Marine Resource Economics, Volume 14, pp. 179–198 0738-1360/99 $3.00 + .00

Firm-Level Hedonic Analysis of U.S. Produced Surimi: Implications for Processors and Resource Managers

SHERRY L. LARKIN
University of Florida

GILBERT SYLVIA
Oregon State University

Abstract *Firm-level data on U.S. produced surimi, the only seafood product that is graded on the objective measurement of several quality characteristics, are used to estimate the effect of production variables (e.g., hours between harvest and processing) and policy variables (e.g., fishing seasons) on product characteristics. Transactions data are then used to estimate hedonic equations and derive implicit prices for each characteristic of surimi used to produce seafood analogs and traditional products in the U.S. and Japanese markets, respectively. Implicit prices are also estimated for surimi grade, production location (onshore, at-sea), and production date. Results indicate that several factors (including species) significantly affect surimi characteristics. Color and gel strength have the largest price impact, and market conditions alter the relative prices associated with improving certain characteristics. Overall results demonstrate that management decisions that affect fish quality—and, therefore, processed product quality and price—directly affect the wholesale value of the fishery.*

Key words *Alaskan pollock, fisheries management, hedonic, Pacific whiting, seafood quality, surimi.*

Introduction

Due to the large number of species, product forms, and heterogeneity of the harvest, processing, and management sectors, seafood quality is difficult to measure and standardize; consequently, there are few quality-graded products compared to terrestrial-based industries (Anderson and Anderson 1991). One exception is a product known as surimi; a protein paste made from minced fish that is used in the fabrication of final food products (Sonu 1986). The evaluation of surimi quality and the surimi market, however, is extremely complicated, since the product appears homo-

---

Sherry L. Larkin is an assistant professor in the Department of Food and Resource Economics at the University of Florida, Gainesville, FL 32611-0240, e-mail: slarkin@ufl.edu. Gilbert Sylvia is an associate professor in the Department of Agricultural and Resource Economics at Oregon State University, Corvallis, OR and superintendent of the Coastal Oregon Marine Experiment Station, e-mail: gil.sylvia@hmsc.orst.edu.
The authors are thankful to several individuals who provided fundamental and substantial information concerning the surimi production process and markets for surimi-based foods, including: Jae Park, Michael Morrissey, Bill Atkinson, Jay Hastings, Diana Wasson, and John Sproul. Support for this research was provided, in part, by Oregon Sea Grant (Award NA36RG0451, Project R/SF-5).

geneous and grade standards are firm specific (Park and Morrissey 1993). In addition, the variation in the condition of the stock at the time of harvest—like all products derived from "wild" natural resources—can have a considerable impact on final product quality, quantity, and value (Sylvia and Larkin 1995). This additional source of variability suggests that resource management that influences industry structure and controls such factors as fishing seasons may have a significant effect on the value of the resource.

Fish surimi is a unique seafood product; the production process is highly technical, the product is graded on objectively measured quality characteristics, and surimi is used to produce hundreds of final products (AFDF 1987; Sonu 1986). However, despite a significant amount of literature on the microbiological and biochemical issues involved with surimi production and storage (Hall and Ahmad 1997, and references cited therein), few economic studies exist. The economic studies that have been conducted concern the market(s) for the final goods (Johnston and Zhang 1996; Sproul and Queirolo 1994). The value of raw surimi characteristics has yet to be examined in the literature.

The paucity of economic studies is somewhat surprising given that the majority of Alaskan pollock (*Theragra chalcogrammus*)—the most abundantly harvested species in the U.S. and the third most abundantly harvested species in the world—is used for surimi production (NPFMC 1996; Sproul and Queirolo 1994). The Pacific whiting (*Merluccius productus*) stock, which is the largest U.S. groundfish resource south of Alaska, is also used primarily for the production of surimi (Freese, Glock, and Squires 1995). Consequently, the U.S. is the world's largest supplier of surimi, producing nearly 155,000 metric tons (mt) in 1995 (NMFS 1996). In terms of "edible fish exports" from the U.S., surimi is second only to salmon; in 1995, exports were valued at over US$350 million (NMFS 1996).

Surimi-based foods—known as "*neriseihin*" products in Japan—are commonly grouped into the following broad categories: *kamaboko* (steamed), *chikuwa* (broiled), *satsumaage* (fried), fish ham and sausages, and seafood analogs (*Seafood Leader* 1994; Sonu 1986). Each type of product requires a specific combination of surimi quality characteristics, such that a wide range of surimi quality is demanded (AFDF 1987; Sonu 1986). In addition, to achieve the quality required for new products, *neriseihin* processors have begun to blend various surimi grades (Park and Morrissey 1993). This production change has increased the substitutability of raw surimi produced from different species, by different firms, and with different additives, which has increased the emphasis on individual product characteristics (Marris 1990).

Surimi grades are based on the quantitative measurement of several product attributes such as color, texture, water content, gelling ability, pH level, and impurities. Since a common grading schedule has not been adopted, each firm decides which characteristics to include, how they are measured, and the levels and nomenclature that define each grade (Park and Morrissey 1993; Marris 1990). Many companies, however, have adopted the nomenclature and relative rankings of the highest grades (*i.e.*, SA and FA) developed by the National Surimi Association in Japan (Park and Morrissey 1993). The lack of objective or consistent standards for "identically" graded products produced by different companies—or vessels/plants operated by the same company—indicates that they may not be perfect substitutes. Since some U.S. companies have chosen not to use the Japanese grading system, and the underlying characteristics and levels that define each grade are unknown, averaged wholesale prices cannot be linked to a pre-defined level of surimi quality. Consequently, data is not available to analyze the market effects of variations in surimi quality.

The lack of available data has limited previous empirical studies of seafood quality attributes to the use of conjoint analysis (Sylvia and Larkin 1995; Anderson and Bettencourt 1993; Halbrendt, Wirth, and Vaughn 1991). Conjoint analysis is a survey-based technique that uses the stated preferences of hypothetical products to estimate the value of each characteristic. An alternative approach is to use transactions data—with corresponding quality measurements—to estimate the implicit price of each attribute (Rosen 1974). This "hedonic price method" has been successfully applied to several agricultural products (Goodwin, Holcomb, and Rister 1996; Davis 1993; Ethridge and Neeper 1987; Jordan *et al.* 1985), but has only recently been applied to seafood products (Salayo, Voon, and Selvanathan 1999). This is because the majority of marine-based foods are not standardized or measured by a set of agreed-upon or binding quality characteristics (Anderson and Anderson 1991).

The information that can be generated from a hedonic analysis is paramount to the determination of optimal processing and management plans, which maximize net benefits while conserving and fully utilizing the resource. This is because surimi producers and managers of Alaskan pollock and Pacific whiting resources must understand the economic consequences of altering product characteristics they control during harvesting, processing, and marketing. Knowledge of economic consequences is especially important given the potential for increased trade of new species and products in nontraditional markets (Kano 1992). The growth of an international industry depends on the successful promotion of surimi as a flexible, adaptive, multipurpose input, and an appropriate labeling or grading system could help foster market development.

The primary objectives of the study are to test quality-related hypotheses regarding U.S. produced Alaskan pollock and Pacific whiting surimi and generate empirical information needed to determine optimal firm-level processing and resource-management strategies. Primary, secondary, cross-section, and time-series data are used to estimate (1) the effect of various producer and management controlled factors on surimi quality characteristics and (2) the implicit prices of the product characteristics, grades, production location, and production date.

Data

All surimi producers and *neriseihin* processors test the individual characteristics of each lot (Park and Morrissey 1993). National and private laboratories in Japan also collect and aggregate statistics for internal use. There is, however, no consolidated firm-level or industry data set that is published in either the U.S. or Japan (Sonu 1986). Consequently, this study employs four sets of data from primary and secondary sources. The variety of data is necessary to examine the issues and hypotheses of interest.

The three sources of primary data used in this study include: (1) a seafood analog producer in the U.S. who purchased multiple grades of pollock surimi from eight companies—onshore and at-sea operations—between 1988 and 1992 (n = 940); (2) a processor of traditional *neriseihin* products in Japan who purchased three grades of onshore and at-sea produced pollock surimi during a two-week period in early 1995 (n = 36); and (3) a catcher-processor vessel that produced both pollock and whiting surimi at-sea in 1994 (n = 677).

The secondary data source was obtained from the National Surimi Association. This organization computes the monthly average of several characteristics measured on Alaskan pollock surimi processed onshore in Japan. Although not confidential, this data is not routinely published. Data from the 1983–84 seasons were included in a NMFS report, and the 1989–90 data was obtained from a researcher in Japan (n = 48).

The following section includes the majority of the discussion and analysis pertaining to specific quality characteristics; however, the secondary data is summarized table 1. Unless otherwise specified, the variable definitions in table 1 are retained throughout the analysis. Table 1 also contains the average characteristic levels in 1983–84 and 1989–90; comparison of the averages indicates that surimi quality has remained relatively stable. In addition, table 1 identifies—for hypothesis testing—whether an increase or decrease in the measure represents a quality improvement.

Surimi Quality

The quality of a given lot of surimi is frequently assessed from basic information such as species, production location (onshore versus at-sea), and relative grade (*Seafood Leader* 1994; Marris 1990). Surimi grades, which typically number from three to six per company, are commonly based on the following four characteristics: color, gel strength, water content, and impurities (Park and Morrissey 1993).[1] Multiple grades result from the traditional production process and variability in each batch of fish. During the production process, minced fish is washed repeatedly with water to remove water-soluble proteins, enzymes, blood, and fat; as washings continue, lower-quality product is funneled out (Hall and Ahmad 1997; Hawco and Reimer 1987).[2] Thus, higher quality surimi is more costly to produce since it requires additional water, time, and fish (Hawco and Reimer 1987).

Figure 1 summarizes the production, by grade, of an at-sea vessel that processed both pollock and whiting surimi in 1994. The names of the grades were changed to protect the identity of the vessel. In this analysis, “A” represents the highest grade

Table 1
Characteristic Definitions and Average Quality for Japanese Onshore, Grade 2, Pollock Surimi in 1983–84 and 1989–90

X_i	Definition	H_o Impact[a] of ΔX_i	Average 1983–84	Average 1989–90
WATER	Water content (percent by weight, %)	–	79.3	78.6
PH	pH level	+/–	7.41	7.47
IMPURITY	Impurities (greater than 2 mm = 1 point, < 2 mm = 0.5 point)	–	N/A	4.89
WHITE	Whiteness (Z value in CIE X,Y,Z; blue region of spectrum)	+/–	22.2	22.0
LIGHT	Lightness (L value in L,a,b; 0 = black, 100 = white)	+	51.9	52.0
FORCE	Force at failure, indicates firmness (g)	+	437.5	441.0
DEPTH	Indentation depth at failure, indicates cohesiveness (cm)	+	1.04	1.06
GEL	FORCE * DEPTH = gel strength, indicates overall texture (g·cm)	+	458.3	472.2

Sources: Sonu (1984–85); *Monthly Working Report* of the National Surimi Association (1989–90).
[a] Hypothesized change in surimi quality and price from an increase in the measure. Uncertain effects are associated with characteristics whose “optimal” level depends on the product being produced; that is, quality improvements can result from increases or decreases in the measure (Sonu 1986; AFDF 1987).

---

[1] Characteristics are typically measured on the raw surimi and after it has been heated or cooled. Duplicate measures are useful since temperature changes simulate the *neriseihin* production process and, therefore, can be used to better predict final product quality (AFDF 1987; Hawco and Reimer 1987).
[2] New technologies are being examined and some—including alternative cooking methods, centrifuge, and Alpha Laval (which increases yields and simplifies the process)—have already been implemented (Fish Info Service 1998). Future studies may need to account for such changes if they become prevalent.

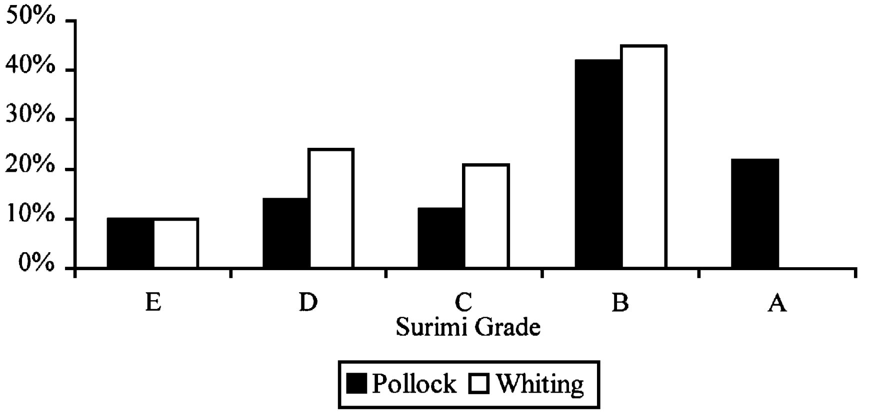

Figure 1. Production Distribution Between Grades for Pollock and Whiting Surimi Manufactured by an At-sea Vessel in 1994

and "E" the lowest. The figure shows that the majority of production was graded "B" for both species. Also, none of the whiting surimi received the highest grade classification. If quality was defined as the proportion of lots graded A or B, then pollock surimi would have the higher average quality.

Concluding that pollock surimi is of higher quality by comparing the proportion of lots with the highest grades is only valid if the grades are defined identically between species. However, the levels that define the grades for this company in 1994 were species-specific.[3] Under such circumstances, it is more appropriate to compare the levels of the underlying characteristics. Using the majority B grade, the average attributes for each species are presented in table 2.

On average, whiting surimi had a lower whiteness score and higher level of impurities due to the addition of protease inhibitors (required to prevent degradation of the flesh) and presence of "dark spots" (myxosporidian related cysts unique to this species), respectively. These factors could further support the claim that Pacific whiting surimi is of lower quality, except that whiting surimi had a lower water content (on average). In addition, the grade bounds on both measures of gel strength are higher for whiting (by 50 and 600 for GEL and GEL2, respectively). This attribute of the grading system—that is, higher bounds for whiting gel strength for the B grade—could explain why no lots of whiting surimi received the highest grade. Recall also, from table 1, that a lower water content and higher gel strength represent a higher quality product.

As presented in table 2, grades are defined by lower or upper bounds on the levels of selected characteristics. Note that the average level of whiteness for Pacific whiting surimi falls below the minimum defined for the grade. Given the standard deviation, the majority of grade B lots of whiting surimi produced by this company in 1994 did not meet the standard; standards, therefore, were not binding for all characteristics.

---

[3] According to the technician who supplied the data, there are two reasons for species-specific grade definitions: (1) they allow the company to produce equal proportions of a certain grade (making it easier to predict supply by grade) from each species, and (2) to conform to the expectations of buyers.

Table 2
Grade Definitions and Average Quality of each Characteristic for the B Grade Surimi Produced by an At-sea Vessel in 1994

		Grade Definition		Average Quality[a] (standard deviation)	
Characteristics	Units	Pollock	Whiting	Pollock	Whiting
WATER	%	< 75	< 75.5	74.6 (0.47)	74.5 (0.65)
IMPURITY	#/40g	< 20	< 20	6.25 (2.99)	8.25 (3.09)
WHITE	Z value	> 49	> 48	52.0 (1.66)	46.3 (1.06)
GEL	g·cm	> 800	> 850	1,226 (150)	1,185 (162)
GEL2 [b]	g·cm	> 1,200	> 1,800	2,132 (335)	2,467 (368)

[a] The vessel manufactured 204 lots of pollock and 123 lots of whiting of this grade.
[b] GEL2 is the gel strength for the cooled surimi, not the raw surimi.

Table 2 also shows that the standard deviation for impurities—for surimi of each species—was large relative to the average. This finding reduces the usefulness of the grade and its representation of accurate information. With the exception of whiteness, the standard deviations for pollock surimi characteristics were less than those observed for whiting on this vessel during 1994. Since standard deviations indicate another aspect of product quality, namely, product quality consistency (an important factor in modern food production), pollock surimi could be considered of higher quality.

There was also a relatively large difference between the averages and the grade definitions for impurities and gel strength. These disparities may reflect the seasonal variation in surimi quality; both the average quality within grades and the proportion of high-graded product was seasonal in this data set (Larkin 1998). Grades, therefore, may have relatively loose standards for some characteristics in order to incorporate the inherent seasonal variation in product quality that is due to the changing condition of the fish (Hall and Ahmad 1997).

What Determines Surimi Quality?

Several factors have been hypothesized to impact surimi quality. Sproul and Queirolo (1994) claim that quality is determined by the production conditions; specifically, they argue that the longer the time between harvest and processing—after the fish have gone through rigor—the lower the quality (hence, the perception that at-sea catcher-processors produce higher quality surimi). The amount of time between harvest and processing causes the flesh to denature (an increase in the breakdown of proteins), a process which can affect surimi color, impurities, and possibly gel strength (Hall and Ahmad 1997; Peters 1996; AFDF 1987; Hawco and Reimer 1987). Besides freshness, some researchers believe that other characteristics of the fish, such as size, are important (Peters 1996; Sonu 1986). And, recent work by Hall and Ahmad (1997) and Peters (1996) describes how spawning cycles affect biological condition (*i.e.*, the protein, moisture, and fat content of fish) which, in turn, influences the water content and gel strength of the surimi. These authors all agree that species is an important factor; in particular, gel strength and whiteness are—on average—higher for pollock.

Using the 1994 data from the catcher-processor vessel depicted in figure 1, the following equation was specified to test these hypotheses:

$$X_i = \alpha_i^o + \sum_{j=1}^{3} \alpha_{ij}^z \cdot Z_j + \alpha_i^d \cdot D + \sum_{j=1}^{3} \alpha_{ij}^{zd} \cdot Z_j \cdot D \qquad (1)$$

where $i = 1, 2, \ldots, 5$ and represents WATER, IMPURITY, WHITE, GEL, and GEL2, respectively; the characteristics that this company used to define its grades. The characteristics (X_i) were assumed a linear function of the Z_j continuous factors, where:

j = 1: HOURS (number of hours the fish were held before processing),
2: WEIGHT (average weight of the individual fish in grams),
3: JULIAN (Julian date of production, January 1 = 1 to December 31 = 365),

whose effect was assumed to vary by species ($D = 1$ for pollock, 0 for whiting) (Davis 1993). Thus, interaction terms ($Z_j \cdot D$) were used to obtain the unique effects of time before processing, fish size, and production date—which can be linked to the spawning cycle—for pollock surimi.[4]

This linear specification was acceptable for WEIGHT and JULIAN given the data only covered the fishing season. If data were available over the entire year, such that it would incorporate periods of spawning and migration, a nonlinear form would be warranted. In addition, given that this operation waited until the fish were post-rigor before processing, further processing delays were hypothesized to reduce surimi quality. If data were available on surimi processed immediately after harvest, a nonlinear form for HOURS would be warranted. The ability to use a linear form allows for straightforward interpretation of results, and the coefficients can be used (with price elasticities for each X_i characteristic) to easily determine the value of a change in each factor, Z_j.

Given the time-series nature of the data, autocorrelation was a concern. Simple correction techniques assume observations are ordered through time; however, in this data set, the order of processing within each day was unknown. Nevertheless, using a similar data, Ethridge and Davis (1982) corrected for first-degree autocorrelation. Following Ethridge and Davis (1982), and given that the Durbin-Watson (*DW*) statistics from the Ordinary Least Squares (OLS) estimations indicated the presence of first-degree autocorrelation in each equation, the Yule-Walker estimation technique was used (SAS). Table 3 contains the estimation results.

In summary, WEIGHT was the only variable to have a statistically significant affect on the same characteristics—WATER, IMPURITY, and WHITE—for both species (*i.e.*, Z_2 and $Z_2 \cdot D$). No single explanatory variable had statistical significance on all five surimi characteristics. The interactive dummy variables indicated that the quality of pollock surimi was higher in terms of water content and gel

[4] Since running separate regressions for each species would not change the estimation results (Kennedy 1992, p. 220), the data were combined to facilitate the comparison of coefficients. The single-equation approach produces an average R^2 and assumes the underlying error variance is constant (an assumption which was considered valid for this study given the identical production conditions; *i.e.*, the surimi was produced in the same season by the same firm, vessel, and crew).

Table 3
Statistical Significance of the Time before Processing, Fish Size, Season, and Species

	Equation (1) Coefficients by Surimi Characteristic				
Variables	WATER	IMPURITY	WHITE	GEL	GEL2
Intercept	77.78***	3.05	50.41***	783.5***	1,765.1***
	(0.47)	(3.27)	(1.36)	(131.8)	(324.5)
$Z_{1:\text{ HOURS}}$	–0.026	–0.034	–0.082**	–8.29**	–23.27**
	(0.018)	(0.119)	(0.039)	(4.01)	(10.3)
$Z_{2:\text{ WEIGHT}}$	–0.005***	0.013**	–0.008***	0.052	0.195
	(0.0008)	(0.006)	(0.002)	(0.22)	(0.561)
$Z_{3:\text{ JULIAN}}$	–0.004***	–0.007	0.009	2.13***	2.74***
	(0.0008)	(0.007)	(0.0056)	(0.456)	(1.03)
$D_{:\text{ POLLOCK}}$	–2.75***	11.72***	–1.877	336.9**	25.64
	(0.526)	(3.61)	(1.597)	(150.1)	(367.6)
$Z_1 \cdot D$	0.047***	–0.369***	0.065	0.946	29.86***
	(0.0202)	(0.13)	(0.042)	(4.37)	(11.23)
$Z_2 \cdot D$	0.004***	–0.019***	0.009***	0.035	–0.153
	(0.0008)	(0.006)	(0.002)	(0.237)	(0.602)
$Z_3 \cdot D$	0.005***	0.011	–0.027***	–1.456***	–1.64
	(0.0008)	(0.008)	(0.006)	(0.508)	(1.14)
n	659	662	665	668	663
R^2	0.29	0.30	0.86	0.66	0.52
DW	2.00	2.36	2.18	2.40	2.38

Notes: Standard errors are reported in parentheses. For each equation, the maximum number of observations for whiting and pollock total 273 and 404, respectively. Single, double, and triple asterisks indicate significance at the 10%, 5%, and 1% levels, respectively.

strength, but lower in terms of impurities. Overall, species (*i.e.*, *D*) had the largest effect on the levels of the surimi characteristics; however, all elasticities of significant variables were close to zero.

The longer the time between harvest and processing, the lower the quality of whiting surimi in terms of whiteness and gel strength. For pollock, increasing the time improved final gel strength and lowered impurity levels. These improved quality effects were, however, accompanied by a slight (undesirable) increase in moisture content. Hence, to produce the highest quality surimi—that is, to improve the level of each characteristic—the time fish are held before processing may need to vary by species.

The heavier the individual pollock, the greater the improvement in the resulting surimi in terms of water content, impurities, and whiteness levels. This result was expected since fillet machines work better with larger fish (Hall and Ahmad 1997; AFDF 1987). Conversely, larger whiting resulted in greater impurities and a lower whiteness value; most likely because a higher proportion of older whiting have parasites which can result in the phenomenon referred to as "black spotting" (Alderstein and Francis 1993). Although this does not affect the functionality of the product, the visible dark spots are undesirable in final products (Park and Morrissey 1993).

When production occurred later in the year—at a higher Julian date—water content and gel strength of whiting surimi improved. Conversely, as the season progressed, water content increased, and whiteness and gel strength of pollock surimi both fell (*i.e.*, quality deteriorated). Season was expected to be important for each species, since the fish experience intra-year biological changes that correspond with spawning and recovery (Hall and Ahmad 1997).

Hedonic Analyses

Rosen (1974) proposed the hedonic method to empirically determine the implicit price of objectively measured characteristics that—when considered collectively—completely describe a market product. Since his pioneering work, hedonics has been used to successfully estimate implicit characteristic prices for various food products (Goodwin, Holcomb, and Rister 1996; Ethridge and Neeper 1987; Salayo, Voon, and Selvanathan 1999). The technique has also been used to examine the appropriateness of federal food grading systems (Ethridge and Neeper 1987; Brorsen, Grant, and Rister 1984). Since surimi quality is graded on a subset of characteristics that varies by company and is measured by both buyers and sellers, the hedonic technique is particularly appropriate for this product. Also, given the multispecies, multisector, multiproduct nature of the industry, the hedonic technique can provide unique and important information for a variety of uses.

In its simplest form, the hedonic regression is specified as: $\mathbf{P} = f(\mathbf{X})$, where $\mathbf{P}$ is a vector of prices, and $\mathbf{X}$ is a matrix of characteristics. This is the equilibrium price function for the characteristic X_i that is implicit in $f(\mathbf{X})$. Evaluating $d\mathbf{P}/dX_i$ at observed characteristic levels generates the implicit price of each characteristic. These prices are frequently referred to as marginal implicit prices (MIPs) (Rosen 1974). If characteristics are qualitative and represented by dummy variables, the implicit prices are price differentials (*i.e.*, premiums or discounts).

According to Ethridge and Davis (1982), product definitions should be truncated to include only distinct characteristics. This is because a high degree of collinearity between explanatory variables—indicated by an absolute correlation coefficient above 0.80—can prevent the estimation of distinct effects (Kennedy 1992). Correlation matrices for each data set revealed high levels of linear correlation between certain variables, most notably between identical measures on the raw and cooled surimi (note 1). Consequently, for this analysis, only the characteristics tested on the raw surimi were included. Among the raw product characteristics, the color measures and the components of gel strength were highly correlated (*i.e.*, WHITE with LIGHT—measuring translucency from the blue spectrum and pure whiteness, respectively—and DEPTH and FORCE with GEL; table 1). Since each characteristic is independently measured and analyzed at a cost by the buyer, all characteristics tested on the raw surimi were assumed important in the production of the final product. Under such circumstances, eliminating a characteristic would introduce model specification bias (Kennedy 1992); therefore, each characteristic measured on the raw surimi was included in the hedonic specification.

Product characteristics are not the only factors that influence price. Outside influences such as supply and demand conditions—in different periods or locations—may also be important and can be accounted for with dummy variables (Bowman and Ethridge 1992; Ethridge and Davis 1982). Dummy and continuous variables can also be used to account for production information that captures real or perceived quality differences (Goodwin, Holcomb, and Rister 1996; Bowman and Ethridge 1992; Ethridge and Neeper 1987). In this study, dummy variables (D) were defined for different surimi grades, processing locations, and years. Continuous variables (Z) were defined for information such as processing date. The general hedonic specification is $\mathbf{P} = f(\mathbf{X}, \mathbf{D}, \mathbf{Z})$; however, the exact set of variables depends on the data available from each source.

In order to estimate the hedonic equation, a functional form needs to be specified. Unfortunately, economic theory does not specify a correct functional form for hedonic equations (Jordan *et al.* 1985). In this study, linearity was assumed to be appropriate because: (1) the product can be ‘unbundled’ by blending several lots (Stiegert and Blanc 1997); (2) dummy variables are included (Beach and Carlson

1993); and (3) the linear form produces the smallest maximum bias if the function is misspecified (Cropper, Deck, and McConnell 1988).

Two hedonic analyses were conducted. The first used transactions data provided by a producer of traditional *neriseihin* products (primarily *kamaboko*) for the Japanese market. The second used transactions data from a U.S. producer of seafood analogs (primarily imitation crab) for the domestic (U.S.) market. Each data set was used to test and compare the variety of hypotheses described earlier and summarized in table 1.

Traditional Neriseihin Producer (Japan)

The data set from the *neriseihin* processor in Japan included prices, grades, and quality measurements on thirty-six lots of pollock surimi purchased from multiple U.S. producers in mid-January 1995. Each lot was of identical size (in weight) and purchased individually (*e.g.*, no price discounts were received for bulk orders). Given the short time period during which purchases were made, the market conditions were assumed constant between sales.

The MIPs of the qualitative and continuous descriptors (D_k and Z_j, respectively) and the surimi characteristics (X_i) were compared between four different model specifications:

$$\mathbf{P} = f(\mathbf{D}) \tag{2}$$

$$\mathbf{P} = f(\mathbf{D}, \mathbf{Z}) \tag{3}$$

$$\mathbf{P} = f(\mathbf{X}) \tag{4}$$

$$\mathbf{P} = f(\mathbf{D}, \mathbf{Z}, \mathbf{X}) \tag{5}$$

where

$D_{k=3}$ (D_1 = 1 if grade A, D_2 = 1 if grade B, D_3 = 1 if produced at-sea; else = 0)
$Z_{j=1}$ (JULIAN date of production)
$X_{i=8}$ (WATER, PH, IMPURITY, WHITE, LIGHT, FORCE, DEPTH, GEL).

The base product, represented by zero values of the three dummy variables, is a grade C surimi produced onshore.

Grades were defined across company because each used the traditional nomenclature and ranking system. Company-specific effects were dropped from the equation after preliminary analysis indicated that (1) company dummies had no statistically significant affect on price and (2) the MIPs for each characteristic were not company-specific. The alternative specifications were needed to test the hypotheses regarding the relative importance of different types of information (Stiegert and Blanc 1997; Brorsen, Grant, and Rister 1984), for example, that grades alone can adequately explain price.

Given the cross-section, time-series nature of the data, simple regression techniques were initially considered inappropriate. For example, a correction for nonsimilar variances would be necessary if the explanatory power of the model varied by producer. According to Marris (1990), company preferences are primarily based on a reputation for quality consistency in all attributes; if so, heteroskedasticity would not be correlated with any particular variable in the model.

When heteroskedasticity is not correlated with the variables in the model, OLS computations are not misleading in large samples (they are consistent, but not efficient) (Greene 1990, p. 403). Given the nature of the heterskedasticity, results of the preliminary analysis, and the large sample size, a correction procedure was deemed unnecessary.

Moreover, we did not correct for autocorrelation because: (1) all lots were purchased at effectively the same time, (2) the lots were tested in random order, and (3) production did not occur at regular intervals throughout the year. As for multicollinearity, relatively high correlation coefficients were found between WHITE and LIGHT (0.94), FORCE and GEL (0.94), JULIAN and LIGHT (0.78), and JULIAN and GEL (0.77). Since the presence of multicollinearity does not violate the underlying assumptions of the model and there is no guaranteed correction for this problem, the equations were estimated using OLS. Table 4 contains the OLS regression results for each model. Given that the OLS technique appeared to ad-

Table 4

Hedonic Results for Surimi Purchased by a Manufacturer of Traditional Products

		Coefficients by Model Specification			
Variables	Average	(2)	(3)	(4)	(5)
Intercept		320.00***	282.62***	–586.67***	–93.16
		(9.14)	(2.92)	(238.8)	(217.7)
$D^1_{1:ATSEA}$	0.54	15.29**	13.93***		10.95***
		(7.18)	(1.84)		(3.35)
$D^1_{2:GRADE\_A}$	0.58	20.00*	55.11***		45.41***
		(11.19)	(3.30)		(5.99)
$D^1_{3:GRADE\_B}$	0.36	39.61***	51.25***		42.41***
		(9.82)	(2.57)		(5.93)
$Z_{1:\text{ JULIAN}}$	78.1		0.17***		0.155***
			(0.008)		(0.022)
$X_{1:\text{ WATER}}$	74.7			–1.45	0.11
				(1.29)	(0.95)
$X_{2:\text{ PH}}$	7.3			–46.97***	–2.27
				(12.73)	(17.8)
$X_{3:\text{ IMPURITY}}$	2.6			0.59	0.30
				(0.55)	(0.29)
$X_{4:\text{ WHITE}}$	53.0			–7.67***	–1.98
				(1.64)	(1.18)
$X_{5:\text{ LIGHT}}$	78.4			14.41***	5.16***
				(2.36)	(1.72)
$X_{6:\text{ FORCE}}$	763.3			0.914***	0.117
				(0.14)	(0.145)
$X_{7:\text{ DEPTH}}$	1.4			441.7***	60.25
				(65.8)	(73.08)
$X_{8:\text{ GEL}}$	1,091.8			–0.607***	–0.074
				(0.095)	(0.098)
R^2		0.40	0.96	0.93	0.98
F–value		7.01***	194.46***	44.54***	133.5***

Notes: For each equation n = 36, price is in yen per kilogram, and standard errors are reported in parentheses. Single, double, and triple asterisks denote significance at the 10, 5, and 1% levels, respectively.

equately pull apart individual explanatory effects for equation (4), multicollinearity between characteristics was not perceived as a significant problem.

The dummy variables representing grade and production location explained only 40% of the variation in price [equation (2)]. This result is somewhat surprising since the grade-price relationship is frequently emphasized in the literature (*Seafood Leader* 1994; Park and Morrissey 1993; Marris 1990). Perhaps more surprising is the higher coefficient on the lower grade. This could be due to the market conditions at the time of purchase (*e.g.*, relatively low supply) or the need for the characteristic levels offered in the B grade by some of the suppliers. In terms of the production location, surimi produced at-sea was paid a higher price as predicted (Johnston and Zhang 1996; Sproul and Queirolo 1994; Park and Morrissey 1993). Given the relatively low explanatory power, grade and production location do not appear to adequately explain surimi price. These results may be tenuous due to the possibility of model misspecification.

Perhaps the most influential variable was the date of production; including the Julian date in equation (3) increased the explanatory power of the model from 40% to 96%. This variable indicates that surimi processed later in the season received a higher price. This could be due to actual or perceived quality differences. For example, this variable could be representing actual quality differences by picking up the effect of the observed seasonal reduction in the standard deviations of each characteristic (*i.e.*, overall quality consistency). Also, surimi processed later in the season would have been frozen for a shorter period of time. According to Lanier and MacDonald (1992), surimi quality deteriorates during freezing. Consequently, the length of frozen storage is commonly used as an indicator of quality; the longer the product is frozen, the lower the quality (Marris 1990). The length of frozen storage may not be significant, however, since surimi can maintain its functionality for over a year while frozen (Hall and Ahmad 1997). If so, the Julian date would represent a perceived quality difference.

Despite the simplicity of the specification and the extremely high explanatory power of equation (3), the results hold little practical value for processors. For example, even if the Julian date represents actual quality differences, the source is unknown; is it from an improvement in overall consistency, shorter frozen storage, or higher gel strength as found in table 3? Only measurements of the individual characteristics can provide information on the functional properties of the product. And only by including these characteristics in a hedonic equation can the relative value of altering each property be obtained. Therefore, equation (4) provides several advantages for producers and buyers, since processors have the ability to independently alter the level of the characteristics in a given lot, and *neriseihin* producers need to minimize costs of producing a specific formulation (*i.e.*, requiring a given level of a certain characteristic).

Equation (4) indicates that the surimi characteristics explained 93% of the price variation. The surimi characteristics were, therefore, a much better indication of quality than the grade or whether production occurred at-sea [equation (2)]. Comparison with equations (2) and (3) reveals that the Julian date explains a relatively large portion of the price variation, but less than the variation explained by the characteristics. The high explanatory power of equation (4) suggests that the linear functional form was reasonable. In addition, since 75% of the characteristics were significant, including the collinear attributes was appropriate (six of the eight characteristics were significant and five had the expected sign; table 1). Gel strength—the interaction variable—was expected to be positive; however, given the inclusion of the force and depth measures, this value is acceptable. The gel strength coefficient reduces (but not offsets) the increase in price predicted from improvements in the underlying components.[5] These results have important implications for grading schedules, since using GEL as a proxy for overall texture (and ignoring the underlying force and depth measures), or using LIGHT or WHITE as a proxy for color, may be insufficient or misleading given the unique explanatory power of each variable.

Price elasticity estimates are frequently used to compare price effects by assuming an equal percentage increase in each explanatory variable. Using the coefficients from equation (4), the following elasticities were calculated at the averages: water content (–0.3), pH (–1.0), impurity count (0), whiteness (–1.2), lightness (3.2), force (2.0), depth (1.8), gel (–1.9). Overall, lightness had the largest effect; a 1% increase in the LIGHT measurement would increase price 3.2%. Note that the elasticities for force, depth, and gel need to be interpreted simultaneously.

These price elasticities are not, however, an effective means to compare the price effects of surimi characteristics due to the wide variation in some of the measures. In particular, the standard deviations range from one-half to ten times the 1% change assumed using the elasticities (similar to table 2). Alternatively, we assumed a one standard deviation improvement (not increase) in the level of each variable in order to standardize the comparisons. The largest price effects were from the components of gel strength; depth and force improvements—equal to one standard deviation—would increase price 9.5% and 8.4%, respectively. The effects of the color variables were identical, a one standard deviation improvement resulted in equal 5.3% price increases. The next largest effect was produced by a decrease in pH (1.3%). The insignificant variables, water content and impurities, had only minimal effects (0.4% and 0.3%, respectively). These variables may be insignificant due to their relatively small deviations in the data; consequently, their effects may be underestimated.

When all of the independent variables were included [equation (5)], the explained price variation increased to 98%. As with equation (3) and as expected, the highest grade surimi—grade A—was paid a higher premium (although only slightly). The remaining production-related variables (*i.e.*, at-sea, grade B, and Julian date) remained significant and robust compared to the model specification that excluded the characteristics [equation (3)]. The characteristics were, however, not robust to the inclusion of the additional variables [equation (4) versus equation (5)]. In general, the coefficients (*i.e.*, implicit prices) were smaller in the model that included all variables [equation (5)]. The moderately high correlations between Julian date and three of the characteristics—lightness (0.78), gel strength (0.77), and whiteness (0.59)—may have prevented the regressions from estimating statistically significant individual price effects.

Seafood Analog Producer (U.S.)

The data from the U.S. seafood analog producer included 940 lots of pollock surimi of various grades purchased from eight U.S. companies (onshore and at-sea) between 1988 and 1992. Production occurred year-round such that the surimi was purchased consistently throughout the year.[6] Quality testing occurred within a week after purchase. Following equation (5) of the previous section, the general model was:

---

[5] An unreported fifth equation excluded the interactive gel strength variable and lightness. With an R^2 of 0.66, only the water content, pH, and force characteristics (3 out of 6) were significant (each, including the intercept, was significant at the 1% level). FORCE was also positive as initially hypothesized (table 1).

[6] To maintain confidentiality, we are prevented from disclosing information concerning lot size total volume. Lot sizes did vary, and price discounts were received for 'non-standard' lots. We were, however, assured that the purchase of relatively large quantities and the incidence of price discounts were not prevalent. Given the relatively large sample size, these observations are not expected to be influential.

$$\mathbf{P} = f(\mathbf{D}^1, \mathbf{D}^2, \mathbf{Z}, \mathbf{X}, D_3^2 \cdot \mathbf{X}) \quad (6)$$

where the dummy variables were redefined as follows:

$D^1_{k=1}$ ($D^1_1 = 1$ if produced at sea; else $= 0$)

$D^2_{k=4}$ ($D^2_1 = 1$ if 1989, $D^2_2 = 1$ if 1990, $D^2_3 = 1$ if 1991, D^2_4 if 1992; else $= 0$)

Annual dummy variables are included to account for changes in the general price level (Etheridge and Neeper 1987). In addition, following Ethridge and Neeper (1987), an interaction term between the characteristics and a dummy variable was used to account for a particular change in the market; namely, the tight supply and corresponding price increase that characterized the market in 1991 (Johnston and Zhang 1996; Sproul and Queirolo 1994).

As specified, the model estimated price differentials for production location and year. Separate equations for each year were not estimated because (1) there were not enough observations for 1992 and (2) an F-statistic of 23.94 indicated that the estimated parameters across 1988–90 were not statistically different. Similarly, seasonal price differences were not estimated due to perfect collinearity. In addition, dummy variables for grade could not be included because the number and names of grades varied across producers. Consequently, company dummy variables were not included, since they would reflect differences in average surimi quality sold, which are already accounted for with the characteristics.[7] Autocorrelation was suspected and supported with a Durbin-Watson test; consequently, the model was estimated using the Yule-Walker technique. Estimation results are presented in table 5.

Overall, the explanatory variables explained 78% of the total variation in price. The water content, impurities, color, force, and gel strength variables were all significant and consistent with the estimation of the hedonic regression of equation (4) in table 4. The relative price responsiveness of the characteristics was also similar.

Assuming average values, lightness had the highest elasticity (10.6), followed by whiteness (–9) and water content (–1.8). The remaining characteristics had elasticities less than 0.5%. Again, the largest price response resulted from improvements in the color variables. Using the standard deviations method of examining price effects, a one standard deviation improvement in the color characteristics increased price from 21% to 24% (WHITE and LIGHT, respectively). The next largest price response was generated from an improvement in gel strength—through changes in force or depth—which would increase price from 4% to 10%, respectively.

It is important to recall that the estimated implicit prices are likely dependent on the type of analog product being produced and the current market for this product. Using the data supplied for this study, the individual characteristics had a greater influence on the price of surimi destined for use in seafood analogs—such as imitation crab (table 5)—than on surimi purchased for traditional Japanese products (primarily *kamaboko*, table 4). It is notable that the results are remarkably similar despite differences in time, end product, testing procedures and equipment, and estimation techniques. One exception is the at-sea variable. Its significance in the Japanese model could be due to the historical structure of the surimi industry in Japan. Ac-

[7] Ideally, there would have been sufficient data to include both grade—using dummy variables for each company—and company. However, given the spotty nature of purchases by company and grade from each supplier, the data was insufficient to include this information.

cording to Sonu (1996), at-sea surimi produced in Japan was of relatively poor quality, since production would occur up to a week after the fish were caught. This industry structure could explain the significant positive coefficient for at-sea product in the Japanese model—reflecting a perceived quality difference from the use of fresher fish—even though contemporary shore-based and at-sea operations in the U.S. each process within one day of harvest (Larkin 1998).

The dummy variables representing 1989–92 were all significant, indicating the presence of other factors which influenced the general level of price between years (Ethridge and Davis 1982). The largest effect was due to the 1991 dummy variable, indicating a significant price jump. This corresponds to reported prices, which increased approximately 75% during 1991 (*Seafood Leader* 1994; Sproul and Queirolo 1994). In addition to the large price increase, the implicit prices of pH, impurities, and whiteness all changed. This result suggests that when prices are high (*e.g.*, due to short supply), the relative importance of certain quality characteristics is affected. In 1991, high pH levels, more impurities, and an increased whiteness score reduced prices relatively more than in the other years (as evidenced by the negative signs on the 1991 interaction variables in table 5). For the harvester and surimi processor, the implication is that strategies may have to be altered in order to maximize benefits if market conditions change. In other words, poor market conditions may limit the willingness of processors to improve the overall quality of their product—or empha-

Table 5
Hedonic Results for Surimi Purchased by an Analog Producer

Variables	Equation (6) Coefficient	Standard Error
Intercept [a]	57.40	49.0
$D^1_{1:ATSEA}$	0.39	1.26
$Z_{1:JULIAN}$	0.011*	0.0068
$D^2_{1:YEAR\,1989}$	–9.36***	1.78
$D^2_{2:YEAR\,1990}$	–19.3***	2.34
$D^2_{3:YEAR\,1991}$	111.4**	51.3
$D^2_{4:YEAR\,1992}$	50.14***	13.22
$X_{1:WATER}$	–2.03***	0.40
$X_{2:PH}$	2.68	2.92
$X_{3:IMPURITY}$ [a]	1.76***	0.67
$X_{4:WHITE}$	–9.71***	2.19
$X_{5:LIGHT}$	11.43***	2.17
$X_{6:FORCE}$	0.128***	0.042
$X_{7:DEPTH}$	14.35	9.37
$X_{8:GEL}$	–0.062**	0.03
$X_1 \cdot D^2_{3:WATER \cdot YEAR\,1991}$	0.20	1.50
$X_2 \cdot D^2_{3:PH \cdot YEAR\,1991}$	–5.0***	1.52
$X_3 \cdot D^2_{3:IMPURITY \cdot YEAR\,1991}$ [a]	–6.91***	2.56
$X_4 \cdot D^2_{3:WHITE \cdot YEAR\,1991}$	–12.16**	5.58
$X_5 \cdot D^2_{3:LIGHT \cdot YEAR\,1991}$	7.80	5.38
$X_6 \cdot D^2_{3:FORCE \cdot YEAR\,1991}$	0.042	0.084
$X_7 \cdot D^2_{3:DEPTH \cdot YEAR\,1991}$	28.11	20.06
$X_8 \cdot D^2_{3:GEL \cdot YEAR\,1991}$	0.027	0.061

Notes: Price (cents per pound) is deflated by the producer price index for intermediate goods (January 1988 = 100). Equation R^2 = 0.78, *DW* = 1.78, *n* = 940. Single, double, and triple asterisks indicate significance at the 10, 5, and 1% levels, respectively.
[a] IMPURITY is defined on an 11-point scale (0–10) where 10 represents the fewest impurities (*i.e.*, highest quality); therefore, a positive sign is expected (opposite of table 4).

size alternative characteristics—since buyers may be less willing to pay for the highest quality product they need.

Implications

In the first stage of this analysis, several producer and public management controlled factors were used to explain variation in surimi quality characteristics. In the second stage, transaction prices were used to estimate the MIPs of these characteristics and other factors hypothesized to influence price. Collectively, these results are important to fishery managers, fishermen, and surimi processors since: (1) fishery management plans include allocations among harvest sectors that are partially based on assumed price and quality differences; (2) pollock and whiting seasons (which are determined by management regulations) occasionally overlap; (3) seasonal intrinsic quality variation affects post-harvest and post-processing product quality and, therefore, price; (4) surimi is an optional product form; and (5) surimi quality can be controlled.

For example, using the empirical results from the first and second stage, assume a whiting surimi processor reduced the time fish are held before processing by one hour (9.7%). Then the levels of each characteristic (*i.e.*, WATER, IMPURITY, WHITE, GEL and GEL2) would fall by amounts equal to the estimated coefficients (table 3). Further, assuming mid-season production aboard an at-sea vessel, the total price effect from changes in the level of this production-controlled variable can be determined by the following equation:

$$\Delta P = \sum_{i=1}^{4} \varepsilon_i^{US} \cdot \hat{\alpha}_{ij=HOURS}^{Z} \cdot \Delta Z_{j=HOURS} \tag{7}$$

In this case, the change in the level of the variable, $\Delta Z_{j = HOURS}$, equals one. The average hedonic price elasticities of each surimi characteristic, for sales to a U.S. seafood analog producer, ε_i^{US}, can be calculated from table 5.[8] The hedonic price elasticities were used in place of the coefficients due to the use of different data. Using these parameters, reducing the time in the hold by one hour would increase surimi price by 3.9 cents per pound. A similar analysis can be conducted for each variable affected by fishery regulations. For example, if Pacific whiting managers delay the season opening such that average fish size increases by 50 grams (8.4%), surimi price is predicted to increase 5.2 cents per pound.

Summary

Surimi quality—as defined by the levels of selected attributes—was found to play a critical role in the determination of the transaction price. Seasonal differences in average quality, production by grade, and quality variation by species were also discovered. Firm-specific grading schedules were also species-specific, but not necessarily binding. Given the consistency of results across time, species, and production location, certain characteristics (*e.g.*, gel strength) appear to be desirable for multiple uses and robust to changing market conditions.

---

[8] Since GEL2 did not appear in the hedonic regression, it could not be included.

The empirical hedonic analyses—the first of a processed marine product using proprietary data—found that: (1) grade and production location (onshore, at-sea) did not adequately explain price variation (R^2 = 0.40); (2) surimi characteristics had substantial explanatory power (R^2 = 0.93); (3) implicit prices varied across buyers, but the color and gel strength measures remained high in both specifications; and (4) the implicit prices of certain characteristics (pH, impurities, color) were affected by significant changes in the general price level (*e.g.*, 1991). In addition, the number of characteristics that had a statistically significant affect on price was greater than the number traditionally used to determine the grade.

In general, the hedonic analyses supported the hypothesis that surimi is a multiattribute product; that is, one or two product characteristics are insufficient to determine overall surimi quality and price. Consequently, the traditional quality evaluation system—that relies solely on grade, production location, and species (without revealing test results or production date)—may be insufficient for conveying accurate quality information. With inaccurate or insufficient quality information, surimi price will not reflect the true value of the input; input price distortions can cause suboptimal allocation of resources and possibly market failure.

According to Hall and Ahmad (1997), "as the applications for surimi increase and more species are investigated to fit them (or vice versa), the quality criteria will change" (p. 86). *Neriseihin* producers have already begun blending grades to create a product with the desired characteristics (Park and Morrissey 1993). In response, researchers at North Carolina State University have drafted guidelines for a new system to evaluate surimi quality (AFDF 1987). This system specifies methods to quantify the functionality of surimi for a variety of uses. There are many who "believe that unless the proposed specifications are adopted, the U.S. surimi industry will be hampered in its efforts to enter the mainstream of the U.S. food industry" (AFDF 1987, p. IV-2). In addition, "it is as important for buyers to know exactly what they are receiving as it is for sellers to receive a fair price for their product" (Park and Morrissey 1993, p. 69). This is especially true for small producers that may be unable to fund an aggressive marketing campaign.

Replacing the hierarchical ranking of grades with a system that provides more information on a wider variety of characteristics would enable processors to quickly evaluate the product before purchase. Consequently, the proposed system—or a comprehensive labeling agreement—should require disclosure of testing methods, average measurements, tolerances, and ingredients. In addition, the traditional reasons that justify common grading systems are also applicable: (1) to reduce search costs associated with collecting product information from alternative suppliers; (2) to increase industry returns by eliminating costly duplicated testing, and (3) to facilitate the collection and dissemination of market information. Despite the difficulties of establishing common standards, a standardized grading system remains a potentially necessary component of this industry for long-run success in the competitive market for food products (Park and Morrissey 1993; AFDF 1987).

Aside from the potential private benefits associated with a standardized quality evaluation system, corresponding market information can greatly improve the ability of harvesters to target fish of the desired quality (that maximize the benefits of the resource). Given the importance of the date of production to surimi quality and price, a flexible harvest season could significantly increase benefits derived from improved surimi quality and price. In addition, the inherent complexity of quality—particularly for "wild" products—and the diverse set of factors that affect surimi quality, increases the potential benefits of a flexible harvest period (Larkin 1998). Such flexibility could be achieved through implementation of a management system that provides individual firms with the flexibility to select optimal harvesting strategies, such as individual transferable quotas.

References

AFDF (Alaska Fisheries Development Foundation). 1987. *Surimi: It's America Now. Project Summary 1982–87*, Alaska Pollock Surimi Industry Development Project, Anchorage, AK.

Alderstein, S., and R.C. Francis. 1993. Offshore Pacific Whiting: A Parasite Study. Fisheries Research Institute, School of Fisheries, University of Washington, Seattle, WA.

Anderson, J.G., and J.L. Anderson. 1991. Seafood Quality: Issues for Consumer Researchers. *Journal of Consumer Affairs* 25(1):144–63.

Anderson, J.L., and S.U. Bettencourt. 1993. A Conjoint Approach to Model Product Preferences: The New England Market for Fresh and Frozen Salmon. *Marine Resource Economics* 8:31–49.

Beach, E.D., and G.A. Carlson. 1993. A Hedonic Analysis of Herbicides: Do User Safety and Water Quality Matter? *American Journal of Agricultural Economics* 75(3):612–23.

Bowman, K.R., and D.E. Ethridge. 1992. Characteristic Supplies and Demands in a Hedonic Framework: U.S. Market for Cotton Fiber Attributes. *American Journal of Agricultural Economics* 74(4):991–1002.

Brorsen, B.W., W.R. Grant, and M.E. Rister. 1984. A Hedonic Price Model for Rough Rice Bid/Acceptance Markets. *American Journal of Agricultural Economics* 66(2):156–63.

Cropper, M.L., L.B. Deck, and K.E. McConnell. 1988. On the Choice of Functional Form for Hedonic Price Functions. *Review of Economics and Statistics* 70:668–75.

Davis, G.C. 1993. Consumer Species Knowledge and the Values of Natural Christmas Tree Characteristics. *Journal of Agricultural and Applied Economics* 25(1):266–77.

Ethridge, D.E., and B. Davis. 1982. Hedonic Price Estimation for Commodities: An Application to Cotton. *Western Journal of Agricultural Economics* 7:293–300.

Ethridge, D.E., and J.T. Neeper. 1987. Producer Returns from Cotton Strength and Uniformity: An Hedonic Price Approach. *Southern Journal of Agricultural Economics* 19(1):91–96.

Fish Info Service. 1998. *Surimi Market Report*. FIS International Co. Ltd., March 4.

Freese, S., J. Glock, and D. Squires. 1995. Direct Allocation of Resources and Cost-Benefit Analysis in Fisheries: An Application to Pacific Whiting. *Marine Policy* 19:199–211.

Goodwin, H.L., Jr., R.B. Holcomb, and M.E. Rister. 1996. Implicit Price Estimation of Rice Quality Attributes for Asian Americans. *Journal of Agricultural and Applied Economics* 28(2):291–302.

Greene, W. H. 1990. *Econometric Analysis*. New York: Macmillan Publishing.

Halbrendt, C.K., F.F. Wirth, and G.F. Vaughn. 1991. Conjoint Analysis of the Mid-Atlantic Food Fish Market for Farm-Raised Hybrid Striped Bass. *Southern Journal of Agricultural Economics* 23(2):155–63.

Hall, G.M., and N.H. Ahmad. 1997. Surimi and Fish-Mince Products, *Fish Processing Technology*, 2nd ed., G.M. Hall, ed., pp. 74–92. London: Blackwell Science Publishers.

Hawco, M., and E. Reimer. 1987. Surimi Process Controls, *Proceedings of the Atlantic Canada Surimi Workshop*, J.F. Roache, ed., pp. 110–30. Department of Fisheries and Oceans, Ottawa, Canada.

Johnston, R.S., and Z. Zhang. 1996. The Japanese Market for Surimi and Surimi-based Products, pp. 299–397. *The Role of the Fisheries of Alaska and the Pacific Northwest in the Global Market for Whitefish*. Report prepared for NMFS under Saltonstall-Kennedy Grant. U.S. Department of Commerce, NOAA, Silver Spring, MD.

Jordan, J.L., R.L. Shewfelt, S.E. Prussia, and W.C. Hurst. 1985. Estimating Implicit Marginal Prices of Quality Characteristics of Tomatoes. *Southern Journal of Agricultural Economics* 17(2):139–45.

Kano, I. 1992. The Situation of Global Surimi, with Special Emphasis on the Japanese Market, *Pacific Whiting Harvesting, Processing, Marketing, and Quality Assurance: A Workshop*. G. Sylvia and M.T. Morrissey, eds., pp. 73–79. Oregon Sea Grant ORESU-W-92-001, Corvallis, OR.

Kennedy, P. 1992. *A Guide to Econometrics*, 3rd ed. Cambridge: MIT Press.

Lanier, T.C., and G.A. MacDonald. 1992. Cryoprotection of Surimi, *Pacific Whiting Harvesting, Processing, Marketing, and Quality Assurance: A Workshop*. G. Sylvia and M.T. Morrissey, eds., pp. 20–28. Oregon Sea Grant ORESU-W-92-001, Corvallis, OR.

Larkin, S.L. 1998. The Multidimensional Role of Intrinsic Quality on Resource Management Decisions: A Bioeconomic Analysis of the Pacific Whiting Fishery. Ph.D. Dissertation, Oregon State University, Corvallis, OR.

Marris, K. 1990. All Surimi is Not Created Equal. *Seafood Business* July/August:98–110.

NMFS (National Marine Fisheries Service). 1996. *Fisheries of the United States, 1995*. Current Fishery Statistics No. 9500. U.S. Department of Commerce, NOAA, Silver Spring, MD.

NPFMC (North Pacific Fishery Management Council). 1996–97. *Newsletter*. Various issues. Anchorage, AK.

Park, J., and M. Morrissey. 1993. The Need for Developing Uniform Surimi Standards, *Quality Control & Quality Assurance for Seafood*, G. Sylvia, A.L. Shriver, and M. Morrissey, eds., pp. 64–71. Oregon Sea Grant, Corvallis, OR.

Peters, G.J. 1996. Determination of Quality Parameters for the Pacific Whiting Fishery using Neural Network and Induction Modeling (Oregon, Surimi). Ph.D. Dissertation, Oregon State University, Corvallis, OR.

Rosen, S. 1974. Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. *Journal of Political Economy* 82:34–55.

Salayo, N.D., T.J.P. Voon, and S. Selvanathan. 1999. Implicit Prices of Prawn and Shrimp Attributes. *Marine Resource Economics* 14(1):65–78.

SAS (The SAS Institute, Inc.). 1987. *SAS/STAT Guide for Personal Computers*, Version 6. Cary, NC.

Seafood Leader. 1994. Surimi Seafoods. March/April:193–271.

Sonu, S.C. 1986. *Surimi*. NOAA Technical Memorandum, NMFS-SWR-013. U.S. Department of Commerce, National Marine Fisheries Service, Terminal Island, CA.

Sproul, J.T., and L.E. Queirolo. 1994. Trade and Management: Exclusive Economic Zones and the Changing Japanese Surimi Market. *Marine Fisheries Review* 56:31–39.

Stiegert, K., and J. Blanc. 1997. Japanese Demand for Wheat Protein Quantity and Quality. *Journal of Agricultural and Resource Economics* 22(1):104–19.

Sylvia, G., and S. Larkin. 1995. Intermediate Firm-level Demand for Pacific Whiting Products: A Multi-attribute, Multi-sector Analysis. *Canadian Journal of Agricultural Economics* 43(3):501–18.