

Incorporating Market Information In The Management Of The US North Atlantic Bluefin Tuna

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Abstract. The US North Atlantic bluefin tuna (*Thunnus thynnus*) fishery is one of the most controversial cases of renewable resource exploitation. Public management of this resource has resulted in substantial public debate. Bluefin tuna is also considered a culture-specific product, as it is almost exclusively consumed uncooked in Japan. Bluefin tuna is regarded as a high-quality product in the Japanese market and is characterized by an unusual marketing system by seafood industry standards. Each fish is individually inspected for freshness, fat content, color, and shape of the individual fish. The first objective of this study is to formally evaluate the degree to which price of US fresh bluefin tuna is determined by those quality attributes of each fish, rather than by just the quantity supplied. This is accomplished using a hedonic model. Further, freshness, fat content, color, and shape grades are known to vary depending on harvest method, area of harvest, and period of capture. Therefore, as a second objective we attempt to show how the quality of the US North Atlantic bluefin tuna depends on harvest practices. The third and final objective of this paper is to combine the results from the hedonic model and production models estimations to find quota allocations that could result in the highest payoffs to the industry.

Keywords: bluefin tuna, Japanese market, quality attributes, hedonic pricing, production methods, market-based management.

1. INTRODUCTION

The US North Atlantic bluefin tuna is one of the most controversial cases of renewable resource exploitation. Public management of the resource has resulted in substantial public debate. This debate has been frequently documented by the media, and it involves several views on the resource use from environmentalists, scientists and industry members (Seabrook, 1994; Liesman, 1998). The dispute between the opposing interests is further instigated by the uncertainty underlying public managerial decisions responsible for setting the limits to the exploitation of the resource (Sissenwine et al., 1998).

Bluefin tuna is considered a culture-specific product, as it is almost exclusively consumed uncooked in Japan. Over 45 countries compete to supply fresh bluefin tuna to Japan. From 1994 to 1997, in terms of unit value, the main sources of fresh bluefin tuna exports to Japan were Canada, the USA, and the Mediterranean region. In 1997, Japanese bluefin tuna imports of fresh, US product accounted for about 15 percent of all imports. However, the US share was greater during the summer months, when it comprised more than 25 percent of total Japanese imports (Food and Agriculture Organization, 1997; Japan Tariff Association, 1990-1998).

US captured bluefin tunas are graded by traders before they are priced at auction markets. In particular, four attributes of the fish are graded in each individual: freshness, fat content, color, and shape. Close to 90 % of the bluefin tunas captured in US waters are then exported to Japan and sold individually in local auction markets

for “sashimi” consumption. A good review on tuna markets in Japan is provided by Williams and Longworth (1989). In fact, the quality of the fish as reflected by its grades is known to be a determinant of price. The grades for the attributes of individual bluefin tuna are also known to vary depending on harvest method, area of harvest, and period of capture. These relationships suggest that there may be an opportunity to increase revenues to the fishery by allowing harvesting to adapt to those practices that lead to highest prices in the Japanese market.

Currently, the US exploitation of the North Atlantic bluefin tuna is managed by NMFS, based on recommendations from the International Commission for the Conservation of Atlantic Tunas (ICCAT). The regulations are directed towards an exploitation cap compliance. They control the amount of resource harvested on a yearly basis in an attempt to ensure the maintenance of an autoregenerative biomass of the resource. The constraints associated with this exploitation focus on the number of fish allowed to be captured per day per boat, fishing season, gear types, and area (Sissenwine et al., 1998). The current management plan for the harvest of US North Atlantic bluefin tuna does not account for the multi-attribute character of the product and it does not evaluate the economic impact of its current management practices. Regulations on the exploitation of bluefin tuna could attempt to maximize returns to the fishery through incorporating information, linking market and production characteristics. In fact, the idea of market-based public management of seafood products has been explored by others in the past (Sylvia and Larkin, 1995), because public management of

common-property natural resources can significantly affect their product markets (Sylvia, 1994). Regulatory schemes for common-property goods often ignore the consumer perceptions of a multi-attribute product by assuming that they are homogeneous commodities. Such a generalization is often inappropriate; in fact, the notion that capture-based products typically display wider variation than alternative perishable products is generally accepted (Anderson and Anderson, 1991). Private and public managers, therefore, should consider the potential market impact of product characteristics, since industry decisions to improve, control, and standardize characteristics are made within the constraints of public regulation (Sylvia, 1994).

The first objective of this study is to formally evaluate the degree to which price of US fresh bluefin tuna is determined by those quality attributes of each fish, rather than by just the quantity supplied. This is accomplished using a hedonic model. Further, freshness, fat content, color, and shape grades are known to vary depending on harvest method, area of harvest, and period of capture. Therefore, as a second objective we attempt to show how the quality of the US North Atlantic bluefin tuna depends on harvest practices. The third and final objective of this paper is to combine the results from the hedonic model and production models estimations to find quota allocations that could result in the highest payoffs to the industry.

2. PRICING US BLUEFIN TUNA IN JAPAN¹

The formal evaluation of the factors that determine price of US bluefin tuna is carried out with a hedonic price model. Hedonic models have also been applied to capture-based products, in particular tuna. Williams and Longworth (1989) used them to determine characteristics critical for yellowfin and bigeye tuna pricing at the Tsukiji Market in Japan.

For this study, individual fish ex-vessel prices, quality attribute grades, dressed weights, broker codes, sale days, forms of sale (consignment or dock settled), and market destination (Japan or USA) are examined using data from the US Department of Commerce (National Marine Fisheries Service, 1998). Tsukiji Market quantity data are obtained from Japanese auction reports. Daily exchange rates are obtained from the Federal Reserve Bank database. The model fitting is carried out using 12,072 individual observations of US bluefin tuna prices and characteristics compiled between 1994 and 1997. In fact, the data used for the analyses accounts for about 50 percent of all the bluefin tuna captured in the USA during that period.

The hedonic equation is a hybrid model in which the

importance of product attributes, as well as other variables, is tested. The dependent variable is the ex-vessel price per pound, P , of a single fish. There are four dummy quality attributes: FR_i are the $i = 1, \dots, 3$, freshness grade dummies of a fish; FT_j are the $j = 1, \dots, 4$, fat content grade dummies of a fish; CL_k are the $k = 1, \dots, 3$, color grade dummies of a fish; and SH_l are the $l = 1, \dots, 3$, shape grade dummies of a fish.

The dummies for freshness, fat content, color and shape are determined from traders' "A" to "E" grades. The aggregation levels are chosen based on experience accumulated from observations at the Tsukiji Market. The first grade dummy for each attribute is dropped to avoid perfect multicollinearity.

Additionally, eight independent variables are included in the model. The first two relate to the individual fish weight in pounds. Weight is incorporated in the model twice, as a linear and also as a quadratic variable. The third continuous independent variable is the yen/US\$ exchange rate on the day of the fish sale. Three other independent variables are the quantity (number of fish) of US bluefin tuna, the quantity of Japanese domestic bluefin tuna, and the quantity of non-US bluefin tuna imports at the Tsukiji Market. These variables are intended to capture the inverse relationship between supply and price. The last two independent variables are quantities of bigeye and southern bluefin tuna at the Tsukiji Market. These are included to test for possible substitutability with US bluefin tuna. These quantities are estimated by averaging the quantities present one day before the sale, on the day of sale, and one day after the sale (traders at Tsukiji know the incoming supply of fish). Tsukiji is the largest auction market for bluefin tuna in the world, and as a result, the abundance of fish in this market is used by traders as an index that helps them price the fish, regardless of its final market destination.

Five other types of dummy variables are included in the hedonic price model. The first one takes into account whether the fish had been sold during the Japanese Obon holiday. Some traders believe that during this holiday period, fish command higher prices than during the rest of the year. The second dummy separates fish that are traded on the last day of the month from those that are traded during the rest of the month. Bluefin tuna traders believe that fish fetch lower prices on the last day of the month due to diminished liquidity among Japanese buyers. The third dummy divides fish priced on Fridays from fish priced on any other day of the week. Fish sold on Fridays are believed to fetch higher prices in anticipation of increased consumption during the weekend. The fourth dummy variable separates consigned fish from non-consigned fish. Consigned fish are shipped to Japan where they are auctioned. Fishermen take the price determined at the auction after subtracting various costs and broker margins. The fisherman is the one economic agent deciding whether to consign a fish or settle on a

¹ Carroll, Anderson, and Martínez-Garmendia (in press).

price with the broker at the dock. Usually, fishermen prefer to consign fish of high quality, while settling on a price at the dock when fish quality is not as high. It takes approximately two to three days until a US captured, consigned fish is auctioned in Japan. The fifth dummy variable differentiates between fish exported to Japan and fish directed towards the US market. Almost 90 percent of the fish evaluated in this study were shipped to Japan, while the rest were sold in the USA for *sashimi* or other fresh markets. Generally, the US market was regarded as a secondary market for lower quality fish. However, the gradual increase in US consumption of raw fish and the continued appreciation of the yen/US\$ exchange rate over the last several years are turning the US market into an increasingly popular destination for fresh bluefin tuna.

An extra dummy variable group captures departures in pricing resulting from heterogeneous broker handling of the fish. The top 30 brokers and the aggregate of the remaining brokers are considered. We eliminate the aggregate of the remaining brokers from the model to avoid perfect multicollinearity among the dummy variables.

The choice of functional form for hedonic price models is a difficult decision. Different authors have pointed out a variety of decision rules for functional form model specification. For example, Brown and Ethridge (1995) proposed an econometric approach to infer a functional form for the model under study. In their paper, however, they assume that all relevant explanatory variables are being included in the model. On the other hand, Cropper, Deck and McConnell (1988) found through simulations that when omission of variables may be a problem, as it often is, simpler forms such as linear, semi-log, double log or Box-Cox approaches perform better than more complex ones. The first three types of functional forms were tested for this study. From preliminary results, we concluded that a double log form behaves particularly well. As a result, and also because the ease of interpretation of its coefficients as price flexibilities, a double log functional form was chosen for this study. The model estimated is

$$\ln P = \alpha + \sum_{i=2}^3 \phi_i FR_i + \sum_{j=2}^4 \chi_j FT_j + \sum_{k=2}^3 \delta_k CL_k + \sum_{l=2}^3 \varepsilon_l SH_l + \beta_1 \ln DRW + \beta_2 DRW + \beta_3 CONS + \beta_4 XPORT + \beta_5 \ln XRATE + \beta_6 \ln US + \beta_7 \ln JAP + \beta_8 \ln OTH + \beta_9 \ln BE + \beta_{10} \ln SBF + \beta_{11} BON + \beta_{12} LDMTH + \beta_{13} FRIDAY + \sum_{m=1}^{30} \gamma_m B_m + e \quad (1)$$

The parameters of the equation are estimated using least squares, and the variances are re-estimated using the Newey-West algorithm to account for autocorrelation and heteroskedasticity (Greene, 1993).

Table 1: Parameter Estimates For The Hedonic Model

Variable	Coefficient	Exp. Coeff.	Prob.
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	2.5038	N/A	0.0000
FR2	0.0772	1.0802	0.1083
FR3	0.1541	1.1666	0.0044
FT2	0.1200	1.1275	0.0018
FT3	0.3646	1.4399	0.0000
FT4	0.5629	1.7557	0.0000
CL2	0.0814	1.0848	0.3213
CL3	0.2439	1.2762	0.0000
SH2	0.2502	1.2842	0.0000
SH3	0.5035	1.6545	0.0000
ln DRW	0.5956	N/A	0.0000
DRW	-0.0021	N/A	0.0000
CONS	0.0568	1.0585	0.0016
XPORT	0.5125	1.6695	0.0000
ln XRATE	-0.8472	N/A	0.0000
ln US	-0.0588	N/A	0.0000
ln JAP	-0.0509	N/A	0.0000
ln OTH	-0.0052	N/A	0.2734
ln BE	-0.0060	N/A	0.7876
ln SBF	0.0011	N/A	0.9318
BON	-0.0354	0.9652	0.2367
LDMTH	-0.0659	0.9363	0.1372
FRIDAY	0.0111	1.0112	0.5632

Results indicate that all quality attributes considered in this model significantly affect price. The grade aggregation chosen for each quality attribute (i.e., freshness, fat content, color, and shape) seems to reflect a gradually increasing positive impact of higher grades on price. This effect is specially notable for fat content, color, and shape, while the dummies for freshness present more modest coefficient magnitudes. A bluefin tuna receiving the highest grade for freshness is expected to command a price 17 percent higher relative to a bluefin tuna receiving the lowest grade, other conditions kept constant. For fat content, on the other hand, the highest grade is estimated to receive a price which is 76 percent higher than that of the lowest grade. A bluefin tuna with the highest color grade results in an expected price which is 28 percent higher than the lowest graded fish. With respect to shape, the highest graded bluefin tuna is expected to receive a price 65 percent higher than the price attained by a fish with the lowest grade. The parameters associated with fish weight are consistent with the hypothesized relationship between price and weight. This relationship is positive for smaller bluefin tuna and negative for large ones. These results support the hypothesis that fresh bluefin tuna is, in fact, priced based on its multi-attribute properties.

The rest of the parameters included in the hedonic price model test hypotheses related to the beliefs of producers and traders. For example, fish consigned to Japan obtain an expected price that is 6 percent higher than fish priced in the USA.

The yen/US\$ exchange rate has a significant negative effect on price received by producers. Bluefin tuna from the USA are purchased with yen in the Japanese markets,

and as a result, a lower conversion rate is preferred by US exporters. In fact, a 1 percent increase in the exchange rate (weakening of the Japanese yen relative to the US\$) results in an estimated 0.85 percent decrease in the price a fisherman receives. The decline in price of US exported bluefin tuna, resulting from such devaluation of the Japanese yen, is shared by all economic agents participating in the transaction (i.e., consumers, brokers, and fishermen).

In terms of quantity, US and Japanese products are negatively correlated with price. Quantities from both origins have a close effect on price, indicating they are perceived very similarly on the market. However, bluefin tuna from other countries seems to have no significant effect on the price of US bluefin tuna. However, an increase of 1 percent in the supply of either US or Japanese bluefin tuna on the Tsukiji Market results in a price decrease of more than 0.05 percent for a single fish. These low price flexibilities are explained by the fact that the observations for this study are daily and there are large supply fluctuations from day to day, from as low as 20 fish to highs well over 1,000. Traders in the Tsukiji Market are aware of these supply fluctuations. When supply is very low in a certain day, traders are not forced to buy product that very same day. They can wait a few days until the supply is higher, and price lower. With regard to other tunas, the simultaneous presence of bigeye and southern bluefin tuna in the Tsukiji Market seems not to have a relevant impact on the price of US bluefin tuna.

The coefficients associated with the tested special sale days present no major bearing on price. The parameters for the Obon holiday, as well as Friday sales, can be considered insignificant at p-values larger than 20 percent.

Among special sale days, the last day of the month has the most significant effect on price, with a p-value smaller than 14 percent. Sales on the last day of the month are expected to be subject to a price decrease of more than 6 percent relative to fish sold at any other time of the month.

Broker effect on price seems to be important, considering that most of the coefficients are statistically different from zero. There are only four brokers out of 30 that result in values insignificantly different from zero (at a 10 percent level of significance): brokers 8, 9, 29 and 30. Differences in personal judgment at the moment of pricing, as well as handling procedures when the bluefin tuna is consigned, could be responsible for the statistical significance of most parameters associated with brokers. In general, the handling of a fish by the top 30 brokers would result in a higher price than when the fish is handled by other brokers. This may suggest that, in general, the brokers that handle the most fish are able to obtain better prices.

3. EFFECT OF HARVEST PRACTICES²

For this study, quality attribute grades, gears, areas, dates of harvest and broker codes for each graded fish are available from the U.S. Department of Commerce (NMFS 1998). The data used for this study comprises 12,645 individual observations of U.S. bluefin tuna attributes and weights compiled between 1994 and 1997. The data used for the analyses presented in this study account for almost 50% of all the bluefin tuna landed in the U.S. between 1994 and 1997.

The four attributes considered as dependent variables are freshness, fat content, color, and shape. A fish is given a separate grade for each of the four attributes. The dummy categories for freshness, fat content, color and shape are created from traders' "A" to "E" grades and are depicted in Table 1. These grade categories are defined on an ordinal scale based on experience from observers at the Tsukiji market in Tokyo. It follows that freshness, color and shape have three possible grades each, while fat content is described by four different grades. Five gears operate in this fishery: harpoon, hand-line, rod-and-reel, long-line, and purse-seines. The NMFS divides the fishing grounds for bluefin tuna into 10 areas. However, in this study, only areas 1 to 8 are considered because fish caught in areas 9 and 10 (which correspond to the Gulf of Mexico) are incidental rather than targeted captures.

Time of capture is divided into weekly units. Observations corresponding to weeks 1 to 24 of the year are lumped together; this period is referred to as "week 0." Observations are also aggregated for weeks 42 to 52; this period of time is referred to as "week N." The need for such aggregations rests on an insufficient number of weekly observations for statistical analysis for those two ranges of weeks.

More than 100 brokers are active in this fishery. The top 28 brokers (based on number of fish graded) are selected and assigned dummy variables, while the rest are lumped together under "other brokers."

Existence of multicollinearity between the exogenous variables gear, area, and week is explored. Multicollinearity between these three variables, however, is rejected by the condition number test (Greene 1993). The condition number has a value equal to 1.98, far below the significant collinearity threshold value of 20 suggested by Belsley et al. (1980).

Considering that the dependent variables in the attribute models are discrete and can take on only a fixed set of ordered values, an ordered response model is used for the analyses (Maddala 1983). In particular, an ordered-probit approach (Aitchison and Silvey, 1957) is followed to

² More details on these analyses can be found in Martínez-Garmendia, Anderson, and Carroll (in press).

estimate the parameters of the following linear models,

$$A_i = \sum_{g=1}^4 \beta_{ig0} D_g + \sum_{a=1}^9 \beta_{ial} D_a + \sum_{w=1}^{18} \beta_{iw2} D_w + \sum_{b=1}^{28} \beta_{ib3} D_b + e_i$$

$$i = \text{fat, freshness, color, shape} \quad (2)$$

where A is the grade of attribute i , β s are the coefficients of the independent variables, D s are dummy variables for 4 gears, g ; 9 areas, a ; 18 weeks, w ; and 28 brokers, b . The gear rod-and-reel, area 1, week 0, and “other brokers” are dropped to avoid perfect multicollinearity. Therefore, the baseline grade of attribute i is for a fish captured with rod-and-reel, in area 1, during week 0, and graded by a broker other than a top 28 broker. The β parameters, therefore, contribute to departures from this baseline.

In addition to the four attributes modeled above, weight of fish was also regressed against the same set of dummy variables, with the exception of brokers. In this case, an ordered-probit approach is not adequate considering that the dependent variable is continuous. Instead, an ordinary least squares estimation procedure was applied for the parameter estimation of the following model,

$$DRW = \delta + \sum_{g=1}^4 \alpha_{g0} D_g + \sum_{a=1}^9 \alpha_{al} D_a + \sum_{w=1}^{18} \alpha_{w2} D_w \quad (3)$$

where DRW is dressed weight of a fish in pounds, δ is the intercept and α s are the parameters for the above mentioned variables.

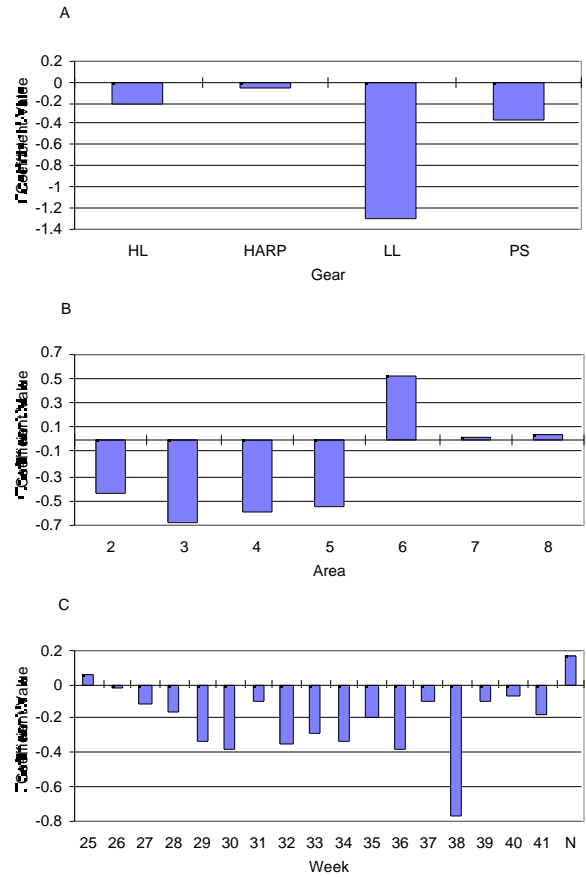


Figure 1: Coefficients for (A) gear (hand-line, HL; harpoon, HARP; long-line, LL; purse-seine, PS; baseline is rod-and-reel), (B) area (baseline is area 1) and (C) week (baseline is week 0) in the ordered-probit for freshness.

Choice of gear seems to be an important factor determining the freshness of fish. Freshness, on the average, attains higher grades when the fish has been captured by rod-and-reel or harpoon rather than by long-line or purse-seine. In fact, long-lines show a much more negative impact (-1.307) on freshness than the other gears do. Although not significantly different from rod-and-reel (the level of significance is 0.466), the most positive coefficient was for harpoon (0.041). Fish captured in areas 1, 6, 7, and 8 seem to result in a fresher product than in the other areas. Area 6 has the most positive coefficient (0.507), while the next positive value is for area 8, although not significantly different from area 1 (the level of significance is 0.795). Area 3 has the most negative coefficient (-0.665), followed by areas 4 (-0.587), 5 (-0.536), and 2 (-0.428). Weeks 0, 25 and N are associated with non-negative coefficients. This may have to do with the fact that it is easier to keep the product fresh during the cooler months. Most brokers present statistically significant (level of significance smaller than 0.05) parameters, with the exception of brokers 6 and 18.

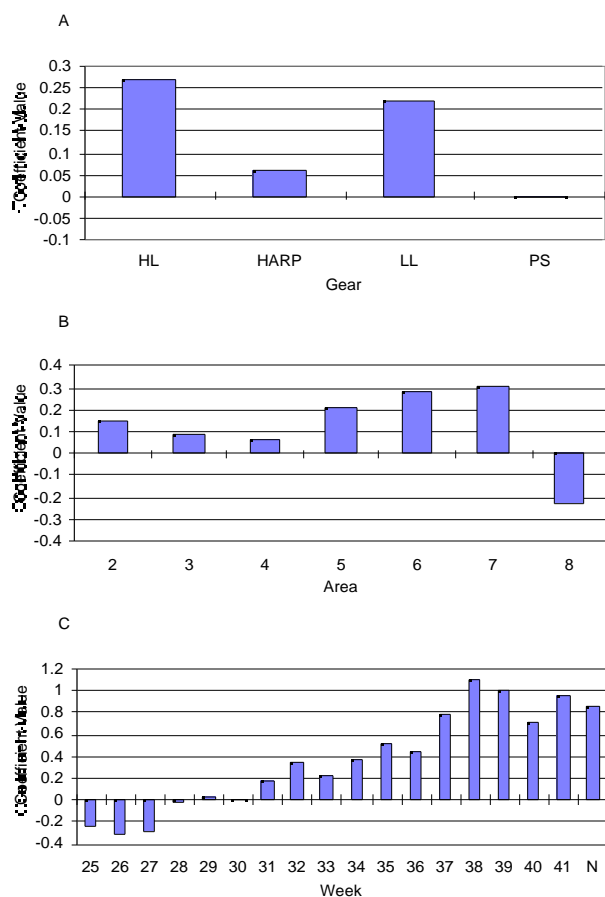


Figure 2: Coefficients for (A) gear (hand-line, HL; harpoon, HARP; long-line, LL; purse-seine, PS; baseline is rod-and-reel), (B) area (baseline is area 1) and (C) week (baseline is week 0) in the ordered-probit for fat content.

For fat content, hand-line (0.271) and long-line (0.221) receive statistically higher grades than harpoon, purse-seine or rod-and-reel. In terms of geographical differences, areas 7, 6, and 5 provide the fish with the richest content in fat (with coefficients 0.302, 0.284, and 0.204 respectively), while the rest of the areas present smaller coefficients, which are not different from the baseline at levels of significance smaller than 0.05. There is a marked increasing trend in the grade for fat content throughout the year. Fish harvested after week 29 receive higher fat content grades than during the rest of the year. The coefficients during that time range from 0.016 to 1.092, while for prior weeks all coefficients are non-positive. All brokers, except 7, 14, 18, 23, and 28, have statistically different (level of significance smaller than 0.05) parameters than the baseline brokers.

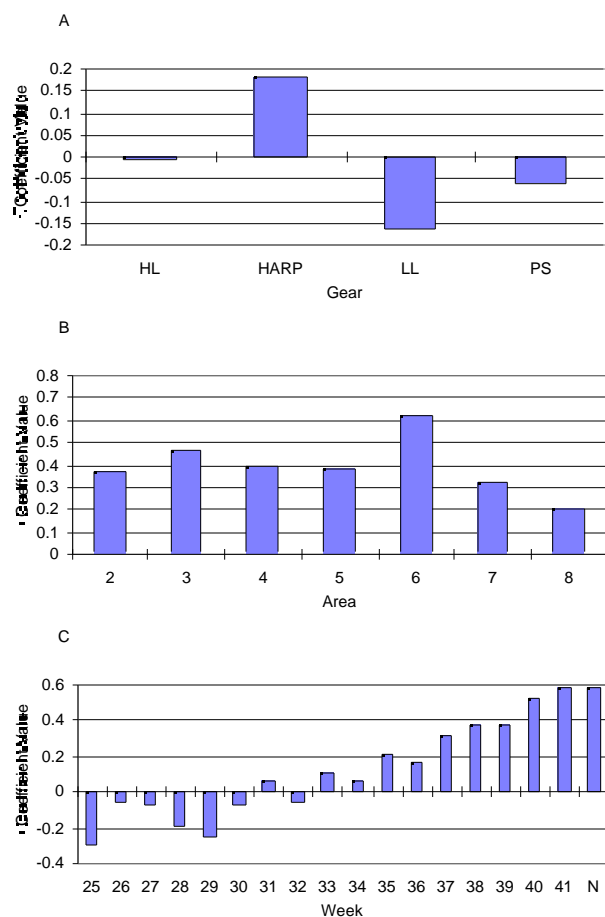


Figure 3: Coefficients for (A) gear (hand-line, HL; harpoon, HARP; long-line, LL; purse-seine, PS; baseline is rod-and-reel), (B) area (baseline is area 1) and (C) week (baseline is week 0) in the ordered-probit for color.

The estimates indicate that harpoon yields significantly higher color grades than the other gears and that purse-seine yields significantly lower color grades (level of significance less than 0.1). Area 6 presents the most positive (0.624) coefficient, followed by area 3 with 0.461. Coefficients for areas 4, 5, 2 and 7 show similar values ranging from 0.321 to 0.461. Areas 8 and 9 are likely to receive the lowest color grades. Color, as it was the case for fat content, improves gradually throughout the year. For the most part, the coefficients are non-significant (level of significance greater than 0.05) for weeks 25-30, while after week 36, coefficients become greater. The trend on the impact of time of harvest is similar to that for fat content. In particular, the greatest coefficients correspond to weeks 41 and N (0.578 and 0.587 respectively). More than half of the brokers are statistically significant (level of significance smaller than 0.05) at grading color of a fish.

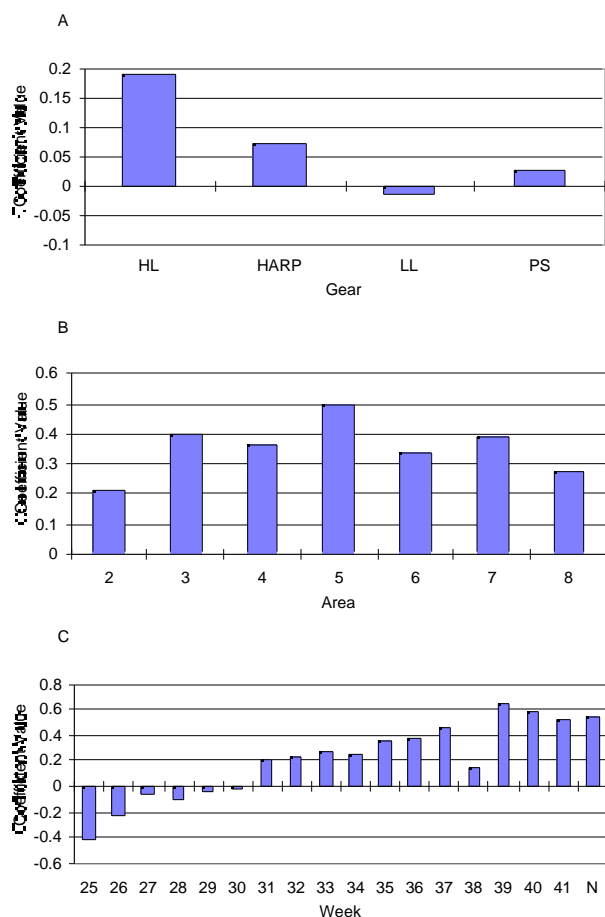


Figure 4: Coefficients for (A) gear (hand-line, HL; harpoon, HARP; long-line, LL; purse-seine, PS; baseline is rod-and-reel), (B) area (baseline is area 1) and (C) week (baseline is week 0) in the ordered-probit for shape.

With regard to shape, bluefin tuna caught with hand-line receives a significantly (level of significance smaller than 0.05) higher grade than when caught with other gears. Harpoon, long-line, purse-seine and rod-and-reel are not statistically different from each other. Shape grades are higher for areas 5, 3 and 7 with coefficients ranging from 0.386 to 0.497. Week of capture presents the same gradual improvement in the contribution to shape grade throughout the year fat content and color do. Between weeks 0 and 30, the coefficients are non-positive, and after week 30, they are greater than zero up to a value of 0.643 for week 39. More than half of the brokers appear to differ significantly (level of significance smaller than 0.05) from the baseline broker group.

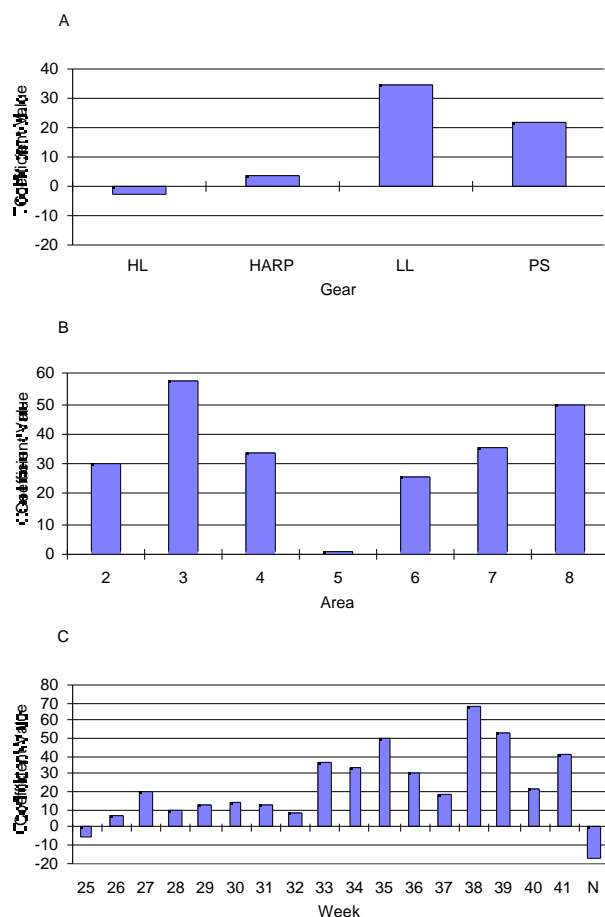


Figure 5: Coefficients for (A) gear (hand-line, HL; harpoon, HARP; long-line, LL; purse-seine, PS; baseline is rod-and-reel), (B) area (baseline is area 1) and (C) week (baseline is week 0) in the ordinary least squares for weight.

The intercept in the regression for weight indicates that the expected weight of an individual captured under baseline conditions (i.e., with rod-and-reel, in area 1, at week 0) is 287.6 pounds. Choice of gear leads to large variations in the weight of the fish captured. Coefficients for long-line and purse-seine suggest that these two gears are expected to catch the heaviest bluefin tunas, with coefficient values of 34.7 and 21.5 respectively. In terms of geographic differences, area 3 seems to yield largest fish (with coefficient 57.1), while the smallest individuals are expected to be captured in areas 1 and 5. A temporal effect can also be identified. Weeks 33 to 41 show a tendency to be associated with captures of heavier animals relative to the rest of the year, with coefficient values between 18.7 and 66.9 above the baseline period (week 0).

4. REVENUE MAXIMIZING HARVEST

Now, we proceed to determine the optimal allocation of a fixed number of individual fish that should be harvested among different weeks of the year, areas and gears ($x_{w,a,g}$).

The objective of this allocation is to maximize revenues, R , subject to a fixed quota of individuals that can be harvested, \bar{X} ,

$$\begin{aligned} \max R = & \sum_{w=0}^N \sum_{a=1}^8 \sum_{g=HP}^{PS} x_{w,a,g} DRW_{w,a,g} P_{w,a,g} \\ \text{s.t.} & \\ & \sum_{w=0}^N \sum_{a=1}^8 \sum_{g=HP}^{PS} x_{w,a,g} = \bar{X} \end{aligned} \quad (4)$$

Extremely preliminary results for this optimization suggest that the fishing season should not start before the 32nd week of the year, focused in area 6, using long-lines and hand-lines as gears.

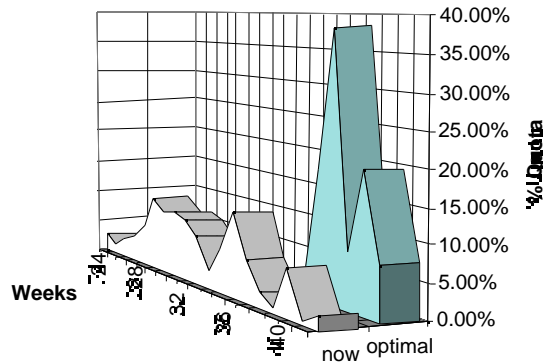


Figure 6: Weekly quota distribution of the actual fishery (now) and based on the revenue maximization (optimal) throughout the year.

These results should not be taken as the only possible combination that leads to greater revenues. There are certain limitations associated with the analyses. For example, evolution of bluefin tuna migratory patterns, environmental variability or changes in supply in Japanese markets from year to year can make the optimal revenue maximizing allocation vary. However, it is clear that to maximize returns from the fishery harvesting should occur towards the end of the year. The identification of long-line and hand-line as revenue enhancing gears can be interpreted as the premium obtained by capturing fish with methods that limit the struggle of the animal during capture. The choice of area 6 as the optimal fishing ground coincides with the southern migration of fish after feeding in northern waters such as in Georges Bank, where their fat content tends to increase.

These preliminary results, however, are limited by the lack of differences in cost of harvest associated with different areas, gears, and periods of the year. An optimization on profits rather than revenues could provide a more informative picture.

We focused our discussion on a market-based public management of the resource. However, yearly variability on environmental, migratory, and market conditions suggest that a degree of flexibility in the allocation of captures should be allowed. Such a flexible allocation could be implemented with the use of tradable individual tuna quotas which could be auctioned off throughout the season.

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