

# **Economic Assessment of Limited Entry Strategies in Multi-Species Fisheries in South Florida**

SHARON D. HUTCHINSON, SHERRY L. LARKIN, DONNA J. LEE, and  
CHARLES M. ADAMS

*Food and Resource Economics Department  
Institute of Food and Agricultural Sciences  
University of Florida  
P.O. Box 110240  
Gainesville, Florida 32611-0240 USA*

## **ABSTRACT**

The commercial fishery that primarily targets king mackerel, stone crab, snappers, groupers, and spiny lobster in Monroe and Collier counties is one of the most important commercial fisheries in Florida. These species currently face problems of overfishing and/or overcapitalization. A dual-based restricted profit function is used to estimate the economic and technical interactions that exist in this multi-species fishery, primarily using own-price and cross-price elasticities of supply. It is found that the production technology does not exhibit input-output separability and nonjointness-in-inputs, over all species groups. This result suggests that these key species may be more efficiently managed as a group, rather than with the use of existing single species regulations. Spiny lobster and stone crab, the dominant value species in the fishery, are shown to have very elastic substitution relationships with king mackerel.

**KEY WORDS:** Multi-species fisheries, duality theory, joint products

## **INTRODUCTION**

Today, "...most U.S. fish stocks are in a state of full exploitation or overutilization," furthermore, the recent depletion of some dominant species has led to the collapse of a few major fisheries (National Research Council 1999). In Florida, the commercial fishing industry is a very important one. Statewide, among the most predominant species in terms of value are shrimp (primarily *Penaeus duorarum*), spiny lobster (*Panulirus argus*), and king mackerel (*Scomberomorus cavalla*). In terms of landings, stone crab (*Menippe mercenaria*) in Florida's Southwest region (i.e., Charlotte to Monroe counties) accounted for approximately 73% of total landings in Florida during the 1995-1996 fishing season. Also in 1996, Monroe and Collier counties accounted for approximately 90% of Florida's spiny lobster landings, 40% of snapper/grouper landings, and 40% of king mackerel landings (Milon et. al. 1998).

There has been rapid growth in many primary South Florida fisheries in the past two decades. For some species, such as king mackerel, this growth has occurred for both the commercial and recreational fisheries (although most of the growth has occurred in the recreational sector). For example, by 1985, the Total Allowable Catch (TAC) for the Gulf migratory group of king mackerel was allocated 9.673

million pounds to the recreational catch and 4.552 million pounds to the commercial catch (GMFMC 1985). This ratio continues today. Traditionally, for each managed species, the stock size that allows for the attainment of the Maximum Sustainable Yield (MSY) is calculated and efforts are made to keep the harvest levels at or below MSY. Today, the stock of king mackerel in the Gulf migratory group is below the level of producing MSY. Furthermore, the stock has been reduced to the point where recruitment has been affected, and uncontrolled fishing would further reduce the biomass. In addition to this problem, there are intense conflicts between recreational and commercial fishermen, and between commercial fishermen who use different gear. Part-time commercial fishermen compete with full-time commercial fishermen for the quota. Further, large catches of mackerel over a short period often causes the quota to be exceeded before closures can be implemented (GMFMC 1999). Snappers and groupers, which are considered in this paper as a single "species" group, have suffered a similar fate. There are no closed seasons in either the king mackerel or snapper/grouper fisheries.

There has been an increasing amount of effort (which is typically represented by the total number of traps available) in the spiny lobster fishery. For example, between 1951 to 1999 the number of traps increased from approximately 12,000 to 540,000 (declining from a high of over 900,000 in the early 1990s before the certificate program was implemented). This increase in effort was accompanied by a rapid decline in Catch per Unit Effort (CPUE), which fell from levels of approximately 150 pounds per trap to less than 10 pounds per trap over the same period. Despite this, total commercial landings have remained relatively stable since 1976 (Milon et al. 1998). The closed season is April 1<sup>st</sup> to August 5<sup>th</sup>.

For stone crab harvests, excessive growth of the trap fishery has reduced the efficiency of the industry such that the likelihood of increased landings with additional effort are minimal. This excessive growth has also caused increased conflicts with the shrimp trawl fishery and there has been an increase in destruction of live bottom species such as soft coral as well as a rise in shore debris from displaced buoys and traps. While the biological viability of this species has not been affected (since the recruits into the fishery are mature and have had an opportunity to spawn), crabs harvested are becoming increasingly smaller, leading to a loss in commercial value. The closed season for this species is May 16<sup>th</sup> to October 14<sup>th</sup>.

Many fishermen in South Florida catch king mackerel, snapper/groupers, spiny lobster, and stone crab depending largely on the availability and profitability of each species at a given time. However, each of these species is currently managed by separate management plans and, in some fisheries, moratoriums exist on increases in effort. It is likely that inputs used in the harvest of one species can result in the harvest of, or use in the harvest of, another species; this type of production process is known as jointness-in-inputs. It is also possible that a particular input does not directly affect the harvest of a given species, however, it may be possible to use a representative input, combine inputs, or create a composite input that is known to affect the harvest levels of each species; a representation of the production process that follows this approach is known as input-output separability.

In South Florida (i.e., Monroe and Collier counties) there are four primary fisheries: king mackerel, spiny lobster, snapper/grouper, and stone crab. Each of these fisheries face problems of overfishing and/or overcapitalization. To date, efforts to address these issues have been on a single-species basis. The main deficiency of this approach is that the production linkages that may exist between fisheries are essentially ignored. As a result, there is a great propensity for effort redirection by fishery participants to other species where similar gear or vessels are utilized. The main objectives of this paper are, therefore, to: (1) assess the temporal fleet components in the fishery; (2) identify resource linkages; and (3) determine if a multi-species management approach would be appropriate for some or all of the primary species in the South Florida.

### EMPIRICAL FRAMEWORK

Models that have been used to describe multi-species fisheries have made assumptions about the underlying decision-making process of the fisherman/fishing firm. These models assume that a firm wishes to maximize profit, but in achieving this objective, many decisions have to be made. These include decisions about fishing locations, target species, gear and homeport, number of crew, length of trip, landing port, and duration at a fishing location. The exact nature of the decision-making framework is not certain, but given a selected fishing location and inputs, such as vessel size and gear type (which are fixed in the short run), profit maximization becomes equivalent to revenue maximization. However, if information on variable inputs is available, a profit function can be defined and both output supply (i.e. production) and input demand functions can be obtained using a duality approach. Several types of revenue/profit functions have been utilized by previous researchers. Recent research of multiproduct firms has described the profit function using a translog form (Thunberg et al. 1995), a quadratic form (Dupont 1990), and a generalized Leontief function (Kirkley and Strand 1988, Squires and Kirkley 1995). These functions are "flexible" in that they are a second-order differentiable approximation to an unknown, twice continuously-differentiable function (Blackorby and Diewert 1979). Therefore, this allows the mimicking of a great deal of curvature when it is used to approximate another function, and it does not restrict the values of the elasticities of substitution, which are second derivatives of the output supply or input demand functions (Greene 1997).

These restricted profit functions can then be transformed via Hotelling's Lemma (Diewert 1971), to obtain a system of (i) input-compensated output supply functions and (ii) input demand functions. The major drawback of the translog functional form is that the derivatives of the profit function yield input and output share equations (i.e. input and output values are in terms of its share of total revenue), which are not easily interpreted. In addition, the translog functional form requires restrictions for linear homogeneity in addition to symmetry restrictions on the parameters.

This paper utilizes a nonhomothetic Leontief functional form, which has an advantage of automatically imposing linear homogeneity in prices (Squires and Kirkley 1995). The basic functional form is represented as:

$$R(E, P) = \sum_i \sum_j \beta_{ij} (P_i P_j)^{1/2} E + \sum_i \beta_i P_i E^2$$

where  $R$  represents net revenue per unit time as a function of fishing effort ( $E$ ), such as the number of trips, and the output and input prices ( $P_i$  where  $i = 1, \dots, M$ ). This basic function can be extended to include a dummy variable,  $D_y$ , that reflects (for example) the year in which a trip was taken:

$$R(E, P) = \sum_i \sum_j \beta_{ij} (P_i P_j)^{1/2} E + \sum_i \beta_i P_i E^2 + \sum_y \alpha_y D_y P_i E.$$

Output supply and input demand functions are obtained using Hotelling's Lemma:

$$\delta R(E, P) / \delta P_i = Q_i(E, P) = \beta_{ii} E + \sum_j \beta_{ij} (P_j / P_i)^{1/2} E + \beta_i E^2 + \sum_y \alpha_y D_y E \quad \forall i'j.$$

The dependent variables in these equations represent outputs and inputs in quantities ( $Q_i$ ). In this paper, the output supply and input demand equations are defined as follows:

$$\delta R(E, P) / \delta P_i = Q_i = \beta_{ii} E + \sum_j \beta_{ij} (P_j / P_i)^{1/2} E + \beta_i E^2 + \sum_y \alpha_y D_y E$$

for all  $i'j$ ,  $i=1, 2, \dots, 5$ , which includes four outputs (i.e., the primary species groups) and one input, labor.  $D_y$  ( $y=1, 2, \dots, 4$ ) = 1 for observations in 1995 to 1998 respectively, zero otherwise. The imposition of symmetry requires that:

$$\beta_{ij} = \beta_{ji} \quad \forall i'j.$$

#### DATA

In Florida, all commercial fishermen are required to fill out a Trip Ticket, which contains various trip data, upon completion of each fishing trip. This information is collected and maintained in a database by the Florida Marine Research Institute (FMRI). Trip level data on the type and quantity of landings of all species for fishermen in Monroe and Collier counties were obtained from FMRI. FMRI also provided the associated landing date and ex-vessel price received (dollars per pound) for each species at landing. This trip level data was obtained for each fishing firm (i.e., Saltwater Products License number and vessel) via coded identification numbers to maintain confidentiality.

The data set included information from trips taken January 1994 through December 1998 and was aggregated on an annual basis for each firm. The minimum wage was used to represent the cost of labor (dollars per hour) for each trip. Information on the average number of crew, trip days, and hours spent per trip for

fishermen that target each species was obtained from a recent survey of Monroe County fishermen (Milon et al. 1999). These data were used to calculate the number of man-hours employed by each firm in each year and represents the annual quantity of labor used.

#### ESTIMATION

Four outputs and one input were specified: king mackerel; stone crab; snapper/grouper (all snapper and grouper species were placed into one group to facilitate the use of cost information from secondary sources); spiny lobster; and labor. The associated output supply and input demand functions were estimated as a system using iterated Seemingly Unrelated Regression (SUR) estimation with SAS®. Since the output supply and input demand equations are all derived from one profit function, this implies that we cannot rule out the possibility that the error terms in different equations are mutually correlated. In this case, we have:

$$E(\varepsilon_i \varepsilon_j') = \sigma_{ij} I_T.$$

where  $\sigma_{ij}$  is the covariance of the disturbances of the *i*th and *j*th equation, which is assumed to be constant over all observations. This covariance represents the only link between the *i*th and *j*th equation. Because this link is subtle, the system of *M* equations is called a system of SUR equations (Kmenta 1997). The SUR method therefore uses the correlations among the errors in different equations to improve the regression estimates.

Only firms that had a minimum \$5,000 average annual income (the minimum required to obtain a Saltwater Products Licence) from the landings of at least one of the target species were included in the estimation. For the years 1994 to 1998, 1550, 1591, 1574, 1563, and 1473 firms, respectively, met this criteria.

Even after aggregating the data, it was found that not all firms landed all species in a particular year. This created a limited-dependent variable problem. According to Maddala (1977), this may lead to biasedness, non-normality in the results, and incorrect rejection of tested hypotheses. To alleviate this problem, zero values for the dependent variable were replaced by a small positive value of 0.01 (similar values were used by Squires and Kirkley (1995) and Larkin and Adams (1999)). Also, for observations in which a specific species was not landed, the prices used for that observation was the mean of all non-missing observations for that year. The total number of trips taken (in order to capture all species) in a specific year was used to represent the effort variable.

The type and strengths of the technical and economic interaction of the fishery was determined using the own and cross-price elasticities. The elasticities were derived from the estimated output supply and input demand equations and are used, specifically, to indicate substitute and complementary relationships among the inputs and outputs. Also, since firms in a multi-species fishery may seek to maximize revenue by directing their effort to the highest valued species, the calculation of the cross-price elasticities can be used to determine the level of redirection of effort that

may take place in the fishery when the relative prices of species change (Roderick, Adams and Taylor 1995). The parameters of the supply and input demand functions were used to calculate own and cross-price elasticities of supply and demand using the following formulas:

#### Own-price Elasticity

$$\frac{\partial Q_i}{\partial P_i} \frac{P_i}{Q_i} = \left[ \sum_j \left( \frac{-\beta_{ij} E}{2P_i} \right) \left( \frac{Q_j}{P_i} \right)^{1/2} \right] \frac{P_i}{Q_i}$$

#### Cross-price Elasticity

$$\frac{\partial Q_i}{\partial P_j} \frac{P_j}{Q_i} = \left[ \left( \frac{\beta_{ij} E}{2} \right) \left( \frac{1}{P_i P_j} \right)^{1/2} \right] \frac{P_j}{Q_i}$$

where the respective variable means are used.

Nonjointness-in-inputs and input-output separability have often been assumed in the management of fisheries. Separability implies that there is no interaction between the harvest of any one species and any one input so that composite input and output bundles can be specified to represent the harvesting function. This suggests that the marginal rates of substitution between pairs of inputs do not rely on the makeup of the catch while the marginal rates of transformation between pairs of species do not rely on the mix of inputs. Therefore, only the level of catch and effort need to be regulated and this does not affect the optimal input combinations (Squires 1987). If the harvest of one species is independent of the inputs used to harvest another, then this suggests that there exists non-jointness in inputs so that each species has an independent harvest function. If nonjointness-in-inputs exists over all species, then:

$$R(E,P) = \sum_j R_i(P_i, E).$$

The test for nonjointness-in-inputs was carried out by testing the following restriction:

$$\frac{\partial^2 R(E,P)}{\partial P_i \partial P_j} = \frac{Q_i}{P_j} = 0, \text{ that is, } \beta_{ij} = 0, \forall i \neq j.$$

If separability exists, then the profit function is separable in output prices and the composite input, that is:

$$R(E,P) = R(p)E.$$

The test for input-output separability was carried out by testing the following restriction:

$$H_0: \beta_i = 0 \quad \forall i$$

This paper therefore presents the following hypotheses:

- i) There exists jointness-in-inputs for the harvest of all four species,
- ii) If jointness-in-inputs exist for stone crab and spiny lobster, then these species are strong substitutes,
- iii) Snappers and groupers are weak substitutes with either stone crab or spiny lobster; and
- iv) Input-output separability does not exist in the harvest of all species. A priori, it is also expected that own-price elasticities are positive.
- v)

## RESULTS

Table 1 reports a summary of sample statistics for the fishery. The target species have, on average, a large difference in their ex-vessel price per pound. For 1994 to 1998, the mean price for king mackerel was \$1.25. At the other end of the range, stone crab had an average price of \$6.89. In addition, there were considerable differences in the variances of prices received, with spiny lobster (one of the species with the most price variability) having a range from \$0.50 to \$14.00 per pound. The mean number of trips was similar for 1994 and 1995, then there was an approximate 10 percent increase in the mean number of trips for 1996 and 1997; however, by 1998, the mean number of trips fell to levels approaching 1994 levels. Therefore, no clear trend was evident in the number of trips taken by each firm. A comparison of annual landings for all years shows substantial variation for the target species. Spiny lobster was the dominant species in terms of landings, with a mean of approximately 4,114 pounds per year over the study period. In order of magnitude, spiny lobster landings were followed by snapper/grouper, stone crab, and king mackerel.

For 1994 to 1998, total landings of the target species for the sample are shown in Figure 1. King Mackerel landings showed the largest increase over the period, from approximately 547,900 pounds in 1994 to 1.3 million pounds by 1998. Landings for stone crab were fairly steady over time, unlike that for snapper/grouper where landings exhibited a declining trend. Spiny lobster landings exhibited no clear trend.

The estimated coefficients of the output supply and input demand equations are reported in Table 2 with standard errors in parentheses. The parameter  $\beta_{ii}$  is reported as the coefficient for the effort variable. The generalized  $R^2$  for the system

of equations was 0.33, which indicated only a moderate fit. Most of the coefficients are significant at the 0.05 percent level. The statistical results suggest that there are annual differences in landings for the target species and in the demand for labor.

Table 1: Sample descriptive statistics

Variable	Mean	Standard Deviation	Minimum Value	Maximum Value
<b>Annual Prices</b>				
King Mackerel	1.25	0.17	0.41	3.00
Stone Crab	6.89	0.81	0.33	10.85
Snapper/Grouper	2.13	0.36	0.33	10.00
Spiny Lobster	4.31	0.80	0.50	14.00
<b>Annual Trips</b>				
1994	71.8	74.1	1.0	537.0
1995	71.4	72.4	1.0	500.0
1996	77.9	75.6	1.0	505.0
1997	78.7	79.5	1.0	538.0
1998	72.9	76.3	1.0	551.0
<b>Annual Landings</b>				
King Mackerel	698.3	4252.7	0	147930.0
Stone Crab	1371.4	3719.9	0	52652.0
Snapper/Grouper	2769.2	8017.0	0	107695.0
Spiny Lobster	4114.1	8056.7	0	73106.0

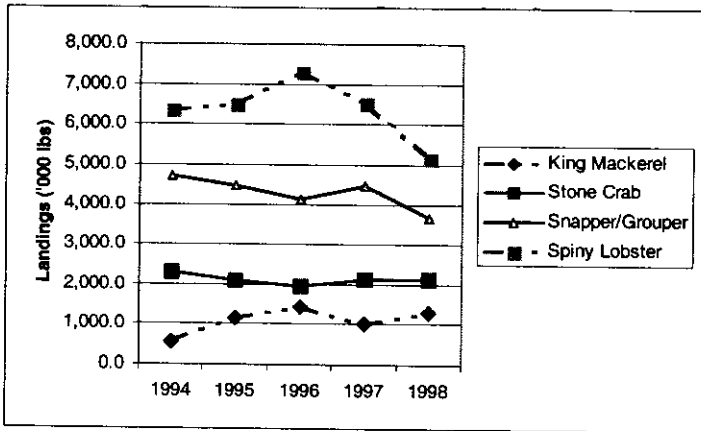


Figure 1. Total landings of target species



Table 2. Parameter Estimates - Output Supply and Input Demand Functions

Independent Variables	Output/Input (Dependent Variables)				
	King Mackerel	Stone Crab	Snapper Groupers	Spiny Lobster	Labor
Fishing Effort	-24.898* (4.930) <sup>a</sup>	-111.199* (5.042)	50.781* (6.058)	-119.529* (8.028)	-50.451* (2.864)
Effort squared	-0.02* (0.003)	0.039* (0.003)	-0.094* (0.005)	-0.016* (0.005)	0.001 (0.0006)
Output Prices:					
King Mackerel					
Stone Crab	-7.202* (2.422)		SYMMETRIC		
Snapper Groupers	1.487 (2.922)	2.194 (4.188)			
Spiny Lobster	-28.956* (3.658)	166.249* (5.302)	-26.200* (5.382)		
Input Price:					
Labor	55.891* (2.716)	-9.206* (1.172)	16.062* (1.373)	14.430* (1.913)	
Dummy Variables:					
1995	1.320 (1.038)	0.206 (1.038)	-2.327 (1.842)	-16.967* (1.911)	2.486* (0.242)
1996	-4.018* (1.270)	8.545* (1.182)	-7.399* (2.031)	-34.198* (2.091)	6.668* (0.312)
1997	-12.695* (1.369)	7.872* (1.117)	-4.904* (1.945)	-36.096* (1.963)	9.803* (0.419)
1998	-14.530* (1.382)	15.050* (1.183)	-9.783* (2.040)	-48.804* (2.130)	9.553* (0.441)

<sup>a</sup> Standard errors in parentheses.

\* Denotes statistically significant at the 0.05 percent level.

The coefficients of the effort variable were all significant at the 0.05 percent level. However, except for snapper/grouper, all the parameters are negative. For this group, an additional trip per year is anticipated to increase landings by 50.8 pounds. These results suggest that additional effort may be directed toward snapper/grouper. However, the rate of change in harvest levels as effort increased for all target species, while significant, were negligible. The model suggests that an additional trip will lead to an increase in the quantity of labor utilized by approximately 50 man-hours.

The results of the tests for nonjointness-in-inputs and input-output separability are presented in Table 3. As shown in Table 3, nonjoint production of all species and input-output separability are rejected.

The rejection of nonjointness implies that the quantity of landings of a particular species is dependent on the inputs used in harvesting other species. This affirms the existence of economic interactions in the production of the four key species groups of Monroe and Collier counties. Therefore, single species management would affect

the harvest of the other species. The rejection of separability suggests that the species could be better managed with the regulation of the composite input, rather than with individual variable inputs. It should be noted, though, that while nonjointness-in-inputs and separability were rejected for all species, these results do not preclude possible interactions between subsets of the species.

**Table 3. Statistical Results of tests - Jointness and Separability in Outputs**

F-Statistics <sup>a</sup>	
Nonjointness (R, MT-K) <sup>c</sup>	Separability (R, MT-K)
157.62 (10, 38,715)	129.03 (5, 38715)

<sup>a</sup> The critical F-value,  $F_{10, 38,715}^{10} = 2.32$ , and for  $F_{5, 38,715}^5 = 3.02$ .

<sup>c</sup> R is the number of restrictions and MT-K is the degrees of freedom

The technical and economic interactions of the fishery are also shown by the calculated own and cross-price elasticities of supply and demand, which are shown in Table 4.

**Table 4. Estimated own-price and cross-price elasticities (1994 - 1998)**

ith species	King Mackerel	Stone Crab	Snapper Grouper	Spiny Lobster	Labor
King Mackerel	-3.722	-11.240	0.400	-22.408	47.690
Stone Crab	-0.189	-6.017	-0.189	0.128	27.942
Snapper Grouper	0.035	0.662	0.209	-1.705	0.035
Spiny Lobster	-0.320	23.719	-0.644	-3.135	0.662
Labor	19.819	-42.154	12.669	32.921	-23.314

The own-price elasticity of snapper/grouper is positive (0.209), but is very inelastic, which indicates that as the price rises by 1 percent, the quantity harvested will increase, but by only 0.2 percent. All other own-price elasticities were negative. The positive cross-price elasticities between king mackerel and snapper/grouper indicate that these outputs are complementary (i.e., joint) in production. However, this effect is inelastic so that a 1 percent increase in the price of snapper/grouper would lead to only a 0.4 percent rise in the harvest of king mackerel. The cross-price elasticity between king mackerel and both stone crab and spiny lobster are negative, which indicates that these species are substitutes. In fact, these relationships were extremely elastic so that, for example, a 1 percent increase in the price of spiny lobster will cause a 22.4 percent fall in the quantity harvested of king

mackerel. These results are consistent with the descriptive statistics, which show that stone crab and spiny lobster are the two highest priced species. The bigger cross-price effect for spiny lobster may be due to the fact that although spiny lobster has the highest price, it had more than twice the volume of landings, on average, than stone crab and is therefore the higher valued species. The nature of these relationships (complements and substitutes) between king mackerel and the other species are consistent for all reported cross-price elasticities. However, the strength of these relationships is much smaller for the mirror cross-price calculations. For example, a 1 percent increase in the price of king mackerel will only lead to a 0.3 percent fall in the landings of spiny lobster. This reinforces the suggestion of the results that indeed stone crab and spiny lobster are the dominant species in the fishery. The relationship between stone crab and snapper/grouper is not consistent. The positive cross-price elasticity between stone crab and spiny lobster indicates that these species are complements. As expected, higher prices for king mackerel, snapper/grouper and spiny lobster increased the demand for labor.

#### CONCLUSION

The four primary fish species in the Monroe/Collier County fishery (i.e., king mackerel, spiny lobster, snapper/grouper and stone crab) all face the problems of overfishing and/or overcapitalization. To date, efforts to address these issues have been on a single-species basis. These target species have, on average, a large difference in their ex-vessel price per pound. Spiny lobster was the dominant species in terms of landings, with a mean of 4,114.1 pounds per year per firm, over the study period. In order of magnitude, spiny lobster landings were followed by snapper/grouper, stone crab and king mackerel. In this preliminary study, total number of trips taken annually was used as the effort variable and labor was the only variable input included.

Nonjoint production of all species and input-output separability were rejected. This implies that the quantity of landings of a particular species was dependent on the inputs used in harvesting other species. This affirms the existence of economic interactions in the production of the four key fisheries in South Florida, therefore, single species management would affect the harvest of the other species.

The own-price elasticity of snapper/grouper was positive but very inelastic (0.209). All other own-price elasticities were negative. The positive cross-price elasticities between king mackerel and snapper/grouper indicate that these outputs are complementary (joint) in production, however, this effect is inelastic. The cross-price elasticity between king mackerel and both stone crab and spiny lobster were negative, which indicates that these species are substitutes. These relationships, however, were extremely elastic. For example, a 1 percent increase in the price of spiny lobster would cause a 22.4 percent fall in the quantity harvested of king mackerel. These results are consistent with the descriptive statistics, which showed that stone crab and spiny lobster are the two highest priced species. The bigger cross-price effect for spiny lobster may be due to the fact that although spiny lobster

has the highest price, it has more than twice the volume of landings (on average) than stone crab and is, therefore, the higher-valued species. The relationship between stone crab and snapper/grouper is not consistent. The positive cross-price elasticity between stone crab and spiny lobster indicates that these species are complements. As expected, higher prices for king mackerel, snapper/grouper and spiny lobster increased the demand for labor.

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