

FRI-UW 8715
October 1987

FISHERIES RESEARCH INSTITUTE
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**ANALYSIS OF FOUR FACTORS AFFECTING
THE SABLEFISH SOFT FISH PROBLEM**

by

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Final Report

submitted to

Saltonstall/Kennedy Program
NOAA/National Marine Fisheries Service, Seattle

Contract No. NA85-ABH00056

October 1987

Date 10-19-87

Approval R.C. Frantz

Director

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PREFACE

This report summarizes the results of a 2-year investigation into the factors affecting sablefish quality. A complete description of the analysis methods and further discussion of the results will be included in a Ph.D. dissertation by James Norris to be published through the University of Washington School of Fisheries.

The NMFS Saltonstall/Kennedy Program requires grant recipients to evaluate the impacts of their work on the fishing industry. We have included a brief questionnaire with this report to satisfy this requirement. We encourage all readers to complete this questionnaire and return it to the Utilization Research Division, National Marine Fisheries Service, 2725 Mountlake Blvd. E., Seattle, Washington 98112. The results will not only help NMFS assess the impacts of this study, they also will help to guide future research on sablefish quality.

ABSTRACT

During the period October 1985 to November 1986, a total of 740 sablefish were collected from the 60-675 fathom depth range using trawl, trap and longline gear. Samples were analyzed for smoked-fish yield, 24-hour drip loss, moisture content, raw fillet yield, and seven sensory qualities. The data were analyzed to determine the effects of four factors: fish size, depth, season, and gear type.

Depth was the factor most significantly correlated with "soft" texture and associated characteristics. For each 100 fathoms of depth, total moisture (%) increased by 0.9 percentage points, drip loss (%) increased by 2.9 percentage points, smoked-fish yield (%) decreased by 1.1 percentage points and raw fillet weight for sablefish of representative length (63 cm) declined by about 5%. During the period August-October, sablefish of representative length (63 cm) from 600 fathoms had 21% less fillet weight than those from 200 fathoms. We estimated that a processor who purchased 10,000 pounds of eastern-dressed, medium-sized sablefish caught in 200 fathoms could expect a yield of 4,860 pounds of marketable fillets, whereas a processor who purchased 10,000 pounds of eastern-dressed, medium-sized sablefish caught in 600 fathoms could expect a yield of only 3,790 pounds of marketable fillets.

Raw fillet weight for sablefish of representative length (63 cm) increased by 9.2% during the period June through October. This result suggests that sablefish yields might be increased by harvesting the fish in the fall rather than in the spring.

Review of the literature suggested that the "soft" textured condition in sablefish is similar to the "jellied" condition observed in American plaice and Dover sole. We hypothesize that the soft textured condition and associated characteristics in sablefish are caused by large water-filled intercellular spaces resulting from protein or fat depletion in skeletal muscle tissues. We speculate that water held between the cells may be the primary source of drip loss.

Our findings suggest that shallow and deep sablefish may not fully commingle throughout the year. A series of research cruises should be conducted from mid-January through mid-March to determine the depth distribution of the spawning stock. We also recommend that histological sections of soft and firm sablefish muscle tissues should be prepared, and research should be conducted to determine

the biochemical characteristics and properties of both intercellular and intracellular fluids.

INTRODUCTION

In the early 1970s, the Utilization Research Division of the National Marine Fisheries Service (NMFS) initiated studies on sablefish, *Anoplopoma fimbria*, quality in response to complaints from sablefish processors that a high percentage of the landings were overly soft. These soft fish had a lower smoked-fish yield and became mushy and unpalatable when cooked. Initial study results indicated that the soft condition is caused by "an alteration in the chemical composition of the flesh. The flesh of these fish have an unusually high water content and an unusually low protein content" (Patashnik et al. 1980). They demonstrated that the soft-textured condition is not caused by parasite infestation, as occurs with Pacific whiting.

In the early 1980s, several scientific articles were published on the topic of sablefish bioenergetics (Sullivan 1982, Sullivan and Smith 1982, Sullivan and Somero 1983). Although these investigations did not address the soft fish problem, they provided information suggesting that the chemical alterations observed by NMFS personnel may be related to physiological stress due to spawning or lower food availability.

Our project investigated fish size, depth, season, and method of capture as likely factors influencing the soft texture of some sablefish. Our measures of quality included objective parameters such as fillet yield, drip loss, moisture content, and smoked-fish yield, as well as subjective characteristics such as appearance, texture, and flavor. We quantified these subjective characteristics by developing a sablefish evaluation system similar in concept to that used by the wine industry to compare different vintages.

The Utilization Research Division of NMFS has continued their research on the sablefish soft fish problem. Their current efforts have focused on the biochemical composition of sablefish skeletal muscle tissues, and their results will provide valuable information concerning the underlying biochemical processes that affect sablefish quality.

METHODS AND MATERIALS

Sample Collection and Handling

From October 1985 to November 1986, a total of 740 sablefish were collected from commercial trawl, trap, and longline vessels and from NMFS trawl and trap survey cruises (Table 1). The north and south geographic limits for sample collections were the U.S.-Canada border and Eureka, California, respectively. Depths of capture ranged from 60 to 675 fathoms, and all market size categories were represented. Samples were allocated to shallow (less than 400 fathoms) and deep (over 400 fathoms) depth strata, tagged for future identification, and pertinent biological data were recorded.

All samples were frozen at 0-10° Fahrenheit; those collected during the NMFS trawl and trap surveys were frozen at sea, and all other samples were frozen at a small cold storage facility (A&J Quality Meats) in Chimacum, Washington. The alternative of freezing and storing all samples at a large seafood cold storage plant was rejected because of the impractical logistics involved with handling the small product lots used in this project. Our goal was to freeze the samples in as consistent a manner as possible. Since the NMFS trawl and trap surveys required the use of sub-optimal on-board freezing methods, we decided that all samples should be frozen in a similar manner.

Samples were analyzed for smoked-fish yield, 24-hour drip loss, total moisture content, raw fillet recovery rate and appearance, texture, and flavor. Smoked-fish processing was performed by Port Chatham Packing Company, which produces a cold-smoked sablefish product. Sensory quality analysis was performed on 399 samples by Jon Rowley of the seafood consulting firm **Fish Works!** The capture history of each fish was unknown to Mr. Rowley at the time of analysis. A scoresheet was used to evaluate each sample on a scale from one (worst) to ten (best) in seven different categories (Fig. 1). A technique termed the "transverse cut" was developed in which a thin, cross-sectional slice was analyzed to determine pre-freezing quality of the fish and the quality of the freezing technique.

Table 1. Summary of sample collections for Sablefish Soft Fish Project.

Date	Gear	Type	Sample Size	Location	Depth Range
<u>Pilot Project</u>					
8/20/85	Comm	Set-Net	12	Wash Coast	100-170
8/30/85	Comm	Set-Net	12	Wash Coast	90-220
9/12/85	NMFS	Trap	40	Wash Coast	148-453
9/13/85	Comm	Set-Net	12	Wash Coast	110-120
9/25/85	Comm	Set-Net	12	Wash Coast	100
<u>Main Project</u>					
10/ 4/85	Comm	Trap	36	Wash Coast	600
1/ 5/86	Comm	Trawl	17	Wash Coast	220-315
1/15/86	Comm	Trawl	28	Wash Coast	200
1/25/86	Comm	Trap	36	Ore Coast	225
3/ 1/86	Comm	Trap	20	Ore Coast	275-300
3/31/86	Comm	Longline	29	Vanc Island	275-300
4/23/86	Comm	Trap	40	Ore Coast	675
6/24/86	Comm	Trap	54	Ore Coast	275
7/26/86	Comm	Longline	48	Wash Coast	170-325
8/13/86	Comm	Trap	56	Ore Coast	225-600
8/30/86	NMFS	Trawl	84	Wash Coast	62-190
10/ 4/86	Comm	Longline	75	Wash Coast	130-500
10/10/86	NMFS	Trap	84	N Cal Coast	155-545
10/20/86	Comm	Trap	45	Ore Coast	215
	TOTAL		740		

Sablefish Quality Assessment

Date: 12/1/86

Cooking Sample #: 4

Tag #: 2415

Assessor: JR

=====

ASSESSMENT OF WHOLE, DRESSED FISH BEFORE COOKING

	10	9	8	7	6	5	4	3	2	1
Appearance				✓						
Firmness		✓								

Color Pattern: *slate - with white belly*
 Remarks: *pectoral bruise - yellow edge on tail*
100% scale loss

=====

ASSESSMENT OF RAW FILLET BEFORE COOKING

	10	9	8	7	6	5	4	3	2	1
Appearance						✓				
Integrity of transverse cut								✓		

Remarks: *10+ nematodes - several contusions*
chestnut hues - off color
T.C. meat + C.T. sep.

=====

ASSESSMENT OF COOKED FILLET

	10	9	8	7	6	5	4	3	2	1
Appearance					✓					
Texture								✓		
Flavor						✓				

Remarks:

Figure 1. Sample scoresheet used to evaluate sensory quality characteristics of sablefish.

Methodology Validation Experiments

We designed several experiments to validate our analytical methods. One experiment investigated the amount of variability in moisture content and drip loss estimates within an individual fillet. Another experiment tested for the degree of correlation between Jon Rowley's sensory quality scores and those of an Expert Taste Panel composed of Kathy Casey, chef, Fullers Restaurant; Karl Beckley, owner/chef, Greenlake Grill; Wayne Ludvigsen, chef, Ray's Boathouse; Karen Malody, Restaurant Services, Inc.; Schuyler Ingle, food writer and restaurant critic; and food consultant Mauny Kaseburg, Kaseburg Associates. Other experiments analyzed the effects of using our sub-optimal, slow freezing method rather than the industry standard of blast freezing. Some samples were frozen at a large commercial seafood cold storage plant (Sea Freeze, Inc.) in Seattle, Washington for this analysis. A final experiment compared small trawl-caught sablefish dressed immediately after capture with those dressed 4 days after capture.

Biological Analysis

Analysis of biological data focused on three topics. The first was the relationship between reproductive effort, season, and depth for each sex, and the second was the relationship between total moisture content, depth, reproductive effort, and sex. Reproductive effort for each fish was quantified by calculating the Wet Gonad Somatic Index (WGSI = ratio of gonad weight to somatic weight). The third topic was the effects of season and depth on raw fillet weight. Since sablefish spawn from mid-January to mid-March and food availability is thought to be lowest during the winter months, one would suspect sablefish to be at their worst physical condition during the spring. Thus, we were specifically interested in determining whether or not sablefish yields could be increased simply by harvesting the fish in the fall rather than in the spring.

Since many biological characteristics are affected by length, we made all our comparisons on the basis of a standardized sablefish with a fork length of 63 cm. We chose this length for several reasons: (1) It is close to the mean length of all of our samples, and therefore should produce the most accurate estimates; (2) most sablefish having a length of 63 cm are sexually mature (length at 50% maturity for males and females is 52 cm and 58 cm, respect-

ively; Mason et al. 1983); and (3) sablefish of this length are well represented in the landings of all three gear types.

Season, Depth, Size, and Gear Type Effects

Our sampling design permitted each of these main effects to be analyzed individually by blocking out the effects of the other three factors. For example, seasonal effects were analyzed by comparing samples within each market size category from the commercial trap fishery, samples which were caught in the same depth region but at different times of the year.

Gear type effects were analyzed by collecting samples during the primary fishing season (late July - early October) from the NMFS trawl and trap surveys and from the commercial longline vessel *F/V Sea Angel*. Trawl and trap samples were bled, dressed, and frozen immediately after capture. Most longline samples were bled and dressed immediately after capture and were held in bulk ice for 24-48 hours before freezing.

Because of the restricted sampling depths of the NMFS trawl survey, most trawl samples were collected in the 90-110 fathom range. All tows during this survey were 30 minutes long, and the average total cod end weight was 633 pounds. Trap samples collected during the NMFS trap survey were captured in conical traps, which were hauled after a 24-hour soak time. Since most trawl samples were not collected in the same depth range as the trap and longline samples, we could not effectively block out the effects of depth when analyzing the gear type effects.

Literature Review

We reviewed the scientific literature for clues to help explain our findings (e.g. Blaxter et al. 1971, Childress and Nygaard 1973, Dawson and Grimm 1980, Tyler and Dunn 1976, Dygert 1985, Haard [in press], Hendrickson et al. 1983, Hendrickson et al. 1984, MacKinnon 1972, Templeman and Andrews 1956, Percy 1961). We found that the sablefish is only one of many marine species that exhibit the soft-textured condition. The similarities appeared strong enough to suggest that the biological mechanisms responsible for soft texture may be common to many species. We therefore developed a speculative theory to explain the soft textured condition in fish. Our

primary goal in speculating on such a theory was to provide the impetus to stimulate new research.

RESULTS

Methodology Validation Experiments

The within-fillet variability test indicated that moisture content and drip loss estimates increased from the anterior to posterior regions of a fillet. The average difference between anterior and posterior estimates of total moisture content (%) and drip loss (%) were 7.1 and 2.7 percentage points, respectively.

We found a strong correlation ($r = 0.915$) between Jon Rowley's sensory assessments and those of the Expert Taste Panel (Fig. 2). All assessors were in general agreement about which samples were good or bad. Two results were quite interesting: (1) Jon Rowley's correlation with the average Taste Panel scores were higher than his correlation with any of the individual Taste Panel members; and (2) no other individual evaluator correlated with the group average as well as Jon Rowley did.

The results from the freezing method experiments were as follows: (1) suboptimal (slow) freezing increased the variance and reduced the differences between means for each depth stratum (Table 2a); (2) sablefish from deep water had higher drip loss, lower smoked-fish yield, and lower sensory quality scores regardless of the freezing method employed (Table 2b); (3) there was an interaction between moisture and depth such that increased moisture decreased quality for deep fish but not for shallow fish (Fig. 3); and (4) the transverse cut test was capable of distinguishing between fast and slow freezing methods.

We found that small, trawl-caught sablefish dressed immediately after capture had higher quality scores than those held for four days in the round before dressing (Table 3).

Biological Analysis

Sablefish in the shallow depth stratum spawned from mid-January through mid-March, and the recovery period lasted until June. Gonad development for males preceded that for females by several months (Fig. 4). During the months of August and September,

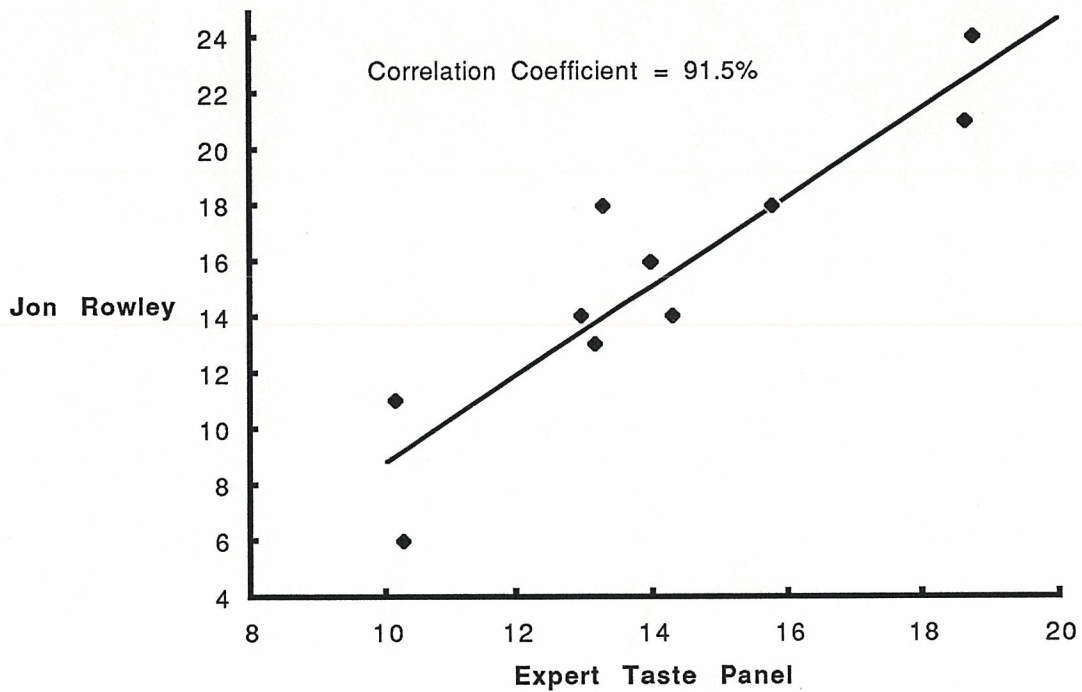


Figure 2. Data plot illustrating the degree of correlation between Jon Rowley's scores for total cooked fillet quality and those of an Expert Taste Panel composed of Kathy Casey, chef, Fullers Restaurant; Karl Beckley, owner/chef, Greenlake Grill; Wayne Ludvigsen, chef, Ray's Boathouse; Karen Malody, Restaurant Services, Inc.; Schuyler Ingle, food writer and restaurant critic; and food consultant Mauny Kaseburg, Kaseburg Associates.

Table 2. Results of freezing method validation test comparing an industry standard blast freezing method (Sea Freeze) with our slow freezing method (A&J). Part (a) compares freezing methods for samples taken from shallow (130 fathoms) or deep (500 fathoms) water and part (b) compares shallow and deep samples frozen at Sea Freeze, Inc. or A&J Quality Meats. Note: ltl values are a statistical measure of the difference between two means (averages) and p values are the probability of observing a ltl statistic as large as the one shown when the means are actually equal. Sample sizes are in parens. (WDF = Whole Dressed Fish; RF = Raw Fillet; CF = Cooked Fillet.)

(a)	Shallow				Deep			
	Means		ltl	p	Means		ltl	p
	Sea Freeze	A&J Meats			Sea Freeze	A&J Meats		
Quality Characteristic	(7)	(8)			(8)	(9)		
Drip Loss (%)	8.2	8.8	.53	.61	19.5	20.8	.37	.72
Smoked Yield (%)	83.8	83.2	.36	.72	71.0	73.4	.70	.50
WDF: Appearance	6.4	6.4	.20	.85	3.7	4.9	1.57	.15
Firmness	7.4	7.4	.10	.92	4.0	5.4	1.64	.13
RF: Appearance	6.8	5.9	1.33	.22	4.0	4.9	1.15	.28
Trans Cut	8.5	7.7	.75	.48	4.3	6.3	1.89	.08
CF: Appearance	7.4	6.3	1.75	.11	4.3	5.8	1.65	.12
Texture	7.9	6.6	1.21	.26	3.3	4.4	1.04	.32
Flavor	7.3	6.3	1.41	.19	4.8	5.1	.58	.58

(b)	Sea Freeze				A&J			
	Means		ltl	p	Means		ltl	p
	Shallow	Deep			Shallow	Deep		
Quality Characteristic	(8)	(9)			(7)	(8)		
Drip Loss (%)	8.2	19.5	4.62	.00	8.8	20.8	4.21	.00
Smoked Yield (%)	83.8	71.0	4.24	.00	83.2	73.4	4.18	.00
WDF: Appearance	6.4	3.7	7.12	.00	6.4	4.9	2.15	.06
Firmness	7.4	4.0	6.09	.00	7.4	5.4	2.51	.03
RF: Appearance	6.8	4.0	5.65	.00	5.9	4.9	1.09	.30
Trans Cut	8.5	4.3	6.09	.00	7.7	6.3	1.15	.27
CF: Appearance	7.4	4.3	3.92	.00	6.3	5.8	.72	.48
Texture	7.9	3.3	6.50	.00	6.6	4.4	1.69	.11
Flavor	7.3	4.8	7.14	.00	6.3	5.1	1.38	.19

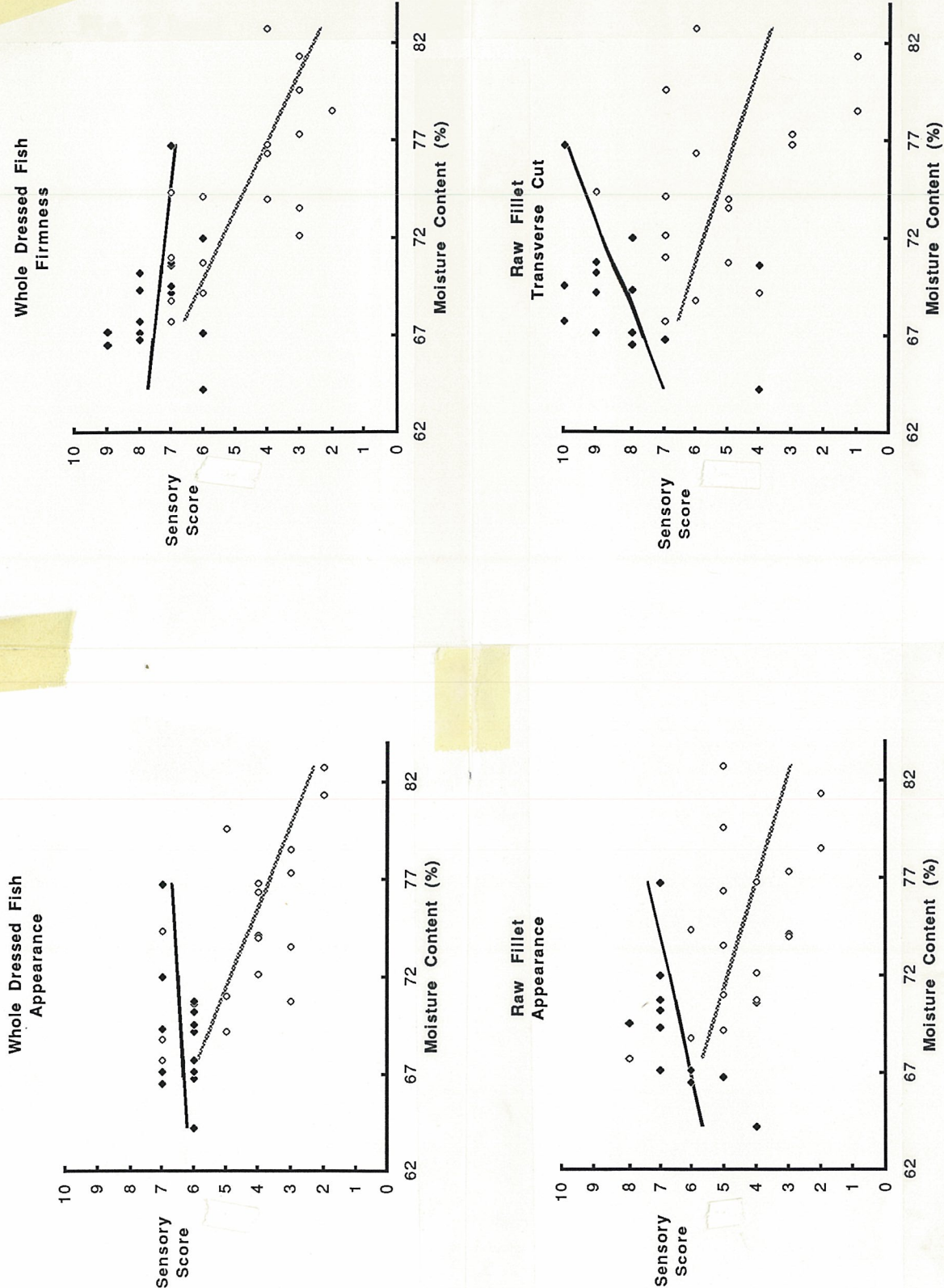


Figure 3. Data plots and trend lines illustrating the generally positive correlation between total moisture content and quality for sablefish captured in 130 fm (solid diamonds and dark trend lines) and the negative correlation between moisture content and quality for sablefish captured in 500 fm (open diamonds and light trend lines). All samples were large females caught by longline gear on October 3-5, 1986.

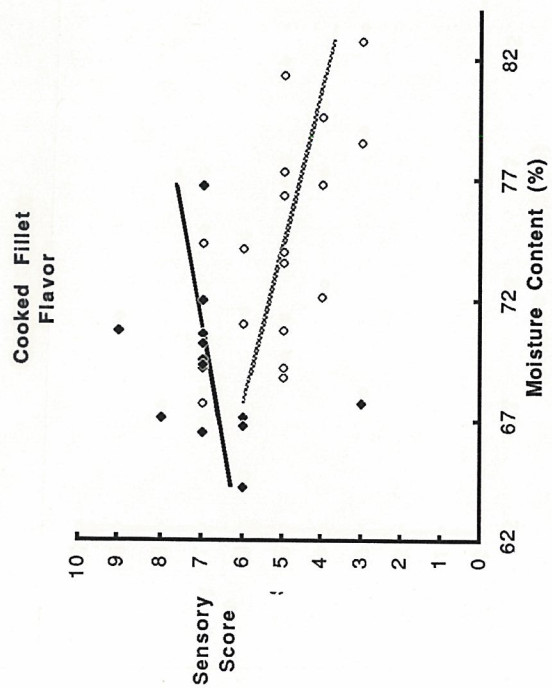
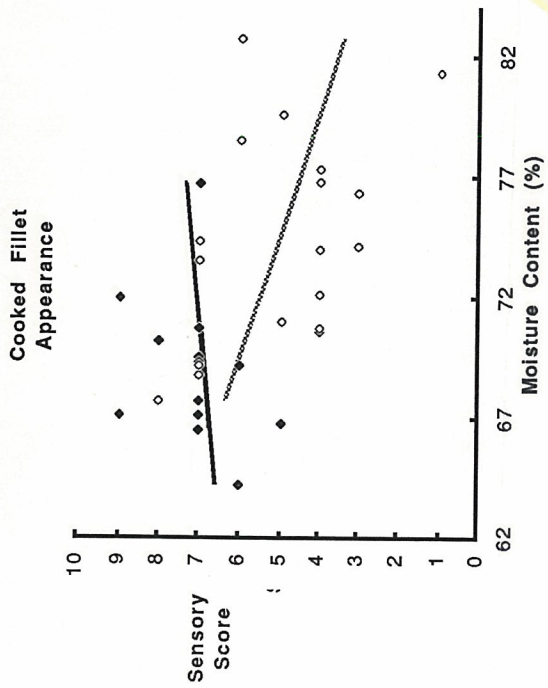
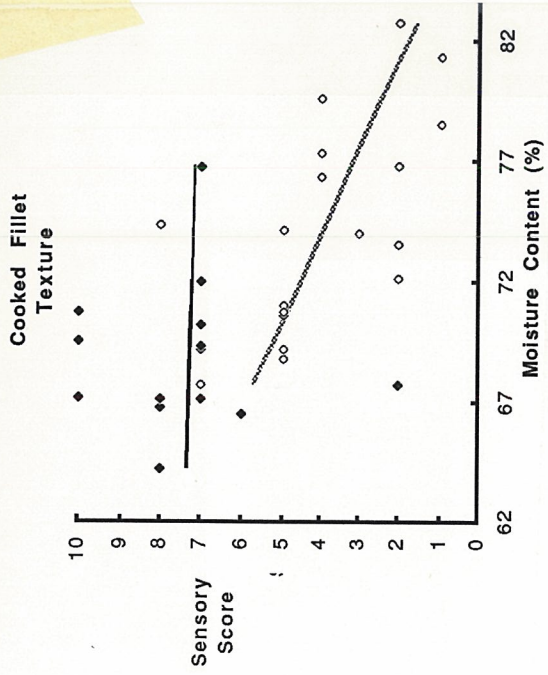


Fig. 3. cont'd.

Table 3. Results of two-sample t-tests for equality of means between small trawl-caught sablefish dressed immediately after capture (DAYS = 0) and four days after capture (DAYS = 4). Sample sizes are in parens.

Quality Characteristic	Means		t	p
	DAYS=0	DAYS=4		
	(7)	(6)		
WDF: Appearance	7.5	7.5	0.00	1.00
Firmness	8.0	6.7	2.50	0.03
RF: Appearance	6.8	5.3	1.64	0.15
Trans Cut	5.0	4.0	0.83	0.43
CF: Appearance	5.6	4.8	0.72	0.50
Texture	4.4	2.7	2.06	0.07
Flavor	4.1	2.7	1.44	0.18

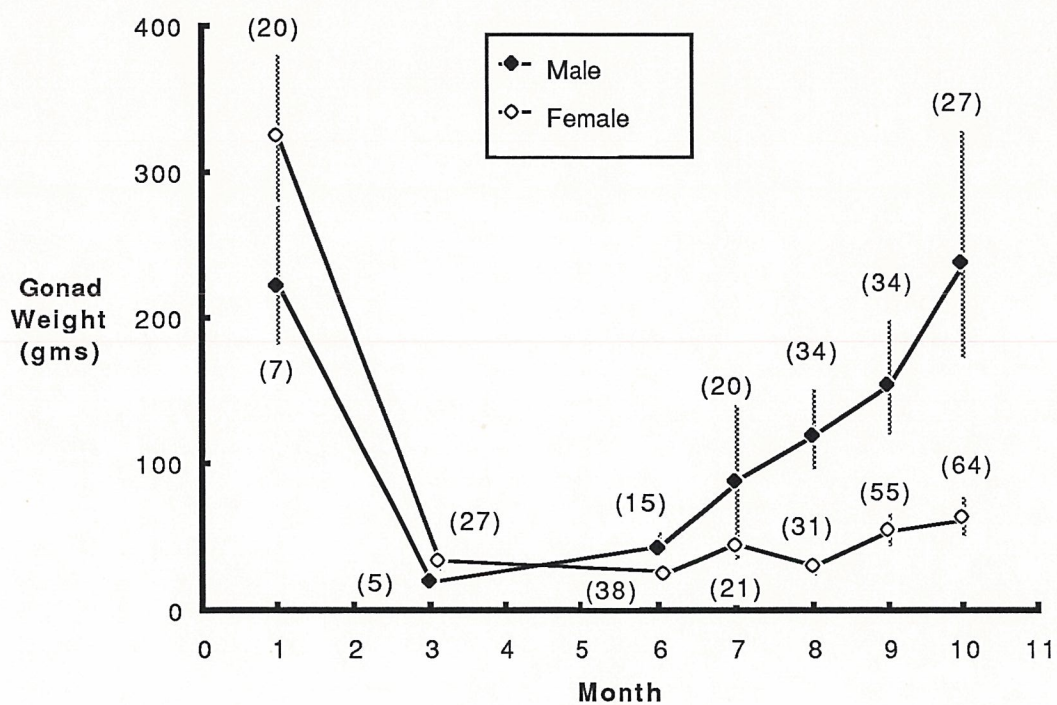


Figure 4. Estimated mean gonad weights for male and female sablefish of representative length (63 cm) in the shallow (0-400 fm) depth stratum by month. Estimates were determined by assuming a linear relationship between the logarithms of gonad weight and length. Separate regression lines were computed for each sex in each month. Vertical bars indicate 95% confidence intervals around regression estimates when length is fixed at 63 cm. Sample sizes are in parens.

males in the shallow depth stratum had higher reproductive effort than males in the deep depth stratum. Reproductive effort for females was the same for both depth strata. (For other months, sample sizes in the deep depth stratum were insufficient to permit statistical analysis of the effects of depth on reproductive effort.)

Total moisture content was significantly affected by depth, reproductive effort, and sex (in order of statistical significance). Total moisture content increased with depth (0.9 percentage points for each 100 fathoms), decreased with reproductive effort (0.3 percentage points for each percent increase in WGS) and was 0.9 percentage points higher for females than for males.

Raw fillet weight for sablefish of representative length (63 cm) captured in the shallow depth stratum increased by 9.2% from June through October (Fig. 5). During the period August through October, skeletal muscle characteristics were affected by depth also. For each 100 fathoms of depth, raw fillet yield (expressed as a percentage of total round weight) declined an average of 1.1 percentage points (Fig. 6), and raw fillet weight for sablefish of representative length (63 cm) declined by about 5% (Fig. 7). For example, sablefish of equal length captured at 600 fathoms had, on average, 21% less skeletal muscle tissue than those captured at 200 fathoms.

Season Effects

We detected no seasonal differences in the sensory quality characteristics of samples caught within either depth stratum by the commercial trap fishery.

Depth Effects

The depth sampling range for the trawl samples was too narrow to distinguish any depth effects. For the trap and longline samples, we found that smoked-fish yield was negatively correlated and drip loss was positively correlated with depth in all size categories (Figs. 8 & 9). For each 100 fathoms of depth, average smoked-fish yield (%) decreased by 2.6 percentage points and average drip loss (%) increased by 2.9 percentage points. Other quality characteristics declined with increasing depth (recall Table 2.).

We noted the following additional characteristics of sablefish captured in the deep (over 400 fathoms) depth stratum:

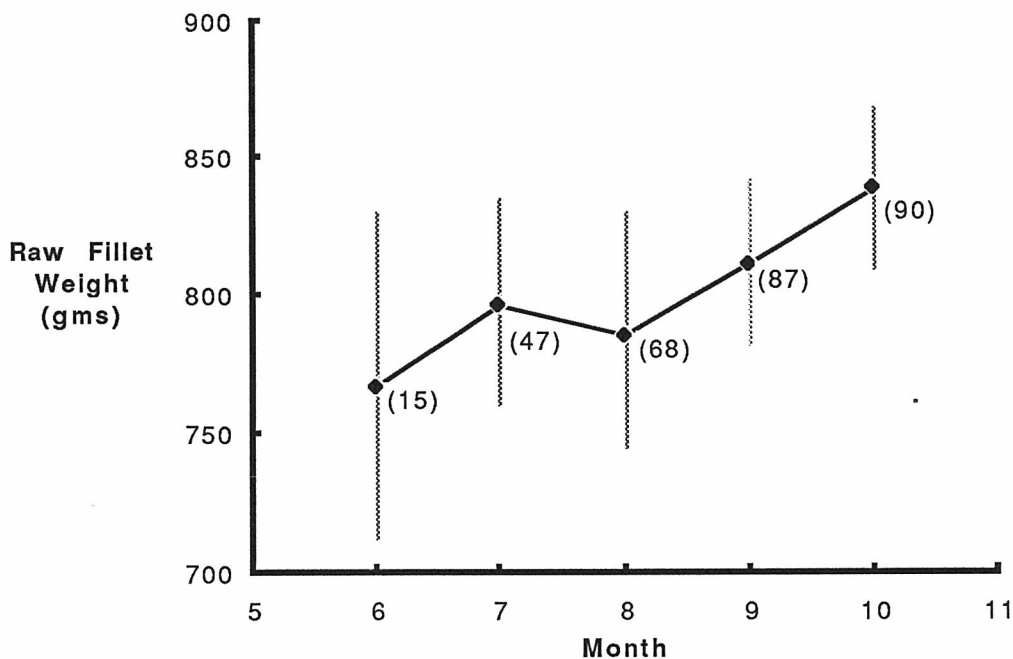


Figure 5. Estimated mean raw fillet weight for sablefish of representative length (63 cm) in the shallow (0-400 fm) depth stratum by month. Estimates were determined by assuming a linear relationship between the logarithms of raw fillet weight and length. Separate regression lines were computed for each month. Sexes were pooled because there was no statistically significant difference between males and females. Vertical bars indicate 95% confidence intervals around the regression estimates when length is fixed at 63 cm. Sample sizes are in parens. Multiple partial F tests indicated a statistically significant month effect at the 90% confidence level. The difference between the point estimates for June and October was 71 grams and represents a 9.2% increase.

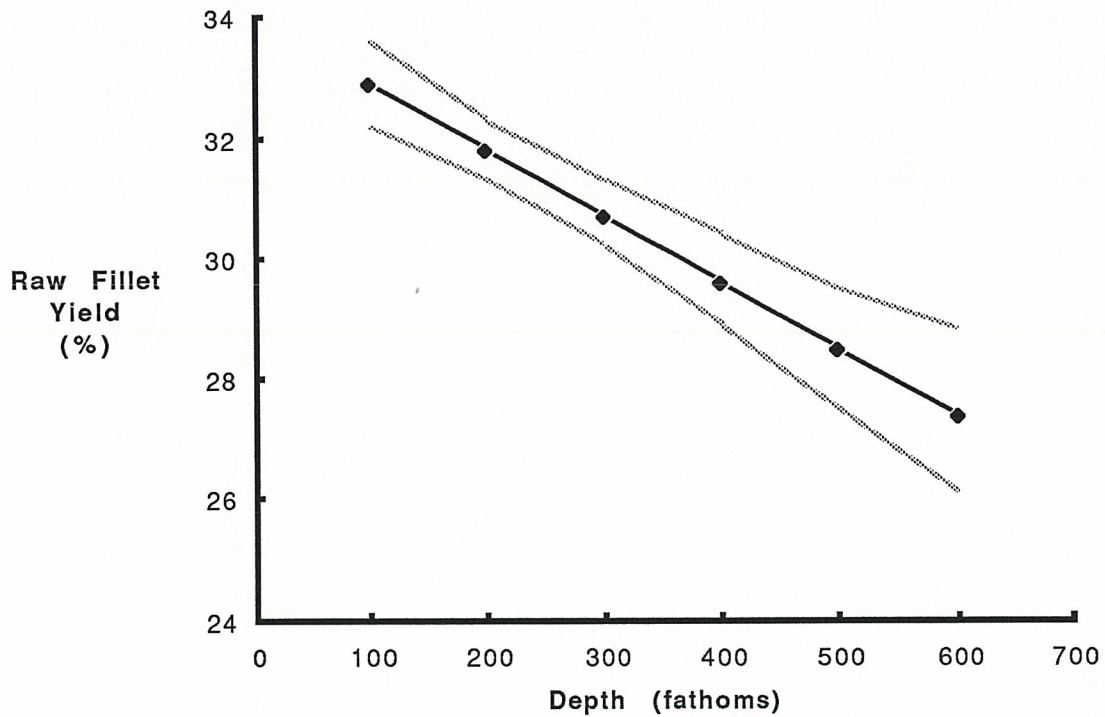


Figure 6. Estimated mean raw fillet yield (expressed as a percentage of total round weight) as a function of depth of capture during the period August-October for sablefish of representative length (63 cm). Estimates were determined by fitting the data to the following model: $\text{Yield (\%)} = B_0 + B_1 * \text{Depth} + B_2 * \text{Length} + B_3 * \text{Depth} * \text{Length}$. Lighter lines indicate the 95% confidence interval around the estimated regression line when length is fixed at 63 cm. Total sample size = 342.

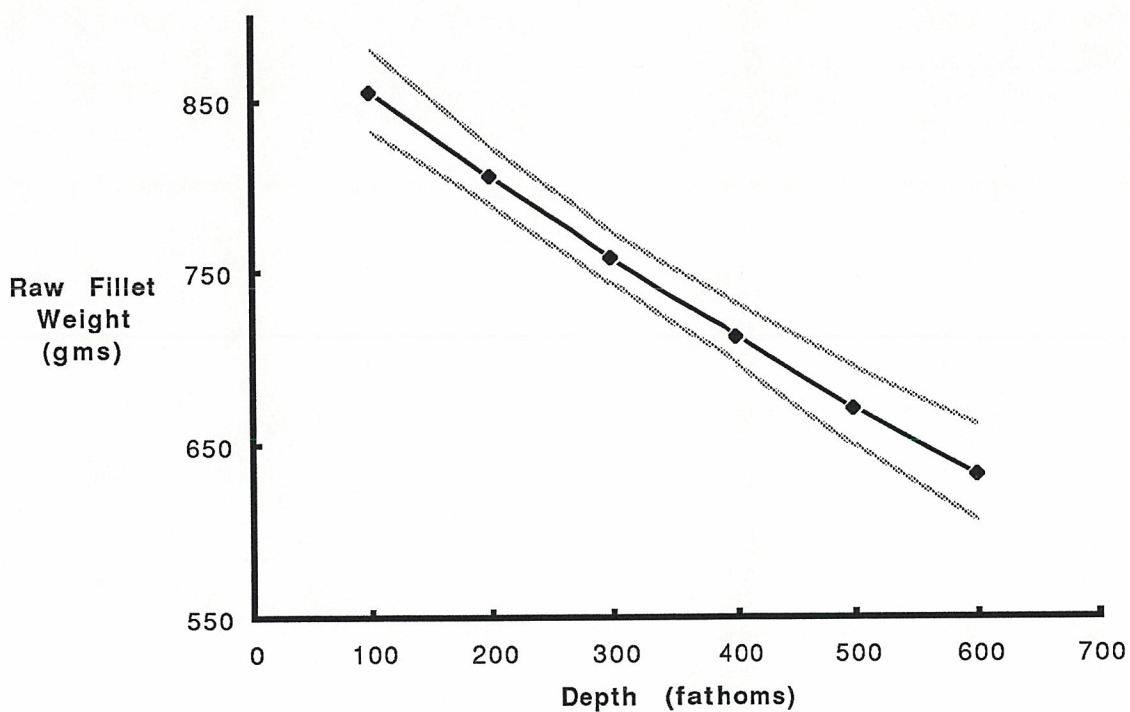


Figure 7. Estimated mean raw fillet weight as a function of depth of capture during the period August-October for sablefish of representative length (63 cm). Estimates were determined by fitting the data to the following model: $\ln(\text{Weight}) = B_0 + B_1 \cdot \ln(\text{Length}) + B_2 \cdot \text{Depth} + B_3 \cdot \ln(\text{Length}) \cdot \text{Depth}$. Lighter lines indicate the 95% confidence interval around the estimated regression line when length is fixed at 63 cm. Total sample size = 285.

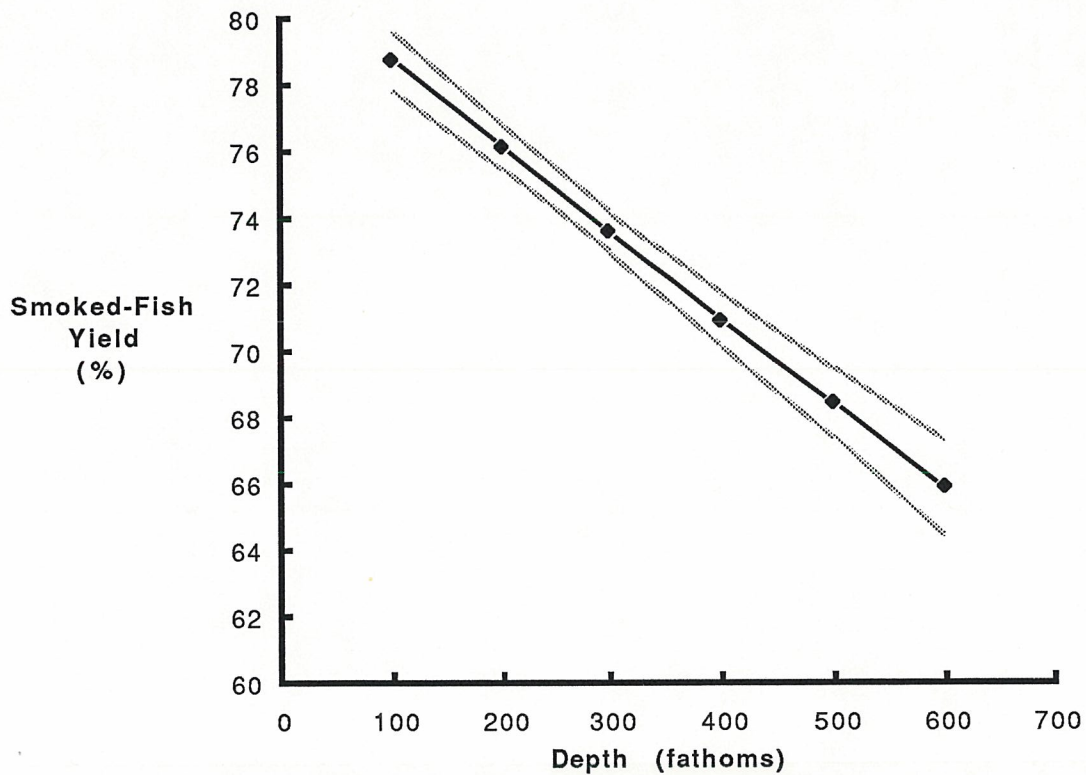


Figure 8. Estimated mean smoked-fish yield as a function of depth of capture during the period August-October for sablefish of representative length (63 cm). Estimates were determined by fitting the data to the following model: $\text{Yield (\%)} = B_0 + B_1 \cdot \text{Depth} + B_2 \cdot \text{Length} + B_3 \cdot \text{Depth} \cdot \text{Length}$. Lighter lines indicate the 95% confidence interval around the estimated regression line when length is fixed at 63 cm. Total sample size = 370.

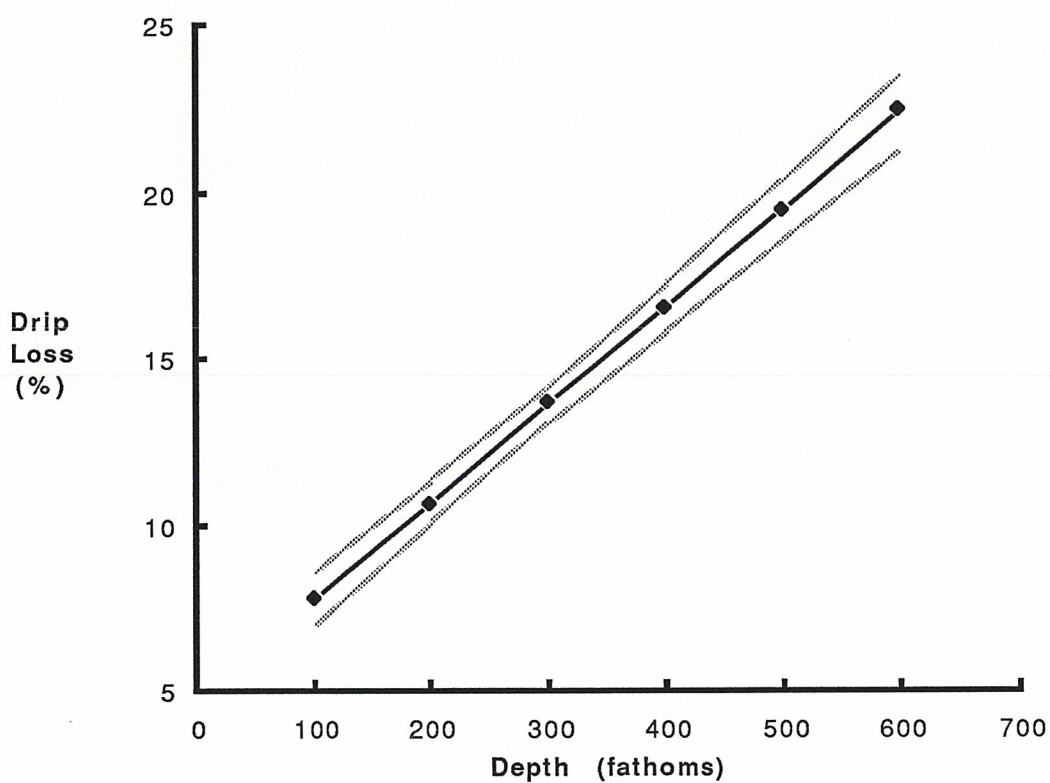


Figure 9. Estimated mean 24-hour drip loss as a function of depth of capture during the period August-October. Lighter lines indicate the 95% confidence interval around the estimated regression line. Total sample size = 280.

- Coal black exterior coloration including darker bellies (which were white or gray in shallow fish);
- White or gray visceral cavity lining (which was darker in shallow fish);
- Whiter fillets (suggesting lower red blood cell counts) exhibiting a lack of pronounced internal bruising despite external evidence of rough handling;
- Increased scale loss;
- Thinner belly walls, different shaped rib cage, and overall emaciated appearance.

These depth effects were observed throughout the year and were not confined to any one season.

Fish Size Effects

Fish size was positively correlated with smoked-fish yield regardless of the capture method (Fig. 10). For other quality characteristics, trawl samples in the small size category showed the most significant correlations between quality and length, especially for cooked fillet flavor (Fig. 11).

Gear Type Effects

In the shallow depth stratum, trawl-caught samples in the small size category had lower scores than trap or longline samples, despite the fact that they were captured in shallower water (Table 4). We also noted that many of the raw fillets from trawl samples in the small size category had a slightly darker, chestnut color compared to the trap and longline samples. In the medium and large size categories, the trap samples had lower scores than the trawl or longline samples for some quality characteristics.

In the deep depth stratum, the longline samples had slightly higher scores than the trap samples, but few of the differences were statistically significant.

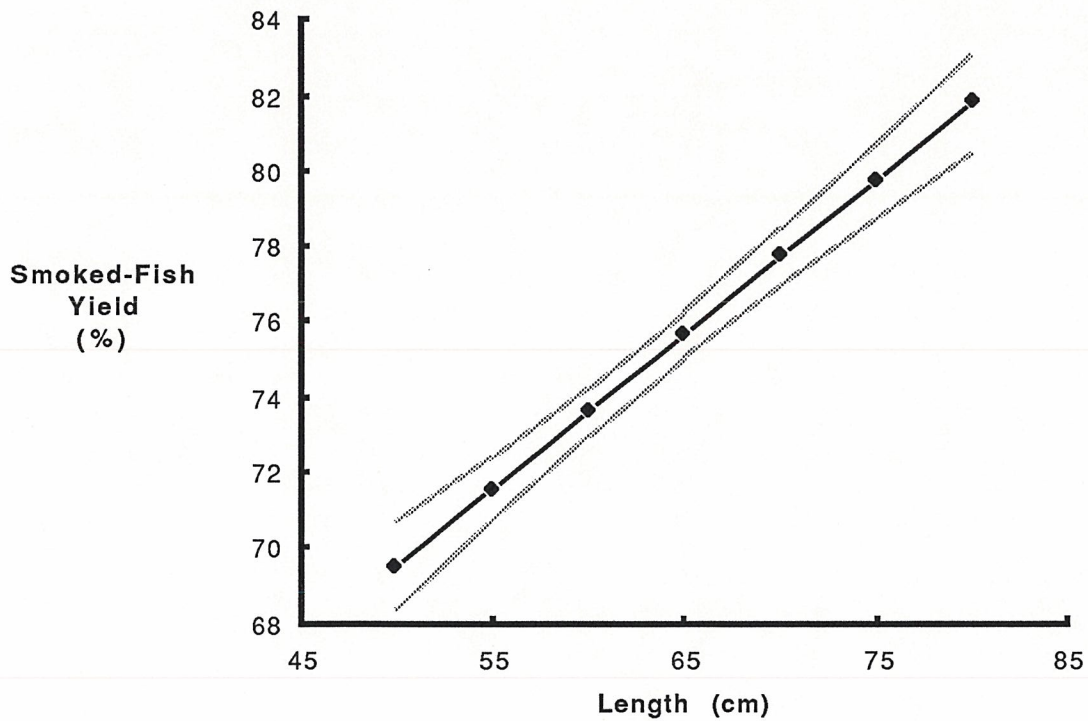


Figure 10. Estimated mean smoked-fish yield as a function of fork length during the period August-October for sablefish caught at a depth of 250 fm. Estimates were determined by fitting the data to the following model: $\text{Yield (\%)} = B_0 + B_1 \cdot \text{Depth} + B_2 \cdot \text{Length} + B_3 \cdot \text{Depth} \cdot \text{Length}$. Lighter lines indicate the 95% confidence interval around the estimated regression line when depth is fixed at 250 fm. Total sample size = 370.

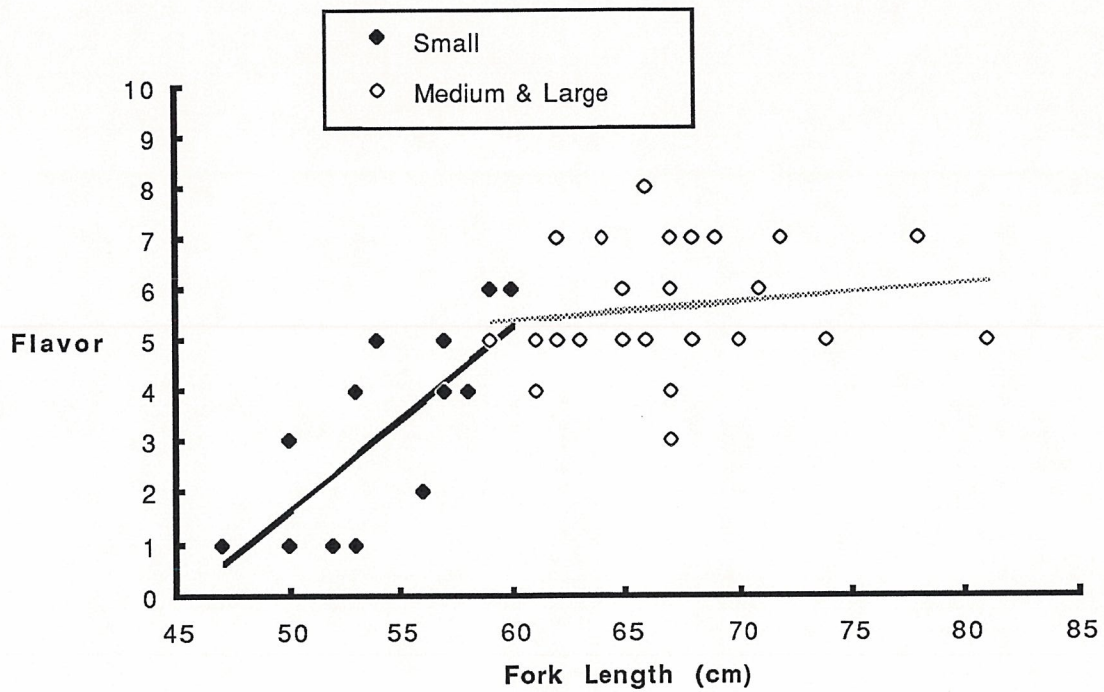


Figure 11. Data plots and trend lines illustrating the positive correlation between cooked flavor and fork length for trawl-caught sablefish in the small (3-5 lb round weight) market size category (open diamonds and light trend line; sample size = 14) and the general lack of correlation for those in the medium (5-7 lb round weight) and large (over 7 lb round weight) market size categories (solid diamonds and dark trend line; sample size = 31).

Table 4. Results of one-way ANOVA overall F tests for gear type effects within the shallow (0-400 fm) depth stratum. Sample sizes are in parens. (* = statistically significant at the 90% confidence level.)

	Means			F	
	Trawl	Trap	Longline		
<u>Small Market Size</u>	(14)	(14)	(18)		
WDF: Appearance	6.6	6.7	7.3	1.89	
Firmness	7.3	7.4	7.0	0.33	
RF: Appearance	5.6	5.8	6.7	1.60	
Trans Cut	2.9	4.8	5.5	4.41	*
CF: Appearance	4.9	6.2	6.4	5.45	*
Texture	3.8	4.9	5.5	2.77	*
Flavor	3.4	4.9	6.3	12.88	*
Length (cm)	53.5	55.5	56.6		
Depth (fm)	108.0	263.0	247.0		
<u>Medium Size Category</u>	(16)	(13)	(13)		
WDF: Appearance	7.2	5.8	7.2	6.18	*
Firmness	8.2	6.3	7.1	8.72	*
RF: Appearance	6.3	5.5	7.0	3.64	*
Trans Cut	4.2	3.7	4.7	0.58	
CF: Appearance	6.4	6.1	6.5	0.47	
Texture	4.7	5.0	3.8	1.09	
Flavor	5.6	5.4	5.2	0.33	
Length (cm)	63.4	64.7	62.7		
Depth (fm)	97.0	276.0	200.0		
<u>Large Market Size</u>	(15)	(10)	(16)		
WDF: Appearance	6.7	6.0	7.0	2.59	
Firmness	7.9	6.6	7.3	2.43	
RF: Appearance	6.5	5.6	6.6	1.35	
Trans Cut	4.5	3.9	7.3	5.84	*
CF: Appearance	6.2	5.8	6.8	1.88	
Texture	5.1	4.3	6.5	4.34	*
Flavor	5.7	5.1	6.4	2.35	
Length (cm)	70.5	72.1	72.3		
Depth (fm)	99.0	270.0	188.0		

Literature Review

The single most important finding of our literature review was that the "jellied" condition in both American plaice and Dover sole is accompanied by large water-filled spaces between the skeletal muscle cells. For example, Templeman and Andrews (1956) prepared histological sections of normal and jellied American plaice and found the following: "Greater spaces are apparent between the muscle fibres of jellied plaice than of normal plaice. Thus, there is less muscle fibre material per unit of area in the sections of jellied fillets than in the sections of normal fillets." They concluded "that the jellied fillets contain a larger fraction of their moisture in the form of lymph in these expanded inter-cellular spaces. This extra-cellular moisture, being more loosely held, would presumably be more available as drip."

We also found evidence that other noncommercial species exhibit characteristics that are similar to sablefish. For example, Blaxter et al. (1971) examined the chemical composition of 22 mid-water fishes near the Canary Islands and concluded: "Mesopelagic fish without swim bladders, found in depths from 100 to 1000 meters [50 to 500 fathoms], have soft bodies with a very high water content, low haematocrits [red blood cell counts], small hearts, a low proportion of red muscle, and large lymph ducts." They also noted that these fish had poorly ossified skeletons.

DISCUSSION

Methodology Validation Experiments

The results of our methodology validation experiments were helpful in interpreting moisture content and drip loss results and confirmed that our sensory quality analyses were consistent with other leaders in the seafood industry. Our freezing method decreased the sensitivity of our experiments to detect differences between shallow and deep fish but did not adversely affect our results. Any quality differences observed by our project will most likely be observed by the industry also.

Biological Analysis

Our findings suggest that food availability during the summer of 1986 was sufficient to support increases in both raw fillet weight (skeletal muscle tissue) and gonad weight. We suspect that the degree of increase in raw fillet weight may vary from year to year, depending on food availability, but that at least some increase will occur in most years. It appears that sablefish yields might be increased by harvesting near the end of the summer feeding season rather than in the early spring after the spawning season. Some production would be lost to natural mortality during the initial shift from a spring harvest to a fall harvest. However, once a fall harvest was established, total annual natural mortality would be the same as for a spring harvest.

A second implication of our results is that, regardless of the season in which sablefish are caught, the depth of capture can have a dramatic influence on the processor's recovery yield. Tables 5 and 6 illustrate how reduced fillet weight and increased drip loss associated with increased depth of capture combine to alter the yields that processors may receive from the raw sablefish they purchase. For example, we estimated that a processor who purchased 10,000 pounds of eastern-dressed, medium-sized sablefish caught in 200 fathoms could expect a yield of 4,860 pounds of marketable fillets, whereas a processor who purchased 10,000 pounds of eastern-dressed, medium-sized sablefish caught in 600 fathoms could expect a yield of only 3,790 pounds of marketable fillets. The difference is 1,070 pounds and, at a value of \$1.80 - \$2.00 per pound at the wholesale level, the value of lost sales could reach \$2,000. Labor costs to process the deeper fish would also be higher because more individual fish would have to be filleted to produce the same pounds of marketable fillets.

Our finding that shallow and deep sablefish have different body condition characteristics also has important implications for sablefish stock assessment and management options. If we consider the question "Why do sablefish of a given length caught in 600 fathoms have 21% less skeletal muscle tissue than sablefish of the same length but caught in 200 fathoms?" two answers come to mind. The first is that the observed differences could be the result of genetic variability. The second is that shallow and deep sablefish are genetically identical but have experienced prolonged exposure to different environmental factors associated with depth (such as food availabil-

Table 5. Estimated weight (pounds) of sablefish product forms and body components used to estimate marketable fillet recovery rates from round, western dressed, and eastern dressed sablefish. All estimates are based on sablefish with a fork length of 63 cm. Conversion rates for western and eastern dressed weights from total round weight are from Klein (1985). All other estimates are based on the results from this study.

Product Form and Body Components	Depth of Capture (fathoms)		
	200	400	600
Total Round Weight	5.73	5.47	5.27
less Head and Viscera	<u>-1.77</u>	<u>-1.74</u>	<u>-1.73</u>
Western Dressed Weight	3.96	3.72	3.53
less Collars	<u>-.71</u>	<u>-.70</u>	<u>-.70</u>
Eastern Dressed Weight	3.25	3.02	2.84
less Skeleton, Fins, & Other	<u>-1.47</u>	<u>-1.45</u>	<u>-1.44</u>
Raw Fillet Weight	1.78	1.57	1.40
less 24-Hour Drip Loss	<u>-.20</u>	<u>-.27</u>	<u>-.32</u>
Marketable Fillet Weight	<u>1.58</u>	<u>1.31</u>	<u>1.08</u>
<u>Recovery Rates (%)</u>			
Round	27.6%	23.9%	20.4%
Western Dressed	39.9%	35.1%	30.4%
Eastern Dressed	48.6%	43.3%	37.9%

Table 6. Estimated weight (pounds) of sablefish product forms and body components used to estimate smoked fillet recovery rates from round, western dressed, and eastern dressed sablefish. All estimates are based on sablefish with a fork length of 68 cm. Conversion rates for western and eastern dressed weights from total round weight are from Klein (1985). All other estimates are based on the results from this study.

Product Form and Body Components	Depth of Capture (fathoms)		
	200	400	600
Total Round Weight	7.33	7.04	6.81
less Head and Viscera	<u>-2.26</u>	<u>-2.26</u>	<u>-2.26</u>
Western Dressed Weight	5.07	4.78	4.55
less Collars	<u>-.91</u>	<u>-.91</u>	<u>-.91</u>
Eastern Dressed Weight	4.16	3.87	3.64
less Skeleton, Fins, & Other	<u>-1.86</u>	<u>-1.84</u>	<u>-1.84</u>
Raw Fillet Weight	2.30	2.03	1.80
times Smoked-Fish Yield Rate	<u>* .77</u>	<u>* .71</u>	<u>* .65</u>
Smoked Fillet Weight	<u>1.78</u>	<u>1.45</u>	<u>1.18</u>
<u>Recovery Rates (%)</u>			
Round	24.3%	20.6%	17.3%
Western Dressed	35.1%	30.3%	25.9%
Eastern Dressed	42.8%	37.5%	32.4%

ity, food quality, activity level, and temperature) leading to different body conditions. Both answers imply that shallow and deep sablefish, as we have defined them, do not fully commingle. We suspect that all sablefish have fairly broad depth preference ranges, but that the midpoints of the individual ranges are quite different. The midpoints of these ranges could vary with the seasons. For example, during the summer months some sablefish may prefer the 100-500 fathom range while others prefer the 400-800 fathom range.

Understanding the factors determining the depth distribution of the stock, especially during the spawning season, is of fundamental importance for accurate stock assessment and management. A series of research cruises should be conducted during the spawning season to determine the depth distribution of the spawning stock.

Season, Depth, Size, and Gear Type Effects

Our results suggest that, in general terms, depth is the most significant factor affecting sablefish quality, followed by length, gear type, and season in order of importance. Depth was particularly important for drip loss, smoked-fish yield, and the external characteristics of the fish, while length appeared to be more important for the final eating qualities of the fish. Since the preferred flavor of sablefish is related to its oil and fat content, it is likely that changes in body composition related to sexual maturity are responsible for the relationship between flavor and length. (Lengths at 50% maturity for males and females are 52 cm and 58 cm, respectively; Mason et al. 1983.)

Our finding that trawl-caught sablefish in the small size category had lower scores for cooked fillet appearance and flavor than the other gear types, combined with our observation that the fillets had a darker, chestnut color, lead us to believe that small trawl-caught sablefish may suffer internal bruising during the capture process. Capillaries in the skeletal muscle tissues may be ruptured as the fish is compressed in the cod end. If the heart is still pumping, small quantities of blood may be released into the tissues, resulting in a darker color and poorer flavor. These effects appear to be most pronounced in the small fish.

The remainder of our results on gear type effects suggest that, with the exception of small trawl-caught sablefish, some of the quality differences between gear types observed by processors may

be due to differences in the depth of gear deployment or on-board handling practices rather than to the effects of the gear itself. For example, trap gear is often fished in deeper water than is longline gear, as is trawl gear when targeting on Dover sole.

We acknowledge that our ability to test for gear type effects was hampered by the fact that we could not completely control for depth, on-board handling, and freezing methods. To more accurately test for possible gear type differences, further research should be conducted using all three gear types from a single vessel and utilizing the same on-board handling and freezing techniques.

Literature Review

Our speculative theory to explain the soft textured condition in sablefish is an extension of the findings by other researchers working on American plaice and Dover sole. We hypothesize that soft texture and associated characteristics in sablefish may be caused by large water-filled intercellular spaces resulting from protein or fat depletion in skeletal muscle tissues. To test this theory, histological sections of soft and firm sablefish muscle tissues should be prepared and research should be conducted to determine the biochemical characteristics and properties of both intercellular and intracellular fluids.

ACKNOWLEDGMENTS

This project was a cooperative effort involving several commercial fishing vessels, seafood processors, consumers and the National Marine Fisheries Service. The authors wish to thank the following people for their invaluable contributions to this project: Arne Lindstrom, Jim Smith, and the crew at Port Chatham Packing Company for collecting the data on smoked-fish yields; Dave Fraser, Jim Prince, and the crew of the F/V **Muir Milach** for assisting in collecting the winter trawl samples; Jim and Mike Schones of the F/V **Collier Brothers**, Richard Arnold, and the crew of the F/V **Lihue II**, and Paul Cho and Rod Schleiger of All Marine Products, Inc. for assisting in collecting the commercial trap samples; Charlie Noggle, and the crew of the F/V **Sea Angel** and Paul Bourke of Ecluelet Seafood Processors Ltd. who provided the longline samples; Frank Shaw, Norm Parks, and Don Fisk who collected the NMFS trap survey

samples; Paul Raymore, Doug Markle, and Don McDonald who helped collect the NMFS trawl survey samples; Brady Coleman who helped on both the NMFS trawl and trap surveys; Malcom Zirges and staff at the Oregon Department of Fish and Wildlife, Newport, Oregon who donated laboratory space; and Kevin Ford, Fisheries Development, NMFS who coordinated all administrative details.

We extend a special thank you to the six Seattle-area chefs who volunteered to participate on the Expert Taste Panel: Kathy Casey, chef, Fullers Restaurant; Karl Beckley, owner/chef, Greenlake Grill; Wayne Ludvigsen, chef, Ray's Boathouse; Karen Malody, Restaurant Services, Inc.; Schuyler Ingle, food writer and restaurant critic; and food consultant Mauny Kasegurg, Kaseburg Associates.

Additional thanks go to the following scientists who donated valuable advice and insights: Robert Francis, Donald Gunderson, Lynwood Smith, and Robert Lauth, Fisheries Research Institute, University of Washington; Gordon Swartzman, Center for Quantitative Science, University of Washington; Harold Barnett, Alice Hall, and Richard Nelson, Utilization Research Division, NMFS; Norman Haard, Department of Food Science and Technology, University of California, Davis; Richard Deriso and Ana Parma, International Pacific Halibut Commission.

We are most grateful to Ken Adkins, who assisted in preparing the illustrations, and Marcus Duke, who assisted in the final editing and printing of this report.

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QUESTIONNAIRE

1. Circle any of the following titles that describe your affiliation with the sablefish industry:

Fisherman Fish Buyer Processor Retailer
 Restaurateur Scientist Administrator Other_____

2. Circle the geographic areas that you are most familiar with:

Bering Sea W. Gulf of Alaska E. Gulf of Alaska
 SE Alaska British Columbia Washington
 Oregon California

3. Do your observations agree or disagree with the findings of this project regarding the following topics:

- | | | |
|---|-------|----------|
| a. Fall fish give a higher fillet yield than spring fish. | Agree | Disagree |
| b. Shallow fish have less drip loss than deep fish. | Agree | Disagree |
| c. Shallow fish have thicker belly walls and appear to be in better condition than deep fish. | Agree | Disagree |
| d. Shallow fish have lighter belly coloration than deep fish. | Agree | Disagree |
| e. Gonad development for males precedes that for females by several months. | Agree | Disagree |
| f. Spawning takes place from mid-January to mid-March. | Agree | Disagree |

4. Circle the depth ranges you have observed spawning (ripe & running) females (circle all ranges that apply):

0-100 fm	100-200 fm	200-300 fm	300-400 fm
400-500 fm	500-600 fm	600-700 fm	700+ fm

5. How much will the results of this project help your business.

Very Helpful Some Help Little Help No Help

6. What further research would you like to see conducted on sablefish quality?

7. Any additional comments.

Return Questionnaires to: Utilization Research Division
National Marine Fisheries Service
2725 Mountlake Blvd. E.
Seattle, WA 98112