From Shark Fin Markets to Shark Populations: An Integrated Market Preference – Cohort Analysis Of the Blacktip Shark (*Carcharhinus limbatus*)

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Abstract. The increasing demand for shark fins in Asia and the shark's life history pattern of slow growth, late maturity, and few offspring, have generated concerns regarding the sustainability of shark resources. Despite this concern, little effort has been spent on understanding the markets for shark fin products and the population dynamics of sharks. This work incorporates the results of a conjoint analysis of dried processed shark fins from Hong Kong into a cohort model of the balcktip shark with the objective of maximizing the utility of Hong Kong shark fin importers/processors. Results show that optimal harvest sizes and ages for all mortality and discount factor scenarios are greater than the maturation sizes and ages for both male and female blacktip. Policy implications for this study are also discussed.

Keywords: shark fin, conjoint analysis, shark management.

1. Introduction

The increasing demand for shark fins in Asia, and the publicity resulting from finning and discarding live sharks have generated concern regarding the sustainability of the world's shark populations. These concerns are due to the nature of the shark's life cycle, which makes them vulnerable to overexploitation (Holden, 1977). For instance, in 1998 population estimates for the US Atlantic blacktip shark stood at 1.4 million, 44 % below maximum sustainable yield (MSY). With a zero-catch policy, the rebuilding of blacktip stocks to MSY levels would take between 10 to 20 years (DOC, 1998). Other biological factors, such as schooling by age, sex, and reproductive state, also make some shark species (*e.g.*, blue shark, *Prionacae glauca*) highly vulnerable to overfishing. High fishing mortality may deplete certain segments of the age class, which may significantly affect the reproductive dynamics of shark populations (Anon., 1996).

Despite an increase in consumption and trade of shark fins and other shark products, and the vulnerability of shark populations once overexploited, relatively little effort has been spent to understand the biology and economics of sharks and shark fisheries until recently (*e.g.,* Pascoe, Battaglene, and Campbell, 1992). The research discussed here adds to the understanding of linkages between the biology and economics of sharks by explicitly incorporating multi-attribute market information to bioeconomic modeling. Specifically, the results of a conjoint analysis of dried processed shark fins from Hong Kong is incorporated into a blacktip shark bioeconomic model with the objective of maximizing economic returns.

2. Bioeconomic Model

The overall structure of the model is presented in Figure 1. First, the biological growth of an individual blacktip shark is modeled with respect to the length and weight of three fin types--caudal, dorsal, and pectoral. Fin growth in length and weight is estimated by combining data from research in Oman, measurements from commercial blacktip shark fin samples from Guyana, and published blacktip age and growth parameters (Branstetter, 1987; Al-Quasmi, 1994; Castro, 1996). Results of a shark fin preference analysis, conjoint analysis, is applied to calculate the utility index of the dried, processed fin set as a function of blacktip shark growth. Finally, the optimal harvest size (age) for a blacktip shark cohort is obtained by maximizing the utility for dried, processed fins under different mortality rates and discount rates using Microsoft Excel Solver (Microsoft, 1997).

3. Biological Component

Age and growth estimates for blacktip shark of both sexes is represented by a von Bertalanffy growth function:

(1) $TL_t = L_\infty [1-e^{-K(t-to)}]$

where TL is the total length of the blacktip in centimeters; L_∞, the attainable maximum size, is 176 centimeters (cm) total length; K, the rate that approaches L_∞, is 0.27; and t_o, the age at which the fish would have been zero size is -1.20 year (Branstetter, 1987). The subscript j represents age in quarters; t=1.0, 1.25, 1.50, …30, assuming the blacktip has an average life expectancy of 30 years. The total length equation is then converted to pre-caudal length by using the following equation estimated by Castro (1996) in millimeters (mm):

(2) $PCL_t = \beta_0 + \beta_1 TL_t$

where PCL is the pre-caudal length of a blacktip (mm); β_0, the constant, is -23.14; and β_1, the coefficient for total length, is 0.74. Equation 6 is then converted to centimeters (cm).

To estimate the functional relationships between shark and fin growth in terms of fin size and weight, data from an unpublished master's thesis on the physico-chemical characterization of shark fins, and measurements from a commercial sample of blacktip shark fins are utilized (Al-Quasmi, 1994). Since the focus of this study is to maximize economic yield from a shark cohort, the scope of biological functional relationships between fin size and body size is not presented here (see Fong, 1999). Instead, two functions are used to represent this relationship:

(3) $FDF_t = f(PCL_t)$

where FDF_t is the length (cm) of fresh dorsal fin measured from the tip to the middle of the fin base (where the cut is made to detach it from the body).

Fresh dorsal fin length is then used as a base measurement from which all dried, processed fin lengths are derived. This relationship is described by Equation (4):

(4) $S_{it} = f(FDF_t)$

where S_{it} is the length (cm) of the anterior edge of the dried, processed shark fin. The subscript i represents the three shark fin types--caudal, dorsal, and pectoral.

Similarly, two functions are used to represent the fin weight/age relationship (see Fong, 1999). It is also represented by two functions:

(5) $DOS_{it} = f(PCL_t)$

where DOS_{it} is the anterior length (cm) of unprocessed shark fin (skin-on, cartilage not removed) for the three fin types.

The dried, processed fin weight measured in kilograms (kg) is obtained by establishing a series of biological functional relationships from Equation (5) as described by Fong (1999). This is represented by Equation (6):

(6) $DPW_{it} = f(DOS_{it})$

where DPW_{it} is the weight (kg) of dried, processed fins by type.

4. Utility Index for an Individual Shark

A market preference model, conjoint analysis, is used to determine the utility of the shark fin set to Hong Kong shark fin importers/processors as a function of blacktip shark growth. Conjoint analysis is a form of multi-attribute utility model, which all, or in part, link to the notion that utility is derived from the attributes that the good possesses (*e.g.*, Lancaster, 1971).

Conjoint analysis of dried, processed shark fin was conducted with Hong Kong shark fin importer/processors (Fong and Anderson, 1999). This method uses field experiments by asking respondents to rank or rate products with predetermined attributes and levels of attributes to measure preference or utility as the dependent variable (Green and Srinavasan, 1978, 1990). For this experiment, respondents were asked to rate twelve real dried processed shark fin products from 0 to 10, 10 being the most preferred and 0 the least preferred. The resultant rating data was then analyzed by using an ordered logit discrete-choice regression (McKelvey and Zvoina, 1975). Using the estimated coefficients from the ordered logit model, the predicted utility scores can be obtained for the three fin types--caudal, dorsal, and pectoral:

(7) $U_i = \gamma_0 + \gamma_1 S_i - \gamma_2 D_i$

where U is the random utility; γ_0 is the estimated constant; γ_1 is the estimated coefficient for dried, processed fin size; and γ_2 is the estimated coefficients for fin type, i, represented by dummy variables, D_i. The results for the estimated conjoint model are presented in Table 1.

Utility indexes for the three fin types are then calculated from the ordered logit model formulation for the probability of being rated the most preferred dried, processed fin from the conjoint experiment:

(8) $UW_i = 1 - [(e^{(23.76-Ui)})/(1+ e^{(23.76-Ui)})]$

where UW_i is the utility per unit weight for the three fin types; and 23.76 is the estimated lower bound threshold level for the most preferred rating from the estimated ordered logit model (Appendix A).

The utility index for fin type, i, is calculated as the product of the utility per unit weight, UW_i, and the dried, processed weight, DPW_i, for fin type i:

(9) $UI_i = UW_i*DPW_i$

where UI_i is the utility index for fin type i.

The total utility index for an individual blacktip is the sum of the utility indexes of the three fin types, taking into account that sharks have one caudal, one dorsal, and two pectoral fins:

(10) $TUI = \Sigma\ UI_i$

where TUI is the total utility index for an individual blacktip shark.

5. Utility Index for Cohort

The total utility index for an individual blacktip shark was estimated in the previous section using the results from the conjoint analysis of dried processed shark fin in Hong Kong. This section presents the equations used to estimate the optimal harvest size (age) of a single cohort of blacktip shark when the utility for a shark cohort is maximized. The initial population of the cohort is assumed to be 10,000, with both sexes combined.

The quarterly numbers-at-age for the blacktip shark cohort is:

(11) $N_{t+1} = N_t \cdot e^{-M/4}$

where N_t is the number of sharks at age t, expressed in quarters; and M is the natural mortality rate. Three quarterly natural mortality rates, 0.025, 0.050, 0.075, and a natural mortality function proposed by Peterson and Wroblewski (1984) are used for sensitivity analysis. The Peterson and Wroblewski (1984) natural mortality function is:

(12) $M_t = 1.92/4 \bullet W_t^{-0.25}$

where M_t is the quarterly natural mortality, and W_t is the dry weight of individual shark in grams, assuming dry weight is 0.2 of wet weight. This mortality function simulates the decrease in natural mortality as the size of a shark increases with age in a cohort.

The weight of an individual blacktip shark is determined by:

(13) $WKG_t = (2.51 \bullet 10^{-9})TLM_t^{3.12}$

where WKG_t is the wet weight of an individual blacktip shark (kg), and TLM_t is total shark length (mm) (Castro, 1996).

The total utility of a cohort using the utility index approach by conjoint analysis is represented by:

(14) $TUC_t = TUI_t \bullet N_t / (1+r)^t$

where TUC_t is the total utility index for the cohort at age t; TUI_t is the total utility index for an individual shark; N_t is the number of sharks in the cohort; and r is the discount rate, which is set at 0, 0.02, 0.03, 0.05, 0.07, 0.1, and 0.2, respectively.

6. Optimal Harvest

Results from a multi-attribute marketing analysis were incorporated into a market preference - cohort model of the blacktip shark. The optimal harvest size of the blacktip shark was investigated for the conjoint preference – cohort model under four natural mortality scenarios. Within each natural mortality scenario, the effects of seven discount factors were also simulated. These results are presented in Table 2.

Three quarterly natural mortality parameters, 0.025, 0.05, and 0.075 are used to determine the optimal harvest size/age of the blacktip shark. Results show that as quarterly natural mortality increases from 0.025 to 0.075 at any given discount rate, the optimal harvest size/age for the blacktip shark decreases. For example, at a discount rate of 0.03, the optimal harvest size estimated with the conjoint market – cohort model decreases from 173.27 cm (14.00 years of age) to 171.88 cm (12.50 years), then to 170.19 cm (11.25 years) as the quarterly mortality rate increases from 0.025 to 0.075 (Table 2).

The performance of the conjoint market – cohort model using a size-dependent natural mortality function is also investigated (Peterson and Wroblewski, 1984). This function assumes that as the size of an individual shark increases with age (expressed in weight), the natural mortality rate for the cohort decreases. This assumption is an improvement in realism over the constant mortality scenarios, since a shark cohort of a small-size class (i.e. younger age) would be more vulnerable to predation than a cohort of a large-size class.

Results show that the size-dependent mortality conjoint market – cohort model provides the least conservative optimal harvest sizes/ages of all mortality scenarios (Table 2). For example, at zero discount rate, the optimal harvest size/age for the size-dependent mortality scenario is 169.34 cm (10.75 years), as oppose to 174.06 cm (15.25 years), 172.40 cm (13 years), 170.58 cm (11.50 years) for 0.025, 0.050, and 0.075 constant quarterly mortality rates respectively.

Seven discount rates, ranging from 0 to 0.2, are used to examine optimal harvest size and age of the blacktip shark. These rates are used to simulate the divergence between the social and private opportunity cost of capital, time reference, and risk premium. In this study, the real discount rates between 0 and 5 percent in the market – cohort models are perceived as the social discount rate for the 30-year horizon (Clark, 1990). The higher discount rates in the simulation represent the divergence from social discount rates by private firms, such as shark fishers. This divergence between private and social discount rates can be attributed to the differences in risk premium perceptions between society and private concerns (Tietenberg, 1998).

Results show that in all scenarios, size (age) of optimal shark harvest decreases as discount rate increases (Table 2). For example, given a social discount rate of 0.03, the optimal harvest size and age for blacktip under a size-dependent natural mortality conjoint market – cohort simulation is 167.82 cm (10.00 years of age). Alternately, the optimal harvest size and age for size- dependent natural mortality given a 0.20 private discount rate is 164.48 (8.75 years of age), two years younger than the social optimum.

7. Summary and Conclusions

This research adds to the growing literature concerning the utilization of market information for fishery management (*e.g.* Larkin and Sylvia, 1999; Crapo, 2000; Martinez-Garmendia *et al.* , in press). Here, market preferences for dried, processed shark fins in Hong Kong are integrated into a bioeconomic model to investigate the optimal harvest size/age of a cohort of blacktip shark. Results from this exercise show that given the reproductive maturation size of 145.00 cm (5.25 years) for males and 158.00 cm (7.25 years) for females, optimal harvest sizes and ages for all scenarios from the conjoint market – cohort model are greater than the maturation sizes/ages for both sexes (Castro, 1996). Given these results, shark fishery managers may consider proposing size limits and/or rights-based fishing management regime to ensure the economic and biological sustainability of the blacktip shark fishery.

Appendix A

Formulation of the Utility Index for Dried, processed Shark Fins

The objective of this appendix is to explain the theoretical foundation and justification for the development of the utility index as specified in equation (8). The first section presents an overview of consumer choice behavior using a random utility framework in the context of a Hong Kong shark fin importer/processor. The second section discusses the model specification and estimation procedure for the conjoint experiment. The third section discusses the formulation of the utility index.

Consumer Choice Behavior

It is assumed that the utility Hong Kong shark fin importers/processors obtained from a specific shark fin product is a function of the utility derived directly from the product's attributes and levels of those attributes (Lancaster, 1971). For example, a Hong Kong shark fin buyer may prefer medium-sized dried, processed dorsal shark fin to large-sized dried, processed pectoral shark fin. The utility derived from a given product may then be expressed in general form as a quasi-concave, twice continuously differentiable utility function:

(A1) $U(s_h) = U\{X_h\}$

where $U(s_h)$ is the utility the buyer derives from the h^{th} composite dried, processed shark fin product s_h; X_h is a vector of levels making up the composite product s_h. Since a decisionmaker obtains some degree of satisfaction from each product, the alternative selected for consumption would be the one that provides the highest satisfaction (Ben-Akiva and Lerman, 1997). For example, a shark fin buyer would choose product s_4 over product s_2, only if $U(s_4)$ is greater than $U(s_2)$. However, the utility of the shark fin importer/processor is not directly observable and is unknown. The utilities, therefore, are treated as random variables, and the probability of choosing alternative dried, processed shark fin product s_4 over s_2 is equal to the probability that $U(s_4)$ is greater than $U(s_2)$ (Manski, 1977).

Random Utility Model Specification and Ordered Logit Estimation

The conjoint experiment evaluates the utility function of Hong Kong shark fin importers/processors directly by asking respondents to rate a set of stimuli from 0 to 10, with 0 being the least preferred, and 10 being the most preferred. In this case, a reduced design of 11 dried, processed shark fins was obtained by using an asymmetrical factorial orthogonal experimental plan (Addelman, 1962). The attributes included were fin size and type. The conjoint model employed in this research uses the traditional non-interaction-effect model, which is assumed to be additive in levels of the attributes (*e.g.*, Green and Srinavasan, 1978; 1990):

(A2) $U(s_h) = \beta'_{ij}\, x^{(h)}_{ij} + \varepsilon_{ij}$ $\qquad \varepsilon_{ij} \sim N(0, 1)$

where $U(s_h)$ is the random utility that an individual derives from h^{th} product, β_{ij} is the parameter matrix that represents the relative importance of the levels, $x^{(h)}_{ij}$ represents the deterministic independent variable matrix associated with attribute j and level i for product *h*, and ε_{ij} is the random error term.

An ordered logit model was used to analyze the rating data generated by the conjoint experiment. The ordered logit model consists of $U(s_h)$, the h X 1 vector of unobserved random utilities specified in equation A2; R is the observed choice alternative in the form of preference ratings; and μ is the estimated threshold variables or cutoff points, which provide the ratings of alternatives. The ordered logit model for this study can be formulated as follows:

(A3) $U = \alpha_0 + \alpha_1 Sz + \alpha_2 Dor + \alpha_3 Pec + e$

and

(A4) $R = 0 \text{ if } U \leq 0$
$R = 1 \text{ if } 0 < U \leq \mu_1$
$R = 2 \text{ if } \mu_1 < U \leq \mu_2$
•
•
•
$R = 10 \text{ if } \mu_9 \leq U$

where U is the unobserved utility for the 11 dried, processed shark fins used in the conjoint experiment; α's are the estimated coefficients; Sz is the continuous variable for size of dried, processed shark fins; Dor and Pec represents dorsal and pectoral fins, the levels of attribute for fin type, coded as dummy variables; μ's are the unknown threshold variables to be estimated with α. Caudal fin, the remaining attribute level for fin type, is not included in the estimated ordered logit model to avoid multicollinearity.

From the specifications stated in equations A2, A3, and A4, the probabilities for the rating preferences are:

(A5) $\text{Prob}(R=0) = \Lambda(-A'x)$
$\text{Prob}(R=1) = \Lambda(\mu_1 - A'x) - \Lambda(- A'x)$
$\bullet$
$\bullet$
$\text{Prob}(R=10) = 1 - \Lambda(\mu_9 - A'x)$
where $\Lambda(\bullet)$ is the logistic distribution function $e^{(\bullet)} / 1+e^{(\bullet)}$; A is the matrix for the coefficients α; and x is the matrix for the independent variables constant, fin size, dorsal fin, and pectoral fin.

The following conditions must also hold in order for all the probabilities to be positive:
(A6) $0 < \mu_1 < \mu_2 < \bullet \bullet \bullet < \mu_9$

For an independent sample of *n* individuals, the log likelihood function, $L(\alpha, \mu)$, is:
(A7)

$$L(\alpha,\mu) = \sum_{q=1}^{n}\sum_{y=1}^{m} R_{q,y} \log(\Lambda_{q,y}(\bullet) - \Lambda_{q,y-1}(\bullet))$$

where *n* is the number of individuals in the experiment, and *m* is the number of stimulus in the conjoint experiment. Maximizing $L(\alpha, \mu)$ provides estimates of the parameters α and μ (McKelvey and Zavoina, 1975).

Utility Index Formulation

Maximizing the log likelihood function in equation A6 provides estimates for the coefficients in equation A3 and the estimation for the μ's, the threshold level between ratings in equation A2.4. The estimated equation is:
(A8) $U_{sc} = 2.8 + 2.4Sz - 8.3Dor - 13.1Pec$
where U_{sc} is the utility score for the three fin types, caudal, dorsal, and pectoral, at various fin sizes. All estimated coefficients are significant at the 0.01 percent level (see Table 2). The estimated utility score equation (A8) and the estimated threshold level (μ) are then used to calculate the probability of a dried, processed shark fin being rated in a certain category (*e.g.*, R=10) for a given fin size and fin type as specified in equation A5.

The ordered logit model specification captures the preference structure for dried, processed shark fin by a representative shark fin processor/importer in Hong Kong. The specific utility score for an index is calculated from the logistic probability function P(R=10), the estimated utility score (U_{sc}) equation (A8), and the estimated μ_9 (23.759; significant at 0.01%)--the lower bound threshold level for the most preferred rating. Thus the formula for the utility index is:
(A9) $UW_{i,Sz} = 1 - (e^{[23.7 - (2.8+2.3Sz-\lambda i)]} / 1 + e^{[23.7 - (2.7+2.3Sz-\lambda i)]})$
where UW is the value index; i is fin type; Sz is size in inches; λ is the coefficient for fin type (dorsal and pectoral), coded as dummy variables.

Table 1. Results of Conjoint Model Estimation (Ordered Logit)

Variable	Coefficient	Standard Error	T – Ratio
Constant	2.78	0.66	4.20**
Size	2.32	0.23	10.19**
Dorsal	-8.36	0.89	-9.41**
Pectoral	-13.11	1.38	-9.47**
MU(1)	3.22	1.72	1.87*
MU(2)	6.16	0.75	8.26**
MU(3)	7.68	0.88	9.34**
MU(4)	10.18	1.85	5.50**
MU(5)	14.26	1.76	8.12**
MU(6)	17.31	1.82	9.49**
MU(7)	18.91	1.90	9.93**
MU(8)	20.43	1.99	10.26**
MU(9)	23.76	2.84	8.38**

Log likelihood function = -192.58 N = 187

Restricted Log likelihood = - 448.41 Chi – squared = 511.66**

**Significant at the 0.01% level * Significant at the 10% level

Table 2. Optimal Harvest for Conjoint Market – Cohort Model

Natural Mortality*	Discount Rate (%)	Total Quality Index	Optimal Harvest Size** (cm) / Age (Years)
0.025	0	86.01	174.06 / 15.25
	2	66.29	173.62 / 14.50
	3	58.56	173.27 / 14.00
	5	46.18	173.07 / 13.75
	7	36.89	172.86 / 13.50
	10	26.87	172.40 / 13.00
	20	10.71	170.94 / 11.75
0.050	0	25.49	172.40 / 13.00
	2	20.51	171.88 / 12.50
	3	18.47	171.88 / 12.50
	5	15.08	171.58 / 12.25
	7	12.42	171.27 / 12.00
	10	9.41	170.58 / 11.50
	20	4.15	169.34 / 10.75
0.075	0	8.99	170.58 / 11.50
	2	7.42	170.19 / 11.25
	3	6.76	170.19 / 11.25
	5	5.64	169.78 / 11.00
	7	4.74	169.78 / 11.00
	10	3.69	169.34 / 10.75
	20	1.76	167.82 / 10.00
P & W***	0	10.77	169.34 / 10.75
	2	8.72	168.87 / 10.50
	3	7.84	167.82 / 10.00
	5	6.47	167.82 / 10.00
	7	5.36	167.82 / 10.00
	10	4.09	166.62 / 9.50
	20	1.84	164.48 / 8.75

* In Quarters

* * Total Length

*** Peterson, I., and S. Wroblewski. 1984. Mortality rate of fishes in the pelagic ecosystem. Canadian Journal of Fisheries and Aquatic Science 41: 1117-1120.

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