were lower than the corresponding cost for vessels fishing fewer traps. However, these cost reductions were significant in only two of the six models. In the models that did not include fixed costs, the marginal cost per trap for vessels fishing relatively more traps was approximately \$27 without labor costs or \$36 if labor was paid the minimum wage. For comparison, vessels fishing fewer traps had costs of approximately \$40 and \$53 per trap (47 percent higher costs per trap), respectively.

Overall the models with dummy variables for the number of traps suggests some economies of scale in the fishery. But, these results do not provide a consistent basis to select an economically optimal size for a firm.

Table 4-11. Alternative Single-species Estimates of Fixed and Marginal Cost by Number of Traps Fished

	Short-run Equation [4-12] $TC = \alpha + \beta E + \delta D + \gamma(D \cdot E)$			Long-run Equation [4-13] $TC = \beta E + \gamma(D \cdot E)$		
	Equal Share	Minimum Wage	No Labor	Equal Share	Minimum Wage	No Labor
Estimated Coefficients:						
Annual Fixed Cost, 113 to 1,200 Traps ($\hat{\alpha}$)	- $ 5,245 (12,881)	- $ 190 (8,630)	$ 2,039 (6,885)	NE	NE	NE
Marginal Cost per Trap, 113 to 1,200 Traps ($\hat{\beta}$)	$67.00*** (15.75)	$53.47*** (10.55)	$38.05*** (8.42)	$61.21*** (6.65)	$53.26*** (4.46)	$40.30*** (3.58)
Fixed Cost Adjustment, 1,354 to 2,570 Traps ($\hat{\delta}$)	$12,870 (40,387)	$12,911 (27,056)	$15,802 (21,584)	NE	NE	NE
Marginal Cost Adjustment, 1,354 to 2,570 Traps ($\hat{\gamma}$)	- $16.50 (25.11)	- $24.13 (16.83)	- $20.44 (13.43)	- $ 6.87 (7.32)	- $17.50*** (4.91)	- $13.69*** (3.94)
Equations Statistics:						
R^2 Statistic	0.62	0.55	0.49	0.89	0.90	0.88

Notes: Parentheses contain the standard errors. NE indicates the parameter was not estimated. Single, double, and triple asterisks indicate significance at the 10, 5, and 1 percent levels, respectively. D=0 if 113-1,200 traps (n=29), D=1 if 1,354-2,570 traps (n=24).

4.4.1.c. Tests for Non-linear Marginal Costs in the Lobster Fishery

Given the inconsistent results regarding differences in fixed and marginal costs by size of operation – either vessel length or number of lobster traps fished – a nonlinear specification of the cost function was examined. By including a non-linear form of the effort variable, it is possible to directly evaluate the effects of scale on marginal costs. Specifically, cost equation [4-1] was respecified:

$$TC_i = \alpha + \beta E_i + \psi E_i^2 \qquad [4\text{-}14]$$

where ψ represents the change in marginal cost from an increase in the number of traps fished. The squared effort variable can also be added to cost equation [4-2] to obtain:

$$TC_i = \beta E_i + \psi E_i^2 \qquad [4\text{-}15]$$

The marginal cost, from either equation, is comprised of two components, a base value (β) and an adjustment that is proportional to the number of traps fished (2ψ):

$$MC_i = \beta + 2\psi E_i$$

Estimation results for equations [4-14] and [4-15] are summarized in Table 4-12. The explanatory power of the short-run models was relatively low, ranging from 47 to 62 percent, and none of the estimated fixed costs were significant. The base value of the marginal cost was significant in each specification, ranging from approximately $42 per trap if labor costs were zero, to nearly $77 per trap if the crew was paid an equal share of gross revenues. The marginal cost adjustment was only significant in a third of the models and only with the long-run specification. Using the long-run models with significant nonlinear terms (if labor was paid minimum wage or labor costs were zero) and assuming the vessel worked the average number of traps (E=1,279), the marginal cost per trap would be approximately $30 and $22 ($MC = \beta + 2\psi E$), respectively. These marginal costs are approximately 23 percent below the estimates derived from the linear models (Table 4-9). The relatively low cost figures estimated from equation [4-15] are the result of estimating a negative nonlinear term, which indicates substantial cost-savings from increased scale. This finding, in addition to the insignificance of a majority of the nonlinear terms and relatively large difference in magnitude of estimated marginal costs compared to the linear model, raises doubts about the validity of defining an optimal vessel size for this fishery.

4.4.2. Multiproduct Cost Function

If investment decisions by firms that participated in the spiny lobster fishery were influenced by revenues from other fisheries, fixed costs should be prorated to the individual fisheries. In other words, if the firm intended to cover fixed costs – vessel depreciation, interest payments, and docking fees – with revenues from multiple species,

Table 4-12. Alternative Estimates of Fixed and Marginal Cost using a Non-linear Specification of the Cost Function

	Short-run Equation [4-14] $TC = \alpha + \beta E + \psi E^{2}$			Long-run Equation [4-15] $TC = \beta E + \psi E^{2}$		
	Equal Share	Minimum Wage	No Labor	Equal Share	Minimum Wage	No Labor
Estimated Coefficients:						
Annual Fixed Cost, All Vessels ($\hat{\alpha}$)	- $ 7,217 (14,160)	$ 2,511 (9,810)	$ 3,306 (7,738)	NE	NE	NE
Marginal Cost per Trap, Base Value ($\hat{\beta}$)	$\$76.58^{***}$ (24.8)	$\$56.32^{***}$ (17.2)	$\$41.98^{***}$ (13.6)	$\$65.21^{***}$ (10.8)	$\$60.27^{***}$ (7.5)	$\$47.19^{***}$ (5.9)
Marginal Cost Adjustment, Adjustment per Trap ($2\hat{\psi}$)	- $ 0.009 (0.009)	- $ 0.010 (0.006)	- $ 0.008 (0.005)	- $ 0.005 (0.006)	- $\$0.012^{***}$ (0.004)	- $\$0.010^{***}$ (0.003)
Equation Statistics:						
R^{2} Statistic	0.62	0.52	0.47	0.89	0.89	0.88

Notes: Parentheses contain the standard errors. Asterisks indicate significance at the 1 percent level.

a single product cost function specification (such as those used in the prior sections) would be inappropriate. In such fisheries, a multiproduct cost function may more accurately represent the costs of vessel operation. To test whether these joint costs were a significant factor for vessels operating in the spiny lobster fishery, a multiproduct cost function was estimated. Because all vessels in the sample did not participate in all five of the defined fisheries (Table 4-1), the normalized quadratic function was selected as most appropriate (Lau 1978). The multiproduct cost specification for each *i* vessel is:

$$TC = \sum_j \lambda_j AVC_j + \frac{1}{2}\sum_j \sum_k \lambda_{j,k} AVC_j AVC_k + \phi_o T + \frac{1}{2}\phi_1 T^{\,2} \tag*{[4-16]}$$

$$+ \varphi_o K + \frac{1}{2}\varphi_1 K^{\,2} + \sum_j \omega_j AVC_j T + \sum_j \mu_j AVC_j K + \eta KT$$

where the subscript *i* is dropped for simplicity and:

j, k = spiny lobster, stone crab, or all other species (i.e., king mackerel, snapper/grouper, and other),

TC = total annual cost for vessel *i* paying labor cost *l*: $TC_l = K + \sum_j VC_{j,l}$

AVC_j = average annual variable cost (*VC*) per unit effort – traps (*E*) for lobster and crab and trips (X^T) for the 'all other' group – for vessel *i* fishing for species *j* (subscript *i* is dropped for simplicity):

$$AVC_{j=lobster,l} = (SUPPLIES_j + DEPR_j^{gear} + Z_{G=j} + Z_F + Z_L + LABOR_{j,l}) / E_j$$

$$AVC_{j=crab,l} = (SUPPLIES_j + DEPR_j^{gear} + Z_{G=j} + LABOR_{j,l}) / E_j$$

$$AVC_{j=all\,other,l} = (SUPPLIES_j + DEPR_j^{gear} + Z_{G=j} + LABOR_{j,l}) / X_j^T$$

T = sum of all trips for vessel *i*: $T_i = \sum_j X_{i,j}^T$

K = sum of all joint annual capital expenditures for vessel *i*:

$$K_i = DEPR_i^{vessel} + LOAN_i + DOCK_i + Z_{V,i}$$

The total annual cost per firm (*TC*) consists of four variables: joint capital (fixed) costs (*K*), and the sum of the variable costs associated with fishing for spiny lobster, stone crab, and all other species. The costs associated with participation in a specific fishery ($VC_{j,l}$), consist of both fixed and variable costs, where the definition of variable cost is specific to each fishery. For example, the annual variable cost in the lobster fishery includes trap depreciation. The annual variable cost is also defined by the units of effort. For example, lobster and stone crab effort are defined by the number of traps used while effort in other fisheries is measured by the number of fishing trips.

The amount of joint fixed costs, relative to the costs associated with a particular fishery, is important since we are interested in whether the joint costs affect the estimated unit costs for each fishery. To examine the relative size of the components of the total cost measure (*TC*), the proportion of total costs accounted for by each species group and the capital expenses are identified in Figure 4-3 by the method of labor payment.

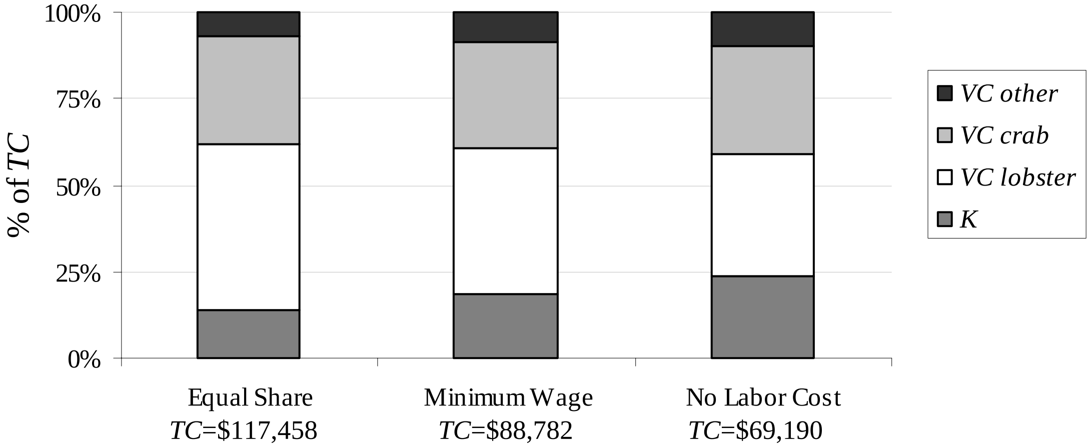

Figure 4-3. Allocation of Total Annual Cost by Method of Labor Payment

The portion of total costs accounted for by joint capital expenses (i.e., vessel depreciation, docking fees, and interest payments) depends on the method of labor payment. Given that joint capital expenses comprise a larger portion of total costs when labor payments are zero (24 versus 14 percent), the capital and capital interaction variables (variables with *K*) would be expected to have greater significance in a model with labor payments.

The estimated multiproduct expenditure model (equation 4-16) contains 20 explanatory variables. Ordinary least squares (OLS) regression results for the models with alternative labor costs are presented in Table 4-13.

Only the variable representing the squared average cost per trip for other species was significant in each model (i.e., independent of the method of labor payment). The model with zero labor payments had the highest R^2 and largest number of significant variables (12 of 20 or 60 percent). Also, all variables relating to joint capital costs (φ_o, φ_1, μ_j, and η) were significant. But, in the model with labor paid an equal share of gross revenues, only one of these six variables was significant, the capital-trips interaction (η). Similarly, when labor was paid the minimum wage, only the capital variable (φ_o) was significant. None of the estimated marginal costs per lobster trap (λ) were significant.

Table 4-13. Estimates of Multiproduct Cost Functions

Variable, Estimated Coefficient	Labor Cost Measure		
	Equal Share	Minimum Wage	No Cost
Intercept,	- 43,962	15,054	- 19,226
$\hat{\alpha}$	(64,096)	(49,923)	(37,045)
Cost per Spiny Lobster Trap,	- 56.3	- 3,476	- 3,328
$\hat{\lambda}_{j\ =\ spiny\ lobster}$	(2,478)	(2,703)	(2,688)
Cost per Stone Crab Trap,	$5,336^{**}$	1,186	1,252
$\hat{\lambda}_{j\ =\ stone\ crab}$	(2,267)	(1,334)	(1,309)
Cost per Trip for All Other Species,	27.6	31.8	3.37
$\hat{\lambda}_{j\ =\ all\ other}$	(41.2)	(22.1)	(15.8)
0.5*Cost per Spiny Lobster Trap Squared,	- 84.5	163.4	273.3^{**}
$\hat{\lambda}_{j\ =\ spiny\ lobster,\ t\ =\ spiny\ lobster}$	(71.7)	(99.2)	(126.9)
0.5*Cost per Stone Crab Trap Squared,	57.2	33.4	59.14
$\hat{\lambda}_{j\ =\ stone\ crab,\ t\ =\ stone\ crab}$	(73.8)	(42.9)	(60.0)
0.5*Cost per Trip for All Other Species Squared,	$- 0.0085^{**}$	$- 0.0088^{**}$	$- 0.012^{***}$
$\hat{\lambda}_{j\ =\ all\ other,\ t\ =\ all\ other}$	(0.0035)	(0.004)	(0.0043)
0.5*Lobster&Crab Trap Cost Interaction,	- 163.2	$- 190.4^{*}$	$- 369.5^{**}$
$\hat{\lambda}_{j\ =\ spiny\ lobster,\ t\ =\ stone\ crab}$	(109.2)	(104.7)	(151.1)
0.5*Lobster Trap & All Other Trip Cost Interaction,	- 0.332	$- 1.87^{*}$	- 1.36
$\hat{\lambda}_{j\ =\ spiny\ lobster,\ t\ =\ all\ other}$	(0.92)	(1.04)	(1.05)
0.5*Crab Trap & All Other Trip Cost Interaction,	$- 2.17^{*}$	- 0.635	$- 1.97^{**}$
$\hat{\lambda}_{j\ =\ stone\ crab,\ t\ =\ all\ other}$	(1.15)	(0.63)	(0.76)
Trips,	160.6	296.7	560.1^{**}
$\hat{\phi}_{o}$	(533.5)	(360.9)	(260.2)
0.5*Trips Squared,	- 1.78	- 0.097	- 2.84
$\hat{\phi}_{1}$	(2.96)	(2.41)	(1.72)
0.5*Joint Capital Squared,	0.00012	- 0.00005	$- 0.0001^{*}$
$\hat{\varphi}_{1}$	(0.0002)	(0.00007)	(0.00006)
Lobster Trap Cost & Trip Interaction,	35.2^{**}	2.49	3.96
$\hat{\omega}_{j\ =\ spiny\ lobster}$	(14.5)	(8.79)	(9.94)
Crab Trap Cost & Trip Interaction,	$- 21.5^{*}$	5.06	9.03
$\hat{\omega}_{j\ =\ stone\ crab}$	(12.04)	(9.51)	(8.98)

Table 4-13. continued

Variable, Estimated Coefficient	Labor Cost Measure		
	Equal Share	Minimum Wage	No Cost
Joint Capital,	3.52	4.71^{**}	5.52^{***}
$\hat{\varphi}_{o}$	(3.02)	(2.10)	(1.79)
Trip Cost for All Others & Trip Interaction,	0.132	0.093	0.186^{**}
$\hat{\omega}_{j=\text{all other}}$	(0.098)	(0.071)	(0.072)
Lobster Trap Cost & Joint Capital Interaction,	0.029	- 0.053	-0.109^{*}
$\hat{\mu}_{j=\text{spiny lobster}}$	(0.079)	(0.049)	(0.062)
Crab Trap Cost & Joint Capital Interaction,	0.076	0.071	0.133^{**}
$\hat{\mu}_{j=\text{stone crab}}$	(0.083)	(0.056)	(0.057)
Trip Cost for All Others & Joint Capital Interaction,	0.0016	0.0012	0.0018^{**}
$\hat{\mu}_{j=\text{all other}}$	(0.0009)	(0.0007)	(0.0007)
Joint Capital & Trips Interaction,	-0.036^{*}	- 0.009	-0.013^{**}
$\hat{\eta}$	(0.018)	(0.007)	(0.006)
R^2 Statistic	0.82	0.85	0.86

Note: Parentheses contain standard errors. Single, double, and triple asterisks indicate significance at the 10, 5, and 1 percent levels, respectively.

The inconsistent results across similar variables in Table 13 suggests that there is no clear statistical relationship between joint capital costs and the costs of operating in the spiny lobster fishery. While firms may make decisions about the total number of traps in each fishery with the intent of contributing to joint costs, the model results for this sample do not provide clear evidence of an appropriate correction to the costs of operating in the spiny lobster fishery.

4.5. Conclusions about the Estimated Marginal Costs for Bioeconomic Modeling

The empirical results presented in this chapter demonstrate that the estimated marginal cost per trap in the spiny lobster fishery was significantly effected by the method of labor payment. The results in Table 4-9 showed that the marginal costs per trap varied in the range of $21.04 to $53.34 in the models where fixed costs were independent of the number of traps fished (equation 4-1). The range was $29 to $55.54 when fixed costs varied with trap numbers (equation 4-2). In both cost models, the assumption that labor costs were zero resulted in the lowest marginal cost estimates while the equal share labor cost assumption resulted in the highest marginal cost estimates. Also, the models with zero labor costs had lower explanatory power. While the zero labor cost estimates are clearly implausible (since the true opportunity cost of labor in the fishery cannot be zero), the lowest cost figures from both models can be considered lower bounds on any realistic estimate of marginal costs of effort for the industry.

The various models estimated to identify economies of scale effects in the fishery (Tables 4-10 to 4-12) suggested that firms employing larger vessels and/or more traps had lower costs per trap. Based on these estimates, firms fishing the largest number of traps had marginal costs per trap that were about half the costs per trap of the smallest operations. These results, however, were not consistent across the different models and the overall improvement in the explanatory power of the models with scale adjustments was not large.

Similarly, the multiproduct cost model (Table 4-13) indicated that joint capital costs may influence the marginal costs of effort in the spiny lobster fishery. But, the results for different specifications of labor payments provided inconclusive results. There is no justifiable basis for adjusting the marginal cost estimates derived from the single- product cost specifications.

In summary, alternative cost specifications that assumed the marginal cost per trap increased with either vessel length, the number of traps fished per vessel, or the number of traps in the fishery, did not perform well enough statistically to warrant further consideration. Therefore, to reflect the range of uncertainty in the estimated costs in the spiny lobster fishery and to maintain some consistency with previous bioeconomic models of the fishery, we utilize the results from equations [4-1] and [4-2] (Table 4-9) in the subsequent combined analysis of MEY-optimal effort in the fishery. Since we are interested primarily in total effort in the fishery (e.g., the economically optimal number of traps), we do not consider how many vessels would operate in an MEY managed fishery. While the model results indicate some cost differences across vessels, the range of estimated marginal costs from equations [4-1] and [4-2] is insufficient to capture the optimal configurations of both the number of vessels and their scale of operations in the fishery.

5. INTEGRATED BIOECONOMIC MODELS

The Florida Sea Grant College Program sponsored several pioneering bioeconomic studies in the late 1970s and early 1980s that indicated the Florida spiny lobster fishery exhibited the classic consequences of an open-access fishery. Williams (1976), Williams and Prochaska (1977), and Prochaska and Cato (1980) showed that the commercial fishery was over-capitalized with declining catch per unit effort (landings per trap). Prochaska and Cato (1980) used 1963-73 landings and 1973 costs to estimate that 169,335 traps would maximize economic yield (MEY) in the fishery. Using updated landings and cost data for the 1978-79 season, Keithly (1981) estimated MEY at 185,535 traps. For comparison, 185,535 traps would have been 67 percent below the number of traps reported during the 1978-79 season (Appendix B, Table B-1). Six years later, Waters (1987) estimated that 300,545 traps, which was 68 percent below the number of traps reported in the 1987-88 season, would be efficient.

The previous studies were limited in the amount of data available for estimating an industry production function since the commercial trap and vessel industry did not essentially begin until 1960 (Labisky, Gregory, and Conti 1980); the lack of a "large" sample size resulted in relatively weak statistical results. For example, the Kiethly (1981) and Waters' (1987) studies fixed the "optimal" number of traps per vessel at the average observed from a 1978-79 survey rather than deriving the MEY-optimal number of traps from a cost function. Also, several studies utilized the average cost per trap (frequently by vessel length) as a proxy for marginal costs. It is unlikely, however, that the average and marginal costs were equal (see, for example, Table 4-9 in this study). Recall from Chapter 3 that the marginal cost, which is needed to determine the MEY solution, represents the change in total industry costs from adding an additional trap to the fishery. Prochaska and Cato (1980) did estimate a short-run marginal cost per trap using 1973 cost data; however, the total cost estimate excluded labor expenses and other issues (such as long-run costs or costs that may differ by vessel size) were not considered.

In this analysis we use the "best" biological production functions (estimated from the most recent 36-year data in Chapter 3) with alternative marginal cost estimates (from 1996-97 survey data in Chapter 4) to identify a range of bioeconomic MEY optimums. The resulting range of efficient landings and total trap number combinations are compared to predictions from the early studies. In addition, dynamic optimums are derived assuming various interest rates. The final section contains comparisons of our MEY solutions with reported landings, trap numbers, and trap certificate prices for the 1997-98 season.

5.1. Static MEY and OAE Optimums

As discussed in Chapter 2, the static MEY solution is found by equating the marginal revenue and marginal cost functions. The marginal revenue function for the Florida spiny lobster fishery can be derived by multiplying the estimated marginal productivity per trap at each (total) effort level by the average price per pound observed in 1996 ($3.79, FDEP). Recall from Chapter 3 that the marginal productivity represents the change in total industry catch from adding an additional trap to the fishery (while all other inputs are held constant); it is the slope of the biological production function at each total effort level. Figure 5-1 shows the marginal revenue functions for the CY&P and BU models, the production models with the most statistical explanatory power (see Section 3.5). Note that all the functions estimate a near zero or negative marginal revenue at effort levels greater than approximately 400,000 traps. At effort levels of 400,000 traps or less, the CY&P model predicts higher marginal revenues. In other words, as traps are reduced below 400,000, the BU model predicts a more conservative increase in total industry revenues.

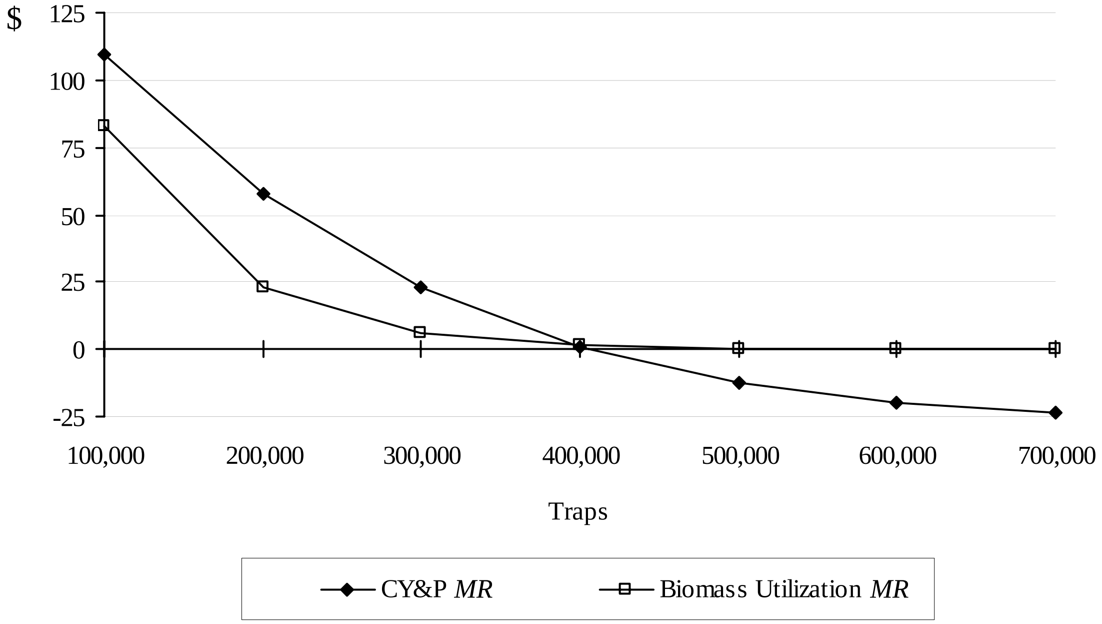

Figure 5-1. Marginal Revenue Functions Estimated for the Florida Spiny Lobster Fishery

The profit-maximizing (MEY) solutions can be identified by adding marginal cost functions to Figure 5-1. In Chapter 4, we estimated several marginal cost functions and found that the marginal cost per trap was highly sensitive to the model specification and labor expenses. In this chapter, we use both the short- and long-run marginal costs derived with the assumption that the crew is paid either the national minimum wage or a share of total revenues. In addition, the marginal cost – that is, the additional cost incurred by the industry from the addition of another trap – is assumed to be independent of the total number of traps in the fishery. The constant marginal costs estimated from such a specification (Table 4-8) were the most accurate given the cost data collected for 1996 (see Section 4.5 for further discussion). Figures 5-2 and 5-3 identify the lowest and highest profit-maximizing number of traps in the fishery assuming the captain and crew are paid an equal share of gross revenues or the captain (if different from the owner) and crew are paid the national minimum wage, respectively.

If crew members are paid an equal share, the economically optimal number of traps would range from approximately 131,000 to 211,000 (Figure 5-2).[15] This range is largely independent of the time horizon since the short- and long-run marginal cost estimates differed by just $2.20 (4 percent). Alternatively, if the captain and crew members are paid the national minimum hourly wage, which amounts to a smaller labor payment, the estimated marginal costs fall. The lower marginal cost estimates increase the MEY-optimal number of traps and widen the range since the marginal revenue curves are flatter at higher trap numbers. The MEY solutions, using the estimated short- and long-run marginal costs when labor is assumed paid the minimum wage, would range from approximately 159,000 to 278,000 traps (Figure 5-3).

The optimums identified in Figures 5-2 and 5-3 encompass differences in the specification of the production and cost functions (i.e., uncertainty as to the "correct" specifications). The sensitivity of the solutions to the assumed market price, however, is also important. An increase in the average lobster price would shift the marginal revenue functions upwards and increase the economically optimal number of traps (E^*_{low} and E^*_{high}). For example, if dockside lobster price was assumed to equal $5 per pound instead of $3.79, then MEY-optimal trap numbers would range from approximately 180,000 to 321,000 if labor is paid minimum wage, an increase of 10 to 14 percent.

Total trap numbers, landings, and profits for the range of MEY-optimal solutions when labor is paid the national minimum wage (corresponding to the MEY solutions in

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[15] For simplicity, optimal trap numbers are determined through iteration (i.e., setting marginal revenue equal to marginal cost and solving for *E*). The degree of precision obtained from this approximation procedure is considered acceptable for this study.

Figure 5-3) are presented in Table 5-1.[16] Total profits (π) range from $13.7 million to $15.4 million. Profits per trap/certificate would range from $52 to $90. Total landings and traps are higher with the CY&P production model (by approximately 23 percent and 55 percent, respectively), however, landings per trap and profits per trap are highest with the BU specification (on average, by 25 percent and 50 percent, respectively).

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[16] These profit calculations are based solely on the estimated marginal costs per trap. Since the cost estimates do not include an opportunity cost for capital invested in the firm, these profits should be interpreted as “accounting profits” rather than “economic profits” (Anderson 1996).

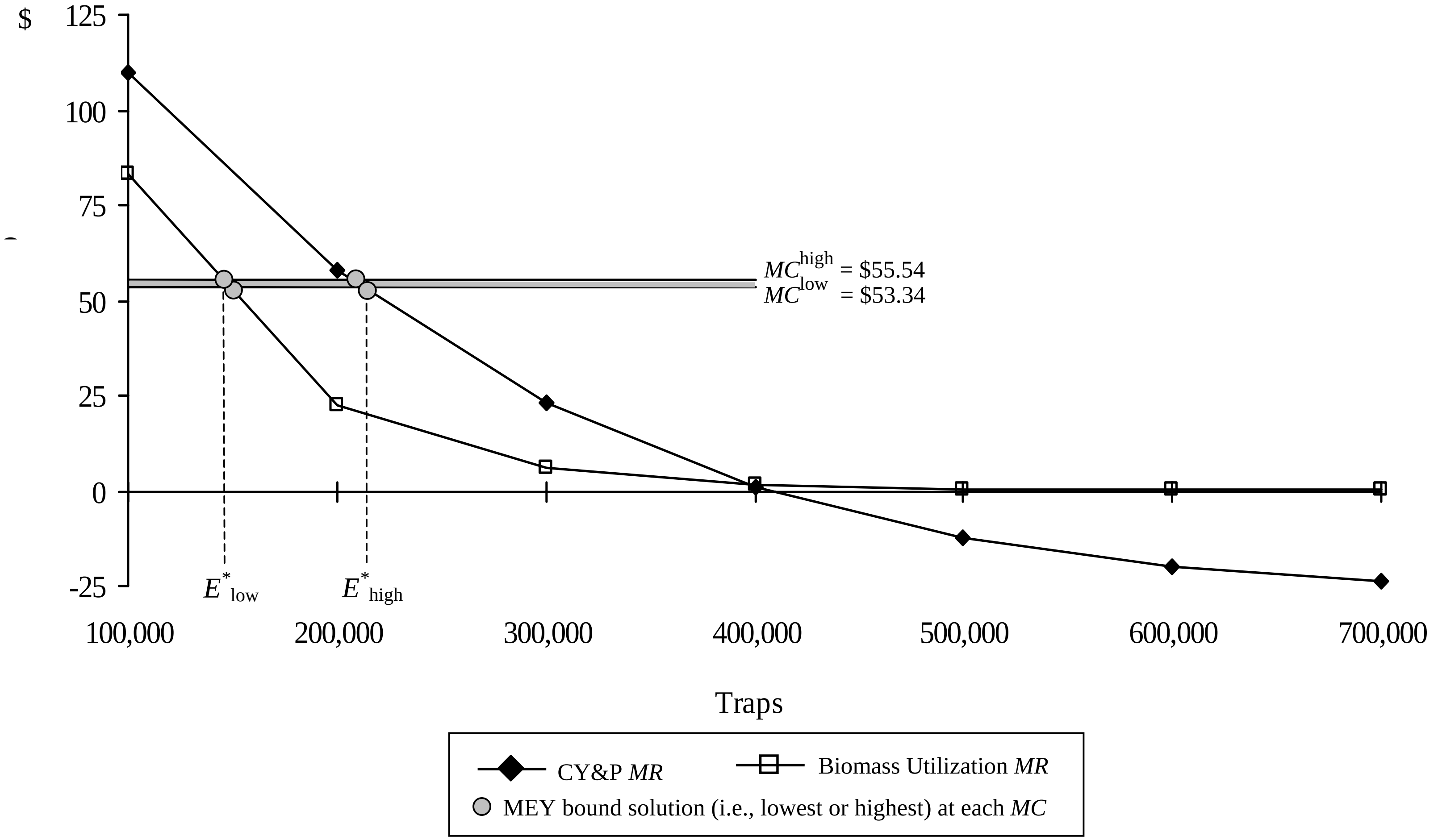

Figure 5-2. Range of Bioeconomic Optimal MEY Solutions if Crew is Paid an Equal Share of Total Revenue

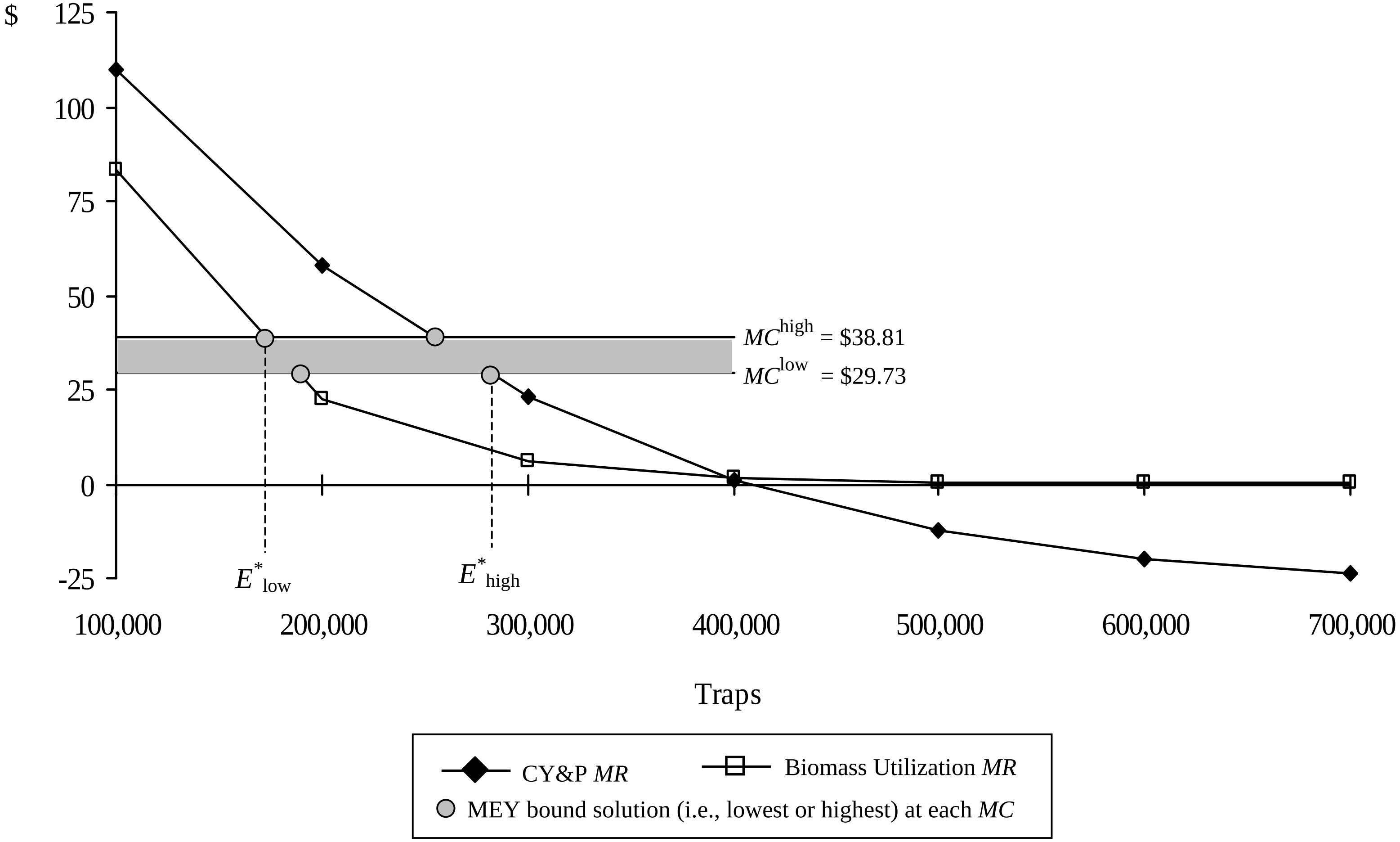

Figure 5-3. Range of Bioeconomic Optimal MEY Solutions if Labor is Paid the Minimum Wage

Table 5-1. Range of Maximum Economic Yield (MEY) Solutions when Labor is Paid the Minimum Wage

	Total Revenue Specifications (p = \$3.79)	
Minimum Wage Cost Specification	Biomass Utilization $p[6{,}180{,}830(1-e^{-0.000013E})]$	CY&P (4d) $p[42.03Ee^{-0.00000246E}]$
TC = \$14,901[a] + 29.73E		
Effort (E^*)	179,159 traps	278,008 traps
Catch (C^*)	5,576,306 pounds (31 pounds per trap)	6,883,634 pounds (25 pounds per trap)
Profit (π^*)	\$13,720,529 (\$76.58 per trap)	\$14,584,861 (\$52.46 per trap)
TC = \$38.81E		
Effort (E^*)	158,619 traps	249,876 traps
Catch (C^*)	5,391,621 pounds (34 pounds per trap)	6,629,936 pounds (27 pounds per trap)
Profit (π^*)	\$14,278,428 (\$90.02 per trap)	\$15,429,771 (\$61.75 per trap)

[a] Assuming each vessel owned 1,279 traps (the sample average) in order to calculate total fixed costs.

For comparison with the MEY solutions, predicted open-access equilibrium (OAE) catch and effort levels (which assume industry profits are zero) are presented in Table 5-2.[17] Assuming labor is paid the minimum wage, the OAE equilibriums ranged from approximately 566,000 to 637,000 traps (two to four times the corresponding MEY level) depending on the biological and cost function specifications. The long-run specifications predicted higher OAE effort levels of four to six percent. The CY&P model predicts a narrower range of OAE equilibrium (from approximately 611,000 to 637,000 traps/certificates). This range more closely matches the number of certificates initially allocated under the trap certificate program (approximately 724,000 certificates were allocated in 1992) (Milon et al. 1998). Average CPUE (landings per trap) were very similar between models at 10 to 11 pounds, which is very near observed catch rates (Milon et al. 1998).

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[17] Assuming industry profits are zero does not rule out the possibility that an individual firm may earn positive inframarginal ("highliner") rents due to lower average costs (Anderson 1986).

Table 5-2. Range of Open Access Equilibrium (OAE) Solutions when Labor is Paid Minimum Wage

Minimum Wage Cost Specification	Total Revenue Specifications (p = \$3.79)	
	Biomass Utilization $p[6,180,830(1-e^{-0.000013E})]$	CY&P $p[49.03E \cdot e^{-0.00000246E}]$
TC = \$14,901[a] + 29.73E		
Effort (E^*)	565,729 traps	611,200 traps
Catch (C^*)	6,176,821 pounds (11 pounds per trap)	6,673,252 pounds (11 pounds per trap)
TC = \$38.81E		
Effort (E^*)	603,350 traps	637,296 traps
Catch (C^*)	6,178,370 pounds (10 pounds per trap)	6,525,983 pounds (10 pounds per trap)

[a] Assuming each vessel owned 1,279 traps, the average observed in 1996. This assumption is necessary to calculate the total fixed costs in the industry.

5.2. Dynamic MEY Optimums

The static optimums of the previous section assumed a discount rate of zero (δ = 0). As shown in Chapter 2, inclusion of a positive discount rate will affect the optimal MEY solution (catch and effort levels) and the predicted profits. To analyze the effect on the commercial spiny lobster fishery in Florida, the static solutions were compared to solutions derived assuming discount rates between three and ten percent. The marginal cost of \$38.81 per trap was used since it includes the most conservative (i.e., lowest) estimate of labor expenses and it assumes all inputs are variable, which is the most appropriate assumption for a long-run analysis. Specifically, the discounted MEY solutions were found using equation [2-3] and solving for the corresponding optimal effort by iteration when $\Delta E = 1$ (i.e, an assumed increase of one trap). Once the optimal effort level was determined the corresponding catch level was found using the catch-effort equations from Chapter 3 (Table 3-4). These MEY solutions for the BU and CY&P models – including the discount rate, catch, effort, CPUE, and profits – are summarized in Table 5-3.

Table 5-3. Optimal Long-run MEY Solutions at Alternative Discount Rates when Labor is Paid the Minimum Wage

Production Model	Discount Rate δ	Catch (pounds) C^*	Effort (traps) E^*	CPUE (lbs/trap) U^*	Profit ($000) Π^*
Biomass Utilization	0.00	5,390,646	158,519	34.0	$14,278
	0.03	5,444,759	163,986	33.2	14,271
	0.07	5,510,100	171,150	32.2	14,241
	0.10	5,555,279	176,524	31.5	14,204
CY&P	0.00	6,629,936	249,876	26.5	$15,430
	0.03	6,683,684	255,204	26.2	15,427
	0.07	6,749,597	262,147	25.7	15,349
	0.10	6,795,205	267,277	25.4	15,381

The results in Table 5-3 show that the annual landings per trap and profits fall (despite increases in total landings) as total trap numbers increase in response to higher discount rates. The static MEY solution with $\delta = 0$ produces the most conservative (lowest) optimal landings and trap levels. At a 10 percent discount rate, the BU production model predicts an 11 percent increase in the economically optimal number of traps and a corresponding 3 percent increase in total catch. The increased trap numbers result, however, in a 7 percent reduction in the annual catch per trap. Overall, increasing the discount rate from zero to 10 percent in the BU specification reduces annual profits by less than one percent. The CY&P production model produced similar, although more conservative, responses from an increased discount rate. These results indicate that the MEY solutions were relatively robust to the choice of a reasonable discount rate. Note also that even with a 10 percent discount rate, trap numbers remain well below the corresponding OAE level for each model presented in Table 5-2.

5.3. Estimated Optimal Certificate Prices using the MEY Solution

Total profits estimated from each MEY solution, such as presented in Tables 5-1 and 5-3, can be used to estimate the economically optimal price for each certificate under the assumption that the price of a certificate should equal the sum of profits derived from its use. This price is the profit per trap attainable over some time period when the total number of traps in the fishery are at the MEY optimum (e.g., from approximately 159,000 to 278,000 traps if the discount rate is zero and labor is paid the minimum wage). Using the more conservative BU results from Table 5-3, the optimal certificate price for a one-year time period would range from approximately $80 to $90 (assuming 10 percent and zero percent discount rates, respectively). The economically optimal certificate price for the CY&P model would be lower, despite the higher catch and effort predictions, ranging from $57 to $61 depending on the discount rate.

Using the BU model and assuming various discount rates and various time horizons, the expected certificate prices with the MEY-optimal number of traps in the fishery are derived using equation [2-3] and compared in Table 5-4.[18] At higher discount rates, MEY effort levels increase (Table 5-3) and – since catch does not increase proportionately (Figure 3-7) – average catch rates decline. Higher total effort and lower catch rates result in lower average profits per trap. As shown in Table 5-4, the average profit per trap for a single season declines 11 percent (from $90 to $80) if total rents are discounted 10 percent. This percentage decline increases when the time horizon is extended to include multiple years. For example, with a 15-year time horizon, the undiscounted profit per trap would equal $1,351. At a 10 percent discount rate, the average profit per trap declines 55 percent to $612. In summary, estimated certificate prices increase with increases in the time horizon. But, higher discount rates reduce the expected profit per trap and this reduction is magnified with longer time horizons.

Table 5-4. Estimated Certificate Prices with MEY-Optimal Effort and Alternative Time Horizons and Discount Rates with the Biomass Utilization (BU) Model

	Time Horizon			
Discount Rate	1 Year	5 Years	10 Years	15 Years
0 Percent	$90	$450	$901	$1,351
3 Percent	87	398	742	1,039
7 Percent	83	341	584	758
10 Percent	80	305	494	612

The estimated profits per trap presented in Table 5-4 were based on a marginal cost estimate that assumed crew members and the captain, if different than the owner, were paid the national minimum wage per hour. If the paid wage was higher, or labor payments equaled the opportunity costs of labor, the estimated profits per trap would overestimate actual profits. Average trap profits would also be overestimated if the crew members were paid an equal share of gross revenues since labor costs would be higher (Table 4-6).

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[18] Equation [2-3] is used to solve for a new equilibrium level of effort assuming $\Delta E=1$. The new profit per trap is then used to calculate discounted profits into the future. The estimated future profit per trap (assuming a 15-year time horizon and 10 percent discount rate) from this simple approximation method differed little from the actual values derived using the underlying equations, so results from equation [2-3] are presented.

6. SUMMARY AND CONCLUSIONS

6.1. Summary of Project and Major Findings

This research project was designed to determine the economically efficient (optimal) level of effort in the commercial spiny lobster fishery in Florida. This goal was accomplished through completion of the following four objectives, to:

1. determine the appropriate methodology to find the optimal effort level;
2. develop and estimate alternative biological production models;
3. collect new cost data to estimate alternative cost functions and test for economies of scale; and
4. integrate the production and cost models into a bioeconomic framework to identify the optimal effort in the fishery.

Optimal effort in the Florida commercial spiny lobster fishery was defined as the total number of traps that would maximize total rents (total revenue less total opportunity costs, assuming no externalities) to the industry. This maximum economic yield (MEY) solution was defined for both static and dynamic frameworks. MEY levels of landings and trap numbers were estimated using a biological production function (which predicted trap yields at each level of total effort) and an economic production function (which predicted production costs at each level of firm effort). The biological and economic functions were integrated into a single profit-maximizing bioeconomic industry model. MEY landings and effort levels were identified by equating the marginal revenue per trap (from the biological production function and assumed market price) with its marginal cost (from the estimated economic cost function).

Using the surplus production model approach, which is appropriate for fisheries with a weak stock-recruit relationship, a biological production function (sustainable yield curve) can be estimated with historical data on aggregate catch and effort. In this study, reported landings were assumed an adequate proxy for catch since undersized lobsters (shorts) can escape from traps due to regulations that govern trap design. Reported total trap numbers were used to represent effort for a number of reasons. First, the number of traps used annually is the only effort variable that has been collected over time. Second, total trap numbers have been used in previous studies of the fishery. Third, total trap numbers are controlled directly under the Trap Certificate Program (TCP). Finally, intraseason differences in effort (due to changes in the numbers of boats, trips, trap pulls, etc.) are implicitly incorporated into new models using an endogenous catchability coefficient.

Several alternative biological production functions were estimated – using a corrected data series that accounted for fishing activity in Bahamian waters from 1964-75 – due to the uncertainty regarding cyclical dynamics of the species and the use of alternative model specifications in previous studies of the Florida lobster fishery. The models differed greatly in their explanatory power and predicted landings per trap function (i.e., the marginal productivity at each total effort level). Two of these models were chosen for inclusion in a bioeconomic model, an integrated Gompertz specification referred to as the CY&P model and the BU model. The BU model predicts that total landings continue to increase with higher trap numbers, while the CY&P model predicts that total landings will eventually fall. Neither model predicted significant marginal benefits from increasing the number of traps in the fishery above approximately 400,000 (Figures 3-8 and 5-1).[19]

Cost functions were used to estimate the marginal cost per trap with data obtained from a survey of commercial fishermen operating in the Florida Keys (Tables 4-1 through 4-7). Each vessel fished from 113 to 2,570 lobster traps during the 1996-97 season and the majority also fished for stone crab, king mackerel, and snapper/grouper. Information was collected on total annual fixed costs (interest payments, depreciation, docking fees), annual miscellaneous expenses (maintenance, repair, certificate tag and leasing fees), and variable trip expenses (bait, fuel, oil, ice, food, supplies, etc.). Other useful information included the vessel length, total landings by species, total number of trips targeting each species, and characteristics of the typical trip (including the number of crew and duration).

Several alternative cost functions were estimated to determine the effect of fixed costs, participation in multiple fisheries, labor cost calculation, and whether economies of scale exist (i.e., if costs are dependent on firm size). In general, the marginal cost estimates differed most by the labor cost calculation. Fixed costs also differed, however, these costs were insignificant in several of the specifications. In summary, some economies of scale were found – based on vessel length and the number of traps fished – but the inconsistency of results did not provide sufficient support for using different costs by vessel size in this analysis. The constant marginal cost estimates ranged from \$21.04 to \$55.54 per trap depending on the labor payment method (Table 4-9). The bioeconomic analyses used the marginal cost estimates derived under the assumption that labor (crew and captain, if different than the owner) were paid minimum wage (\$5.15 per hour). These estimates were \$29.73 and \$38.81 per trap in the short- and long-run, respectively. These marginal costs, which include the most conservative measure of labor costs, provide a lower bound estimate of opportunity costs of participating in the fishery.

The bioeconomic analysis integrated the CY&P and BU marginal revenue functions with the minimum wage marginal cost estimates (short- and long-run) to

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[19] Appendix C contains results from estimating the Schaefer, Fox, Schnute, CY&P, and Threshold models with the nominal data, a dummy variable to distinguish seasons that include fishing activity in the Bahamas, and using the corrected landings with the nominal traps. Each model was robust with respect to the data series used, therefore, the main text included only those results from using the corrected data.

identify a range of MEY solutions (i.e., number of traps that would maximize industry rents). The resulting optimal number of traps ranged from approximately 159,000 to 278,000 (Table 5-1).[20] Corresponding catch levels ranged from approximately 5.4 million pounds to 6.9 million pounds annually, which is within the range of observed landings since 1975 (Appendix B). At the low end of this range, 159,000 traps is 6 percent below the optimal number estimated by Prochaska and Cato (1980). At the high end of the range, 278,000 traps is approximately 7 percent below the optimal number estimated by Waters (1987).[21] The estimates by Prochaska and Cato (1980) and Waters (1987) imply average annual landings per trap would equal 34 and 22 pounds, respectively. For comparison, our lower and upper bound estimates predict annual average landings per trap would be 34 and 25 pounds, respectively. The similarity of the updated predictions with earlier predictions and with the actual data is somewhat surprising given the use of additional data points. Also, reported average annual landings per trap from survey data in 1972 for Florida's West Coast totaled 32 pounds (with approximately 147,000 traps in the fishery) (Williams and Prochaska 1976). This similarity indicates the stability of the basic catch relationship over time and suggests that the bioeconomic model predictions are not unrealistic.

Although it is tempting to compare the optimal MEY profits per trap (Table 5-4) with the average transfer prices reported to the FDEP under the TCP, a direct comparison is cautioned. This is because the profit per trap calculated from the bioeconomic solution is based on the optimal (i.e., lower) total number of traps in the fishery. For example, economically optimal trap numbers ranged from 158,519 to 176,524 with the BU model (Table 5-3). The corresponding annual profit per trap ranged from $80 to $90 (Table 5-4). The estimated profits, and the related certificate prices, would vary directly with the time horizon used for the analysis.

For comparison, a total of 604,920 certificates (approximately three times the optimum number of traps from this particular bioeconomic model) were available in the 1996-97 season (Milon et al. 1998). Since the total number of traps in the fishery was close to the predicted open-access equilibrium (OAE) solution of 603,352 (Table 5-2), we would not expect the observed certificate prices – which averaged $4.47 to $15.52 depending on the certificate type and calculation method during the 1996-97 season (Milon et al. 1998) – to reflect potential future profits. This is because industry profits are zero in a competitive market (Chapter 2, Section 2.2). Using the 1998-99 trap level of approximately 544,000 (Milon et al. 1998), the undiscounted annual profit per trap (assuming crew are paid minimum wage) from the BU model would equal $13.30 (from

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[20] When future profits were discounted to determine the long-run MEY solution, the optimal number of traps increased. With a 10 percent discount rate, the economically optimal number of traps increased 11 percent and 7 percent at the low and high ends of the range, respectively.

[21] The estimate by Waters (1987) was derived by multiplying the optimal number of firms, from a statistically insignificant Scheafer model, by the average number of traps reported in a 1978 survey. Since the cost estimate(s) used by Waters (1987) excluded labor payments, the 303,545 trap optimum may have been biased upwards.

average trap yield of 11.4 pounds), which falls within the range of reported average transfer prices to date (Milon et al. 1998).

6.2. Use of Results for Policy Analysis

Since the TCP was initiated in 1992, the number of certificates in the fishery has been reduced from 825,179 (original allocation plus appeals awards) to 544,062 in 1998-99 (Milon et al. 1998). Despite the effectiveness of the program in reducing trap numbers to date, this analysis indicates that further reductions would be necessary to achieve an economically efficient level of effort in the fishery.

Future reductions in allowable traps in the spiny lobster fishery toward a long-run MEY solution could have the following effects:

1. **Increase economic profits per trap and the value of certificates.** Additional certificate reductions to an economically optimal number could increase the annual profits per trap to between \$80 and \$90 per year (Table 5-4). Expected trap certificate prices would increase significantly depending on the time horizon and discount rate considered in the pricing decision.
2. **Reduce the total number of vessels in the fishery.** Using the average number of traps per vessel reported in the sample (1,279 per vessel), the economically optimal fleet size would range from 124 to 217 depending on the model. If economies of scale exist and the efficient number of traps per vessel is above 1,279, then the fleet size at MEY would be smaller (and vice versa). For comparison, during the 1996-97 season the 500 largest firms held nearly 95 percent of total certificates and averaged 1,148 traps per vessel (Milon et al. 1998).
3. **Increase concentration of certificate ownership.** The TCP contains restrictions that limit individual ownership to 1.5 percent of the total number of certificates available (Florida Statute 370.142(2)a,2). Under the most conservative aggregate MEY effort level (158,519 traps), this restriction would prohibit any one individual to hold more than 2,378 certificates.
4. **Reduce some individual certificate holdings.** The upper bound on certificate holdings under the undiscounted BU MEY solution (2,378) is less than the maximum number currently held by some individuals. In 1998-99, the maximum held by any one individual increased to 5,631 certificates (Milon et al. 1998).
5. **Reduce revenues collected by the State.** Fewer certificates translate to lower revenues from the annual certificate fee. In addition, if certificate reductions cause fishers to exit the industry, annual licensing/endorsement fees could decline. Revenues from certificate transfers (presently collected on all transfers including a one-time surcharge on first transfers) would be expected to fall.
6. **Reduce administrative costs.** Since administrative costs (such as postage and handling fees) are proportional to the number of certificate holders, reducing the

number of certificate holders would reduce total costs. If cost reductions were realized, they could be passed along to certificate holders in the form of lower annual certificate fees.

7. **Change enforcement duties and costs.** If enforcement costs (such as verifying certificate ownership) are proportional to the number of certificate holders, reducing the number of certificate holders could reduce costs. Unlike administrative cost reductions, however, if enforcement expenses were reduced they would likely not be passed on to certificate holders since industry members currently do not directly pay for enforcement. On the other hand, the significant increase in CPUE predicted from the bioeconomic models could result in poaching and illegal harvesting effort. Efforts to control these activities may increase overall enforcement costs.
8. **Allow the State to collect (and redistribute if desired) a resource rent.** If certificate reductions to the MEY solution allowed the annual profits to reach $80 per certificate (assuming a 10 percent discount rate), the state could justify the collection of an annual rent as stipulated in the TCP legislation. Any determination of an actual rent per trap should be based on a careful analysis of actual revenues (landings) and costs that would result from a reduced number of certificates.

The potential effects of reducing the number of certificates (traps) to the economically optimal level depends on a number of exogenous factors. The optimal solution may not be realized if policymakers do not consider all aspects of the fishery. Some of these factors, which can undermine the management of the spiny lobster fishery in Florida and the effectiveness of the TCP, are discussed in the following section.

6.3. Future Management of the Fishery

The companion report to this study, “The Performance of Florida’s Spiny Lobster Trap Certificate Program” (Milon et al. 1998), contained several suggestions for improving the effectiveness of the TCP. Although some of the following discussion will overlap the suggestions in the prior report, this section identifies other factors that need to be addressed in order to effectively manage the fishery and summarizes the limitations of the bioeconomic analysis.

This report proposes several estimates of the total number of traps that would maximize returns to the industry. Each of these estimates provides a target for the number of traps in the commercial fishery. Regardless of which target is chosen, the selection of target will reduce uncertainty among fishers and accelerate the determination of an equilibrium certificate transfer price.

The MEY solutions assume a constant market price and ex-vessel demand for spiny lobsters in the long-run. Although Florida's supply is currently relatively small compared to the national market, this may not be the case in the future. For example, import restrictions or demand competition (when the Asian economy improves) could limit foreign supply and increase the market price. As discussed in the text, a price increase would indicate higher levels of effort in the fishery would be economically efficient.

To facilitate the performance of the TCP, Milon et al. (1998) suggested that transfer price information should be published at regular intervals. The objective of increasing the availability of this information was to help certificate buyers and sellers determine appropriate sales prices and for resource managers to determine whether appropriate surcharges and transfer fees were being paid. In addition, an equilibrium market price could help determine an applicable rental fee. As an alternative to allowing the participants to establish the market price over time, the National Research Council has recently suggested the use of auctions (1999). The advantages of an auction in this fishery include the ability to raise revenue to cover administrative expenses or to fund the additional buyout of certificates. The disadvantages include the possibility of artificial price inflation (especially if other fishery participants were allowed to bid) and the undermining effect it would have on the need to reduce certificate numbers (i.e., if auctioning part or all of the 10 percent reduction). The FDEP could offer to auction abandoned certificates and certificates that have been volunteered for auction. The advantage of auctioning the latter is that certificates held by several smaller holders could be bundled (this is another means to self-finance a buyout program). The managers of this fishery would have to weigh the benefits of an auction (quick determination of market price, ability to set appropriate fees, ability to bundle small allotments, etc.) against the costs such as administrative expenses, possible slow-down of reductions, and possible downward pressure on price if used to determine fees.

The challenge of determining a rental charge is far more difficult than theory suggests. A potentially simpler and more 'equitable' alternative would be to require all participants (including the recreational sector) to pay a research/management cost recovery fee (based on number of traps or other 'equitable' criteria) that covers not only the cost of the TCP program but all related research and management costs. Requiring such payments forces all the policy players to face the question of whether the fishery and the supporting management system generate positive social benefits. Such a fee structure would compel industry, managers, and policymakers to search for efficient solutions in not only the harvesting sector, but also the research and management sector.[22]

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[22] We thank Dr. Sylvia, Director of the Coastal Oregon Marine Experiment Station and Associate Professor in the Department of Agricultural and Resource Economics at Oregon State University, for these observations.

The MEY solutions represent the most efficient level of trap gear in the commercial fishery. They do not consider equity issues or, for example, the regional benefits from employment in the spiny lobster fishery. In addition, these economically optimal solutions are the expected outcomes assuming all other commercial and recreational effort in the fishery remain at current levels. However, increased recreational or commercial dive effort (from either an increase in the number of participants or an increase by current participants) could lower average trap yields and undermine the effects of the reduction on trap CPUE. The potential for future unrestricted entry from other sectors of the lobster fishery could also explain why observed prices for trap certificates have been lower than expected (Milon et al. 1998).

Since non-trap commercial gear and recreational effort were not directly considered in this analysis, the study did not determine the best use of the resource among all alternatives. It is possible that these other industry sectors may be relatively more efficient (deserve more value) than the commercial trap sector. This possibility emphasizes the need for management programs to encompass all sectors and all gears. However, since valuable property rights have already been established in the commercial sector, problems/conflicts with the recreational fishery may be intensified since any attempts to allocate or manage either sector influences the value of both. These values become explicit and transparent to those paying or receiving the value for the rights (i.e., transferable certificates), so any direct or indirect 'reallocation' will be quickly challenged. For example, New Zealand has had to contend with significant allocation problems by incorporating the recreational sector within individual transferable quota (ITQ) programs.[23]

A number of issues must be addressed in determining the most desirable number of traps in the commercial spiny lobster fishery. The analysis and models presented in this report indicate that significant economic gains in the commercial fishery could be realized from future reductions in trap certificates. These economic gains should be assessed in relation to the effects on allocation within the fishery, employment and effort levels in other fisheries, and the administrative costs of managing the fishery. Addressing all of these issues within the framework of the existing TCP will be a difficult task.

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[23] We thank an anonymous reviewer for this observation.

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APPENDICES

Appendix A: Figures Relating to the Development of the New Production Models

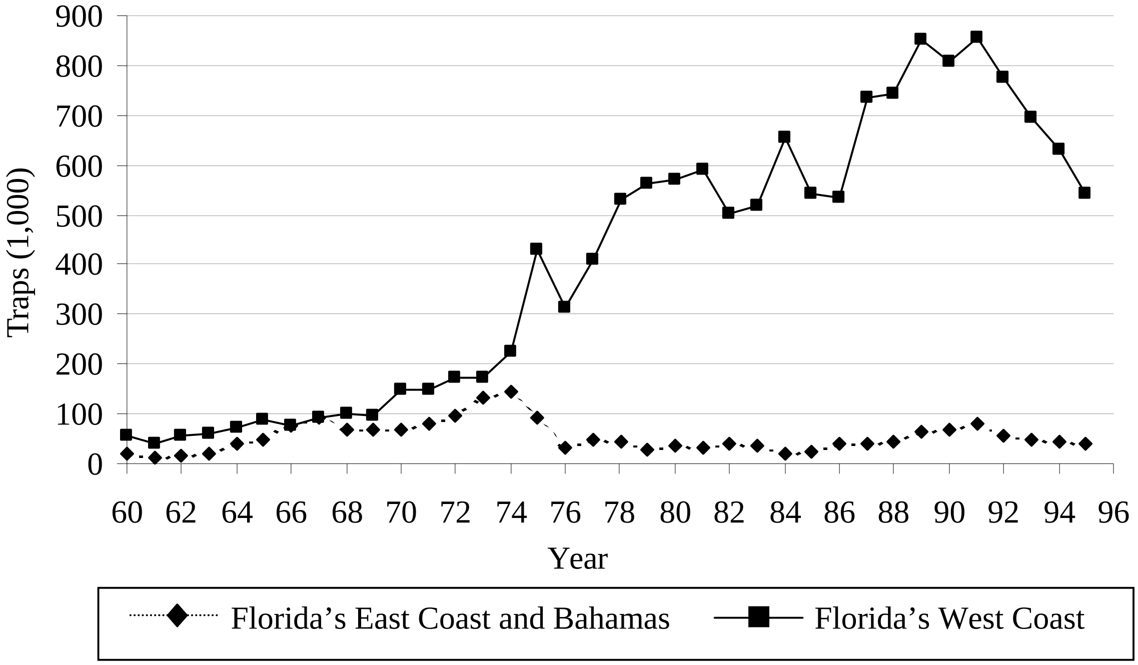

Figure A-1. Commercial Traps by Coast in the Florida Spiny Lobster Fishery, 1960-95

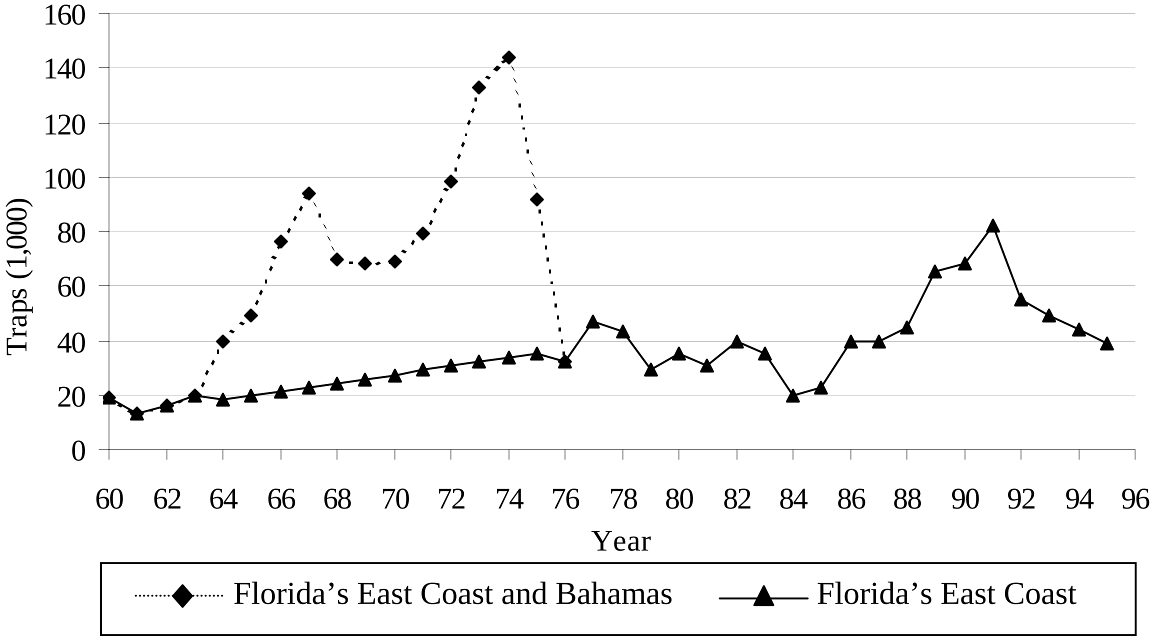

Figure A-2. Reported and Corrected Traps for Florida's East Coast, 1960-95

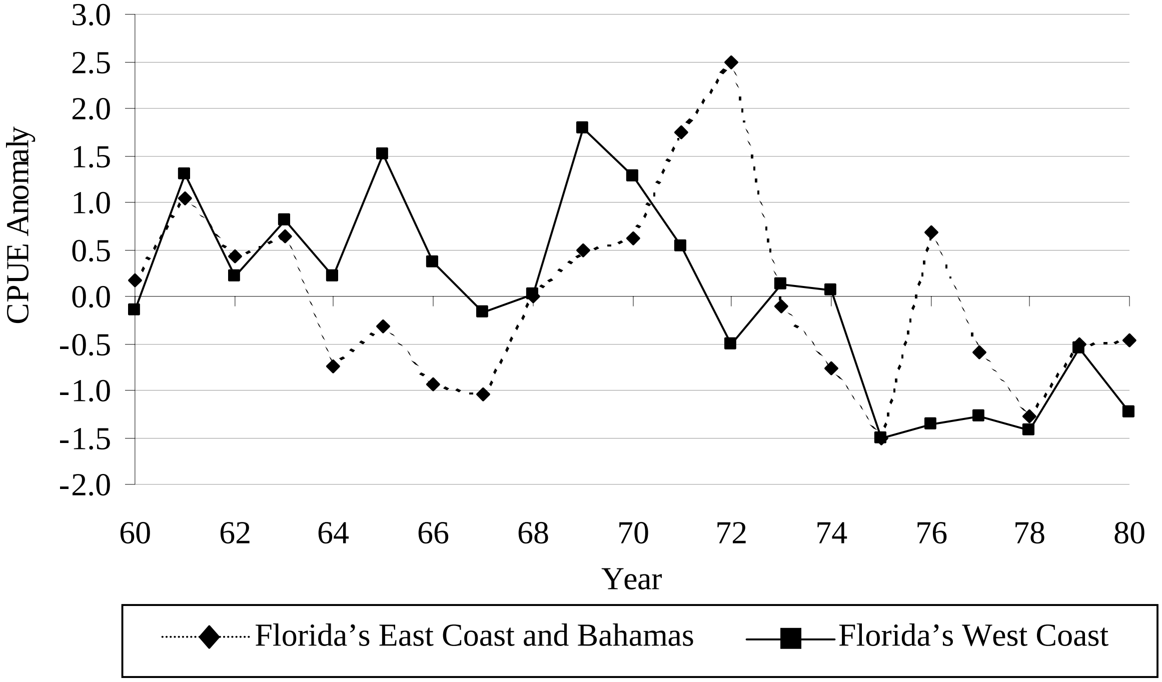

Figure A-3. CPUE Anomaly Measurement for the Florida Spiny Lobster Fishery by Coast, 1960-80

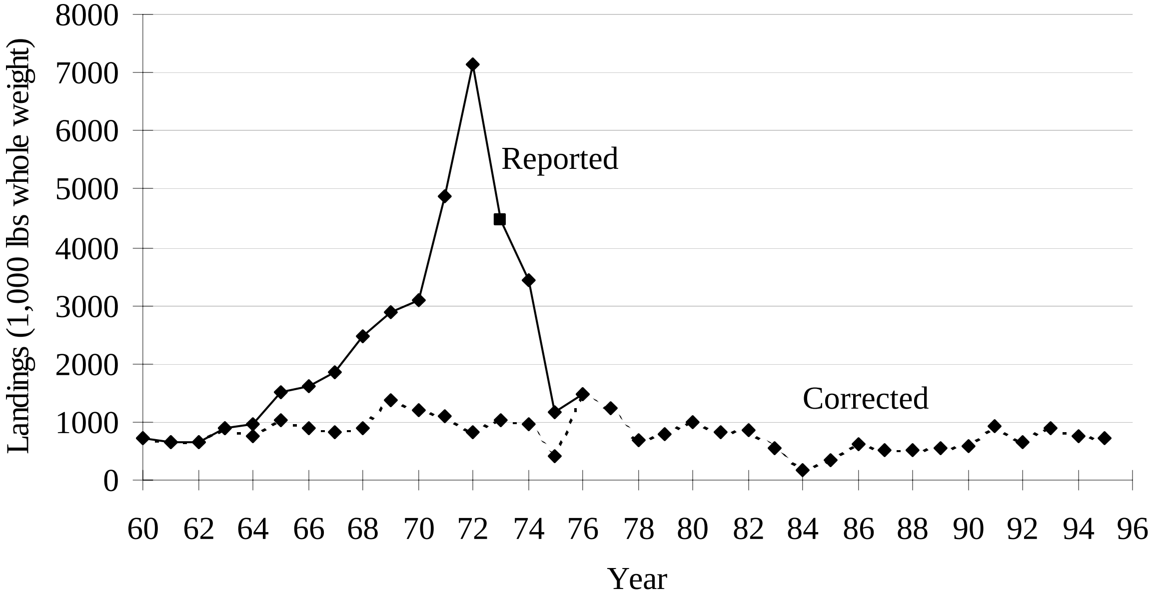

Figure A-4. Reported and Corrected Landings for Florida's East Coast, 1960-95

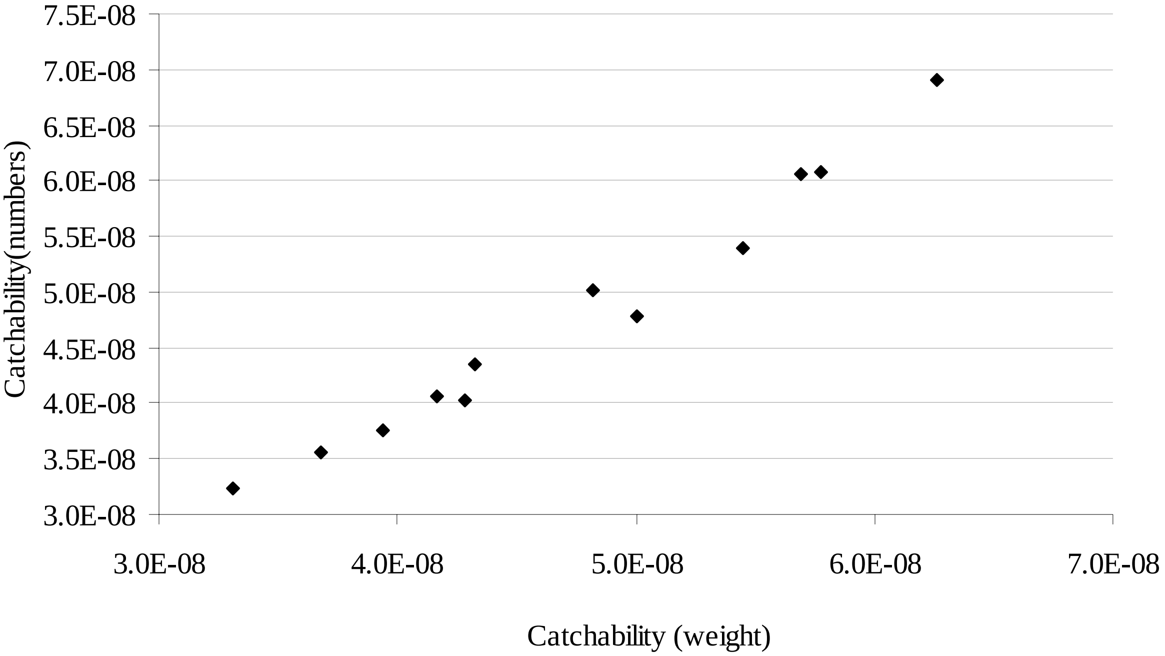

Figure A-5. Relationship between Trap Catchability in Weight and Numbers

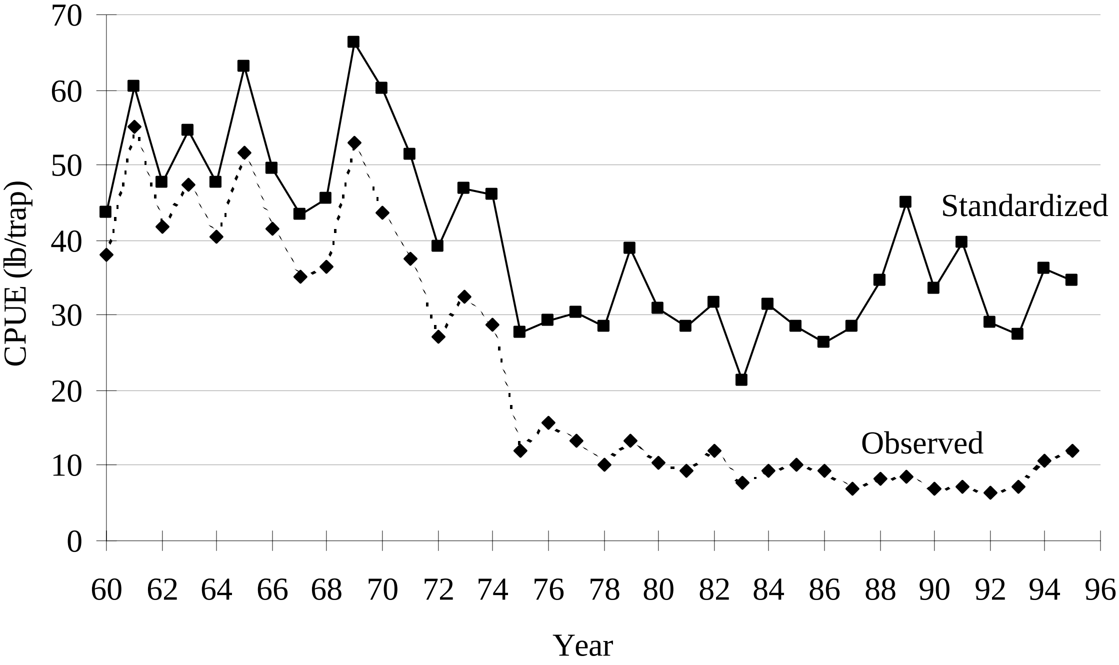

Figure A-6. Observed and Standardized CPUE in the Florida Spiny Lobster Fishery, 1960-96

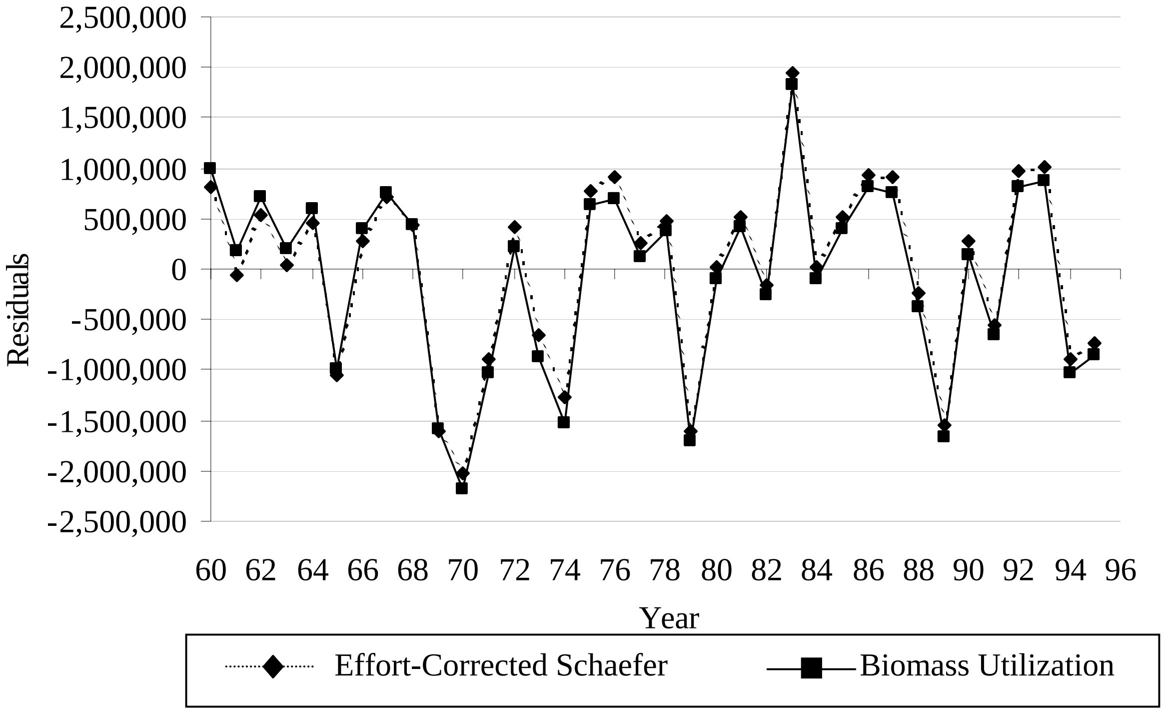

Figure A-7. Residuals of the Effort-Corrected Schaefer and Biomass Utilization Models, 1960-96

Appendix B: Florida Spiny Lobster Commercial Catch-Effort Data

Table B-1. Florida Spiny Lobster Commercial Catch-Effort Data

	Nominal		Standardized	Bahamian-Corrected	
Season	Landings (1,000 lb)	Traps (1,000)	Traps (1,000)	Landings (1,000 lb)	Traps (1,000)
1960	2,821	74.0	65.0	2,821	74.0
1961	2,863	52.0	47.0	2,863	52.0
1962	3,092	74.0	65.0	3,092	74.0
1963	3,784	80.0	69.0	3,784	80.0
1964	3,947	114.0	78.0	3,730	92.5
1965	6,151	139.0	90.0	5,683	110.0
1966	4,725	151.0	81.0	4,017	96.5
1967	5,073	186.0	50.0	4,041	115.0
1968	6,081	169.0	99.0	4,491	123.5
1969	8,040	165.0	98.0	6,519	123.0
1970	9,626	219.0	129.0	7,746	177.5
1971	10,374	226.0	128.0	6,591	176.0
1972	11,862	272.0	141.0	5,537	204.5
1973	10,047	305.0	141.0	6,612	204.0
1974	9,944	371.0	163.0	7,490	260.5
1975	6,271	520.0	201.0	5,534	463.0
1976	5,425	347.0	185.0	5,425	347.0
1977	6,044	455.0	200.0	6,044	455.0
1978	5,804	572.0	203.0	5,804	572.0
1979	7,887	593.0	203.0	7,887	593.0
1980	6,268	605.0	203.0	6,268	605.0
1981	5,767	622.0	202.0	5,767	622.0
1982	6,436	542.0	204.0	6,436	542.0
1983	4,347	555.0	204.0	4,347	555.0
1984	6,280	675.0	199.0	6,280	675.0
1985	5,777	564.0	204.0	5,777	564.0
1986	5,359	576.0	203.0	5,359	576.0
1987	5,427	777.0	191.0	5,427	777.0
1988	6,560	787.0	190.0	6,560	787.0
1989	7,855	916.0	175.0	7,855	916.0
1990	6,045	876.0	180.0	6,045	876.0
1991	6,842	939.0	172.0	6,842	939.0
1992	5,367	831.0	185.0	5,367	831.0
1993	5,315	746.0	194.0	5,315	746.0
1994	7,208	674.0	199.0	7,207	674.0
1995	7,024	582.0	203.0	7,024	582.0

Appendix C: Surplus Production Models Estimated with Alternative Data

The estimated catch-effort equations are critical to the determination of the optimal – net benefit maximizing – number of traps in the fishery. Consequently, is it important to examine the robustness (sensitivity) of the model to the data series. In this appendix, the production models (Table 3-2) and resulting biological parameters (Table 3-3) and catch-effort equations (Table 3-4) are regenerated using (1) nominal catch and effort, (2) nominal effort with corrected landings, and (3) nominal catch and effort with dummy variables to distinguish years of fishing activity in the Bahamas. Selected models are also estimated using only the data from Florida's West Coast, the region unaffected by Bahamian fishing activity.

Table C-1 contains the surplus production models estimated using the reported (nominal) landings and traps. The explanatory power (R^2 value) of the Schaefer, Fox, and Threshold models improved, however, the proportion of variation explained by the Scheafer and Fox models remained below 15 percent. The explanatory power of the Schnute model fell to 7 percent, while that of the CY&P models did not change. The explanatory power of the Threshold model that assumes the maximum catch equals 16 million pounds, increased from 38 to 61 percent due to the higher peak landings in the nominal series. However, the effort variables were insignificant.

Table C-2 contains the models estimated using the corrected landings and nominal traps. The explanatory power of each model was within three percentage points of the models estimated using the corrected traps that were described in the main text (Table 3-2). The CY&P model experienced the most noticeable change as explanatory power dropped from 91 to 88 percent and the CPUE variable became insignificant.

The CY&P model, the model with the highest R^2 and most significant variables in Tables 3-2, C-1 and C-2, was re-estimated with dummy and interaction variables that represent the years of suspected fishing in Bahamian waters (D=1 if season began in years 1964-1975, D=0 otherwise). Regression results are presented in Table C-3 exclusive of 4b, which had insignificant coefficients in previous estimations. In terms of explanatory power, the estimated models are equivalent; the dummy and interactive variables did not increase the explained variation. The dummy variable was significant in only one model (4d) indicating a higher average CPUE from 1965-75 and a larger negative effect of traps on CPUE from fishing in the Bahamas. In addition, the lagged CPUE parameter was statistically insignificant in equation 4e. Overall, the lack of significance of the variables distinguishing the 1965-75 seasons indicates that Bahamian fishing activity (landings and effort) recorded with Florida's East Coast does not affect the estimated CY&P catch-effort equations and resulting bioeconomic analysis. Moreover, the parameter estimates from model 4f, which only used Florida's West Coast data, were in the range of reported values generated from the previous specifications.

Table C-1. Estimates of Surplus Production Models using Nominal Data

Model	Estimated Equation[a]	Model Statistics[b]			
		method	R^2	df	D-W
(1) Schaefer	$\Delta U_t/2U_t = -0.208 + 0.0033\, U_t + 0.00020\, E_t$ (0.231) (0.0047) (0.0003)	MLE	0.13	30	1.90
(2) Fox	$\Delta U_t/2U_t = -0.278 + 0.056\, U_t + 0.00017\, E_t$ (0.532) (0.131) (0.0003)	MLE	0.12	30	1.91
(3) Schnute	$\ln(U_{t+1}/U_t) = -0.161 + 0.0023\, [(U_{t+1}+U_t)/2] + 0.00016\, [(E_{t+1}+E_t)/2]$ (0.293) (0.006) (0.0003)	MLE	0.07	31	1.88
(4a) CY&P	$\ln U_{t+1} = 2.178 + 0.449 \ln U_t - 0.000698\, (E_{t+1} + E_t)$ (0.617)*** (0.151)*** (0.00021)***	OLS	0.91	32	N/A
(4b) CY&P[c]	$\ln U_{t+1} = 4.543 - 0.147 \ln \widehat{U_t} - 0.0014\, (E_{t+1} + E_t)$ (1.34)*** (0.33) (0.0004)***	MLE	0.91	29	N/A
(5b) Threshold	$\ln(12{,}000 - C_t) = 8.510 + 0.0000213\, E_t$ (0.415)*** (0.0008)	MLE	0.34	33	2.13
(5c) Threshold	$\ln(16{,}000 - C_t) = 9.232 - 0.000137\, E_t$ (0.165)*** (0.00028)	MLE	0.61	33	1.89

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[a] U_t is catch per unit effort (C_t/E_t) where catch (pounds landed) and effort (number of traps) are measured in thousands. Standard errors appear in parentheses below the estimated parameter. Single, double, and triple asterisks indicate significance at the 10, 5, and 1 percent levels, respectively.

[b] Equations were estimated using either MLE, corrected for first-degree autocorrelation, or OLS. The total R^2 value (adjusted R^2 if estimated using OLS), degrees of freedom (df), and Durbin-Watson (D-W) statistics are also presented.

[C] The ^ symbol indicates an instrumental variable regression was used to predict the lagged dependent variable.

Table C-2. Estimates of Surplus Production Models using the Bahamian-Corrected Landings and Nominal Traps

		Model Statistics [b]			
Model	Estimated Equation [a]	method	R^2	df	D-W
(1) Schaefer	$\Delta U_t/2U_t = -0.222 + 0.0034\, U_t + 0.000248\, E_t$ (0.196) (0.0047) (0.000235)	MLE	0.07	30	1.83
(2) Fox	$\Delta U_t/2U_t = -0.377 + 0.0766\, U_t + 0.00027\, E_t$ (0.565) (0.149) (0.00035)	MLE	0.06	30	1.83
(3) Schnute	$\ln(U_{t+1}/U_t) = -0.231 + 0.00399\, [(U_{t+1}+U_t)/2] + 0.00026\, [(E_{t+1}+E_t)/2]$ (0.240) (0.0061) (0.00028)	MLE	0.13	31	2.03
(4a) CY&P	$\ln U_{t+1} = 2.816 + 0.247 \ln U_t - 0.000843\, (E_{t+1} + E_t)$ (0.682)*** (0.177) (0.00022)***	OLS	0.88	32	N/A
(5a) Threshold	$\ln(8{,}000 - C_t) = 8.089 - 0.001317\, E_t$ (0.308)*** (0.000583)**	MLE	0.16	33	1.96
(5b) Threshold	$\ln(12{,}000 - C_t) = 8.928 - 0.000429\, E_t$ (0.087)*** (0.000164)***	MLE	0.36	33	1.92
(5c) Threshold	$\ln(16{,}000 - C_t) = 9.359 - 0.000269\, E_t$ (0.053)*** (0.000101)***	MLE	0.39	33	1.93

[a] U_t is catch per unit effort (C_t/E_t) where catch (pounds landed) and effort (number of traps) are measured in thousands. Standard errors appear in parentheses below the estimated parameter. Single, double, and triple asterisks indicate significance at the 10, 5, and 1 percent levels, respectively.

[b] Equations were estimated using either MLE, corrected for first-degree autocorrelation, or OLS. The total R^2'd value (adjusted R^2'd if estimated using OLS), degrees of freedom (df), and Durbin-Watson (D-W) statistics are also presented.

Table C-3. Estimates of Alternative CY&P Surplus Production Models to Examine Effect of Bahamian Fishing Grounds

		Model Statistics[b]	
Model	Estimated Equation [a]	R^2	df
(4a)	$\ln U_{t+1} = 2.178 + 0.449 \ln U_t - 0.00069 (E_{t+1} + E_t)$	0.903	32
	(0.617)*** (0.151)*** (0.0002)***		
(4c)	$\ln U_{t+1} = 2.335 + 0.391 \ln U_t - 0.00072 (E_{t+1} + E_t) + 0.097 D$	0.902	31
	(0.643)*** (0.165)*** (0.0002)*** (0.109)		
(4d)	$\ln U_{t+1} = 2.209 + 0.410 \ln U_t - 0.00066 (E_{t+1} + E_t) + 0.409 D - 0.00058 (E_{t+1} + E_t) D$	0.909	30
	(0.624)*** (0.160)*** (0.0002)*** (0.201)** (0.00032)*		
(4e)	$\ln U_{t+1} = 2.809 + 0.261 \ln U_t - 0.00085 (E_{t+1} + E_t) - 0.765 D + 0.258 \ln U_t D$	0.903	30
	(0.758)*** (0.199) (0.0002)*** (0.747) (0.222)		
(4f)[c]	$\ln U_{t+1} = 2.387 + 0.378 \ln U_t - 0.0008 (E_{t+1} + E_t)$	0.906	31
	(0.707)** (0.179)* (0.0002)**		

[a] U_t is catch per unit effort (pounds). Effort, E_t, is the number of traps (thousands). Standard errors appear in parentheses below the estimated parameter. Single and double asterisks indicate significance at the 5 and 1 percent levels, respectively. D=1 if season 1965-66 through 1977-78, zero otherwise.

[b] The equations were estimated using OLS. The model adjusted R^2 value and degrees of freedom (df) are presented. The Durbin-Watson statistic is not applicable to these equations due to the lagged dependent variable.

[c] Equation estimated using only the data from the west coast region.

Given the poor results of Schaefer, Fox, and Schnute equations as reported in Tables C-1 through C-3, biological parameters – namely, the growth rate (*r*), catchability coeffiecient (*q*), and stock level (*K*) – were not derived for these models. In addition, the biological parameters were only calculated from the CY&P and Threshold models whose explanatory variables were significant. These parameters are compared to determine the sensitivity of the estimates with respect to Bahamian fishing activity. Since the Florida fleet was harvesting in international waters from 1964-65 through the 1975-76 seasons, the biological parameters derived from the CY&P models that identify this period reflect stock abundance in fishing areas no longer available. Consequently, the biological parameters from these models were calculated for the years unaffected by Bahamian waters ($D = 0$). The parameters are summarized in Table C-4.

Table C-4. Biological Parameters from Selected Models using Alternative Data

Data & Model[a]	growth rate (r^*)	catchability coefficient (q^*)	stock level (K^*)
Nominal Data, Landings and Traps (Table C-1)			
(4a) CY&P	0.760	0.000001926	27,111,630
Corrected Landings and Nominal Traps (Table C-2)[b]			
(5b) Threshold	N/A	0.000000429	7,542,000
Nominal Data with Dummy for 1964-75, D=0 (Table C-3)			
(4c) CY&P	0.875	0.000002082	22,227,860
(4d) CY&P	0.836	0.000001860	22,789,822
Nominal Data only for West Coast (Table C-3):			
(4f) CY&P)	0.903	0.000002322	19,987,417

[a] From equations when estimated in original units. Threshold parameters should be interpreted as lower bounds (see Chapter 3).

[b] Model 5a was not included due to its relatively low explanatory power. Model 5c was not included since the assumed maximum catch level nearly doubled the corrected peak level.

With the CY&P models the intrinsic growth rate for the Florida spiny lobster fishery was estimated to fall between 0.76 and 1.34 and the catchability coefficient ranged from 1.9 E-6 to 3.4 E-6. The maximum stock level ranged from a low of 15.3 million to a high of 27.1. The extreme stock levels were generated from the use of the nominal (uncorrected) data. The nominal data also produced the lowest estimate of the intrinsic growth rate (i.e., 0.76), the highest intrinsic growth rate, and the largest catchability coefficient.

The Threshold model produced the lowest estimated values of q and K. These values appear reasonable given results from the CY&P models. Recall that Threshold models (5b) utilize an assumed value of the maximum catch level. If the value is increased as high as possible without sacrificing explanatory power (see footnote 4), both parameters increase toward the higher CY&P estimates.

Table C-5. Catch-Effort Equations from Selected Models using Alternative Data

Data & Model	Catch-Effort Equation
Nominal Data:	
(4a) CY&P	(i) $C = 52.23Ee^{-0.00000253E}$
Corrected Landings and Nominal Traps:	
(5b) Threshold	(ii) $C = 12{,}000{,}000 - e^{(15.84 - 0.000000429E)}$
Nominal Data with Dummy for 1964-75:	
(4c) CY&P	(iii) $C = 46.27Ee^{-0.00000238E}$
(4d) CY&P	(iv) $C = 42.40Ee^{-0.00000223E}$
Nominal Data only for West Coast:	
(4f) CY&P	(v) $C = 46.41Ee^{-0.00000257E}$

The CY&P models in Table C-5 bound the model estimated with the corrected data in the main text (Table 3-4), which had a coefficient of 49 and a catchability of 2.43 E-6. The parameters of the exponential term in the Threshold model estimated with the nominal traps are slightly higher than when estimated with the corrected traps (Table 3-4). To better assess the impact of using alternative data series on the predicted catch, the catch-effort equations in Table C-5 are graphed with the corresponding equations from the main text in Figure C-1.

The highest catch among the CY&P models was predicted with the nominal data. The corrected data series, which was used in the main text, predicted the next highest catch at every effort level. It also predicted larger catch reductions at higher effort levels than the models derived using dummy variables for the period of Bahamian fishing activity (Equations iii and iv). The model derived using only the West Coast data produced the most conservative catch levels above approximately 250,000 traps.

CY&P Models

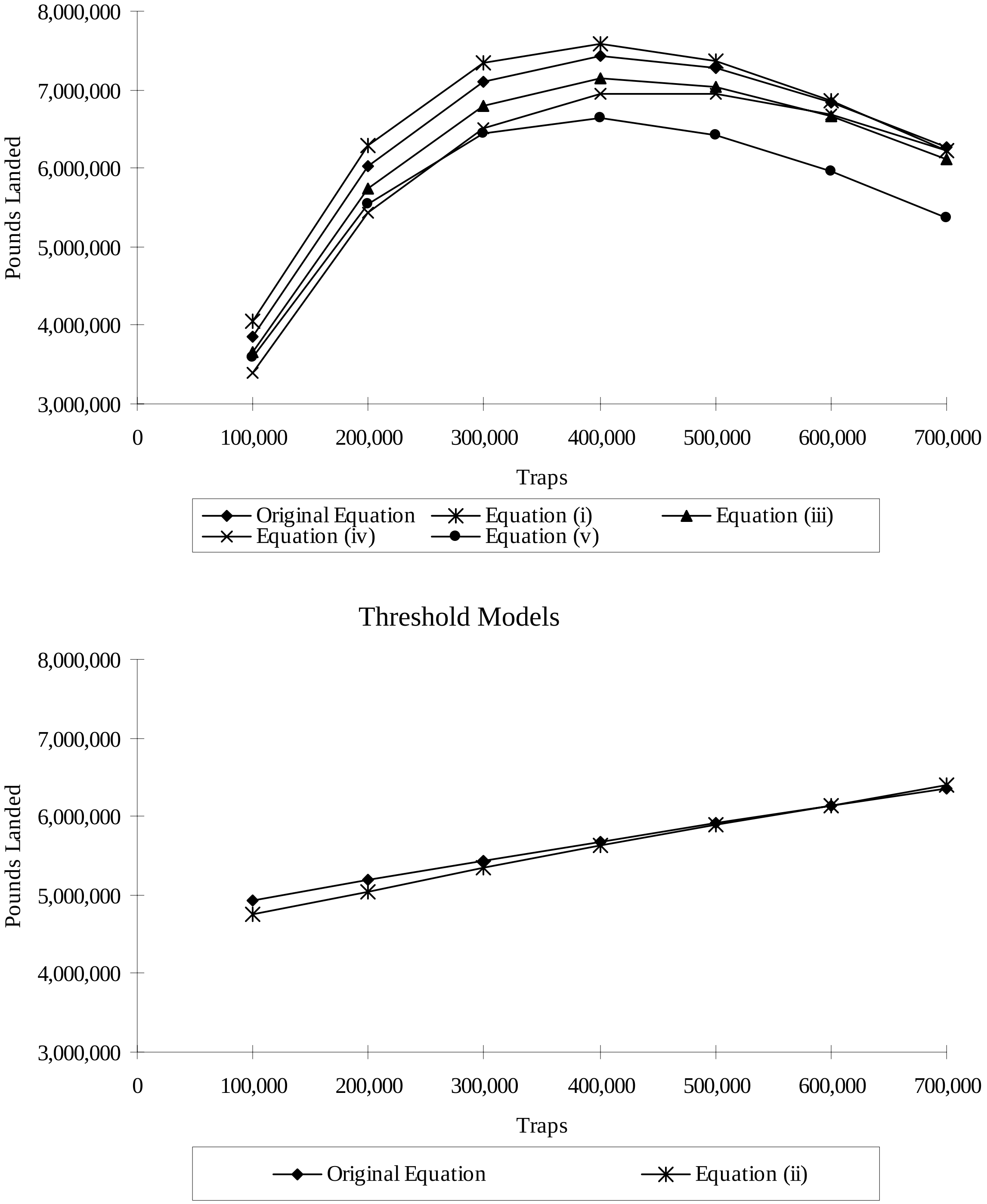


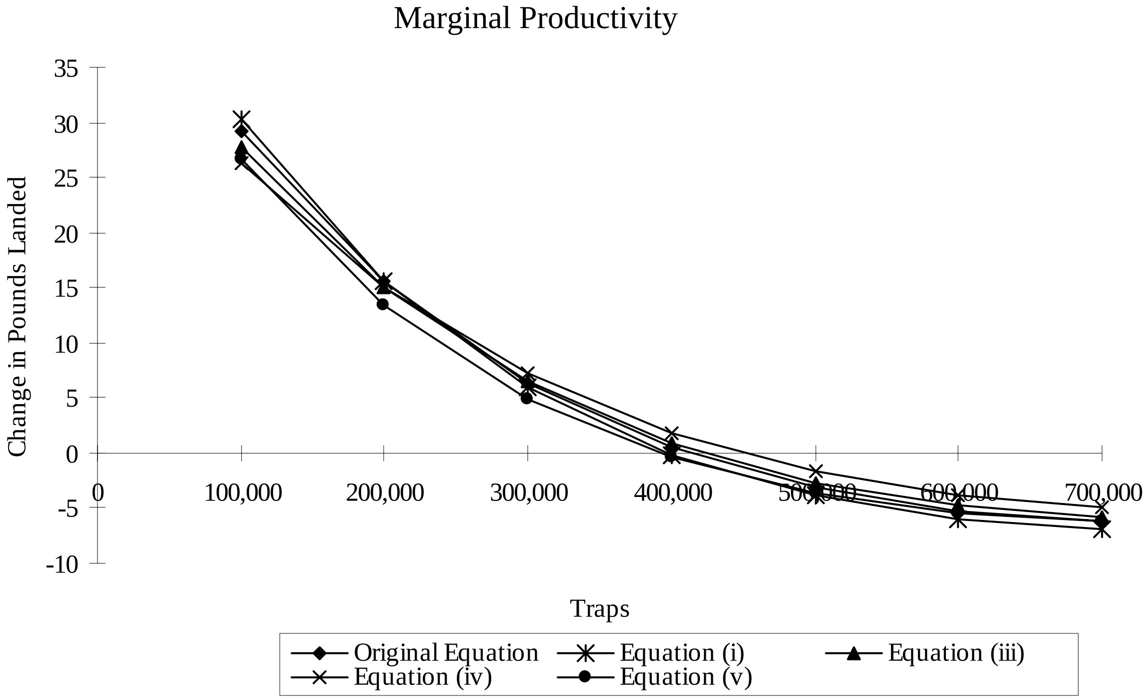
Figure C-1. Catch-Effort Equations from Alternative Data

The Threshold model estimated with the nominal landings predicted slightly lower catch levels at fewer than 500,000 traps. The higher slope of the catch-effort relationship predicted with this new model indicates higher trap yields, however, the relationship remains linear. A linear catch-effort relationship does not correspond with the observed characteristics of this fishery, therefore, this model is considered inappropriate for the commercial spiny lobster trap fishery in Florida.

When the marginal productivity curve is derived from each CY&P catch-effort equation, as shown in the top panel of Figure C-2, the differences between the models (for purposes of determining the bioeconomic optimum) diminishes. The marginal productivity curves derived from the alternative data series effectively bound the marginal productivity relationship predicted using the corrected data. The marginal productivity derived from the corrected landings and traps is neither the most liberal nor most conservative.

When the marginal productivity at each effort level (i.e., the change in landings associated with the addition of a trap to the fishery) is multiplied by the lobster price, the marginal revenue curve is generated. The intersection of the marginal revenue curve with the marginal cost per trap identifies the bioeconomic optimum (Chapter 2). Consequently, the location of the marginal revenue curve is a critical element in the determination of the economically optimum number of traps in the fishery. The bottom panel of Figure C-2 contains the marginal revenue of each CY&P model. The horizontal difference between the curves reflects the bias, in terms of the economically optimal number of traps in the fishery, from using the alternative data series. For example, if the marginal cost per trap equaled $25, the economically optimal number of traps would range from approximately 280,000 to 310,000 (a 10 percent difference). The optimum determined with the marginal revenue from the corrected data falls within this range.

Overall, the relative similarity of the models to the alternative data series verifies the robustness of the analysis to the method of correcting for fishing activity in the Bahamas from 1964 through 1975.



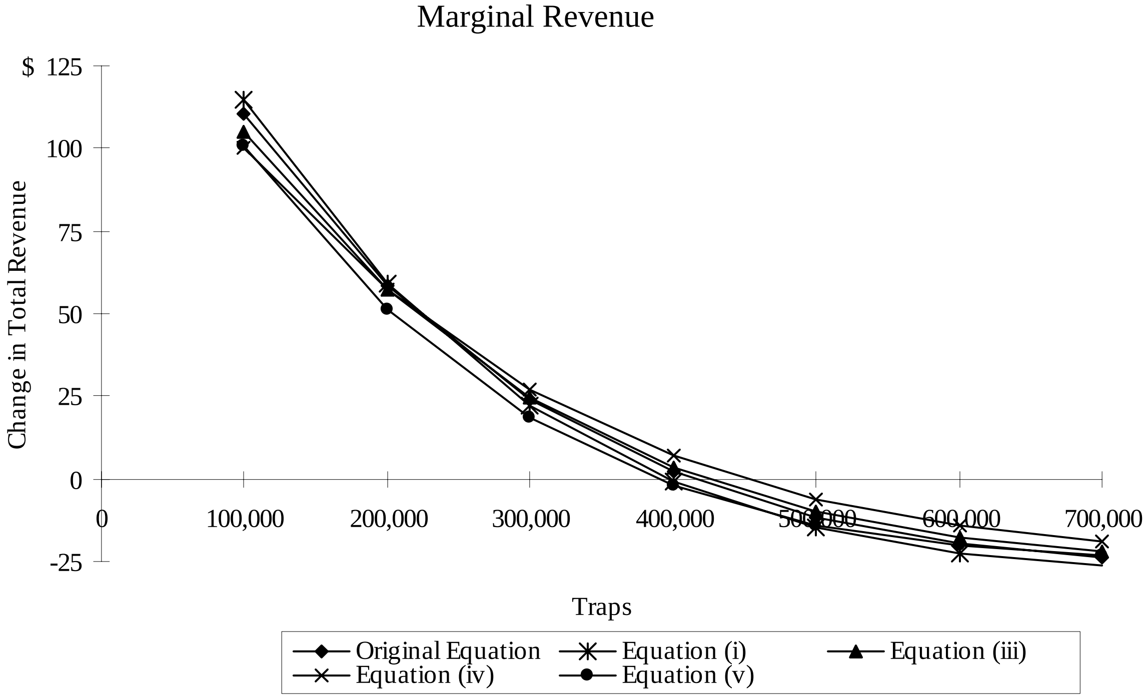


Figure C-2. Marginal Productivity and Marginal Revenue Curves for the CY&P Models