Economic Determinants of Fishing Effort in Colombia's Caribbean Spiny Lobster Fishery

Determinantes Económicos del Esfuerzo de Pesca en la Pesquería de Langosta Espinosa del Caribe Colombiano

Les Déterminants Economiques de l'Effort de Pêche dans la Pêche de la Colombie Langouste Blanche des Caraïbes

JOSH NOWLIS[1]*, ERICK CASTRO[2,3], MARTHA PRADA[3], TRISHA FORBES[2], HUGO WILSON[2], HEINS BENT[2], and LUCY ALVAREZ BUSTILLO[4]

*[1]Bridge Environment, 947 NE Boat Street, Seattle, Washington USA. *Josh@BridgeEnvironment.org. [2]Secretaría de Agricultura y Pesca, Coral Place, Avenida Newball, San Andrés Isla, Colombia. [3]Corporación para el Desarrollo Sostenible del Archipiélago de San Andrés, Providencia y Santa Catalina—CORALINA, Via San Luis, San Andrés Isla, Colombia. [4]Antillana SA, Zona Industrial Portuaria, Cr1 Noroeste 8-41, Relleno Muelle, San Andrés Isla, Colombia.*

ABSTRACT

In assessing fisheries, effort information can often be a limiting factor. This is true of well documented legal fishing fleets, and even more so of illegal, unreported, and unregulated (IUU) fleets. We studied the insular Colombian Caribbean spiny lobster fishery to see if economic conditions have influenced fishing effort in the observed fleet. We have catch per unit effort data from the diver- and trap-based industrial fishing vessels with Colombian permits spanning a period of light fishing, expansion, stock collapse, and recent signs of rebuilding. Economic data were available on the costs of fishing and expected revenues over the past 15 years. We performed a regression analysis of various measures of fishing effort on expected costs of fishing and on expected revenue per unit effort. Effort measures included annual participation (a binary variable), trips per season, and days per trip. Expected costs of fishing were calculated by accounting for a wide range of factors, but fuel price drove annual variability. Expected revenues per unit effort were determined by multiplying the price of lobster by last season's fleet-specific catch per unit effort, both of which varied from year to year. Our results indicate that boats were more likely to participate and take more trips per year when fishing costs were lower and expected revenue per unit effort were higher. Trips were also longer when costs were lower. Our results imply that economic conditions may be crucial in determining fishing pressure, and provide insight for better modeling of IUU fishing.

KEY WORDS: Fisheries economics, predicting fishing effort, spiny lobster

INTRODUCTION

In textbook form, assessment models present a simplified view of a fishery, in which science dictates management measures and these measures motivate compliance. While most scientists with any real-world experience will admit to frequent gaps between science and management, both of these links are tenuous. A more realistic view of a fishery treats it as a system that includes ecological dynamics, which are beyond our direct control; human nature in the form of personal and social incentives, which are also beyond our control; and a management system, which is our best attempt at control. Failures in the motivation of compliance can lead to illegal, unreported, and unregulated (IUU) fishing activities. This paper uses a stock assessment combined with economic analyses to examine IUU fishing. It asks two fundamental questions:

i) How much control do we have over fisheries?
ii) Can we improve assessments by using economic variables to estimate IUU fishing pressure?

Colombia's insular fishery for Caribbean spiny lobster (*Panulirus argus*) provided us with a particularly useful chance to study economic incentives and IUU fishing. For the San Andrés archipelago, also known as the Seaflower Biosphere Reserve, the spiny lobster is the largest fishery, valued at over six billion COP of legal product annually, and represents the only major export from this region. It also has an important local cultural history (Shacochis 1985). As with other Colombian fisheries, this one is managed through annual quotas, size limits, and closed seasons and areas. However, enforcement is made difficult by the remoteness of the fishing grounds, which also increase the cost of fishing due to heavy fuel consumption. The high value of the fishery, combined with proximity of fishing grounds to Nicaragua and Honduras, creates conflict and persistent unpermitted fishing, which further undermine enforcement and compliance.

METHODS

We first assessed the health of the Seaflower Biosphere Reserve's spiny lobster fishery in 2006, and revised the assessment each year from 2008 – 2012. These assessment efforts relied primarily on estimated catches and abundance indices calculated from the catch-per-unit-effort of the two main fishing sectors: dive boats and trap boats. There is also limited size information available, but not enough to build into the assessment model.

Catch Data

Artisanal landings since 2004 were compiled from user's monthly and annual trip reports, which list the name and location of the fisher. Reports were compared against independent landings surveys conducted by the Secretaría de Agricultura y Pesca. Data prior to 2004 were obtained from compilation of historical trade certificates integrated into a database (Prada et al. 2009, Prada and Castro In press).

These artisanal catch data were summed to produce annual landings measured in kg of lobster tails by year, all of which were assumed to have been collected by divers. From 1996 to 2010 industrial boats that had misreported their landings as artisanal were identified using historical records and local knowledge. For these boats, as well a few we could not identify as legitimate artisanal vessels, we created a new landings category: misreported industrial. These landings were scaled up by 25% to account for non-reporting. While legitimate artisanal landings were assumed to come from divers, the misreported industrial landings were split among diver and trap fleets based on the proportional contribution of each to industrial catches in that year. Artisanal reports were missing in 1982 and from 1985 – 1991. These gaps were filled by averaging the two previous and two subsequent years and extrapolating linearly between them.

Industrial landings were compiled from a similar source as described for artisanal fishers. Since 2004 technicians have verified all landings when they enter the processing plant. Thus, in most cases there were agreements between the two industrial data sources. Previous years were obtained from compilation of historical annual trip reports integrated into the same database and validated against export certificates (Prada et al. 2009, Prada and Castro, In press).

The industrial catches were expressed in kg of lobster tails and summed by year and gear (diver or trap). Landings that were reported without identification of a gear type were split among diver and trap fleets based on the proportional contribution of each to reported industrial catches in that year.

Non-authorized foreign vessels fish in this area despite Colombian prohibitions, and their catches go unreported. To produce an initial estimate of these catches, we used data from four impounded vessels. Three of these vessels collectively contained 14,030 kg of lobster tails. The fourth, impounded in 2011, had only been fishing for half a month and had 2,077 kg of lobster tail. We assumed this boat would have doubled its catch had it not been impounded, so the four boats would have had a total of 18,184 kg, for an average of 4,546 kg per trip per vessel. We assumed that half of this catch came from Colombian waters, the focus of this assessment. Based on interviews of air force personnel and local boat captains, it was further assumed that around five illegal fishing vessels made monthly trips during open season (12 months through 2003, nine months from 2004 onwards) through 2007. Starting in 2008, we assumed a 40% increase in illegal fishing operations because the Nicaraguan government made public claims to the northern archipelago and began impounding Colombian vessels, while the Colombian government attempted to avoid conflict by ending their own enforcement of illegal fishing by Nicaraguan vessels. Prior to 2000, these boats lacked basic technologies, particularly outboard motors on launch vessels and GPS. Therefore, it was assumed that illegal foreign catches caught a third of values from 2000 onwards. Our long-term goal is to use the results of this study to improve upon these estimates.

We explored the effect of many of these assumptions through sensitivity analyses. For instance, the model was run with assumptions of three and seven illegal fishing vessels, and with an increase of 0 or 80% in illegal fishing by foreign vessels since 2008. A final sensitivity analysis explored a recent regulation change. In mid-2007, diving for lobsters on industrial boats was prohibited for the entire Biosphere Reserve. However, the trip data suggested that some industrial diving might still take place. Consequently, the final sensitivity analysis reclassified trips from late 2007 onwards as dive trips if the boat had a history of dive fishing and the crew was primarily from Colombia (trap boats tend to work more with Nicaraguans).

Effort Data

The industrial landings data were accompanied by measures of fishing effort. For most trips, we had a measure of the days fished separate from travel time. If not, we assumed it was one day less than the total days at sea. For dive trips, we multiplied the days fished by the number of divers. We also scaled effective effort down by 2/3 prior to 1996 to account for a lack of outboard motors and GPS (these technologies were adopted by Colombian fleets before Nicaraguan fleets), and the lack of outboard engines. The effectiveness of trap effort was assumed to increase at 2% per year to account for better technologies over time. A similar factor accounted for increased experience among captains over the development of the fishery. To model gains from experience, we modeled relative effort using an effort multiplier, *K*, from the formula:

$$K = 2 + \frac{Y-1985}{20}$$

where *Y* is the year. This formula was developed in direct consultation with experienced lobster captains and results in a first-year increase in effective effort of 2.5%, decreasing to under 1.5% in the last years of our series. Captains have also increased the number of traps hauled up to 2000 and kept constant since then (Prada et al. 2009). We accounted for this trend by determining the average number of trap lines used each year (available from logbooks, not landings reports) and including this as an effort multiplier.

Catch per unit effort was then calculated per trip and averaged to produce an index of abundance. No standardization was possible given a paucity of data on other factors. There was the option to develop a separate trap index from the logbook data. This index did not correlate with any possible explanatory variables, so index values were simply the annual means. Further weaknesses were that these data vary by two orders of magnitude in extent each year and only extend from 1993 to 2005. Consequently, they were used only as a sensitivity analysis. Other sensitivity analyses included varying the trap technology effect (0% increase, 4% increase), and the influence of outboards and GPS on diving effectiveness starting in 1997 (no change from before, a doubling of previous effort).

Economic Analyses

We examined economic incentives to fish and their correlation with fishing effort. At this point, our results are preliminary but have the potential to guide estimates of unreported illegal fishing, any future effort to limit the number of licenses, and identification of economic conditions that might warrant the need for stricter regulations.

In this analysis, various measures of effort were regressed on the expected revenue (in US dollars) per unit effort ($PUE) and the expected costs of fishing. Effort measures included a binary variable for participation in a given year, an integer measure of the number of trips taken per year for active boats, and a measure of the length of each trip in days. Lobster prices were found in the Urner Barry database. We used the average price from May of that year. Expected revenue per unit effort was the product of this price and catch per diver or trap per day from the previous year (assuming the expectation of catch per unit effort was the fleet average from the past year). Finally, costs were modeled taking into account engine size as a function of fuel use, fuel price, and costs of oil, administrative fees, maintenance, traps or divers, and crew and food.

RESULTS

Surplus Production Model

The data showed some clear signals of a fishery that started with high stock abundance, was fished down, and has recently rebuilt. Catches increased gradually through the 1980s and dramatically through the 1990s before declining through the current decade, with a slight increase in the most recent years (Figre 1a). Overall landings were dominated by industrial catches, which also drove the patterns of increase and decline. Note that catches seem to be unaffected by the annual quota. In most years, the Colombian fleet failed to reach the quota, even when it was increased in the late 2000s. However, the quota also failed to limit catches in the late 1990s and early 2000s, when catches exceeded quotas. Indices of abundance showed generally consistent trends of high but volatile early values, steep declines in the 1990s, and recent signs of recovery (Figure 1b).

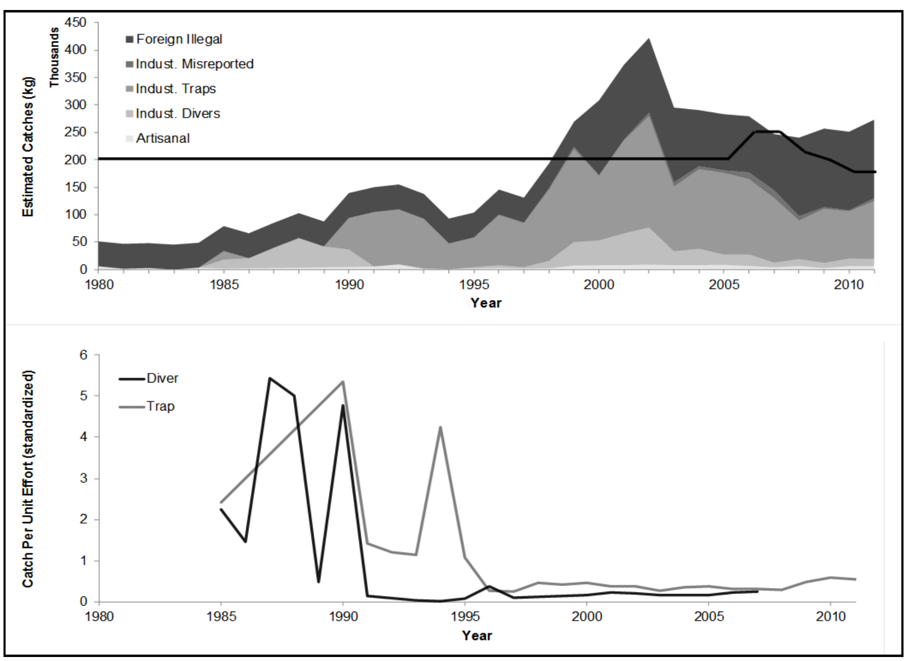

Figure 1. Catches and Relative Abundance Through Time. A. Catches. Note the black line, which represents quotas over time. Other elements are identified in the legend. B. Abundance. Fleet-specific catch per unit effort series, which were standardized to average 1 over time.

Surplus production models contain few free parameters. Their rigid structure assumes a constant relationship between biomass and surplus production. As such, they have a difficult time fitting data when catches and abundance indices trend in the same direction. This pattern is encountered surprisingly often, most likely because the fishery data span a relatively short timeframe and a homogeneous set of conditions. In these circumstances, natural variability can swamp patterns driven by changes in biomass and production.

Unlike most simple assessments, the data for spiny lobster were consistent with a surplus production model. Catches increased during the late 1980s and 1990s while indices of abundance dropped, and indices of abundance have increased in recent years following reductions in catches. This consistency is most likely a result of a data series that started before the explosive growth of the fishery but may also be an indication of strong local recruitment patterns. As a result of the data consistencies, all model runs converged on parameter estimates quickly and without problems of multiple local optima.

The model estimated that the population started at near pristine condition (pristine occurs at a biomass ratio of 2) in the early data years, declined rapidly in the late 1990s, and rebounded in recent years when fishing pressure was light (Figure 2). The results suggest that the fishery experienced overfishing (a fishing mortality rate above F_{MSY}, the rate that would produce maximum sustainable yields (MSY)) for most of the past decade, and that the stock dropped below B_{MSY}, the biomass level that could sustain MSY catches in equilibrium. The model estimated that fishing pressure recently dropped below F_{MSY} and allowed the stock to rebuild above B_{MSY}, so that the fishery now appears to be healthy. The model estimated that the fishery is capable of an MSY of 328 metric tons, of which 185 mt would be available to Colombians after accounting for estimated levels of illegal foreign fishing.

Economic Analyses

Prices varied a great deal over the past 15 years. Whereas the price paid per pound of lobster increased gradually until 2008 and then dropped precipitously with the world recession, fuel prices have risen for the most part since 2000 (Figure 3). The result has been increasingly hostile economic conditions for the lobster fishing fleets.

Regression analyses revealed a strong link between incentives to fish and fishing effort. For industrial trap boats, fishers were more likely to participate in a given year, and participants made more trips in a year, if expected revenues per unit effort ($PUE) were high and expected costs were low (see Table 1). For both trap and dive boats, days per trip were significantly correlated with the expected costs of fishing. However, whereas higher cost expectations were associated with shorter trips in the trap fishery, they were associated with longer trips in the dive fishery. In general, the results showed higher effort with more expected revenues and less expected costs (as suggested by Figure 4). This finding supports the idea that this fishery is limited by economic conditions and makes plausible the ability to estimate past IUU fishing effort and predict future fishing effort by legal and illegal vessels from the prices of lobster and fuel.

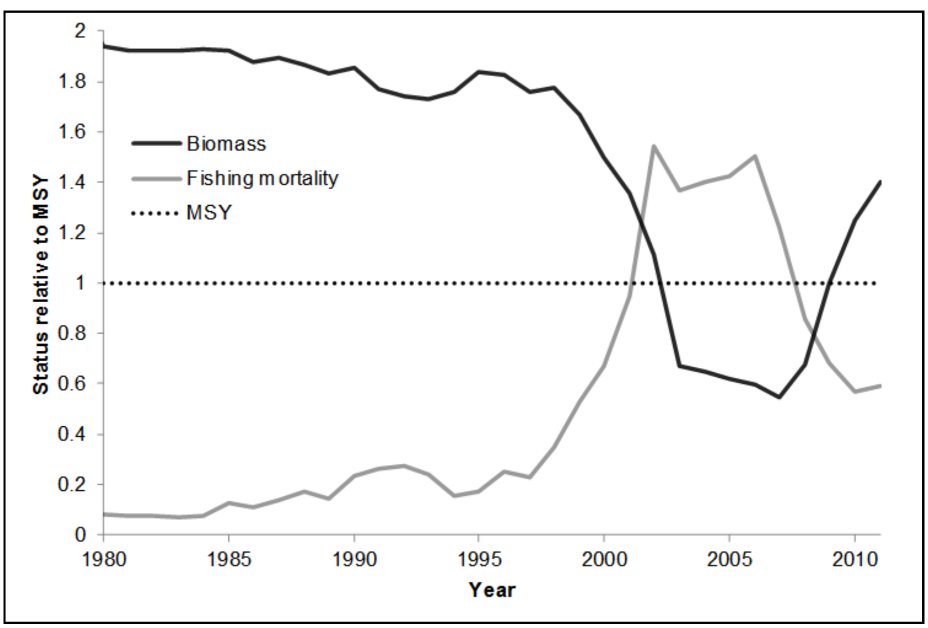

Figure 2. Assessment Results. Based on the available data, the model estimated that the stock started in near-pristine condition, declined into overfished status over the late 1990s, and rebounded in the late 2000s.

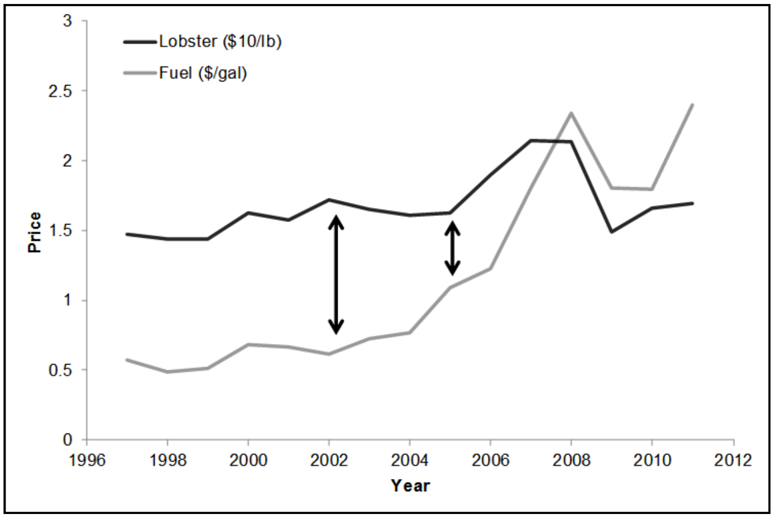

Figure 3. Economic Variables. Over the past 15 years, the price of fuel has increased relative to the price of lobster, making fishing less economical.

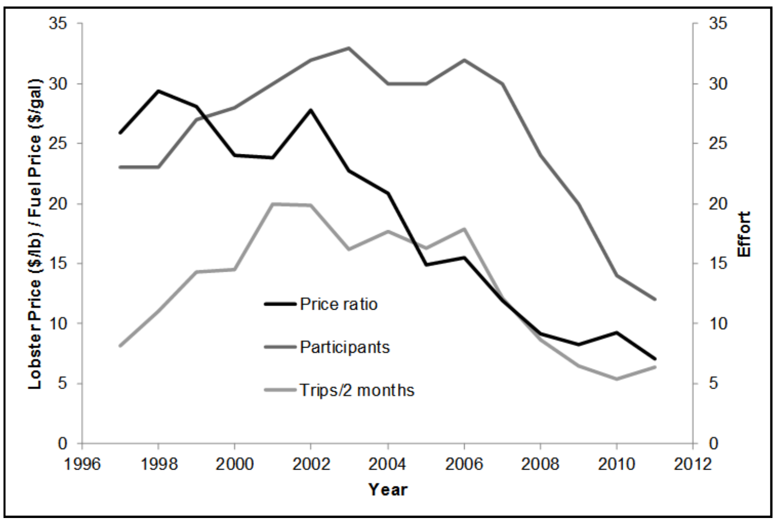

Figure 4. Economic Effects on Effort. As prices became less favorable for fishermen, represented here as the ratio of the lobster to fuel price, participation and number of trips per participant both declined.

Table 1. Economic Regression Results. Parameter values of interest are indicated in **bold** font. p-values marked with ** are statistically different from 0 with 95% confidence.

	$PUE parameter	*p*-value	Cost parameter	*p*-value	Intercept	*p*-value
TRAPS						
Annual participation	**1.04**	0.029**	**-1.17e-5**	0.025**	0.869	0.14
Trips/year	**1.23**	<0.0001**	**-1.37e-5**	<0.0001**	4.63	<0.0001**
Days/trip	0.114	0.12	**-1.14e-5**	<0.0001**	57.9	<0.0001**
DIVERS						
Annual participation	-0.038	0.65	7.23e-6	0.45	-1.97	0.016**
Trips/year	-0.0763	0.34	-6.73e-6	0.47	7.05	<0.0001**
Days/trip	-0.0166	0.91	**7.15e-6**	0.0024**	20.2	<0.0001**

DISCUSSION

These results provide a number of notable observations and implications for fisheries science and management. First, they indicate that, at least in this fishery, the annual quota does not effectively control catches legal catches. The scale of unpermitted foreign fishing only emphasizes this point. Though conventional wisdom would lead us to predict a history of overages, the reality is that this fishery rarely meets the quota. It is of concern, however, that overages do occur when fishing is good. Note that the Colombian government does consider catches by foreign vessels when establishing the annual quota and so the expectation is that the quota would apply to the Colombian fleet alone.

Second, the results indicate that economic conditions have a great deal of influence over fishing effort. In the industrial trap fishery, where data was most complete, a unit increase in $PUE was associated with a 4.75% increase in participation, and 1.2 more trips annually for each participating boat. A unit increase in the cost per gallon of gas was associated with a 2.68% drop in participation and 0.68 fewer trips annual for each participating boat. In combination, the large fluctuations in expected lobster revenue and fishing costs were strongly linked with reduced fishing effort during the world recession of the late 2000s. It was during this time that the fishery recovered, suggesting that economic conditions may be responsible for the current health of Colombia's Caribbean spiny lobster fishery.

Though unusual in the remoteness of fishing grounds, this is not the only fishery where fuel prices and market demand may influence effort. Some fisheries have had recent drop in prices as a result of competition from cultured versions (e.g., salmon, shrimp) and gas prices remain a major contributor to the costs of fishing for many fisheries. In cases where market prices for fish are volatile and where fuel costs are a major portion of budget, we should consider that economic conditions may be playing a role in controlling a fishery, thus creating the potential for uncontrolled growth if economic conditions improve.

On the plus side, this technique suggests we may be able to predict effort based in some fisheries based on a couple of simple prices. This ability would help us with more accurately estimating IUU fishing and thus more accurately assessing stocks. It also offers the potential to predict regulatory needs early on in a fishing season. Further research will help to develop tools to take advantage of this improved understanding.

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