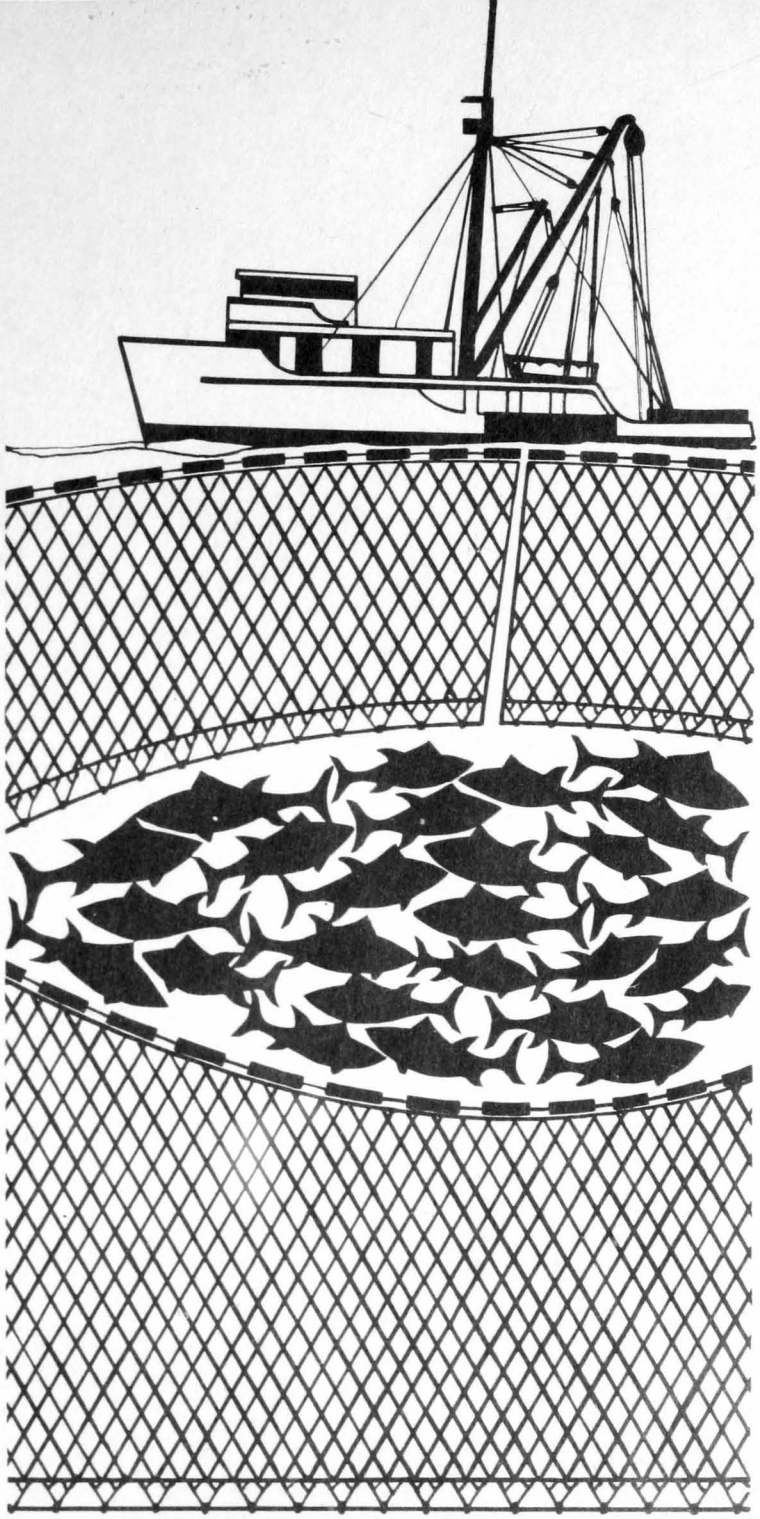

FISHERY INDUSTRIAL RESEARCH

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FISHERY INDUSTRIAL RESEARCH

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CONTENTS

INTRODUCTION

The first study (Barrett, Brinner, Brown, Dolev, Kwon, Little, Olcott, and Schaefer, 1965) in this series showed that the species of fish used was more important to the quality of canned tuna than were such variables as length of fish, time the fish were held on deck after capture, and the fact that the fish had been frozen and stored in brine wells aboard the fishing vessel. In the first study, samples of tuna muscles were obtained at sea, aboard commercial fishing vessels. The samples were taken from fish that were subjected to treatments reflecting the various methods of handling fish aboard the commercial fishing vessel and were tagged for identification. When the fish were unloaded at a cannery, the lengths of the individual fish were measured, and additional muscle samples were taken. All muscle samples were analyzed biochemically to gain an understanding of the changes in quality that had occurred. After the tagged fish had been canned, the organoleptic quality of the canned product was evaluated by an industry panel.

A statistical analysis of the data showed that a larger number of specimens from each treatment group would be necessary to clarify the various interrelations between the variables. Also, other changes in the sampling design seemed desirable. Accordingly, the study was extended into a second year. The second year's work, which is reported in this paper, was directed specifically toward determining the relative effect on canned-tuna quality of (1) length of fish, (2) time of holding the fish on deck after capture, and (3) biochemical changes during holding of fish in frozen storage.

In the present study of the relation of these three variables to the quality of canned yellowfin tuna, length emerged as the predominant one. The question then arose as to how closely the quality of the product could be predicted from fish length and whether the use of biochemical data would add to the precision of the forecast. Accordingly, this report deals with two main subjects:

I. Interrelation of biochemcial data, fish-handling data, sensory data, and fish-length data.

II. Use of fish length, with and without biochemical analyses, to predict quality of canned tuna.

I. INTERRELATION OF BIOCHEMICAL DATA, FISH-HANDLING DATA, SENSORY DATA, AND FISH-LENGTH DATA

The following three relations were studied by statistical analysis:

A. Relation of biochemical data to fish-handling data.

B. Relation of fish-handling data and biochemical data to sensory data.

C. Relation of fish-length data to biochemical data and sensory data.

A. RELATION OF BIOCHEMICAL DATA TO FISH-HANDLING DATA

Fish handling included handling the tuna on deck for various periods of time and then placing them in brine wells for frozen storage. Only the time on deck was varied. The time the fish were held in the brine wells was essentially uniform. Thus, the only factor studied in relation to the frozen storage was whether the samples of the fish were taken before the fish were stored or after they were stored. The main topics reported in this subsection accordingly are (1) the relation of biochemical data to time on deck and (2) the relation of biochemical data to changes due to frozen storage.

1. Relation of Biochemical Data to Time on Deck

Although we were interested in all factors affecting the quality of canned tuna, we were primarily interested in color and rancidity. Our biochemical analyses therefore were directed especially toward gaining information about these two aspects. The biochemical variables chosen for study were heme protein concentration, Soret peak position, iron, pH, and thiobarbituric acid (TBA) value, the first four of which contribute to an understanding of color and the last to an understanding of rancidity.

There was a good likelihood that heme protein concentration would be found to affect color. Derivatives of these proteins are responsible for color in canned tuna. Since lightness of color is a desirable attribute, it might be expected that lower concentration of pigments in raw tuna would be related to better final color.

For good color of tuna, heme protein should be retained in the reduced ferrous form. The state of oxidation can be determined by measuring the Soret peak position spectrophotometrically; oxidation changes the position of the peak to a lower wave length. Thus, the relative amounts of pigments present in either the oxidized or the reduced forms can be ascertained. The peak position of the oxidized form (metmyoglobin, methemoglobin) is at 406 millimicrons, whereas that of the reduced form (oxymyoglobin, oxyhemoglobin) is at 412 millimicrons. Peaks for mixtures of the two fall in between, depending upon the relative proportions of the two forms.

It should be stressed that the value expressed for total heme protein concentration represents only extractable heme proteins and therefore is influenced not only by the total amount of heme proteins in the muscle tissue but also by the amount of denaturation that rendered the pigments insoluble. Total muscle iron, on the other hand, gives essentially the true value of total hemoglobin and myoglobin, which account for most of the iron in muscle. It should be unaffected by treatment or storage, for it is measured on whole muscle by a digestion procedure and thus does not reflect any changes in heme proteins associated with denaturation. Accordingly, total muscle iron gives an indication of how completely heme proteins are extracted.

pH was found to be related to the rate of oxidation of heme protein. Lower pH was associated with a faster rate.

TBA reacts with malonaldehyde or related compounds produced as a result of lipid oxidation. For that reason, TBA measurements give information concerning rancidity.

Thus, in our study of the relation of time on deck to the results of biochemical analyses, the following five variables were investigated: (1) extractable heme protein, (2) Soret peak position, (3) iron, (4) pH, (5) TBA.

a. Heme protein.

(1) Procedure.—The main steps in determining extractable heme protein involved sampling the fish at sea and then ascertaining the concentration of heme protein in the samples.

(a) Samples.—Eight batches were sampled. Each batch had 15 yellowfin tuna, from catches made by a purse-seine vessel off the Pacific Coast of Central America. The first group of samples, taken on 1 August 1964, was designated Group I. These samples (fish numbered 1 to 75; Batches I to V) were from tuna taken out of the first two brails from the net. The water temperature at the time of capture was 28.3° C. Individual batches of the fish were left on deck (the air temperature was 29.4° C.) for 0, 1, 2, 3, and 4 hours before the muscles were sampled. The second group of samples, taken on 2 August 1964, was designated Group II. These samples (fish numbered 76 to 120; Batches VI to VIII) were also from tuna taken out of the first two brails from the net. The water temperature was 27.3° C. Individual batches of the fish were left on deck (the air temperature was 27.8° C.) for 0, 2, and 5 hours before the muscles were sampled. (When we planned the research, we intended to have the same holding times on deck for the batches in both Group I and Group II, but the actual holding times for Group II had to be altered, owing to unfavorable circumstances when the second group was sampled.)

After the indicated time on deck, wedges of dorsal muscle were excised from the first 10 fish in each batch. Each wedge weighed about 100 grams, and each was taken from the left side of the fish, just below the origin of the dorsal fin. The wedges were immediately packaged in individual, double, plastic bags, sealed, and placed in a −80° C. mixture of dry ice and ethanol. This procedure required about 5 minutes. The frozen samples were then put in a specially designed freezer and held at −30° C. or lower until they were analyzed. These samples were designated "at-sea" samples.

We recognize the possibility that changes may have taken place in the samples held at −30° C. or below. A better procedure for handling a large number of samples on a fishing vessel, however, is difficult to conceive. We have found that repeated biochemical analyses made on a sample held at this temperature for several months give constant values. Corroborating this finding, Bito (1965) has reported that pigments in tuna held for 9 to 13 months at −35° C. were not oxidized.

(b) *Analyses.*—In the determination of heme protein concentration, frozen or semisolid muscle samples were finely minced, a 10-gram portion was placed in a Waring[1] blendor that was jacketed with ice water, 25 milliliters of water was added to facilitate blending, and four drops of octanol were added to reduce foaming. The mixture was blended at top speed for 2 minutes, then centrifuged for 30 minutes at 10,000 revolutions per minute (12,000 x gravity) in a refrigerated centrifuge. The spectra

[1] Use of trade names for the description of experimental materials and equipment does not imply endorsement.

of the supernatant were recorded on a Cary Model 15 Spectrophotometer, and the concentration of heme protein was determined by use of known extinction coefficients (Brown, Martinez, Johnstone, and Olcott, 1962).

In our earlier studies, we had separated hemoglobin from myoglobin by making use of the ease of denaturation of hemoglobin and its resulting loss of solubility. This method failed in the present study, owing to recurrent problems with turbidity. A procedure for correcting this turbidity has now been developed (Goldbloom and Brown, 1966), but it was not available during the course of these experiments.

(2) Results.—Extractable heme protein for the samples taken at sea tended to decrease with the time the fish were held on deck (Table 1). Nevertheless, the heme protein values did not differ significantly from sample to sample (Table 2).

b. Soret Peak Position.—The absorption spectrum of the heme protein extract, prepared as described above, was measured in the range of 406 to 412 millimicrons by means of a Cary Model 15 Spectrophotometer.

The position of the Soret peak differed significantly between batches within groups (Table 2). The difference between batches in Group I appeared to be associated with the time the fish were held on deck, since the Soret peak generally decreased as time on deck increased (Table 1). In Group II, Batch VIII, which was held 5 hours on deck, had a lower Soret peak position (Table 1) than did Batches VI and VII, which were held 0 and 2 hours, respectively.

c. Iron.—Total muscle iron was determined by digesting portions of tuna muscle sample, taken as described earlier, and reacting the resulting digest with a,a'-dipyridyl (American Association of Cereal Chemists, 1962).

The values of iron determined for the various batches are shown in Table 1.

Table 1.—Mean values of biochemical variables studied by the use of yellowfin tuna held for varying times on deck after capture and then sampled at sea

Group No.	Batch No.	Time on deck	Extractable heme protein concentration		Soret peak position		Iron		pH		TBA	
			Mean	S. E.[1]	Mean	S. E.	Mean	S. E.	Mean	S. E.	Mean	S. E.
		Hours	*Mg./g.*		*Mμ*		*Mg./100 g.*				*Mg. malonaldehyde/ 1,000 g.*	
I	I	0	1.52	0.11	409.8	0.39	0.73	0.06	5.92	0.03	0.66	0.08
	II	1	1.39	0.10	409.6	0.34	0.63	0.04	5.88	0.02	1.05	0.21
	III	2	1.46	0.17	408.7	0.40	0.79	0.12	5.86	0.02	0.90	0.08
	IV	3	1.13	0.07	408.8	0.26	0.72	0.08	5.89	0.04	1.18	0.29
	V	4	1.17	0.11	408.4	0.24	0.67	0.04	5.96	0.03	0.64	0.04
II	VI	0	1.37	0.08	408.4	0.34	0.68	0.05	5.78	0.02	0.82	0.15
	VII	2	1.22	0.07	408.6	0.56	0.75	0.07	5.77	0.01	0.86	0.18
	VIII	5	1.28	0.08	407.1	0.36	0.76	0.08	5.81	0.02	1.34	0.20

[1] Standard error.

Table 2.—Summary of the analysis of variance of biochemical variables studied by the use of yellowfin tuna held for varying times on deck after capture and then sampled at sea

Biochemical variables	Analyses of variance for:							
	Group I (Batches I-V) [Between batches]		Group II (Batches VI-VIII) [Between batches]		All batches			
					[Between batches within groups]		[Between groups]	
	F[1]	D.f.[2]	F	D.f.	F	D.f.	F	D.f.
Extractable heme protein	2.24	4,45	0.94	2,27	2.06	6,72	0.20	1,6
Soret peak position	2.89*	4,45	3.40*	2,27	3.05*	6,72	4.83	1,6
pH	1.49	4,45	1.21	2,27	1.50	6,72	23.73**	1,6
TBA	1.96	4,45	2.35	2,24	2.08	6,69	0.21	1,6

Note.—Iron is not included because of uncertainty in sample numbers.
[1] Variance ratio.
[2] Degrees of freedom.
* = significant (indicates a value that is significantly larger than would be expected by chance at the 5-percent level of probability).
** = highly significant (indicates a value that is significantly larger than would be expected by chance at the 1-percent level of probability).

d. pH.—The pH of the muscle extract, prepared as described above, was measured with a glass electrode in a Radiometer pH meter.

The pH determinations showed no significant differences between batches within groups, but the difference between the two groups was highly significant (Table 2).

This difference may be related to the size of the fish, since those in the second group were larger (longer).

There were no notable differences in technique of capture.

e. TBA value.—TBA values on samples taken as described earlier were determined by the method of Tarladgis, Watts, Younathan, and Dugan (1960).

No difference in TBA values appeared between batches (Table 2). Because the mean TBA value increased in proportion to the time the fish in the batches in Group II (Table 2) were held on deck, some lipid oxidations may have occurred during that time. We cannot explain the absence of increase in Group I.

Resume' — Effect of "standing on deck".—The amount of extractable heme proteins and the Soret peak position tended to be lowered. Some heme proteins may have been oxidized during this period, resulting in a shift of the Soret peak to lower wave lengths. The lowering of extractability of heme proteins was likely due to partial denaturation. The effect of such partial denaturation on oxidation rates of heme protein, however, is not known.

2. Relation of Biochemical Data to Changes Due to Frozen Storage

a. Heme protein.—After the muscle wedges of tuna were taken on the vessel in the manner indicated earlier all of the fish of each batch were individually labeled with the appropriate specimen number (International Tropical Tuna Commission plastic tags were used), mixed with the vessel's catch, and put into brine wells.

When the vessel was unloaded on 21 September 1964, muscle wedges were taken both from fish that had previously been sampled at sea (except a few specimens that were not recovered) and from fish that had not. These muscle wedges were frozen by the same method as that used on board the vessel at sea (dry ice and ethanol) and were transported to the Institute of Marine Resources Laboratory at Berkeley for biochemical analysis.

The samples taken at the cannery from the fish that had also been sampled at sea were called "cannery with at sea". The samples from the fish that had not been sampled at sea but only at the cannery were called "cannery only".

The same method of extractable heme protein and other analyses were used as described earlier.

Table 3 summarizes the results.

The differences in extractable heme protein values were highly significant between batches within groups, both for cannery-with-at-sea samples and cannery-only samples (Table 4). These differences in values, however, were due entirely to differences between batches within Group II. Although the heme protein concentration for the at-sea samples tended to decrease with the period of time the fish were held on deck (Table 1), this trend was not duplicated with the cannery samples (Table 3).

b. Soret peak position.—Soret peak position for cannery samples, as for the at-sea samples, showed significant differences between batches within groups (Table 4), but these differences were due entirely to the differences among the three batches of Group II. For the biochemical samples taken at the cannery, no relation was evident between position of Soret peak and the time the fish were held on deck before being frozen (Table 3). Although the trend was for at-sea samples to exhibit a positive relation between Soret peak and the time the fish were held on deck, the cannery samples exhibited no relation or perhaps a positive relation. A general lowering of the Soret peak position occurred between the time the samples were taken at sea and the time they were taken at the cannery (as can be seen by comparing Tables 1 and 3, only the values for Batch VIII in Table 3 were anomalous—that is, higher than the corresponding value in Table 1); this lowering was apparently larger than the lowering caused by the time the fish were held on deck.

c. Iron.—Iron values were determined for individual fish, but the records were ambiguous as to whether the values were those of samples taken at sea or at the cannery. In any event, as was discussed earlier, there should be no difference in iron values between at-sea and cannery samples of the same fish.

No significant differences in iron content were exhibited among the different batches of the cannery-only samples (Table 4).

d. pH.—Biochemical determinations on the cannery-only samples showed no significant differences in pH between batches or between groups (Table 4). Examination of the data for cannery-with-at-sea

Table 3.—Mean values of biochemical variables studied by use of yellowfin tuna held for varying times on deck after capture, placed in brine wells, and then sampled at the cannery.

Group No.	Batch No.	Time on deck	Extractable heme protein				Soret peak position			
			Cannery with at sea		Cannery only		Cannery with at only		Cannery sea	
			Mean	S.E.[1]	Mean	S.E.	Mean	S.E.	Mean	S.E.
		Hours	*Mg./g.*		*Mg./g.*		*Mμ*		*Mμ*	
	I	0	0.93	0.05	0.98	0.06	407.6	0.38	407.9	0.37
	II	1	1.01	0.09	1.05	0.07	407.2	0.38	407.7	0.35
I	III	2	0.93	0.05	0.95	0.04	408.2	0.53	408.3	0.39
	IV	3	0.83	0.05	0.88	0.04	406.9	0.45	407.5	0.47
	V	4	1.05	0.07	1.07	0.06	408.2	0.53	408.2	0.40
	VI	0	1.40	0.06	1.39	0.10	408.4	0.31	406.9	0.24
II	VII	2	0.87	0.06	1.02	0.07	406.4	0.27	406.8	0.22
	VIII	5	1.20	0.07	1.20	0.06	409.4	0.57	408.6	0.54

Group No.	Batch No.	Time on deck	Iron		pH				TBA			
			Cannery only		Cannery with at sea		Cannery only		Cannery with at sea		Cannery only	
			Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
		Hours	*Mg./100 g.*						*Mg. malonaldehyde/ 1,000 g.*			
	I	0	0.73	0.06	5.90	0.04	5.88	0.03	1.00	0.16	1.12	0.16
	II	1	0.63	0.04	5.80	0.03	5.82	0.02	1.29	0.20	1.24	0.17
I	III	2	0.79	0.12	5.84	0.02	5.85	0.01	1.70	0.37	1.44	0.26
	IV	3	0.72	0.08	5.80	0.04	5.84	0.03	1.30	0.32	1.26	0.21
	V	4	0.67	0.04	5.94	0.03	5.91	0.03	1.19	0.20	1.12	0.16
	VI	0	0.68	0.05	5.82	0.02	5.81	0.03	0.73	0.05	0.64	0.05
II	VII	2	0.75	0.07	5.81	0.02	5.80	0.01	1.29	0.25	1.46	0.23
	VIII	5	0.76	0.08	5.79	0.02	5.78	0.02	1.55	0.36	1.62	0.23

Note.—Iron was not included in the "cannery-with-at-sea" samples because of a confusion in sample numbers.
[1] Standard error.

Table 4.—Summary of the analysis of variance of biochemical variables studied by the use of yellowfin tuna held for varying times on deck after capture, placed in brine wells, and then sampled at the cannery

Biochemical variables	Group I (Batches I-V) [Between batches]		Group II (Batches VI-VIII) [Between batches]		All batches			
					[Between batches within groups]		[Between groups]	
	F[1]	*D.f.*[2]	*F*	*D.f.*	*F*	*D.f.*	*F*	*D.f.*
			Analysis of variance for cannery-with-at-sea samples					
Extractable heme protein	1.90	4,44	13.87**	2,21	5.64**	6,65	2.71	1,6
Soret peak position ..	1.59	4,44	12.75**	2,21	4.94**	6,65	0.05	1,6
pH	3.87**	4,44	0.49	2,21	3.23**	6,65	1.52	1,6
TBA	0.96	4,43	2.20	2,19	1.29	6,62	0.12	1,6
			Analysis of variance for cannery-only samples					
Extractable heme protein	1.87	4,69	5.53**	2,34	3.48**	6,103	5.44	1,6
Soret peak position ..	0.66	4,69	6.94**	2,34	2.48*	6,103	0.82	1,6
Iron	0.73	4,66	0.38	2,33	0.64	6,99	0.28	1,6
pH	2.15	4,69	0.38	2,34	1.80	6,103	6.89*	1,6
TBA	0.44	4,67	5.36**	2,35	2.10	6,102	0.09	1,6

Note.—Iron was not included in the "cannery-with-at-sea samples" because of the confusion in sample numbers.
[1] Variance ratio.
[2] Degree of freedom.
* = significant (indicates a value that is significantly larger than would be expected by chance at the 5-percent level of probability).
** = highly significant (indicates a value that is significantly larger than would be expected by chance at the 1-percent level of probability).

samples of fish revealed that the difference between batches in Group I was highly significant. Values of pH for the different batches, however, did not seem to be associated with time on deck (Table 3). The various significant differences in pH, both at-sea samples and cannery samples, appeared to be associated with the length of fish more than with treatment. This apparent correlation will be examined later.

e. TBA value.—With the sole exception of the cannery-only samples in the three batches composing Group II, no demonstrable difference in TBA existed between batches, either for at-sea samples or for cannery samples (Figure 4).

Resume' — Effect of "frozen storage".—Heme protein concentration decreased markedly during frozen storage of the fish aboard the vessel. These results confirm the findings made in the first study. The values for the Soret peak position were markedly higher for the samples obtained at sea than for the corresponding samples subsequently obtained at the cannery; only the values for Batch VIII were anomalous—that is, lower for the at-sea sample. In general, the pH decreased between the time of sampling at sea and the time of sampling at the cannery. TBA, as expected, increased during frozen storage.

The decrease of extractable heme proteins between the time of storage and the time of unloading at the cannery and the clearly demonstrable lowering of the Soret peak position were possibly due to some oxidation and slight denaturation. The decrease in pH was likely associated with the production of lactic acid. The increase in TBA was undoubtedly due to a slight amount of lipid oxidation, which takes place even at freezing temperatures. Similar changes in heme protein concentration, Soret peak position, and pH were noted in the previous study (Barrett et al., 1965).

B. RELATION OF FISH-HANDLING DATA AND BIOCHEMICAL DATA TO SENSORY DATA

1. Relation of Fish-Handling Data to Sensory Data

After the tuna were landed and the muscle wedges were taken at the cannery as described earlier, the fish were thawed, measured for length, butchered, cooked, and canned in a commercial cannery. Commercial processing operations were followed as closely as possible. The tuna were handled individually, however, to ensure that the coding on the cans would correspond identically with the coding given the individual fish.

A panel of industry representatives from different tuna processing firms evaluated the canned fish for eight quality attributes. "Scoresheet instructions" served both as a statement of the criteria of quality and as a record sheet for the evaluations. This scoring system was developed from that used in earlier work (Barrett et al., 1965) by discussions and cooperative experiment between the Bureau of Commercial Fisheries and technological staffs of the tuna industry. It is designed to evaluate only the inherent quality attributes of the samples. Other scoring systems used in industry consider in addition other "workmanship" factors (such as freedom from bones, bruises, etc.) that are also a factor in consumer acceptance. The texture score was specifically designed to evaluate hand-made solid-pack sample and could not be used for evaluating, for example, commercial chunk-pack tuna.

The subjective grades of the following quality attributes were analyzed statistically: (1) scorch, (2) color, (3) flakiness, (4) general texture, (5) fiber, (6) odor, (7) flavor, and (8) overall quality. Because the code numbers on several of the cans were questionable, subjective quality judgments for four of the fish (those numbered 36, 43, 46, and 96) were discarded. For each attribute and for each batch, the subjective grades assigned by the judges were compared by the analysis of variance. Where the variance showed that the judgments were not constant, there being significant differences between the scores given the same samples, the data were edited by Duncan's Multiple Range Test. Thereby the data from those judges whose scores differed significantly from the rest were removed.

The procedures used and results obtained in the evaluation of each of the eight quality attributes were as follows:

a. Scorch.—In scoring the canned tuna sample for scorch, the judge:

1. Opened the can, turned out the contents carefully, and noted the color of the headspace.
2. Evaluated the scorch, using a scale of from 1 (severe scorch) to 5 (no scorch) on the basis simply of a light-meat sample and not on the basis of a yellowfin tuna sample.
3. Chose a value that represented as closely as possible the average scorch of all the cans in the sample, when the sample was made up of two or more cans.
4. Entered the score on the scoresheet.

Holding time on deck was not a significant variable (Table 5). Judgments of scorch did not differ significantly between batches within groups, but they did differ significantly between groups (Table 6). As will be discussed later, the difference could be associated with fish length.

b. Color.—In scoring the canned tuna sample for color, the judge:

1. Disregarded the headspace color and any cleaning defects or bruises.
2. Broke the pieces of tuna apart and evaluated the color of the flesh on a scale of 10, using the following points as guidelines:

   10: Excellent, very light, bright color (equivalent to the color of albacore).

   6: Medium pink; no more than slightly off color.

   1: Extremely dark or severely off color.

3. Checked the score on the scoresheet together with any off colors in the indicated categories.

Table 5.—Data on the means of the subjective grades of canned yellowfin tuna in relation to the holding time of the tuna on deck

Group No.	Batch No.	Time on deck	Scorch			Color			Flakiness			General texture		
			Judges	Mean	S. E.[1]	Judges	Mean	S. E.	Judges	Mean	S. E.	Judges	Mean	S. E.
		Hours	*Number*			*Number*			*Number*			*Number*		
I	I	0	7	4.27	0.07	5	7.38	0.12	6	4.18	0.09	3	4.44	0.09
	II	1	8	4.08	0.07	4	7.51	0.16	5	4.08	0.08	3	3.00	0.14
	III	2	7	4.01	0.08	4	7.76	0.15	4	4.22	0.08	4	4.24	0.10
	IV	3	7	4.13	0.07	4	8.52	0.14	4	4.20	0.10	3	3.10	0.12
	V	4	7	4.17	0.06	3	8.26	0.14	3	4.19	0.09	3	4.67	0.09
II	VI	0	7	3.37	0.11	4	7.05	0.20	5	4.04	0.10	4	4.08	0.15
	VII	2	6	3.15	0.10	6	6.83	0.20	5	3.88	0.10	3	4.74	0.08
	VIII	5	6	3.36	0.11	6	7.08	0.16	4	3.75	0.11	3	3.29	0.15

Group No.	Batch No.	Time on deck	Fiber			Odor			Flavor			Overall quality		
			Judges	Mean	S. E.	Judges	Mean	S. E.	Judges	Mean	S. E.	Judges	Mean	S. E.
		Hours	*Number*			*Number*			*Number*			*Number*		
I	I	0	8	3.68	0.09	4	4.68	0.07	6	3.73	0.08	6	4.14	0.06
	II	1	7	3.45	0.10	5	4.53	0.07	5	3.67	0.09	4	4.02	0.08
	III	2	5	3.71	0.13	4	4.44	0.09	6	3.65	0.08	6	3.63	0.07
	IV	3	6	3.31	0.12	4	4.45	0.10	5	3.86	0.08	5	3.64	0.07
	V	4	5	3.46	0.12	4	4.34	0.11	5	3.77	0.09	5	3.80	0.08
II	VI	0	7	3.21	0.13	7	4.06	0.08	4	3.58	0.10	6	3.53	0.09
	VII	2	4	2.90	0.17	5	4.19	0.10	6	3.73	0.09	5	3.56	0.10
	VIII	5	4	3.60	0.13	4	3.64	0.09	6	3.65	0.09	6	3.52	0.08

[1] Standard error.

Table 6.—Summary of analysis of variance of subjective grades of canned yellowfin tuna in relation to groups and batches of the tuna that had been held for varying times on deck

Subjective variables	Group I (Batches I-V) [Between batches]		Group II (Batches VI-VIII) [Between batches]		All batches			
					[Between batches within groups]		[Between groups]	
	F[1]	D. f.[2]	F	D. f.	F	D. f.	F	D. f.
Scorch	1.85	4,499	1.33	2,229	1.63	6,728	110.75*	1,6
Color	12.09**	4,275	0.52	2,197	5.82**	6,472	8.62*	1,6
Flakiness	0.39	4,303	1.90	2,165	0.96	6,468	18.08*	1,6
General texture	42.33**	4,215	31.93**	2,116	42.81**	6,331	0.04	1,6
Fiber	2.37	4,430	5.66**	2,172	3.60**	6,602	2.68	1,6
Odor	2.05	4,288	8.97**	2,185	4.58**	6,473	13.66*	1,6
Flavor	0.93	4,376	0.49	2,198	0.76	6,574	1.41	1,6
Overall quality	10.99**	4,351	0.05	2,203	5.88**	6,554	4.73	1,6

[1] Variance ratio.
[2] Degree of freedom.
* = significant (indicates a value that is significantly larger than would be expected by chance at the 5-percent level of probability).
** = highly significant (indicates a value that is significantly larger than would be expected by chance at the 1-percent level of probability).

samples of fish revealed that the difference between batches in Group I was highly significant. Values of pH for the different batches, however, did not seem to be associated with time on deck (Table 3). The various significant differences in pH, both at-sea samples and cannery samples, appeared to be associated with the length of fish more than with treatment. This apparent correlation will be examined later.

e. TBA value.—With the sole exception of the cannery-only samples in the three batches composing Group II, no demonstrable difference in TBA existed between batches, either for at-sea samples or for cannery samples (Figure 4).

Resume' — Effect of "frozen storage".—Heme protein concentration decreased markedly during frozen storage of the fish aboard the vessel. These results confirm the findings made in the first study. The values for the Soret peak position were markedly higher for the samples obtained at sea than for the corresponding samples subsequently obtained at the cannery; only the values for Batch VIII were anomalous—that is, lower for the at-sea sample. In general, the pH decreased between the time of sampling at sea and the time of sampling at the cannery. TBA, as expected, increased during frozen storage.

The decrease of extractable heme proteins between the time of storage and the time of unloading at the cannery and the clearly demonstrable lowering of the Soret peak position were possibly due to some oxidation and slight denaturation. The decrease in pH was likely associated with the production of lactic acid. The increase in TBA was undoubtedly due to a slight amount of lipid oxidation, which takes place even at freezing temperatures. Similar changes in heme protein concentration, Soret peak position, and pH were noted in the previous study (Barrett et al., 1965).

B. RELATION OF FISH-HANDLING DATA AND BIOCHEMICAL DATA TO SENSORY DATA

1. Relation of Fish-Handling Data to Sensory Data

After the tuna were landed and the muscle wedges were taken at the cannery as described earlier, the fish were thawed, measured for length, butchered, cooked, and canned in a commercial cannery. Commercial processing operations were followed as closely as possible. The tuna were handled individually, however, to ensure that the coding on the cans would correspond identically with the coding given the individual fish.

A panel of industry representatives from different tuna processing firms evaluated the canned fish for eight quality attributes. "Scoresheet instructions" served both as a statement of the criteria of quality and as a record sheet for the evaluations. This scoring system was developed from that used in earlier work (Barrett et al., 1965) by discussions and cooperative experiment between the Bureau of Commercial Fisheries and technological staffs of the tuna industry. It is designed to evaluate only the inherent quality attributes of the samples. Other scoring systems used in industry consider in addition other "workmanship" factors (such as freedom from bones, bruises, etc.) that are also a factor in consumer acceptance. The texture score was specifically designed to evaluate hand-made solid-pack sample and could not be used for evaluating, for example, commercial chunk-pack tuna.

The subjective grades of the following quality attributes were analyzed statistically: (1) scorch, (2) color, (3) flakiness, (4) general texture, (5) fiber, (6) odor, (7) flavor, and (8) overall quality. Because the code numbers on several of the cans were questionable, subjective quality judgments for four of the fish (those numbered 36, 43, 46, and 96) were discarded. For each attribute and for each batch, the subjective grades assigned by the judges were compared by the analysis of variance. Where the variance showed that the judgments were not constant, there being significant differences between the scores given the same samples, the data were edited by Duncan's Multiple Range Test. Thereby the data from those judges whose scores differed significantly from the rest were removed.

The procedures used and results obtained in the evaluation of each of the eight quality attributes were as follows:

a. Scorch.—In scoring the canned tuna sample for scorch, the judge:

1. Opened the can, turned out the contents carefully, and noted the color of the headspace.
2. Evaluated the scorch, using a scale of from 1 (severe scorch) to 5 (no scorch) on the basis simply of a light-meat sample and not on the basis of a yellowfin tuna sample.
3. Chose a value that represented as closely as possible the average scorch of all the cans in the sample, when the sample was made up of two or more cans.
4. Entered the score on the scoresheet.

Holding time on deck was not a significant variable (Table 5). Judgments of scorch did not differ significantly between batches within groups, but they did differ significantly between groups (Table 6). As will be discussed later, the difference could be associated with fish length.

b. Color.—In scoring the canned tuna sample for color, the judge:

1. Disregarded the headspace color and any cleaning defects or bruises.
2. Broke the pieces of tuna apart and evaluated the color of the flesh on a scale of 10, using the following points as guidelines:

   10: Excellent, very light, bright color (equivalent to the color of albacore).

   6: Medium pink; no more than slightly off color.

   1: Extremely dark or severely off color.

3. Checked the score on the scoresheet together with any off colors in the indicated categories.

Table 5.—Data on the means of the subjective grades of canned yellowfin tuna in relation to the holding time of the tuna on deck

Group No.	Batch No.	Time on deck	Scorch			Color			Flakiness			General texture		
			Judges	Mean	S. E.[1]	Judges	Mean	S. E.	Judges	Mean	S. E.	Judges	Mean	S. E.
		Hours	*Number*			*Number*			*Number*			*Number*		
I	I	0	7	4.27	0.07	5	7.38	0.12	6	4.18	0.09	3	4.44	0.09
	II	1	8	4.08	0.07	4	7.51	0.16	5	4.08	0.08	3	3.00	0.14
	III	2	7	4.01	0.08	4	7.76	0.15	4	4.22	0.08	4	4.24	0.10
	IV	3	7	4.13	0.07	4	8.52	0.14	4	4.20	0.10	3	3.10	0.12
	V	4	7	4.17	0.06	3	8.26	0.14	3	4.19	0.09	3	4.67	0.09
II	VI	0	7	3.37	0.11	4	7.05	0.20	5	4.04	0.10	4	4.08	0.15
	VII	2	6	3.15	0.10	6	6.83	0.20	5	3.88	0.10	3	4.74	0.08
	VIII	5	6	3.36	0.11	6	7.08	0.16	4	3.75	0.11	3	3.29	0.15

Group No.	Batch No.	Time on deck	Fiber			Odor			Flavor			Overall quality		
			Judges	Mean	S. E.	Judges	Mean	S. E.	Judges	Mean	S. E.	Judges	Mean	S. E.
		Hours	*Number*			*Number*			*Number*			*Number*		
I	I	0	8	3.68	0.09	4	4.68	0.07	6	3.73	0.08	6	4.14	0.06
	II	1	7	3.45	0.10	5	4.53	0.07	5	3.67	0.09	4	4.02	0.08
	III	2	5	3.71	0.13	4	4.44	0.09	6	3.65	0.08	6	3.63	0.07
	IV	3	6	3.31	0.12	4	4.45	0.10	5	3.86	0.08	5	3.64	0.07
	V	4	5	3.46	0.12	4	4.34	0.11	5	3.77	0.09	5	3.80	0.08
II	VI	0	7	3.21	0.13	7	4.06	0.08	4	3.58	0.10	6	3.53	0.09
	VII	2	4	2.90	0.17	5	4.19	0.10	6	3.73	0.09	5	3.56	0.10
	VIII	5	4	3.60	0.13	4	3.64	0.09	6	3.65	0.09	6	3.52	0.08

[1] Standard error.

Table 6.—Summary of analysis of variance of subjective grades of canned yellowfin tuna in relation to groups and batches of the tuna that had been held for varying times on deck

Subjective variables	Group I (Batches I-V) [Between batches]		Group II (Batches VI-VIII) [Between batches]		All batches			
					[Between batches within groups]		[Between groups]	
	F[1]	D. f.[2]	F	D. f.	F	D. f.	F	D. f.
Scorch	1.85	4,499	1.33	2,229	1.63	6,728	110.75*	1,6
Color	12.09**	4,275	0.52	2,197	5.82**	6,472	8.62*	1,6
Flakiness	0.39	4,303	1.90	2,165	0.96	6,468	18.08*	1,6
General texture	42.33**	4,215	31.93**	2,116	42.81**	6,331	0.04	1,6
Fiber	2.37	4,430	5.66**	2,172	3.60**	6,602	2.68	1,6
Odor	2.05	4,288	8.97**	2,185	4.58**	6,473	13.66*	1,6
Flavor	0.93	4,376	0.49	2,198	0.76	6,574	1.41	1,6
Overall quality	10.99**	4,351	0.05	2,203	5.88**	6,554	4.73	1,6

[1] Variance ratio.
[2] Degree of freedom.
* = significant (indicates a value that is significantly larger than would be expected by chance at the 5-percent level of probability).
** = highly significant (indicates a value that is significantly larger than would be expected by chance at the 1-percent level of probability).

Although the differences in color between the fish in Groups I and II and between batches within Group I were significant, the differences in color between batches in Group II were not significant (Table 6). Differences between batches within Group I were almost certainly related to the time the fish were held on deck before they were put in frozen storage, for the longer the fish were held the better was the color (Table 5). Apparently, two factors affected color: the fish's length, which was related to poor color (this relation will be examined statistically later), and the time the fish were held on deck, which was directly proportional to an improvement in color. The tendency for the color to improve with the time the fish were held on deck was also observed in the experiments in the study in the preceding year.

c. Flakiness.—In scoring the canned tuna samples for flakiness, the judge examined the turned-out contents of the cans to see if the tuna separated readily. He scored the meat on a scale of from 5 to 1 according to the following guidelines:

5: Very firm—pieces hold together well when the tuna meat is turned out of the can and touched with a spatula.

1: Very flaky—pieces largely flake apart when the tuna meat is turned out of the can and when touched with a spatula.

Batches differed little with respect to flakiness (Table 5), but the average difference between the two groups was highly significant (Table 6). The reasons for this difference are not known.

d. General texture.—In scoring the canned tuna samples for general texture, the judge placed a piece of tuna in his mouth, chewed gently, and noted whether or not it was soft, mushy, or firm. He scored the meat on a scale of from 5 to 1 according to the following guidelines:

5: Very firm—meat does not break apart into pieces or mush under moderate (normal) pressure.

1: Very mushy—meat is very mushy or pasty, or breaks down readily under light pressure.

Differences in texture between batches within groups were highly significant (Table 6), but texture differences between groups were no larger than would be expected in view of the variability of texture between batches within groups. The differences between batches did not appear to be related to the time of holding on deck. Because of the inconsistency of the scoring (Table 5), we could retain the scores of only four judges for two batches and of only three judges for the remaining six batches. The observed differences between batches may, therefore, be due simply to the editing process. With so much disagreement between judges, texture does not appear to be useful for judging the quality of canned yellowfin tuna.

e. Fiber.—In scoring the canned tuna samples for fiber, the judge chewed the fibers more firmly than when ascertaining general texture and noted whether they disintegrated readily or were tough. He scored the meat on a scale of from 5 to 1 according to the following guidelines:

5: Very tender—fibers break down readily on being chewed.

1: Very tough—fibers strongly resist breaking down on being chewed.

The analysis of variance shows that the only significant difference in fiber was the difference between batches in Group II (Table 6), the reasons for which are obscure. The possibility that fiber may be related to fish length will be examined later.

As can be seen (Table 6), the judgments on some of the characteristics agreed much more closely than did others. For example, judgments of scorch were in good agreement. In contrast, judgments of general texture and of fiber rarely agreed. Inasmuch as each set of judgments for a given batch and quality characteristics was edited separately, the editing technique itself may have resulted in standard errors somewhat smaller than the variations between fish would have caused. Consequently, some of the differences between batches, differences that are shown by the analysis of variance in Table 6 and that will be discussed later, may be statistical artifacts.

f. Odor.—In scoring the canned tuna samples for odor, the judge smelled the sample and scored it on the basis of a scale of from 5 to 1 according to the following guidelines:

5: Pleasant, mild, characteristic tuna odor, completely free of the odor of rancidity or of other off odors.

1: Very strong off odors.

Quality, as judged by odor, tended to decrease with the length of time the fish were held on deck (Table 5). The analysis of variance in Table 6, however, shows that this decrease was not statistically significant in Group I. The difference between the odor of the three batches in Group II was significant, owing to the low quality of Batch VIII, which was held on deck for 5 hours before it was put in frozen storage.

g. Flavor.—In scoring the canned tuna samples for flavor, the judge tasted the sample and scored it on the basis of a scale of from 5 to 1 according to the following guidelines:

5: Excellent, mild, light, pleasant flavor typical of good yellowfin tuna; no trace of off flavor.

1: Strong, rancid, or other off flavor.

The judges detected no differences in flavor between batches or between groups.

h. Overall quality.—In scoring the canned tuna samples for overall quality, the judge evaluated the sample and scored it on the basis of a scale of from 5 to 1 according to the following guidelines:

5: Excellent.

1: Very poor.

No differences in overall quality between the three batches of Group II were evident. Although batches within Group I differed significantly, the differences did not seem to be related to the time the fish were held on deck. The main factor related to overall quality appeared to be length of fish, which will be examined later.

Resume' — Sensory data.—The quality of the canned tuna appeared to be unrelated to time (0 to 5 hours) the fish were held on deck prior to being stored in the vessel's wells, with two exceptions: (1) the longer the fish were held on deck the better their color, as was indicated also by the previous study (reconciling this finding with the tendency toward oxidative changes in the heme proteins, however, is difficult); (2) odor seemed to deteriorate with the time the fish were held on deck, but the proof of a relation between these variables is tenuous.

2. Relation of Biochemical Data to Sensory Data

Product-moment correlation coefficients (r) for the relation between the biochemical data and the organoleptic data are listed in Table 7. To a significant extent, heme protein concentration was inversely correlated with flavor. It also was inversely correlated with scorch, color, and flakiness, although these relations were not statistically significant. Between Soret peak position and fiber a highly significant and positive correlation appeared. pH was significantly and positively correlated with scorch, flakiness, and fiber. It was also positively correlated with the other quality characteristics; however, the correlations were not significant.

Table 7.—Summary of correlations between biochemical and sensory variables for yellowfin tuna

Biochemical variables	Correlations for:							
	At-sea samples				Cannery-only samples			
	Heme protein	Soret peak	pH	TBA	Heme protein	Soret peak	pH	TBA
Extractable heme protein	—	+0.443	+0.029	—	—	−0.209	−0.435	—
Soret peak position ..	—	—	+0.471	—	—	—	+0.325	—
Iron	—	—	—	—	−0.279	+0.211	−0.155	+0.554
TBA	−0.300	−0.496	−0.358	—	−0.505	+0.471	−0.241	—

Biochemical and sensory variables	Cannery-only samples:							
	Scorch	Color	Flakiness	General texture	Fiber	Odor	Flavor	Overall quality
Extractable heme protein	−0.597	−0.565	−0.491	+0.015	−0.186	−0.660	+0.749*	−0.371
Soret peak position ..	+0.448	+0.345	+0.089	−0.189	+0.871**	−0.091	+0.027	+0.191
Iron	−0.267	−0.184	−0.194	+0.263	+0.160	−0.229	+0.012	−0.427
pH	+0.787*	+0.645	+0.776	+0.452	+0.826*	+0.647	+0.489	+0.559
TBA	−0.114	−0.025	−0.396	−0.180	+0.174	−0.227	+0.229	−0.161
Color	+0.761*	—	—	—	—	—	—	—
Flakiness	+0.845**	+0.731*	—	—	—	—	—	—
General texture	−0.120	−0.204	+0.142	—	—	—	—	—
Fiber	+0.616	+0.285	+0.340	−0.187	—	—	—	—
Odor	+0.789*	+0.468	+0.839**	+0.140	+0.194	—	—	—
Flavor	+0.472	+0.702[1]	+0.373	−0.036	−0.131	+0.421	—	—
Overall quality	+0.733*	+0.181	+0.479	+0.001	+0.429	+0.749*	+0.200	—

Note.—All values in this table are associated with 6 degrees of freedom.
[1] Barely below 5-percent level of significance (r = .707).
* = significant (indicates a value that is significantly larger than would be expected by chance at the 5-percent level of probability).
** = highly significant (indicates a value that is significantly larger than would be expected by chance at the 1-percent level of probability).

C. RELATION OF FISH-LENGTH DATA TO BIOCHEMICAL DATA AND SENSORY DATA

Data related to the lengths of the individual fish are shown in Table 8. In Table 9, the mean length of the fish and the standard error of the mean are shown by batch for: (1) fish sampled at sea, (2) fish sampled at the cannery but not at sea, and (3) all fish sampled in the batch. Fish 100 in Batch VII was sampled at sea, but the same fish sampled at the cannery yielded a sample large enough for only two biochemical tests (iron and TBA). It accordingly was not included in the mean length calculated in Table 9.

The results of the analysis of variance of the lengths of the fish sampled at the cannery ("total fish" in Table 9) show that the lengths of the fish in the various batches of each group do not differ more than would be expected by chance, although

Table 8.—Data related to the lengths of individual yellowfin tuna

Batch No.	Time on deck after brailing	Fish	Length	Time cooked at 216° F.	Batch No.	Time on deck after brailing	Fish	Length	Time cooked at 216° F.
	Hours	*Number*	*Cm.*	*Hours*		*Hours*	*Number*	*Cm.*	*Hours*
I	0	1	58.4	1.5	V	4	61	76.9	2.25
		2	56.8	1.5			62	91.4	4.25
		3	65.5	1.5			63	68.5	2.25
		4	58.0	1.5			64	77.9	2.25
		5	75.1	2.25			65	56.3	1.5
		6	62.2	1.5			66	71.0	2.25
		7	60.8	1.5			67[1]		
		8	81.1	1.5			68	68.3	2.25
		9	60.8	1.5			69	80.6	2.25
		10	63.2	1.5			70	60.2	1.5
		11	66.5	1.5			71	73.4	2.25
		12	63.9	1.5			72	62.0	1.5
		13	63.7	1.5			73	75.6	2.25
		14	58.8	1.5			74	96.7	4.25
		15	58.0	1.5			75	68.1	1.5
II	1	16	62.4	1.5	VI	0	76	96.5	4.25
		17	56.0	1.5			77[1]		
		18	98.5	4.25			78	94.5	4.25
		19	76.3	2.25			79	89.0	4.25
		20	107.1	4.25			80	95.4	4.25
		21	73.3	2.25			81	106.5	4.25
		22	85.9	2.25			82	98.3	4.25
		23	100.1	4.25			83[1]		
		24	58.6	1.5			84[1]		
		25	53.7	1.5			85[1]		
		26	59.7	1.5			86	101.5	4.25
		27	59.0	1.5			87[1]		
		28	77.0	2.25			88	96.9	4.25
		29	72.5	2.25			89	75.3	2.2[illegible]
		30	57.6	1.5			90	104.4	4.2[illegible]
III	2	31	103.6	4.25	VII	2	91	80.8	2.25
		32	51.8	1.5			92[1]		
		33	83.6	2.25			93	92.2	4.25
		34	85.7	4.25			94	82.5	2.25
		35	71.5	2.25			95	103.9	4.25
		36	64.3	2.25			96	100.6	4.25
		37	69.9	2.25			97	103.0	4.25
		38	71.9	2.25			98	107.4	4.25
		39	73.5	2.25			99	103.9	4.25
		40	61.1	1.5			100	107.4	4.25
		41	87.1	4.25			101	100.9	4.25
		42	58.5	1.5			102	104.4	4.25
		43	73.0	2.25			103	102.7	4.25
		44	58.5	1.5			104	103.3	4.25
		45	91.1	4.25			105	82.7	2.25
IV	3	46	58.8	1.5	VIII	5	106	103.6	4.25
		47	59.4	1.5			107	80.1	2.25
		48	73.8	2.25			108	97.2	4.25
		49	87.7	4.25			109	100.0	4.25
		50	57.8	1.5			110	88.0	2.25
		51	58.3	1.5			111	70.9	2.25
		52	74.6	2.25			112	77.8	2.25
		53	82.4	2.25			113	85.6	2.25
		54	77.0	2.25			114	79.8	2.25
		55	57.5	1.5			115	61.2	1.5
		56	75.6	2.25			116[1]		
		57	70.9	2.25			117	100.3	4.25
		58	60.0	1.5			118	107.5	4.25
		59	61.2	1.5			119	85.6	2.25
		60	60.8	1.5			120	89.5	4.25

[1] Fish not recovered at cannery.

Table 9.—Data on the mean lengths of yellowfin tuna

Group No.	Batch No.	Time on deck	Data for: Fish cut at sea			Fish not cut at sea			Total fish		
			Fish in sample	Mean	S. E.[1]	Fish in sample	Mean	S. E.	Fish in sample	Mean	S. E.
		Hours	*Number*	*Cm.*	*Cm.*	*Number*	*Cm.*	*Cm.*	*Number*	*Cm.*	*Cm.*
I	I	0	10	64.20	2.50	5	62.18	1.62	15	63.53	1.73
	II	1	10	77.19	6.26	5	65.16	3.99	15	73.18	4.54
	III	2	10	73.69	4.58	5	73.64	6.87	15	73.67	3.67
	IV	3	10	68.73	3.68	5	65.70	3.18	15	67.72	2.63
	V	4	9	72.34	3.58	5	75.16	5.88	14	73.33	3.00
II	IV	0	6	96.70	2.34	4	94.52	6.59	10	95.83	2.78
	VII	2	8	96.79	3.65	5	98.80	4.06	13	97.56	2.64
	VIII	5	10	84.42	4.21	4	95.72	5.02	14	87.65	3.52

[1] Standard error.

the combined differences between batches within groups is just significant at the 5-percent level (Table 10). The difference in length composition between the two groups, however, is highly significant.

Additional analysis of variance of fish lengths segregates the variance according to batches and also according to whether the fish were or were not sampled at sea. This analysis (Table 10) shows that there is no significant difference between fish sampled at sea and those not sampled at sea. It does show, however, that there is a significant difference between the lengths of fish in the various batches and that this difference arises mostly from the difference between groups rather than from the difference between batches within groups.

It is evident that the fish in Group II (Batches VI, VII, and VIII) are, on the average, significantly longer than the fish in Group I (Batches I to V). It is also evident that the fish of the several batches within a group may not be completely random samples from the same population of fish, although their lengths approximated randomness. Finally, there is no evidence that the fish sampled at sea were not drawn at random from the fish of a given batch.

In this subsection, we consider the following:

1. The relation of fish length to biochemical data.
2. The relation of fish length to sensory data.

1. Relation of Fish Length to Biochemical Data

a. Procedure.—Inasmuch as the identities of some of the fish had been lost during storage, the statistical analyses were complicated. Regressions of

Table 10.—Analysis of variance of fish lengths

Source of variation	D. f.[1]	Sum of squares	Mean square	F[2]
Categories (fish sampled at sea or not	1	0.20	0.20	0.001 (1,95)
Batches	7	15116.33	2159.48	14.67** (7,95)
Interaction	7	940.84	134.41	0.91 (7,95)
Within subclasses .	95	13979.83	147.16	
Total	110	30037.22		
Batches	7	15116.35		
Between batches within groups ..	6	1960.12	326.69	2.22* (6,95)
Between groups ...	1	13156.23	13156.23	40.27** (1,6)

[1] Degrees of freedom.
[2] Variance ratio.
* = significant (indicates a value that is significantly larger than would be expected by chance at the 5-percent level of probability).
** = highly significant (indicates a value that is significantly larger than would be expected by chance at the 1-percent level of probability).

the variables dependent on length alone were computed by desk calculator. Multiple regressions were computed on a digital computer at the University of California at San Diego; the program BIMD-6, originally written by the biomedical group at the University of California at Los Angeles, was used.

b. Results and discussion.—The batch means for the various biochemical measurements made on at-sea and cannery-only samples are presented in Table 11. Also shown in this table are the batch means for fish lengths.

A highly significant inverse correlation existed between pH and fish length for the at-sea samples (Table 12). The Soret peak position may have been inversely correlated with fish length, but the value of r of −0.482 is not statistically significant. Because of the loss of some fish between sampling at sea and measurement ashore, the batch means

Table 11.—Batch means of biochemical analyses of yellowfin tuna

Group No.	Batch No.	Batch means of at-sea samples: Extractable heme protein concentrate	Soret peak position	pH	TBA	Length
		Mg./g.	*Mμ*		*Mg. malonaldehyde/1,000 g.*	*Cm.*
I	I	1.525	409.75	5.919	0.656	64.20
	II	1.386	409.44	5.879	1.054	77.19
	III	1.459	408.70	5.864	0.900	73.69
	IV	1.134	408.85	5.886	1.179	58.73
	V	1.170	408.45	5.955	0.645	72.34
II	VI	1.368	408.40	5.777	0.822	96.70
	VII	1.216	408.55	5.774	0.864	96.79
	VIII	1.276	407.10	5.810	1.339	84.42

Group No.	Batch No.	Batch means of cannery-only samples: Extractable heme protein concentrate	Soret peak position	Iron	pH	TBA	Length
		Mg./g.	*Mμ*	*Mg./100 g.*		*Mg. malonaldehyde/-1,000 g.*	*Cm.*
I	I	0.974	407.90	0.734	5.885	0.115	63.53
	II	1.049	407.67	0.627	5.817	1.240	73.18
	III	0.950	408.27	0.786	5.848	1.437	73.67
	IV	0.881	407.53	0.722	5.843	1.264	67.72
	V	1.066	408.21	0.667	5.912	1.123	73.35
II	VI	1.389	406.90	0.682	5.807	0.641	95.83
	VII	1.018	406.77	0.751	5.803	1.459	97.56
	VIII	1.198	408.57	0.757	5.785	1.624	87.65

Table 12.—Summary of the correlations (r) between length and the results of the biochemical analyses

Biochemical variables	Length correlations for: At-sea samples	Cannery-only samples
Extractable heme protein	−0.183	+0.684[1]
Soret peak position	−0.482	−0.518
Iron	--	+0.106
pH	−0.899*	−0.702[1]
TBA	+0.117	−0.053

Note: This table is based upon the batch means in Table 11; all values in this table are associated with 6 degrees of freedom.

[1] This value is only slightly less than r = 0.707, which is at the 5-percent level of significance.

* = significant (indicates a value that is significantly larger than would be expected by chance at the 5-percent level of probability).

for fish length at-sea samples and the batch means for the biochemical determinations do not correspond exactly to the same fish. For this reason, and also in order to examine the correlations between biochemical characteristics and fish lengths, we computed the product-moment correlation coefficients between fish length and biochemical variables both for individual fish sampled at sea and for the batches of these fish (Table 13). In this analysis, the only fish used were those for which both biochemical and length data were available. The negative relation between pH and fish length was highly significant. When the data for individual fish were used, the inverse correlation between Soret peak and fish length was also highly significant. There was no suggestion of a relation between length and extractable heme protein, iron, or TBA.

The scientific literature has liitle information on details of biochemical changes that take place during

Table 13.—Correlations (r) of biochemical data of at-sea samples of tuna with fish length for individual fish and for batch means of these fish

Biochemical variables	Correlation data for: Individual fish	Batch means
Extractable heme protein	+0.018	−0.319
Soret peak position	+0.363**	−0.594
pH	−0.473*	−0.865**
TBA	+0.033	+0.171
Degrees of freedom	69	6
Iron[1]	+0.009	+0.290
Degrees of freedom	100	6

[1] All samples; origin not given.

* = significant (indicates a value that is significantly larger than would be expected by chance at the 5-percent level of probability).

** = highly significant (indicates a value that is significantly larger than would be expected by chance at the 1-percent level of probability).

rigor mortis in fish, particularly regarding any such changes that can be attributed to age. Information available on other animal species in this regard does not provide a clear-cut base for explaining the observed relations between length and some of the biochemical variables. It is well documented that in most animals the amount of myoglobin in muscle tissue increases with age, but much less has been reported concerning the exact effect of age on the tendency of heme proteins to oxidize.

For the cannery-only samples (Table 12), the data suggest inverse correlations between pH and fish length and between Soret peak and fish length as well as a positive correlation between extractable heme protein concentration and fish length. Except for Soret peak position, these correlations are just below the 5-percent level of significance; for Soret peak position, the correlation coefficient is well below the 5-percent level.

To examine these relations more precisely, we also compared the product-moment correlation coefficients between each of these three biochemical variables on cannery-only samples and the lengths of the individual fish (Table 14). In this instance, since all of the fish included in the batch means for lengths were also included in the biochemical samples and conversely, the batch means did not change. The product-moment correlation coefficients for the individual fish indicate a highly significant positive correlation between extractable heme protein and length and highly significant inverse correlations between Soret peak position and length and between pH and length.

Table 14.—Correlation (r) of biochemical data of cannery-only samples of tuna with length, for individual fish and for batch means of these fish

Correlations calculated for	Correlation data for:			
	Extractable heme protein	Soret peak position	pH	D. f.[1]
Individual fish ..	+0.260**	−0.364**	−0.306**	109
Batch means	+0.684	−0.518	−0.702	6

[1] Degrees of freedom.
** = highly significant (indicates a value that is significantly larger than would be expected by chance at the 1-percent level of probability).

2. Relation of Fish Length to Sensory Data

To examine the relations between length of fish and the various subjective quality characteristics of the canned product, we used the mean quality grades of each batch (Table 15) and the mean lengths of fish in each batch measured at the cannery (Table 11) and calculated the product-moment correlation coefficients between the batch means of fish length and the batch means of each of the several quality characteristics (Table 16). Many of the quality characteristics of the canned product were highly correlated with the length of the fish. Quality (as judged from scorch, color, flakiness, odor, and overall quality) varied inversely and significantly with fish length. The inverse correlation between fish length and fiber was just below the 5-percent level of statistical significance.

Batch means of fish length measured at the cannery did not correspond exactly to the fish for which the quality of the canned product was judged (Table 15) because four fish were eliminated from the calculations, owing to a confusion of codes. To examine correlations that were based on batch means for length and quality characteristics of exactly the same fish and also to examine the data for individual fish correlations between fish length and quality, we calculated the product-moment correlation coefficients (Table 17). In Table 17, the values of "r" for fish length and quality characteristics are based on measurements of individual fish, and the values for batch means are based on measurements of these same fish. The score for each quality characteristic of the canned product from each individual

Table 15.—Batch means of quality estimates of yellowfin tuna

Group No.	Batch No.	Means of quality estimates for:							
		Scorch	Color	Flakiness	General texture	Fiber	Odor	Flavor	Overall quality
I	I	4.27	7.38	4.18	4.44	3.68	4.68	3.75	4.14
	II	4.08	7.51	4.08	3.00	3.45	4.53	3.67	4.02
	III	4.01	7.76	4.22	4.24	3.71	4.44	3.65	3.63
	IV	4.13	8.52	4.20	3.10	3.31	4.45	3.86	3.64
	V	4.17	8.26	4.19	4.67	3.46	4.34	3.77	3.80
II	VI	3.37	7.05	4.04	4.08	3.21	4.06	3.58	3.53
	VII	3.15	6.85	3.88	4.74	2.90	4.19	3.73	3.56
	VIII	3.36	7.08	3.75	3.29	3.60	3.64	3.65	3.52

Table 16.—Summary of the correlations (r) for the correlations between length and the quality estimates for canned yellowfin tuna

Sensory variables	Length correlations
Scorch	−0.969**
Color	−0.720*
Flakiness	−0.744*
General texture	+0.204
Fiber	−0.669[1]
Odor	−0.736*
Flavor	−0.528
Overall quality	−0.716*

Note: This table is based on the batch means in Table 15; all values in the table are associated with 6 degrees of freedom.
[1] This value is only slightly below r = 0.707, which is at the 5-percent level of significance.
* = significant (indicates a value that is significantly larger than would be expected by chance at the 5-percent level of probability).

Table 17.—Correlations (r) of organoleptic data on quality of canned tuna with fish length for individual fish and for batch means of these fish

Quality variable	Correlation data for:	
	Individual fish	Batch means
Scorch	−0.701**	−0.970**
Color	−0.382**	−0.713*
Flakiness	−0.374**	−0.729*
General texture	−0.167	+0.199
Fiber	−0.407**	−0.659[1]
Odor	−0.402**	−0.739*
Flavor	−0.153	−0.532
Overall quality	−0.380**	−0.732*
Degrees of freedom	106	6

[1] Barely below 5-percent level of significance (r = 0.707).
* = significant (indicates a value that is significantly larger than would be expected by chance at the 5-percent level of probability).
** = highly significant (indicates a value that is significantly larger than would be expected by chance at the 1-percent level of probability).

fish was taken as the mean score given the batch in which the fish appeared (Table 15).

Results of the correlations of batch means in Table 17 are nearly identical with the results shown in Table 16.

When the data for individual fish were used, fish length was, to a highly significant extent, negatively correlated with scorch, color, flakiness, fiber, odor, and overall quality.

Resume' — Fish length.—Biochemical variables.—Differences in the biochemical constituents associated with fish length were more pronounced than were differences associated with the time the fish were held on deck before being put in frozen storage. In both at-sea and cannery-only samples, there were highly significant inverse correlations between fish length and pH and between fish length and Soret peak position. Among cannery-only samples, there were highly significant inverse correlations between fish length and Soret peak position and between fish length and pH, and a highly significant positive correlation between fish length and heme protein concentration.

It is generally believed that, except under pathological conditions, iron is present in muscle almost exclusively in the form of heme pigments. It follows from the somewhat constant iron contents of the fish examined that the total tissue heme content showed no tendency to correlate with length. This is born out also by the apparent nonassociation with length of the extractable heme protein contents of the at-sea samples. When the fish were landed, however, a positive correlation appeared. Since only the form, and not the amount of the total heme pigments is likely to have changed in the interval, it seems that it is the extractability that has changed — it apparently not only decreased, but in such a manner as to be related to length. This decrease in extractability may be due to slower freezing of the larger fish or to some biochemical characteristic that changes the extractability. It may be noted, for instance, that the pH is highly significantly correlated with length. A practical consequence may also be considered. The subjective color is apparently negatively related to extractable heme pigment at the cannery, although not at a significant level (though both relate to length). Since the total heme pigments do not show any significant variation, perhaps only the extractable, and presumably nondenatured, fraction of the total heme enters into the hemochrome formation that determines the final subjective color. If so, this extractable fraction too could be controlled instead by some other associated factor such as pH.

Quality of canned product.—As judged from color, scorch, flakiness, fiber, odor, and overall quality, the quality of the canned tuna decreased as the length of the fish increased. Fish length seemed to be a more important determinant of quality than did time on deck—at least up to 4 or 5 hours.

It should be kept in mind that the length of the fish was also associated with cooking and freezing time. The longer fish (those of overall inferior quality) had to be cooked longer during the precook process than did the shorter fish (Table 8); they also required more time during the freezing process on board the vessel. There was no way in the present study, however, to differentiate between a length effect per se and the effects of increased freezing or cooking time.

II. USE OF FISH LENGTH, WITH AND WITHOUT BIOCHEMICAL ANALYSES, TO PREDICT QUALITY OF CANNED TUNA

The foregoing statistical analyses suggested highly significant correlations between length of fish and quality of canned product. It was of interest to determine how well the quality of the canned product, as judged during various organoleptic tests, could be predicted from fish length alone, and from fish length together with biochemical measurements. In consequence, we used averaged, edited data from several judges to examine, for individual fish, each of the following organoleptic characteristics as dependent variables:

Y_1 Scorch
Y_2 Color
Y_3 Odor
Y_4 Flavor
Y_5 Overall quality

(It will be recalled that on these variables, the judges were in relatively close agreement). We then attempted to predict each characteristic from the following independent variables:

X_1 Length
X_2 pH
X_3 Soret peak position
X_4 Heme protein

For the analysis of each dependent variable in relation to fish length and overall organoleptic quality, 108 fish were used. For the calculation of multiple regressions, however, data were available for only 107 fish (some of the biochemical determinations were not made on Fish 100 in Batch VII).

A. SCORCH

Scorch was highly correlated with fish length (Table 18). A multiple regression analysis (Table 19) showed that the accuracy of predicting scorch was not improved by including data from the three biochemical determinations, since the contribution of these determinations to the variance that could be accounted for by regression was negligible and since the correlation coefficient was only slightly increased. About one half of the total variance of scorch was accounted for by fish length.

B. COLOR

Color was negatively correlated with fish length, but the coefficient, though significant (Table 18), was small. The regression coefficient for fish length was significant at only the 5-percent level, and the inclusion of the biochemical measurements somewhat improved the correlation coefficient (Table 19). The regression coefficients for Soret peak and heme protein were not quite significant at the 5-percent level; they did, however, contribute a little to the estimation of the color score. Fourteen point three (14.3) percent of the variance accountable for by regression was attributable, however, to fish length alone, the Soret peak and the heme protein contributing only about 1 percent and 2 percent, respectively. The inclusion of the biochemical variables increased the correlation coefficient from 0.382 to 0.417.

C. ODOR

Odor score could be predicted from fish length alone substantially as well as from fish length in combination with the biochemical variables (Tables 18 and 19). The addition of the biochemical variables did not make any significant change in the residual variance and, consequently, in the correlation coefficient.

D. FLAVOR

No significant differences were found among batches with respect to flavor, and flavor was only marginally correlated with fish length. The multiple regression analysis showed that the flavor score could not be accurately predicted from fish length or from a combination of fish length and the biochemical variables.

Table 18.—Regressions of sensory estimates of quality on fish length.

Sensory variables	Regression equation	Correlation coefficient		Standard error of estimate ($s_{y.x}$)
		r	r^2	
Scorch ...	$Y_1 = 6.032 - 0.02790^{**}X_1$	−0.701	0.491	0.475
Color	$Y_2 = 9.394 - 0.023335^{**}X_1$	−0.382	0.146	0.946
Odor	$Y_3 = 5.237 - 0.01189^{**}X_1$	−0.402	0.162	0.455
Flavor ...	$Y_4 = 3.981 - 0.003476X_1$	−0.153	0.0234	0.376
Overall ...	$Y_5 = 4.631 - 0.01133^{**}X_1$	−0.380	0.144	0.462

Table 19.—Multiple regressions of organoleptic measures on fish length and biochemical determinations

Scorch:	$Y_1 = 6.6336 - 0.02718^{**}X_1 + 0.80752X_2 - 0.01282X_3 - 0.14767X_4$		
	Multiple correlation coefficient (R) = 0.7274		
	Coefficient of determination (R^2) = 0.5291		
	Standard error of estimate (S. E.) = 0.4664		
	Proportion of total variance accounted for by regression (Prop. var.):		
		X_1	.51233
		X_2	.01169
		X_3	.00225
		X_4	.00278
			.5291
Color:	$Y_2 = -37.9100 - 0.0164^{*}X_1 + 0.48411X_2 + 0.10923X_3 - 0.60131X_4$		
	R = 0.4175	Prop. var.:	X_1 .14278
	R^2 = 0.1753		X_2 .00261
	S. E. = 0.9481		X_3 .00935
			X_4 .01958
			.1753
Odor:	$Y_3 = 6.9888 - 0.01125^{**}X_1 + 0.32808X_2 - 0.00864X_3 - 0.18620X_4$		
	R = 0.4287	Prop var.:	X_1 .16864
	R^2 = 0.1838		X_2 .00366
	S. E. = 0.4572		X_3 .00348
			X_4 .00798
			.1838
Flavor:	$Y_4 = 3.8968 - 0.00342X_1 + 0.30938X_2 - 0.00424X_3 - 0.00180X_4$		
	R = 0.1843	Prop. var.:	X_1 .02831
	R^2 = 0.0340		X_2 .00518
	S. E. = 0.3798		X_3 .00026
			X_4 .00000
			.0340
Overall quality:	$Y_5 = 1.18137 - 0.01036^{**}X_1 + 0.74667X_2 - 0.00418X_3 + 0.08108X_4$		
	R = 0.3993	Prop. var.:	X_1 .14068
	R^2 = 0.1595		X_2 .01728
	S. E. = 0.4659		X_3 .00001
			X_4 .00150
			.1595

E. OVERALL QUALITY

Overall quality was correlated with fish length and could be predicted therefrom with a standard error of estimate of about one half a unit on the quality scale used for this characteristic. When both length and pH were considered, accuracy of prediction was very slightly improved, but the regression coefficient for pH was not quite significant at the 5-percent level. The multiple correlation coefficient was 0.399 compared with a correlation coefficient of 0.380 for length alone.

Resume'—Quality correlatons.—Length of fish was a useful indicant of scorch, color, odor, and overall quality. The addition of the biochemical measurements, made at the time of unloading, slightly improved the accuracy of the predictions, but the contribution of these data to the precision of estimate was quite small and possibly not significant.

CONCLUSIONS

Compared with samples used in the earlier study, those obtained in this study were generally of a more uniform quality. This uniformity made differences somewhat less apparent and made the task of ascribing relations between handling and quality more difficult. The relation of length of fish to quality was quite clear as had been the relation, noted in the earlier study, of species to quality. The following conclusions are based on the combined studies of both years:

1. Deck-holding time and the changes occurring during frozen storage are less important to good quality than are differences in length of fish for yellowfin tuna.

2. Changes during frozen storage are probably associated with oxidation. Such phenomena, as they relate to oxidation of heme pigment, have some effect on color quality.

3. The pH of muscle is related to color quality, higher pH is associated with better color.

4. Among the factors we have studied so far, those important to the quality of canned tuna, particularly to color, are, in order of decreasing significance:

    a. Species.

    b. Length.

    c. Biochemical changes occurring during frozen storage on board vessel.

    d. Time of holding on deck after capture.

Of even greater importance than some, or any, of these factors may be the temperature at which the fish are held aboard the vessel prior to unloading at the cannery. This factor, which has not yet been possible to examine, should be investigated in detail.

RECOMMENDATIONS

Because the inverse relation between fish length and quality of the canned product was clearly demonstrated in this study, further studies of the effects of handling after capture should eliminate or minimize fish length as a variable. The experimental design of these studies should involve careful use of large samples of muscle from individual fish, precise determination of biochemical changes as a function of time and temperature, and evaluation of the relation of such changes to the quality of the canned product.

SUMMARY

In 1965, we published a report showing that species is an important factor affecting the quality of canned tuna. In continuation of that study, we have subjected 120 yellowfin tuna to biochemical, sensory, and statistical analyses to determine how extensively the resulting data could be used to predict the quality of the canned product. Specifically, we examined how the method of handling affected the fish's biochemical characteristics, what relation fish length might have to the biochemical characteristics and to the quality of the product, and whether a knowledge of the handling procedure plus various biochemical characteristics could be used to predict quality.

Holding the yellowfin tuna on deck for as long as 5 hours before putting them in frozen storage caused apparent heme protein concentration to decrease. The values of these concentrations, though not significantly different from sample to sample, were directly related to the time the fish were held on deck. The pH values were not significantly different from batch to batch held for different times on deck within a group, but the difference between two replicate groups was marked. The position of the Soret peak differed significantly between batches. The difference between batches could be related to the time the fish were held on deck, for the Soret peak generally decreased as time on deck increased, the lowest peak of all being exhibited by the batch that was held on deck for 5 hours. Although no difference in TBA values appeared between batches, the mean TBA for the batches in the second group increased in proportion to the time the fish were held on deck; such increases were not shown by the batches in the first group. Total muscle iron was unaffected by the time the fish were held on deck.

Holding the fish in frozen storage caused highly significant differences to appear. In the heme protein values, however, these differences were confined to differences between batches within the second group. The decrease in extractable heme protein during frozen storage was greater for small fish than for large fish. The Soret peak position and the pH for samples taken at sea were markedly higher than for samples taken in the cannery (despite the fact that one at sea-batch had a lower Soret peak and a higher pH). In contrast, the TBA increased with frozen storage. No significant differences in total muscle iron were evident between any of the batches.

The lowering of the Soret peak and the decrease of extractable heme protein during frozen storage were probably due to oxidation and a slight denaturation. The decrease in pH was likely associated with the production of lactic acid. The increase in TBA value was undoubtedly due to a slight amount of lipid oxidation, which takes place even at freezing temperatures. Similar changes in heme protein concentration, Soret peak position, and pH were noted in the previous study.

To determine the relation of length of fish to the biochemical characteristics of the tuna, we calculated both regressions of the variables dependent on length alone and multiple regressions. The differences between the biochemical characteristics that could be attributed to the fish's length were much more pronounced than were the differences caused by time on deck. All samples showed a highly significant inverse correlation between fish length and pH and between fish length and Soret peak. The samples taken at the cannery showed a highly significant positive correlation between fish length and heme protein concentration; the samples taken at sea showed little or no such correlation, nor did they show any correlation between fish length and iron or between fish length and TBA.

We also compared the product-moment correlation coefficients between the length of individual cannery-sampled fish and their Soret peak position, pH, and heme protein concentration. A highly significant positive correlation appeared between heme protein and length, and highly significant negative correlations appeared between Soret peak position and length and between pH and length.

After the tuna were canned, a panel of industry representatives tested the contents of each can for color, scorch, flakiness, general texture, fiber, odor, flavor, and overall quality. The grades assigned by the judges were compared by the analysis of variance. Color was negatively correlated with fish length; about 14 percent of the variance was attributable to length alone. The correlation coefficient for color, though small, was significant. Inclusion of the biochemical variables increased the correlation coefficient only from 0.382 to 0.417.

Two factors affected color: fish length, which was related to poor color, and time on deck, which was directly proportional to an improvement in color. Length, however, seemed to be a more important determinant of quality than did time on deck. The regression coefficients for the Soret peak and the heme protein contributed about 1 and 2 percent, respectively, to the color variance.

Scorch was highly correlated with length, about one half the total variance of scorch being accounted for by length. Time on deck was not significant. Although the scorch-length correlation was high, multiple regression analysis showed that the accuracy of predicting scorch was not improved by including biochemical data, since these variables contributed little to the variance that could be accounted for by regression.

The differences in flakiness between batches were small, but the average differences between groups were more noticeable.

Differences in texture between batches within groups, though highly significant, seemed to be unrelated either to fish length or to time on deck. Unreconcilable disagreements between judges regarding texture — and fiber — were such as to make the usefulness of either of these qualities suspect as criteria of quality.

Odor, which deteriorated with the length of time the fish were held on deck, could be predicted from fish length alone as well as from fish length in combination with the biochemical variables.

Since no differences in flavor were detected either between batches or between groups, either with length of fish or with time on deck, criteria for predicting flavor could not be established.

No differences in overall quality between the batches in the second group appeared; in contrast, the batches in the first group differed significantly. The main factor governing overall quality seemed to be length of fish; time on deck seemed to be inconsequential. Overall quality, which was highly correlated with fish length, could be predicted from length with a standard error of estimate of about one half a unit on the quality scale. When both length and pH were considered, the accuracy of prediction was slightly improved, the multiple correlation coefficient rising to 0.399 from 0.380, which was the accuracy when length was used alone.

The results of this study, combined with the results of the previous study, show that the factors most important to quality, particularly to color, are, in decreasing order of significance: species, length, storage, and time on deck. With two exceptions, the quality of canned tuna was unrelated to time on deck — the longer the fish were held on deck before being stored, the better their color and the poorer the odor. On the other hand, because we established the relation of fish length to quality so conclusively, we believe that continued study of length as a factor for determining quality is unnecessary.

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MS #1626

EXTENDING THE SHELF LIFE OF FROZEN CHUB (*Leucichthys hoyi*) FILLETS THROUGH THE USE OF ASCORBIC ACID DIPS

by

R. A. Greig

ABSTRACT

Chub fillets, prior to being frozen, were dipped in ascorbic acid solutions of three different concentrations to ascertain the comparative effectiveness of each solution in retarding the onset of rancidity in the frozen, stored fillets. Treated and nontreated fillets were examined periodically by sensory methods and by 2-thiobarbituric acid and peroxide-value tests. Results showed that all three treatments with ascorbic acid effectively extended the shelf life of the frozen fillets.

INTRODUCTION

Fresh-water chub *(Leucichthys hoyi)*, which make up a substantial part of the fish taken from the Great Lakes, are caught primarily in Lakes Huron, Michigan, and Superior. Large chub (eviscerated but not headed and weighing about 1/4 pound or more on the average) are marketed as a smoked product; small chub are sold principally for animal food. Yet, since the small chub are considerably more abundant, attempts have been made by the industry to produce a marketable product for human consumption from the smaller fish. Production of a frozen, breaded, chub fillet has thus far proved to be unsuccessful because storing the product for more than about 3 months at 0° F. causes it to develop strong, rancid off-flavors.

Previous laboratory investigations (Greig, Emerson, and Fliehman, 1967; Greig, 1967[1]) have shown that a dip of ascorbic acid will significantly extend the frozen shelf life of cisco *(Coregonus artedii)* and white bass *(Roccus chrysops)*. Bauernfeind, Smith, and Siemers (1950) showed that an ascorbic acid treatment will extend the shelf life not only of cisco but of various marine fishes as well. The object of the present study therefore was to determine the effectiveness of such treatment in extending the shelf life of frozen chub fillets.

I. MATERIALS AND METHODS

The following subsections describe the methods in the preparation of the fillets and in the evaluation of their rancidity.

A. PREPARATION OF FILLETS

Trawl-caught Lake Michigan chub were obtained in January 1966, held in the round on ice for 1 day, and then machine filleted. The fillets in turn were held on ice for 1 day and then treated, frozen, and stored. The treatment consisted of the fillets being dipped in one of three ascorbic acid solutions (Table 1), drained for a short time on a galvanized wire rack, and quick-frozen on a plate freezer (plate temperature, −30° F.). After being frozen, all fillets

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Author: R. A. Greig, *Chemist*, Bureau of Commercial Fisheries Technological Laboratory, Ann Arbor, Michigan 48103

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Table 1.—Frozen shelf life of chub fillets treated with various concentrations of ascorbic acid prior to being frozen

Ascorbic acid dipping solution		Immersion time of fillets	Ascorbic acid concentration of fillets after treatment	Frozen shelf life of fillets stored at −5° F.
Concentration	Temperature			
Percent	*° F.*	*Seconds*	*Percent*	*Months*
0.0	--	--	0.0	3
0.2	50	20	0.01-0.025	8
0.4	50	20	0.03-0.050[1]	7-8
0.8	50	20	0.07-0.090[1]	9-11

[1] Range of values obtained from individual analysis of six different fillets.

were packaged in 3-mil polyethylene bags (six fillets to a bag), the bags were heat-sealed, and the products were placed in storage at $-5° \pm 3°$ F. without additional packaging protection. Nontreated fillets were similarly frozen and stored to serve as controls.

B. EVALUATION OF FILLETS

Samples of each group of the fillets, usually six fillets to a sample, were examined monthly by sensory and chemical methods. While still frozen, the fillets were cut cross sectionally in half, and the halves were equally divided for the sensory and chemical tests.

Samples for the sensory examination were breaded (while still frozen), deep-fat fried, and presented to taste panels consisting of from four to six laboratory members trained in sensory evaluation of fishery products. The taste panels rated the samples according to the following scale:

5 — not rancid
4 — barely detectably rancid
3 — slightly rancid
2 — moderately rancid
1 — strongly rancid

An average score of less than 3 was arbitrarily selected as indicating that the product was objectionably rancid. The panelists also rated the samples as to whether they were acceptable, borderline, or unacceptable in overall flavor. This latter information was not numerically rated; it was obtained because we recognized that although the fillets might not be rancid, they could be unacceptible owing to off-flavors produced either by the treatment or by some other factor.

Chemical examination for the development of rancidity in the fillets consisted of a peroxide and a 2-thiobarbituric acid (TBA) test. For the peroxide test, the samples were first thawed and ground three times. Then the oil was extracted from the samples according to the procedure of Bligh and Dyer (1956). The oil was left dissolved in chloroform, and 12-milliliter aliquots of this solution were used for determination of peroxide values (expressed in terms of milliequivalents of peroxide per 1,000 grams of oil) according to the procedure of the American Oil Chemists' Society (1955) official method Cd 8-53. Similar 12-milliliter aliquots were oven-dried to allow for determination of the amount of oil present. For the TBA test, the procedure of Tarladgis, Watts, Younathan, and Dugan (1960) was used, with modifications as reported by Greig (1966); TBA values — the absorbance at 536 millimicrons of 5 milliliters of distillate and 5 milliliters of TBA reagent — were the units used.

Chemical and sensory results were compared statistically through the use of correlation coefficients.

II. RESULTS AND DISCUSSION

A. UNTREATED FILLETS

Sensory results (Figure 1) showed that the untreated fillets were acceptable and of good quality through about 8 weeks of storage. These fillets were near borderline in quality, owing to the onset of rancid off-flavors through 16 weeks of storage, at which time the panel found the samples to be objectionably rancid. TBA values increased rapidly through the first 4 weeks of storage, decreased sharply during the next 4 weeks, and then increased fairly rapidly until the end of the test. No reason can be offered for the rapid increase and then decrease in TBA values at the 2-, 4-, and 8-week sampling times. The peroxide values increased fairly rapidly and progressively during the storage test. Correlation coefficients for TBA and peroxide values versus sensory values were $r = -0.813$ ($P<0.05$) and $r = -0.902$ ($P<0.05$), respectively. Thus, the chemical and sensory results were significantly correlated in the samples tested.

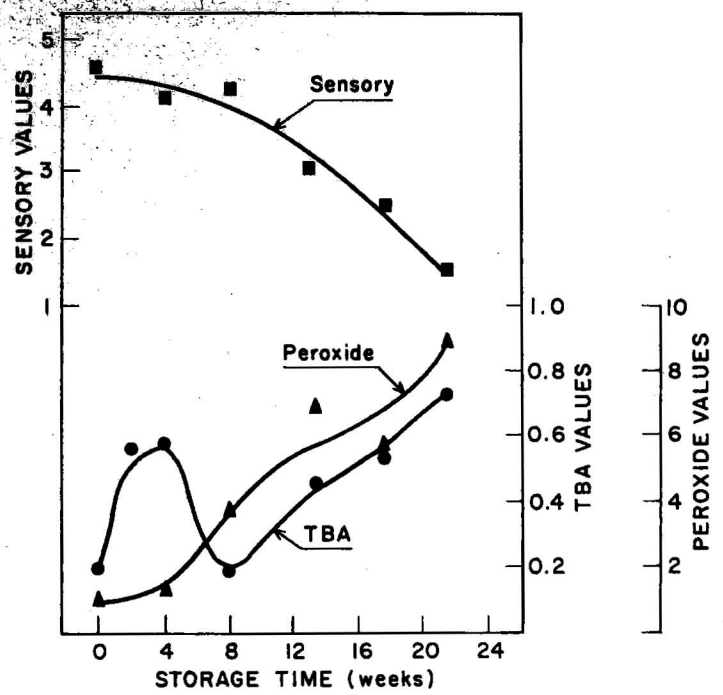

Figure 1.—Results of sensory and chemical tests on untreated chub fillets stored at −5° F.

B. TREATED FILLETS

Sensory results of fillets dipped in the 0.2-percent ascorbic acid solution (Figure 2) showed that this product was acceptable and of good quality through 30 weeks of storage; the product became unacceptable, owing to objectionable rancid off-flavors, after the 35-week storage period. TBA and peroxide values are also shown in Figure 2. Except for one (unexplainable) high value at the 17-week storage period, the TBA values increased progressively during storage and reached maximum values when the product became organoleptically unacceptable. The calculated correlation coefficient for TBA versus sensory values was $r = -0.767$ ($P<0.05$). Peroxide values increased somewhat similar to the TBA values during storage of these samples. The correlation coefficient calculated for peroxide versus sensory values for these samples was $r = -0.782$ ($P<0.05$).

Sensory results of fillets dipped in the 0.4-percent ascorbic acid solution (Figure 3) showed that this product was acceptable and of good quality through about 25 weeks of storage; the product became objectionably rancid after the 32-week storage period. The chemical evaluation of these fillets consisted of the TBA test only. TBA values increased

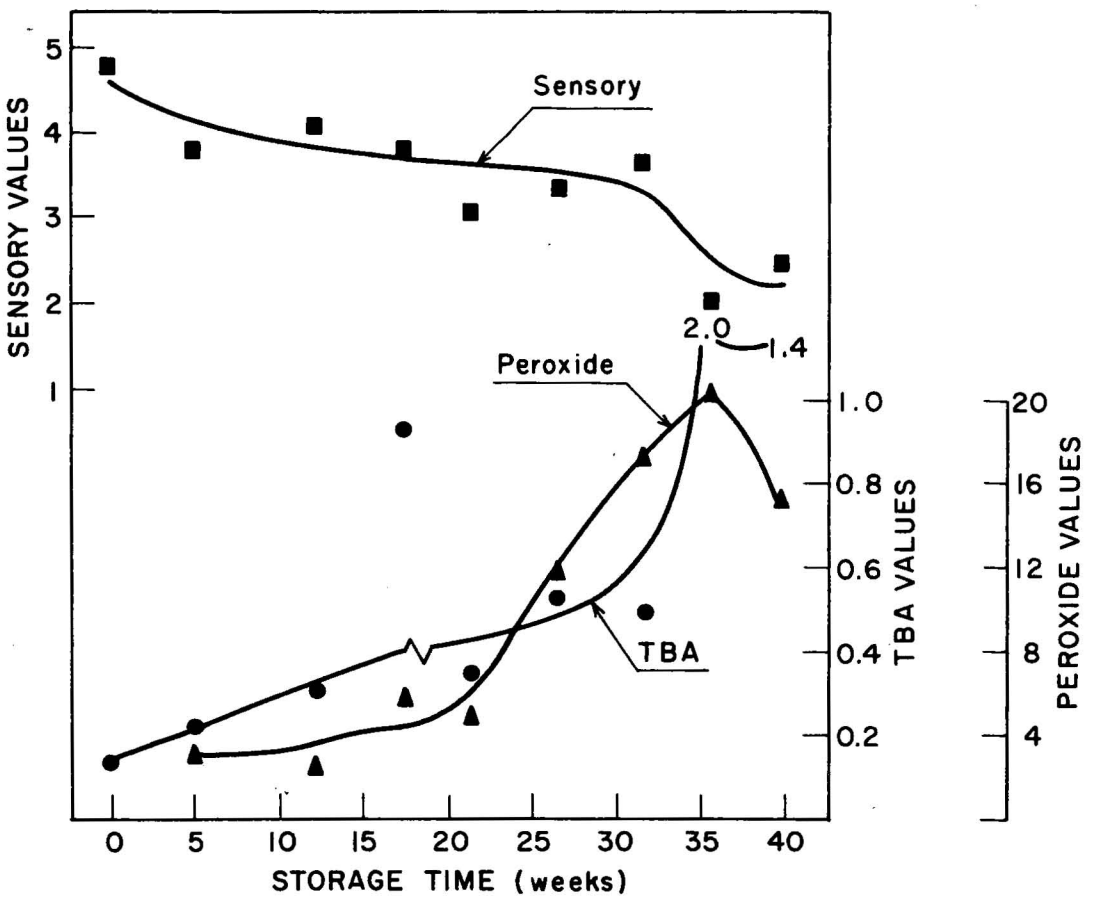

Figure 2.—Results of sensory and chemical tests on chub fillets dipped in a 0.2-percent ascorbic acid solution and stored at −5° F.

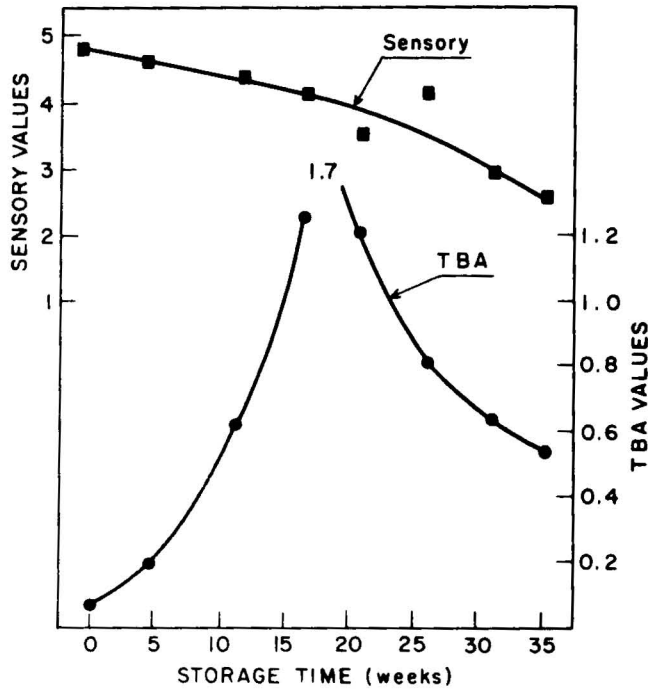

Figure 3.—Results of sensory and TBA tests on chub fillets dipped in a 0.4-percent ascorbic acid solution and stored at −5° F.

rapidly throughout 18 weeks of storage and then decreased steadily during the remainder of the study (35 weeks). The correlation ($r = -0.229$) between sensory and TBA data for fillets treated at the 0.4-percent level of ascorbic acid was not significant.

According to sensory data (Figure 4), fillets dipped in the 0.8-percent ascorbic acid solution were of good quality through 35 weeks of storage. This product then was found near borderline in acceptance by the panel through about 43 weeks of storage; the product became objectionably rancid after the 45-week storage period. TBA data (Figure 4) showed that oxidation of the samples was prevalent as early as the seventh week of storage as shown by the substantial increase in values at that time. TBA values did not substantially increase after that time, indicating that oxidation of the product was well advanced. The TBA results, therefore, disagreed with sensory data and the correlation coefficient calculated for TBA versus sensory results of $r = -0.173$ (not significant at 5-percent level of confidence) agreed with this finding.

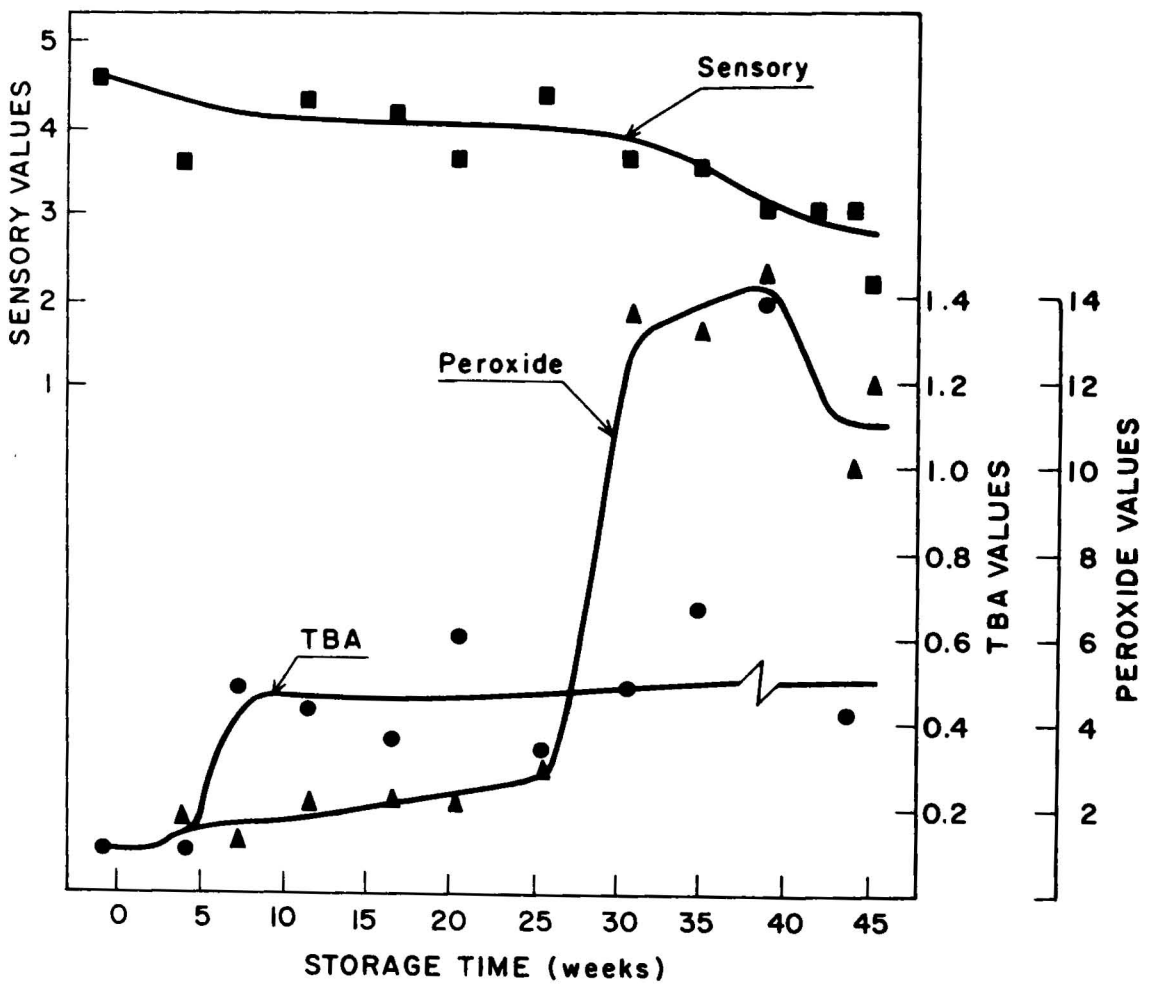

Figure 4.—Results of sensory and chemical tests on chub fillets dipped in a 0.8-percent ascorbic acid solution and held at −5° F.

The sensory curves for the fillets dipped in the various solutions were based only on the numerical scores assigned to the development of rancidity. The panelists, however, also rated the samples for overall flavor. From this latter rating, we concluded that rancid off-flavors were almost the only flavors that were considered undesirable in any of the fillets. Nevertheless, throughout the study, some panelists found the fillets treated with the highest concentration of ascorbic acid to be slightly "acidic" or "lemonlike". They did not rate the fillets unacceptable because of this flavor, however.

Both types of sensory information lead to the conclusion that the shelf life of chub fillets stored at −5° F. can be extended about threefold if they are dipped in an ascorbic acid solution (at any of the strengths empolyed in this study) before they are frozen.

SUMMARY

The effectiveness of ascorbic acid for retarding the onset of rancidity in frozen chub fillets was examined. Fillets were treated by being dipped in ascorbic acid solutions of different concentrations before being frozen; untreated fillets also were prepared to serve as controls. All fillets were stored at −5° F.

The samples were subjectively evaluated by a taste panel. They also were objectively evaluated for rancidity development through the use of two chemical tests: TBA and peroxide. Sensory results showed that the nontreated fillets had a shelf life of about 3 months before they became unacceptable. The fillets dipped in 0.2-, 0.4-, and 0.8-percent ascorbic acid solutions had shelf lives of 8, 7 or 8, and 9 to 11 months, respectively. Peroxide values generally supported the taste-panel findings as shown by correlation coefficients. TBA results were erratic and generally did not statistically support the sensory data.

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MS #1649

CONTROL OF SALMONELLAE IN FISH MEAL

by

B. J. Carroll and B. Q. Ward

ABSTRACT

Environmental studies showed the presence of Salmonellae in three fish-meal plants examined. Data derived from thermal studies indicate factors that should be taken into account when a meal requires reprocessing, owing to postprocessing contamination with Salmonellae.

Protein was not significantly damaged under the time-temperature combinations studied.

INTRODUCTION

Reports of salmonellosis in domestic animals have been widespread in recent years. Many of the outbreaks have been attributed to Salmonellae infestation of animal-feed ingredients. Fish meal, an important ingredient in animal feeds, has frequently been implicated as a source of Salmonellae (Boring, 1958; Bischoff and Rhode, 1956; Adam, 1957; Watkins, Flowers, and Grumbles, 1959; Morehouse and Wedman, 1961). These reports and others have caused a number of European countries to demand "*Salmonella*-free certification" for all imported fish meal. Fish meal, however, is not the only feed ingredient involved in salmonellosis. Bone meals, feather meals, and rendered products have also been implicated (Galton, Harless, and Hardy, 1955; Gray, Harley, and Noble, 1960; Rasmussen, Hansen, Jacobs, and Wilder, 1964; Morehouse and Wedman, 1965).

The elimination of Salmonellae from foods destined for human consumption has received much attention (Angelotti, Foter, and Lewis, 1960), and animal-feed ingredients have also been subjected to scrutiny (Rasmussen, Hansen, Jacobs, and Wilder, 1964).

The purpose of this paper is to report on a preliminary study made on the control of *Salmonella* in fish meal. The main divisions of the research were concerned (1) with environmental studies to determine the extent to which Salmonellae are to be found in and about the premises of fish-meal plants and (2) with thermal studies on the postproduction destruction of Salmonellae in fish meal, since the environmental studies proved positive.

Authors: B. J. Carroll, *Microbiologist*, and B. Q. Ward, *Research Microbiologist*, Bureau of Commercial Fisheries Technological Laboratory, Pascagoula, Mississippi 39567.

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I. ENVIRONMENTAL STUDIES OF SALMONELLAE CONTAMINATION

In reporting our environmental studies, we consider first the specific details of Salmonellae contamination and then the broader picture of the problem.

A. EXPERIMENTAL WORK AND SPECIFIC FINDINGS

To determine the extent of Salmonellae contamination in and about production facilities, we collected three types of samples — bottom sediment, water, and in-plant materials — at three Gulf Coast menhaden plants. In all, we collected and analyzed 391 samples.

1. Bottom Sediment

All bottom samples were collected with an alcohol-flamed Petersen dredge[1]; 50-gram samples were taken.

The following procedure was used to test the samples for the presence of Salmonellae: The sediment was mixed with 450 milliliters of Tetrathionate Broth Base to which Brilliant Green had been added (BGT). The material was incubated at 35° C. for from 24 to 48 hours at which time several Brilliant Green Agar (BGA) plates containing sodium sulfadiazine were streaked. The plates were incubated for 24 hours at 35° C., and typical colonies were transferred to Triple Sugar Iron (TSI) slants according to the methods outlined in Agriculture Research Service 91-36 (United States Department of Agriculture, 1962). All typical TSI cultures were subjected to complete serological examination.

No Salmonellae were found in the 44 sediment samples taken from the immediate plant areas.

2. Water

The water samples were collected and were tested for the presence of Salmonellae as follows: All the water samples were collected with an alcohol-flamed Kemmerer water sampler, and 500-milliliter amounts were filtered through an H A (0.45 micron) Millipore mebrane filter. After filtration was completed, the filter pad was placed in 250 milliliters of BGT and incubated for from 24 to 48 hours. The Salmonellae present were then isolated and identified in the same way as outlined for the sediment samples.

Salmonellae were demonstrated in 12 percent of 191 water samples collected.

3. In-Plant Materials

The in-plant samples were collected and were tested for the presence of Salmonellae in the following manner: Fish or scrap at various stages of production or refuse from past operations were sampled. We attempted to utilize 50-gram portions, but at times this size of sample could not be obtained. In these instances, the volume of the media was adjusted. Each sample was treated according to the procedure outlined for sediment samples.

Salmonellae were demonstrated in 9.1 percent of 156 samples collected from various points within the three plants.

B. OVERALL FINDING AND DISCUSSION

Of the total number of samples collected, 9.2 percent were positive for Salmonellae; they represented 11 different serotypes. Often, positive samples were sporadic, with indications neither of a set contamination pattern nor of a seasonal influence.

A consideration of questionable practices and potentially hazardous circumstances that could arise between the capture of fish and storage of fish meal is beyond the scope of this study; however, a comprehensive study is envisioned. Attention by fish-meal processors to the findings should further minimize such difficulties as have occasionally been experienced.

II. THERMAL STUDIES

Our thermal studies involved two aspects: (1) the effect of heat on the micro-organism under study and (2) the effects of heat on the nurtitional quality of the meal — specifically on the resistance of the protein in fish meal to damage by the heat needed in the destruction of Salmonellae during the reprocessing of meal.

A. MICROBIOLOGICAL ASPECTS

We had two groups of experiments. The first (time-temperature experiments) was to determine the effectiveness of various processing variables by the use of several temperatures and heating periods. The

[1] Trade names referred to in this publication do not imply endorsement of commercial products.

second (thermal destruction experiments) was to determine the effectiveness of various time-temperature combinations in the destruction of Salmonellae in several reprocessed commercial fish meals.

1. Time-Temperature Study

a. Procedure.—For each time-temperature combination, nine containers of meal were inoculated, sealed, heated, cooled, and examined for survivors, as follows:

(1) Meals.—Two high-quality menhaden fish meals (Table 1) were used.

Table 1.—Proximate composition prior to heating of the two major meals tested

Constituents	Concentration in:	
	Meal A	Meal B
	Percent	*Percent*
Protein	63.00	61.29
Fat (ether soluble)	10.61	10.80
Water	6.55	7.96
Ash	19.35	19.15
Calcium	5.54	5.52
Phosphorous	3.80	3.89

(2) Containers.—Two types of meal containers were used to determine rates of heat penetration — soft-glass thermal-death-time tubes and 5-milliliter glass ampules. The use of either container yielded similar heat-penetration characteristics; accordingly, for convenience, most of our data were obtained by use of the glass ampules.

In filling an ampule, we added meal and compacted it by gently tapping the ampule until it was full. The filled weights and the subsequent heat-penetration curves were found to be very nearly uniform with ampules so prepared.

(3) Serotype used.—For the determination of specific thermal death time, a single serotype (*Salmonella senftenberg* 775W) was used. *S. senftenberg* 775W was selected as the test strain on the basis of its thermal resistance in liquid media (Angelotti, Foter, and Lewis, 1960). The methods used in making the determinations were those of Ball (1943), Anellis, Lubas, and Rayman (1954), Schultz and Olson (1940), Stumbo, Murphy, and Cochran (1950), and Bigelow and Esty (1920).

(4) Inoculation.—We used two methods of inoculation.

In the first method, the inoculum was introduced into the meal (5 grams) with the least amount of buffer possible, usually 0.001 milliliter, which represented only an 0.02 percent increase in the concentration of moisture in the meal. An 0.10-milliliter syringe was used for the inoculation, the point of inoculation being as near as possible to the geometric center of the column of meal.

The second method of meal inoculation was used with equal success. The meal was inoculated in 100-gram amounts, which were then thoroughly mixed for 5 minutes in a Waring blendor operated at a slow speed. The inoculated meal was subsequently introduced into the ampules for heating tests. No significant differences in thermal destruction was attributable to the different inoculation procedures used.

(5) Storage.—After the meals had been inoculated, they were divided into two groups for the determination of thermal death time. In one group, thermal-death-time determinations were made within 2 hours after inoculation. In the other group, the meals were allowed to stand 2 months before the thermal-death-time determinations.

In the designation of our samples, we have been somewhat arbitrary. We have termed fresh contamination "artificial" because, in laboratory experiments, work is usually done immediately following such deliberate introductions. Similarly, we have termed 2-month-old inoculations "natural" because in natural contamination one can usually say only that it occurred in the past. Designations should be equated perhaps, with words such as "fresh" and "aged".

(6) Temperature and time.—Temperature and time were determined as follows: A No. 22 gauge (B and S) thermocouple was inserted through a rubber stopper into the center of the meal column, and the ampules were placed into a 37° C. waterbath and allowed to equilibrate. Once the temperature of the meal stabilized at 37° C., the ampules were quickly transferred to another bath preset to the desired temperature. The temperature of the bath was maintained within ±0.5° C. After the meal in the ampules had attained the bath temperature, the ampules were quickly transferred to ice water. The time necessary for the meal to reach the bath temperature and cool again to 37° C. was recorded.

(7) Test for survivors.—After the heat treatments, survivors were tested for as follows: The contents of the ampules were aseptically added to bottles or tubes containing 100 milliliters of BGT broth and incubated for 24 hours. Plates of BGA were streaked and incubated for 24 hours at which time typical colonies were transferred to TSI slants. Confirmation of survivors was made by serological procedures.

(8) Heat-penetration curves.—Using the average values of several determinations, we calculated the heat-penetration curves for the meals according to the method of Ball (1943) and of Anellis, Lubis, and Morton (1954).

b. Results and discussion.—Upon initiation of thermal-destruction studies of the portions of the meals that had been stored for 2 months, they were found to contain a residuum of about 430 cells per gram. In contrast, the meals analyzed within 2 hours after inoculation were found to contain 2.0 x 10^6 cells per gram.

The thermal-death-time experiments produced a wide range of F values (minutes of exposure at a certain temperature resulting in a nondetectable cell level). Most of the variations, however, can be attributed to one or more of the following factors: composition of the meal, number of organisms present, and time since contaminant introduction ("artificially" contaminated meal versus "naturally" contaminated meal). The last mentioned factor seemed, in this instance, to be central to any consideration of the F value discrepancies. Rasmussen, Hansen, Jacobs, and Wilder (1964) noted similar differences in studies of naturally contaminated versus artificially contaminated materials.

One would think that the meal containing 2.0 x 10^6 cells per gram would require longer heating periods for complete cell inactivation than would the same meal containing only 430 cells per gram. However, in this instance, the opposite is true. The average F_{165} (minutes exposure at 165° F. resulting in a nondetectable cell level) values of the "artificially" contaminated Meals A and B (heated 2 hours after inoculation) were 7.8 and 6.5 respectively,

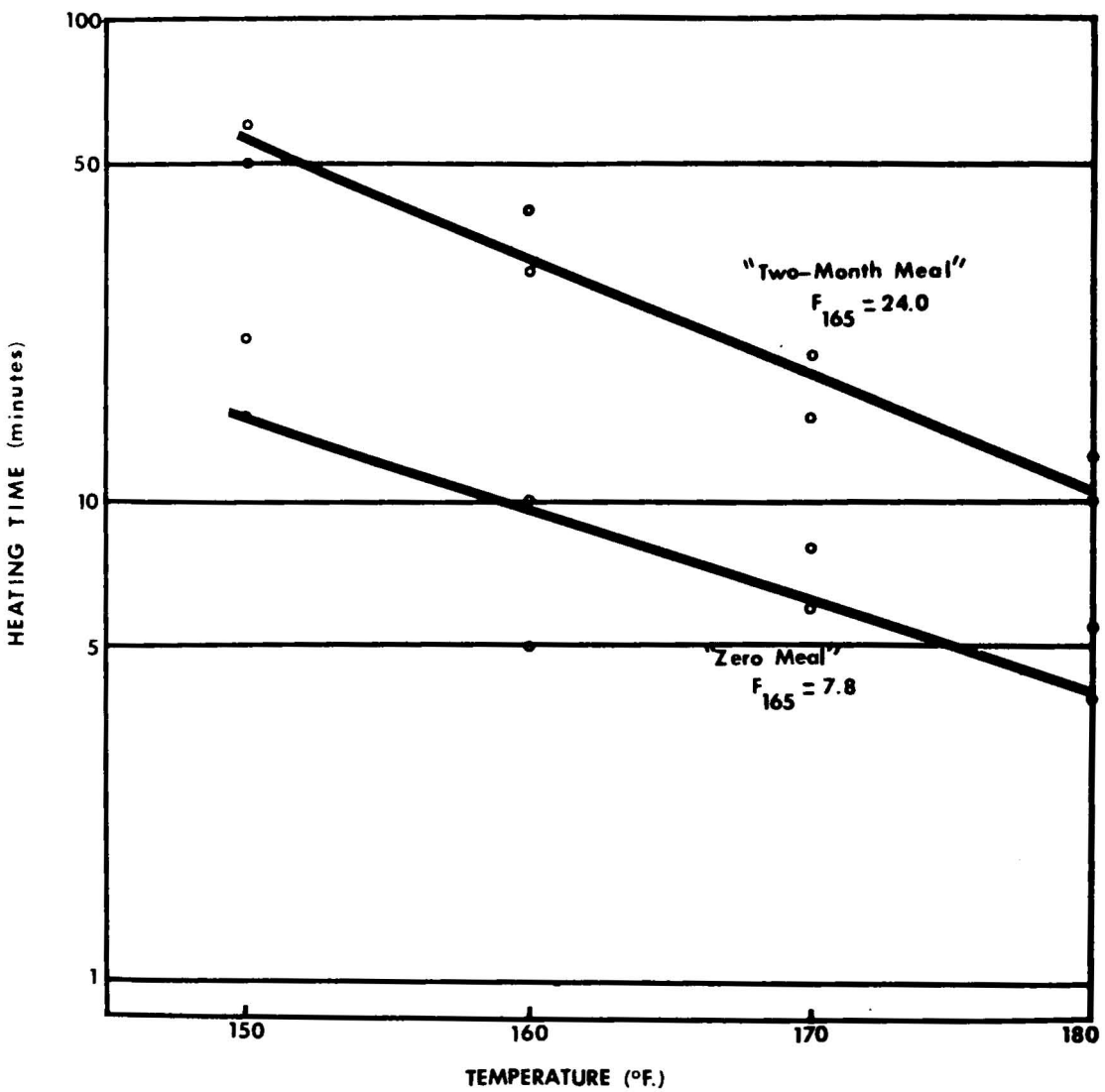

Figure 1.—Heat resistance of *Salmonella senftenberg* 775W in Fish Meal A, about 2.0 x 10^6 cells per gram in the zero meal, and about 4.3 x 10^2 in the 2-month meal.

whereas the average F_{165} values for the "naturally" contaminated Meals A and B (heated 2 months after inoculation) were 24.0 and 18.5 respectively (Figures 1 and 2).

This same phenomenon was then demonstrated with Meals A and B inoculated 1 week before thermal-death-time determinations. The cell density during this period was reduced from the original 2.0×10^6 to about 1×10^5 cells per gram. The average F_{165} values obtained on the 1-week-old meals were 16.5 and 17.0, respectively. No verified explanation for these differences can be offered at this time; however, several possibilities exist. Some of these possible explanations have been suggested by Rasmussen, Hansen, Jacobs, and Wilder (1964). Our data indicate that thermal resistance under our conditions is more a function of time than of cell numbers. By this statement, we mean that the length of time between inoculation or contamination and heating definitely influences the F values obtained. Possibly, this period affords the cells an opportunity to migrate into the residual fats or protein particles present. Further examination of this possibility is planned.

Although the reasons behind these differences are not yet clear, one fact must be recognized: thermal-death-time determinations obtained using freshly inoculated fish meal are unreliable when applied to a natural situation.

2. Thermal Destruction

Experiments were made to determine the effectiveness of various time-temperature combinations in the destruction of Salmonellae in several reprocessed commercial fish meals.

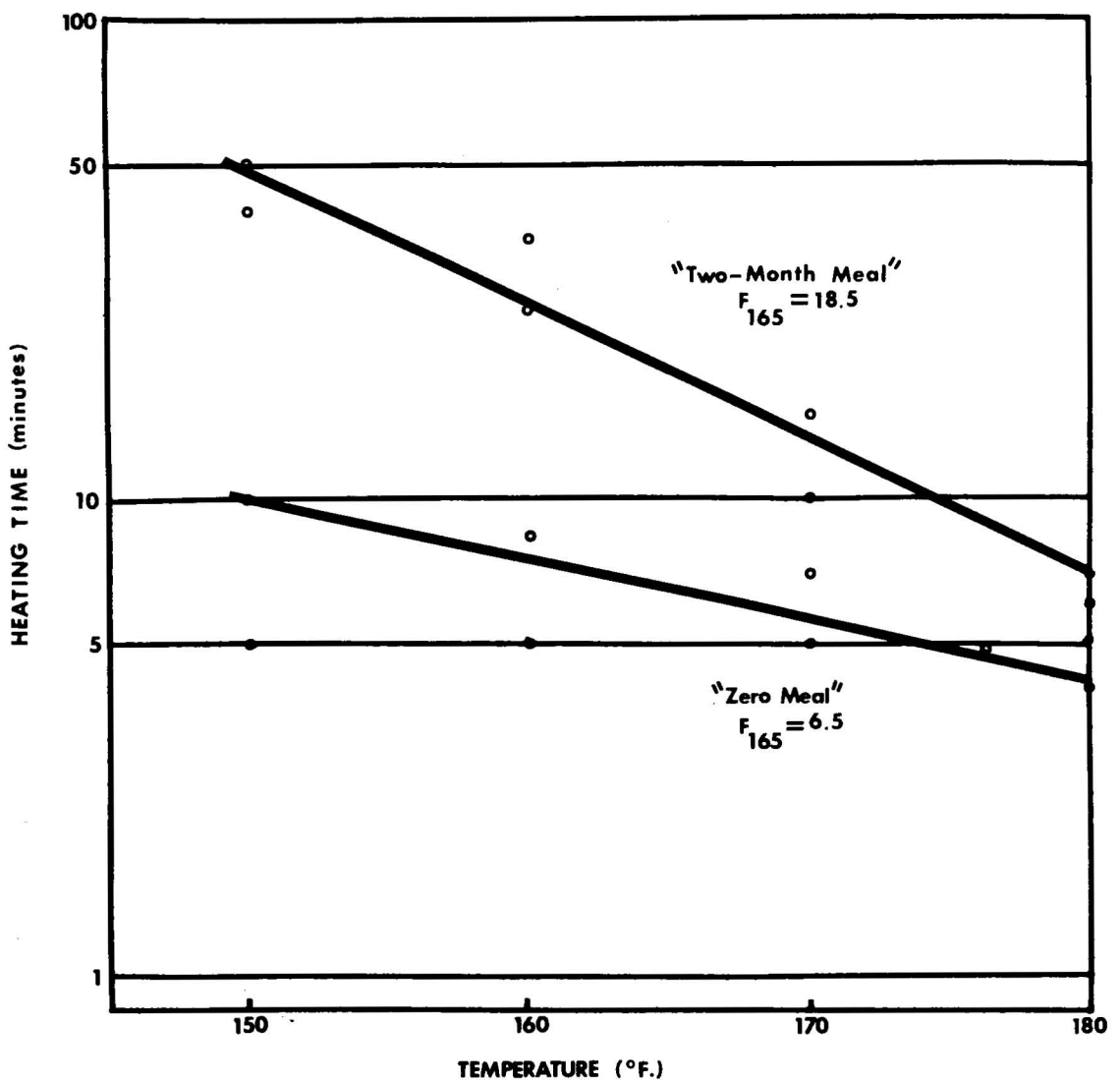

Figure 2.—Heat resistance of *Salmonella senftenberg* 775W in Fish Meal B, about 2.0 x 10^6 cells per gram in the zero meal, and about 4.3 x 10^2 in the 2-month meal.

a. Procedure.—For each time-temperature combination, nine ampules prepared as described earlier were inoculated, sealed, heated, cooled, and examined for survivors. For these thermal-destruction studies, all of the serotypes were mixed in equal numbers to give a single inoculum.

The following organisms were used: *Salmonella senftenberg* 775W, *S. cerro*, *S. montevideo*, *S. thomasville*, and *S. oranienburg*. We selected these particular serotypes because they have been among the most frequent isolates from fish meal. All of the above cultures were obtained through the courtesy of the United States Public Health Service's Communicable Disease Center, Atlanta, Georgia.

The cultures were each subjected to complete serological and biochemical examination before the start of the inoculum preparation. Initial cultures were made in Trypticase Soy Tryptone broth (TST) and incubated for 48 hours. Secondary transfers were made to TST and incubated for 24 hours at which time the cultures were centrifuged and washed three times in sterile phosphate buffer (Butterfields) and adjusted to the desired inoculum level by means of a Bausch and Lomb Spectronic 20 set at 620 millimicrons.

An inoculum thus prepared to contain about equal numbers of *S. senftenberg* 775W, *S. cerro*, *S. montevideo*, *S. thomasville*, and *S. oranienburg* was added to sterile meal to a final concentration of about 2.0 x 10^6 cells per gram. Thermal-destruction determinations were conducted on the meals at 0, 48, 96, and 144 hours following inoculation and at 2 months after inoculation.

b. Results.—The results, shown in Table 2, indicate that *S. senftenberg* 775W was not the most heat-resistant strain used. *S. montevideo* and *S. oranienburg*, on several occasions, demonstrated a greater tolerance to heat than did the 775W strain. The results also indicate that no single set of conditions applied was completely satisfactory. Although a particular set of conditions may appear adequate for one meal, it may, applied to another, be either inadequate or excessive.

As indicated in Table 2, the meals were heated at 150°, 160°, 170°, 180°, and 190° F. for various time intervals. Regardless of the initial storage time, surviving Salmonellae could always be demonstrated in meals that had been heated to 150° F. for 40 minutes or to 160° F. for 30 minutes. In freshly contaminated meal (artificial), 10 minutes of heating at 170° F. was adequate for the destruction of all *Salmonella* strains, but after storage of contaminated meals for periods of 144 hours to 2 months, even 20 minutes of heating was inadequate. At 180° F., 10 minutes of heating was adequate for all meals stored less than 96 hours, but 10 minutes of heating no longer sufficed to free these meals of Salmonellae after 2 months of storage. At 190° F., 5 minutes of heating did not consistently result in Salmonellae-free meal,

Table 2.—Thermal destruction of an equal mixture of *Salmonella senftenberg* 775W, *S. cerro*, *S. thomasville*, *S. montevideo*, and *S. oranienburg* in Fish Meal A

Time after inoculation	Salmonellae	Heating temperature	Heating period	Samples heated	Samples positive	Surviving serotypes
Hours	*Approx. no. per gram*	*°F.*	*Minutes*	*Number*	*Number*	
0	2.0 x 10^6	150	15	9	9	All serotypes present
0	2.0 x 10^6	160	15	9	3	*S. senftenberg, S. oranienburg*
0	2.0 x 10^6	170	10	9	0	No survivors
0	2.0 x 10^6	180	4	9	2	*S. senftenberg, S. oranienburg, S. thomasville*
0	2.0 x 10^6	190	5	9	1	*S. senftenberg, S. oranienburg, S. cerro, S. montevideo*
48	1.5 x 10^5	150	15	9	2	All serotypes present
48	1.5 x 10^5	160	15	9	3	All serotypes present
48	1.5 x 10^5	170	15	9	1	All serotypes present
48	1.5 x 10^5	180	6	9	1	*S. senftenberg*
48	1.5 x 10^5	190	10	9	0	No survivors
96	2.2 x 10^4	150	30	9	1	*S. montevideo*
96	2.2 x 10^4	160	20	9	1	*S. montevideo, S. senftenberg, S. cerro*
96	2.2 x 10^4	170	20	9	0	No survivors
96	2.2 x 10^4	180	10	9	0	No survivors
96	2.2 x 10^4	190	10	9	0	No survivors
144	7.0 x 10^3	150	35	9	3	All serotypes present
144	7.0 x 10^3	160	30	9	2	All serotypes present
144	7.0 x 10^3	170	20	9	1	*S. montevideo, S. oranienburg*
144	7.0 x 10^3	180	12	9	0	No survivors
144	7.0 x 10^3	190	10	9	0	No survivors
1,440	4.3 x 10^2	150	40	9	9	All serotypes present
1,440	4.3 x 10^2	160	30	9	9	All serotypes present
1,440	4.3 x 10^2	170	20	9	1	*S. montevideo, S. oranienburg*
1,440	4.3 x 10^2	180	10	9	4	*S. montevideo, S. oranienburg*
1,440	4.3 x 10^2	190	10	9	0	No survivors

but heating for 10 minutes consistently destroyed all Salmonellae regardless of the length of storage.

These data indicate that postproduction heating of meals at the lower temperatures (150°, 160°, 170° F.) require excessive time periods to produce Salmonellae-free meals consistently. From the data, the best combination appears to be 190° F. for 10 minutes, since this time-temperature combination consistently reduced any Salmonellae present to nondetectable levels. However, a note of caution must be added regarding complete reliance on the above-mentioned combination: the inactivation of Salmonellae in fish meal is influenced by a multiplicity of factors (for example, percent oil, particle size, percent moisture, serotypes present, number of organisms present, and length of time following contamination), so the most economic postproduction processing conditions should be decided upon only after these factors have been evaluated for the meal in question.

B. PROTEIN-HEAT-RESISTANCE ASPECT

1. Method

To determine any adverse effects produced as a result of various postprocessing heat treatments, we heated and had tested about 100 pounds of two meals.

The meals were packed into No. 202 x 214 cans and sealed. The specific heat treatments used were as follows: 150° F. for 30 minutes; 165° F. for 20 minutes; 180° F. for 5 minutes; and up to 230° F. without holding. The controls were held at 0° F.

Prior to the heat experiments, we made numerous heat-penetration determinations to determine correction factors for the necessary processing periods. These determinations were made using an Ecklund nonprojecting thermocouple mounted in the side of the can as described by Alstrand and Ecklund (1951). Continuous temperature readings were made on a Leeds and Northrup Model 8692 potentiometer. During the heating periods, several can-contained thermocouples were placed at various points in the water-bath, which enabled us to monitor the temperature continuously.

The protein-evaluation phase of this investigation was conducted by the Bureau of Commercial Fisheries Technological Laboratory at College Park, Maryland. A chick bioassay was utilized for this purpose. Each assay was based on three replicates of 10 chicks each for each meal according to Tukey's Test (Snedecor, 1957).

2. Results

No proteins were significantly damaged by any of the time-temperature combinations (Table 3).

Table 3.—Protein evaluation by means of a 20-day chick assay, at the 15-percent protein level, of fish heated at various times and temperatures

Protein source	Heat treatment		Average chick weight	Relative growth response
	°F.	*Minutes*	*Grams*	*Percent*
Soybean meal	0	—	197	60
Soybean meal plus 0.3 percent methionine	0	—	331	100
Fish Meal A	0	—	252	76
	150	30	252	76
	165	20	271	82
	180	5	253	76
	230	—	254	77
Fish Meal B	0	—	270	82
	150	30	276	83
	165	20	258	78
	180	5	272	82
	230	—	251	76

SUMMARY

In a determination of the extent of Salmonellae contamination in and about menhaden-meal production facilities, 9.2 percent of the samples collected were positive; 11 different serotypes were found.

Results of Salmonellae thermal-death-time studies indicate that the length of time between initial inoculation or contamination of fish meal and thermal-death-time determinations definitely influences the process required to inactivate all Salmonellae. Processing results derived from artificially contaminated meal are not usually valid when applied to naturally contaminated meal.

S. senftenberg 775W did not consistently display exceptional heat resistance. *S. montevideo* and *S. oranienburg* on several occasions displayed greater heat resistance than did the 775W strain.

Of the postprocessing variables investigated, only the combination of 190° F. for 10 minutes consistently reduced the Salmonellae present to nondetectable levels.

Postproduction processing conditions for the elimination of Salmonellae in fish meal should be formulated only after careful consideration has been given to such variables as oil content, moisture con-

tent, particle size, number of Salmonellae present, serotypes present, and the length of time since initial contamination. The last variable in this investigation appears to have markedly influenced the results obtained.

Data from a 20-day chick bioassay at a 15-percent level revealed no significant protein damage in two fish meals that were exposed to the following post production heat treatments: 150° F. for 30 minutes, 165° F. for 20 minutes, 180° F. for 5 minutes, and up to 230° F. without holding.

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MS #1678

IRRADIATION OF PACIFIC COAST FISH AND SHELLFISH. 6--PRETREATMENT WITH SODIUM TRIPOLYPHOSPHATE

by

J. Spinelli, G. Pelroy, and D. Miyauchi

ABSTRACT

The effects, during storage, of dipping fish fillets and steaks into sodium tripolyphosphate-salt solution prior to irradiation were evaluated relative to drip, sensory factors, and protein alteration and to spoilage microflora. In general, the dipping treatment proved beneficial.

INTRODUCTION

The purpose of food irradiation is to extend the shelf life of a product and to maintain as closely as possible its freshlike characteristics during the storage period. Although low-dose irradiation (less than 1 megarad) delays the appearance of gross quality changes by destroying a large part of the bacterial population, other changes not associated with microbiological growth occur during storage and affect the ultimate quality and appearance of the irradiated product. These changes include loss of drip, alteration in color, alteration in texture, and some loss of flavor.

The extent to which these changes adversely affect the quality of the irradiated product depends largely on the species of fish, the method of butchering the fish, and the length of time the product has been stored. Generally, fillets lose most of their drip during the first 10 days of storage. Alterations in color, particularly in whitefish, are noticed after 2 weeks of storage. In halibut steaks and in Pacific ocean perch fillets, texture changes begin to occur after 2 weeks of storage and are quite apparent after 3 weeks of storage. The flavor of some fish fillets is lost noticeably after 10 days of storage. This loss has been implicated with the degradation of inosine monophosphate (Spinelli and Miyauchi, 1967)[1].

It has been known for some time that various forms of condensed phosphates, such as pyro- and poly-, increase water-holding capacity when incorporated into proteinaceous foods (Sherman, 1961; Hellendoorn, 1962). Also it has been asserted that fish fillets treated with solutions of sodium tripolyphosphate and salt (sodium chloride) prior to freezing prevents loss of both drip and flavor from the thawed-cooked product (Mahon, 1962; Boyd and Southcott, 1965).

[1] J. Spinelli and D. Miyauchi. Irradiation of Pacific Coast fish and shellfish. V. The effect of 5' IMP on the flavor of irradiated fish fillets. Bureau of Commercial Fisheries Technological Laboratory, Seattle, Washington 98102, 1967, 14 manuscript pages.

Authors: J. Spinelli and D. Miyauchi, *Research Chemists*, and G. Pelroy, *Microbiologist*, Bureau of Commercial Fisheries Technological Laboratory, Seattle, Washington 98102.

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Some preliminary work on the use of sodium tripolyphosphate has been done at the Bureau of Commercial Fisheries Technological Laboratory, Seattle. Petrale sole fillets were treated, prior to irradiation, in a 10-percent sodium tripolyphosphate solution containing 4 percent of salt. The loss of drip was reduced practically to zero during 28 days of storage, and, after this period, both the color and appearance of treated fillets were superior to the color and appearance of nontreated fillets.

To evaluate more fully this preliminary work on whether pretreatment of fillets with sodium tripolyphosphate or combinations of sodium tripolyphosphate and salt would complement the irradiation process, we studied the effectiveness of these treatments on several species of fishes that are suitable for radiation processing. The effects, during storage, of these treatments were evaluated relative to (I) drip, sensory factors, and protein alteration and (II) spoilage microflora.

I. DRIP, SENSORY FACTORS, AND PROTEIN ALTERATION

A. DRIP

1. Materials and Methods

We prepared samples and made measurements as follows:

a. Sample preparation.—In the preparation of samples, we were concerned with the fish, the sodium tripolyphosphate-salt solutions, the dipping treatment, the packaging method, and the method of irradiation and storage.

(1) Fish.—The English sole, petrale sole, and Pacific ocean perch used in these experiments were obtained from local commercial processors and were from 2 to 9 days old when landed; halibut was 10 to 18 days old when landed.

(2) Sodium tripolyphosphate-salt solution.—The optimum concentration of sodium tripolyphosphate-salt solutions and the contact time between solution and fish needed to retard drip were determined by dipping the fish in various concentrations of these solutions for different periods of time. All solutions of sodium tripolyphosphate and salt were prepared on a percent-weight basis.

(3) Dipping treatment.—Fish fillets or steaks were dipped for about 22 seconds in the sodium tripolyphosphate-salt solutions and drained for 15 minutes. Control samples were similarly dipped in water. The temperature of the dipping solutions was about 70° F.

(4) Packaging method.—About 5 pounds of the fillets were vacuum packed in laminated mylar-polyethylene pouches (½ x 2 mil medium density) or in No. 10 cans.

(5) Irradiation and storage.—Immediately after being packed, the samples were irradiated in the Brookhaven National Laboratory Mark II Food Irradiator at the University of Washington, Seattle. All samples were stored at 33° to 35° F.

b. Measurements

(1) Sodium tripolyphosphate determination.—The amount of sodium tripolyphosphate solution (or water, in the case of the controls) that was absorbed by the fish was determined by weighing the fillets before and after treatment.

Analyses for total phosphorus content of both treated and untreated fillets were then made to determine the amount of sodium tripolyphosphate that was absorbed by the fish. In the analysis, whole fillets were blended, and phosphorus was determined on aliquots by the methods of the Association of Official Agricultural Chemists (1960).

(2) Drip determination.—After storage of the cans or pouches, their contents were spread on screens and allowed to drain for 30 minutes. The fillets and the collected drip were weighed, and the drip was calculated on a percent-weight basis.

2. Results

a. Absorption of sodium tripolyphosphate.—Fish dipped for from 15 to 30 seconds in solutions of either 7.5-percent or 10-percent sodium tripolyphosphate containing 2 percent of salt absorbed between 2.5 percent and 3.0 percent of the dipping solution. The concentration of tripolyphosphate in the treated and untreated fillets indicated that the uptake of sodium tripolyphosphate was fairly uniform.

Figure 1 shows the concentration of phosphorus in Pacific ocean perch fillets dipped in solutions of sodium tripolyphosphate-salt ranging in concentration from 0 to 10 percent. The amount of sodium tripolyphosphate (as phosphorus) absorbed by the fillets shows an almost linear relation to the sodium tripolyphosphate concentration—that is, 10 milligrams of phosphorus was absorbed for each 2.5-percent increase in the concentration of sodium tripolyphosphate in the dipping solution.

Values from individual Pacific ocean perch fillets (dipped in 7.5 percent sodium tripolyphosphate solution containing 2 percent of salt) taken from different lots and different experiments show a mean phosphorus uptake of 32 milligrams per 100 grams of fish (Table 1). This amount of phosphorus is equivalent to about 136 milligrams of sodium tripolyphosphate per 100 grams of fish or 0.136 percent.

Table 1.—Phosphorus concentrations in Pacific ocean perch fillets dipped in a 7.5-percent solution of sodium tripolyphosphate containing 2 percent sodium chloride.

Concentration in untreated fillets			Concentration in treated fillets		
Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3
Mg./100 g.	*Mg./100 g.*	*Mg./100 g.*	*Mg./100 g.*	*Mg./100 g.*	*Mg./100 g.*
90	108	81	117	113	132
83	74	85	110	112	115
83	67	77	115	98	110
88	72	78	117	108	120
88	78	74	115	106	115
Range	67-108		98-132		
Mean	82		114		
Mean phosphorus uptake	--		32		

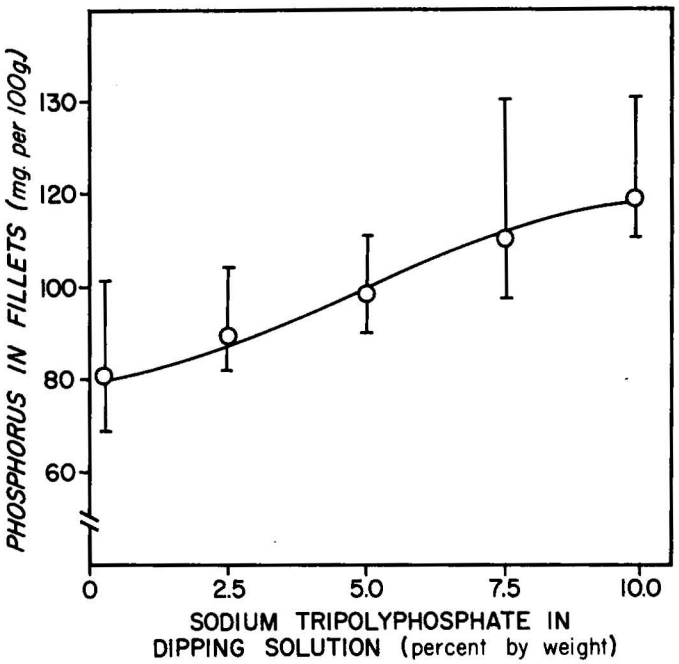

Figure 1.—Phosphorus concentration in Pacific ocean perch fillets dipped in sodium tripolyphosphate solutions containing 2 percent of sodium chloride.

b. Effectiveness of the treatments in retarding drip.—We were concerned with the effect of both the tripolyphosphate and the salt on the retardation of drip.

(1) Effect of tripolyphosphate.—To determine the effect of tripolyphosphate in retarding drip in different species of fishes, we used fillets from Pacific ocean perch, petrale sole, and English sole. In addition, we used steaks from halibut.

(*a*) *Pacific ocean perch, petrale sole, and English sole fillets.*—Figure 2 shows the amount of drip that forms in irradiated Pacific ocean perch fillets during storage. Also shown is the relation between the amount of drip that is formed during storage and the concentration of sodium tripolyphosphate-salt solutions. The formation of drip is effectively retarded only when the concentration of sodium tripolyphosphate in the dipping solution exceeds 5 percent. No appreciable decrease in drip formation was noticed when the concentration of sodium tripolyphosphate was increased from 7.5 to 10 percent. Similar data were obtained with petrale and English sole fillets.

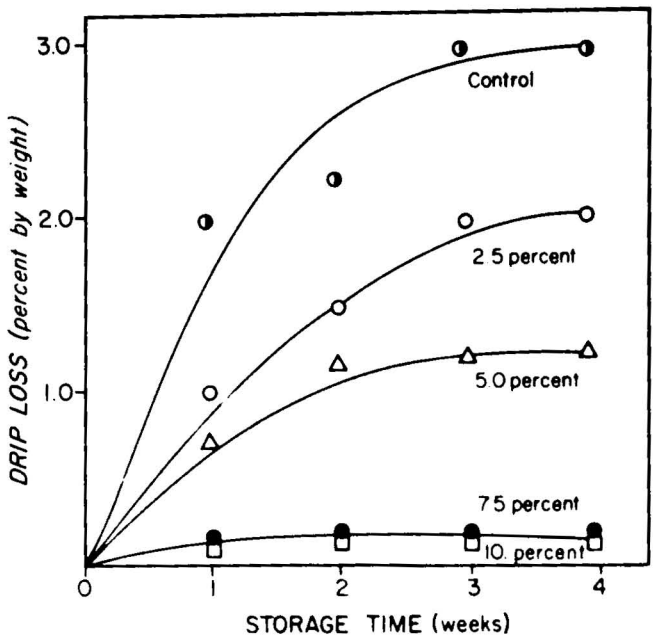

Figure 2.—Loss of drip during storage of irradiated Pacific ocean perch fillets pretreated with various concentrations of sodium tripolyphosphate containing 2 percent of sodium chloride.

(*b*) *Halibut steaks.*—Figure 3 shows the amount of drip that was found in treated and untreated fish after 3 weeks of storage. The amount of drip that formed in halibut steaks is significantly higher than the amount that formed in Pacific ocean perch, petrale sole, and English sole. Also, more variation was found in both the treated and untreated halibut steaks. This difference in species may be due to the fact that halibut sometimes is 10 to 18 days old when landed commercially. Some cellular damage and protein denaturation probably occur in the fish stored for this length of time. Cellular damage would have an influence on the amount of fluids that the tissue is capable of retaining; denatured protein does not react with phosphates in the same way that undenatured protein does (Fukazawa, Hashimoto, and Yasui, 1961).

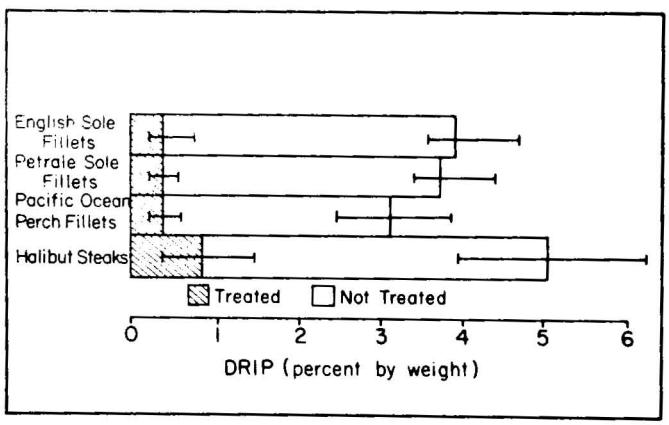

Figure 3.—Loss of drip in fish that were irradiated at 0.2 megarad and then stored for 3 weeks at 33° F. The drip in fish that were treated with tripolyphosphate-salt solution prior to irradiation is compared with the drip in fish that were not treated.

(2) Effect of salt.—We found, as was found earlier by Mahon (1962), that salt increases the effectiveness of sodium tripolyphosphate in promoting water-holding capacity. However, whereas Mahon (1962) found that maximum effectiveness in treating fish to be frozen required (1) solution strengths of 12-percent sodium tripolyphosphate containing 4 percent of salt and (2) a dipping time of 2 minutes, we found that the formation of drip could be effectively retarded by dipping the fish for about 22 seconds in a 7.5-percent solution of sodium tripolyphosphate containing only 2 percent of salt.

B. SENSORY FACTORS

The sensory factors determined were (1) physical characteristics (feel) and (2) color, texture, and flavor and odor.

1. Physical Characteristics

Immediately after the fillets were dipped, the surface of the fillets became gelatinous and slippery to the touch. This characteristic might be a disadvantage for the process if the fish are to be rehandled manually prior to irradiation. The slipperiness decreased fairly rapidly during storage but was still noticeable after 3 weeks.

2. Color, Texture, and Flavor and Odor

a. Sensory examination.—Sensory changes in color, texture, and flavor and odor were followed during storage by an experienced panel of four to six judges using a 10-point differ-

ence rating scale (Miyauchi, Eklund, Spinelli, and Stoll 1964)[2].

The fillets were cooked by steaming them for 10 minutes in 4- by 1¼- by 4-inch closed aluminum trays. To compensate for any treatment-induced flavor change, we organoleptically compared the treated fillets with non-irradiated but treated control fillets.

b. Results of sensory examination for color, texture, and flavor and odor

(1) Color.—Freshly cut fish fillets have a bright hue that gradually fades during storage of the fillets on ice. Retailers find that bright fillets have greater sales appeal than dull-appearing fillets do. Hence, unsold fillets are often washed to help restore their original hue.

We found that phosphate-treated fillets maintained their original hue during the entire storage period whether they were irradiated in cans or in polyethylene bags.

The color of the treated cooked fillets was also superior to that of the untreated fillets. Untreated fillets (particularly Pacific ocean perch fillets) that have been stored for more than 2 weeks often tend to be darker than cooked fresh fish. No darkening was observed in phosphate-treated fillets after they were cooked.

(2) Texture

(*a*) *Fillets treated with 10-percent sodium tripolyphosphate and 2 percent of salt.* The comparative overall sensory scores and texture scores between fillets treated with 10-percent sodium tripolyphosphate solution containing 2 percent of salt are shown in Table 2. After the fillets were stored for 3 weeks, the sensory scores of the treated fillets did not vary significantly from those for the untreated fillets. The texture of the ocean perch was significantly improved in the treated sample. The low texture score for the untreated ocean perch is a reflection of toughening of the fish, which became quite apparent after 2 weeks of storage. In the species of sole, poor texture scores were due to a softening of the fish.

Table 2.—Mean overall sensory scores and texture scores of irradiated fillets treated with 10-percent sodium tripolyphosphate solution containing 2 percent of sodium chloride

Species	Storage time	Overall sensory score		Texture score	
		Untreated fillets	Treated fillets	Untreated fillets	Treated fillets
	Weeks				
Pacific ocean perch	0	---	---	9.0	9.0
	1	7.2	7.8	8.3	9.0
	2	7.0	7.8	7.4	8.5
	3	7.0	7.5	7.1	8.7
Petrale sole	0	---	---	9.0	9.0
	1	8.5	8.0	9.0	8.1
	2	8.0	8.0	8.2	8.2
	3	7.2	6.8	7.2	7.8
English sole	0	---	---	9.0	9.0
	1	8.7	7.3	8.8	8.3
	2	8.3	7.2	8.2	8.2
	3	6.7	7.3	7.4	8.0

Note: All samples were irradiated at 0.2 megarad and stored at 33° F. The scores are the means of six individual judgments.

(*b*) *Fillets treated with 7.5-percent sodium tripolyphosphate and 2 percent of salt.* —Comparative sensory changes were studied with Pacific ocean perch fillets using a 7.5-percent sodium tripolyphosphate solution containing 2 percent of salt. The results (Table 3) from this experiment were essentially the same as those obtained when the fillets were treated with 10-percent sodium tripolyphosphate solution containing 2 percent of salt (Table 2).

Table 3.—Overall sensory scores of treated and untreated Pacific ocean perch fillets irradiated at 0.2 megarad and stored at 33° F.

Storage time	Overall sensory scores			
	Untreated control[1] fillets	Irradiated untreated fillets	Treated control[1] fillets	Treated and irradiated fillets
Weeks				
0	9.2	7.5	9.1	8.0
1	9.0	7.2	9.0	7.4
2	8.8	6.4	8.8	7.2
3	8.5	7.2	9.1	7.0
4	8.6	5.6	9.0	6.2

[1] Frozen control.
Note: All treated fish were dipped for 15 seconds in a 7.5-percent sodium tripolyphosphate solution containing 2 percent of salt.

[2] D. Miyauchi, M. Eklund, J. Spinelli, and N. Stoll. Application of radiation-pasteurization process to Pacific crab and flounder. Final summary for the period November 1963 to November 1964. United States Atomic Energy Commission, Division of Isotopes Development, Report No. TID 21404, Isotopes-Industrial Technology TID (19th edition), Contract No. AT(49-11)-2058, November 1964, 109 pages. Processed paper filed at the Bureau of Commercial Fisheries Technological Laboratory, Seattle, Washington 98102.

(*c*) *General observations.*—The loss of fluid after cooking was considerably less in all the treated fillets. This loss ranged from 15 to 21 milliliters per 100 grams of untreated fillets and from 9 to 15 milliliters per 100 grams of treated fillets. The retention of fluids probably helps maintain the texture of the Pacific ocean perch.

Softening apparently is an intrinsic characteristic of sole. The phosphate treatment does not seem to affect this property.

(3) Flavor and odor.—In judging flavor and odor, we were concerned with (a) saltiness, (b) rancidity, and (c) any changes in normal fish flavor and odor other than saltiness or rancidity.

(*a*) *Saltiness.*—The addition of 4 percent of salt to sodium tripolyphosphate solutions resulted in objectionable saltiness when the fish were examined organoleptically. The addition of 2 percent of salt, however, did not result in objectionable saltiness.

(*b*) *Rancidity.*—All the fish in this study were irradiated in a vacuum. Previous work showed that when halibut, petrale sole, and English sole were irradiated in air, rancidity became apparent after about 10 to 14 days of storage. Although investigators have shown that rancidity can be retarded in frozen fish by the addition of phosphates, we found that when the irradiation was in air, rancidity in treated samples could be detected after the same period of time as in untreated samples. The rancidity was not salt-induced, however, because the rancidity was evident regardless of the presence or absence of salt in the sodium tripolyphosphate solution.

(*c*) *Normal fish flavor and odor.*—Other than saltiness and rancidity, no other changes in normal fish flavor and odor were found.

C. PROTEIN ALTERATION

The comparative changes that occurred in the muscle protein of English sole and Pacific ocean perch fillets were determined by measuring changes in the total salt-soluble, myofibrillar, and nonprotein nitrogen content periodically during storage of the fillets. Tyrosine also was measured to ascertain any evidence of protein degradation during storage.

Tables 4 and 5 show the results of this study. Each value is the mean of three determinations. Comparisons between treated and untreated fillets at each sampling interval were made on paired fillets. Samples for these analyses were taken from a complete cross section of the fillet.

During 4 weeks of storage, the nitrogen fractions of treated and untreated fillets did not differ significantly. The small increases in tyrosine values would indicate that treatment with sodium tripolyphosphate has little influence on the rate of protein degradation. The amount of myofibrillar protein that was extractable decreased significantly in both species of fish after 2 weeks of storage, but the amount of myofibrillar protein that could be extracted from either treated or untreated fillets did not differ significantly. Since several workers have correlated protein solubility with texture, and since the amount of soluble protein was essentially the same in both treated and untreated fillets, we were surprised to find a textural difference between treated and untreated fillets.

One explanation for the textural difference would be that the treated fillets retain considerably more water and other soluble constituents during cooking. The effect of retained water and other ionic material undoubtedly exerts some influence on the final sensory textural characteristics of the fish.

Another explanation for the textural difference would be that a portion of the structural protein of the fish tissue has been modified by the phosphate treatment. It is known that the absorption of ions by the tissue proteins changes the internal forces of attraction in the protein and that those changes exert an influence on the physical nature of the protein even after denaturation by heat (Sherman, 1962).

Table 4.—Comparison of changes in the nitrogenous constituents in untreated English sole fillets and fillets treated with 10-percent sodium tripolyphosphate solution containing 2 percent of salt, irradiated at 0.25 megarad, and stored at 33° F.

Storage time	Salt-soluble nitrogen		Myofibrillar nitrogen		Nonprotein nitrogen		Tyrosine value[1]	
	Treated fillets	Untreated fillets	Treated fillets	Untreated fillets	Treated fillets	Untreated fillets	Treated fillets	Untreated fillets
Days	*Mg.N/g.*	*Mg.N/g.*	*Mg.N/g.*	*Mg.N/g.*	*Mg.N/g.*	*Mg.N/g.*	*Mg./g.*	*Mg./g.*
0	29.7	28.9	19.7	18.0	3.2	3.1	0.04	0.04
7	27.8	27.4	19.3	18.0	3.3	3.5	0.04	0.04
14	29.7	29.0	19.0	19.2	4.0	3.9	0.05	0.045
21	24.8	25.8	15.3	14.2	3.7	3.6	0.05	0.05
28	20.5	23.5	10.9	12.9	4.1	4.1	0.065	0.065

[1] Tyrosine used as a standard.

Table 5.—Changes in the nitrogenous constituents in Pacific ocean perch fillets treated with 10-percent sodium tripolyphosphate solution containing 2 percent of salt, irradiated at 0.25 megarad, and stored at 33° F.

Storage time	Salt-soluble nitrogen		Myofibrillar nitrogen		Nonprotein nitrogen		Tyrosine value[1]	
	Treated fillets	Untreated fillets	Treated fillets	Untreated fillets	Treated fillets	Untreated fillets	Treated fillets	Untreated fillets
Days	*Mg.N/g.*	*Mg.N/g.*	*Mg.N/g.*	*Mg.N/g.*	*Mg.N/g.*	*Mg.N/g.*	*Mg./g.*	*Mg./g.*
0	33.0	33.0	22.3	22.2	4.2	4.4	0.03	0.03
7	30.5	28.3	18.5	16.9	4.2	4.3	0.04	0.04
14	31.0	30.0	17.5	16.6	4.1	4.1	0.04	0.04
21	29.1	29.2	14.4	14.6	4.3	4.3	0.05	0.05
28	24.7	25.0	12.7	12.2	4.7	4.6	0.065	0.06

1 Tyrosine used as a standard.

II. SPOILAGE MICROFLORA

A. PROCEDURE

Pacific ocean perch fillets were treated in 7.5-percent polyphosphate solution, vacuum packed in cans, irradiated at 0.2 megarad, and stored at 33° F. Microbiological determinations were made by methods described by Miyauchi, Eklund, Spinelli, and Stoll (1964)[2].

[2] See footnote [1].

B. RESULTS

After storage of the fillets for 17 days, *Lactobacillus* was the predominating organism in the nondipped irradiated fillets, whereas *Achromobacter* was the predominant organism in the polyphosphate-treated irradiated fillets (Table 6). At the time of spoilage, however, *Lactobacillus* predominated in both the treated and untreated fillets.

Table 6.—Microflora from untreated and polyphosphate-treated Pacific ocean perch fillets after irradiation and storage at 33° F.

Type of fillets	Radiation dose	Storage time	Total isolates	Microflora											
				Bacteria								Yeast		Not identified	
				Achromobacter		Coryneforms		*Lactobacillus*		*Bacillus*					
	Mrad.	*Days*	*No.*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
	0	0	55	3	5	17	31	1	2	1	2	1	2	32	58
Untreated fillets	0.2	0	26	25	96	0	0	0	0	0	0	1	4	0	0
		17	36	2	3	0	0	84	97	0	0	0	0	0	0
		29-31	123	0	0	0	0	123	100	0	0	0	0	0	0
		36	68	0	0	0	0	68	100	0	0	0	0	0	0
Polyphosphate treated fillets	0.2	0	6	4	66	0	0	0	0	0	0	1	17	1	17
		17	118	106	89	0	0	11	9	0	0	0	0	2	2
		29-31	120	0	0	0	0	120	100	0	0	0	0	0	0
		36	166	0	0	0	0	166	100	0	0	0	0	0	0

In another experiment, *Lactobacillus* was found to be the predominant organism at the time of spoilage of seven samples of ocean perch fillets that had been treated with polyphosphate solution, vacuum packed, and irradiated at 0.2 megarad.

From this work, it appears that polyphosphate treatment has little effect on the composition of the spoilage microflora of vacuum-packaged irradiated fillets.

SUMMARY

Dipping fish fillets and steaks into sodium tripolyphosphate-salt solutions of appropriate concentrations (7.5-percent sodium tripolyphosphate containing 2 percent of salt) prior to irradiation is compatible with the irradiation-pasteurization of these products.

Pretreatment has an economic advantage in that, during storage, drip is minimized, the original appearance of the fish is largely retained, and the texture is less altered, particularly with such species as halibut and Pacific ocean perch. Dipping does, however, result in a marked but not serious increase in slipperiness of the fish. Other factors relating to flavor or to odor were not affected. Treatment with sodium tripolyphosphate-salt solutions did not significantly alter the salt-soluble, myofibrillar, and nonprotein nitrogen content of the fillets during storage.

No significant differences were found in the spoilage flora between treated and untreated vacuum-packed fillets.

Thus, the overall effect of dipping fillets and steaks into sodium tripolyphosphate-salt solutions of appropriate concentrations was beneficial.

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MS #1695

EXTENDING THE SHELF LIFE OF FROZEN WHITE BASS (*Roccus chrysops*) THROUGH THE USE OF ASCORBIC ACID DIPS

by

R. A. Greig

ABSTRACT

The effectiveness of ascorbic acid and ascorbic acid plus citric acid in retarding the development of rancidity in white bass fillets during frozen storage was evaluated. Sensory and 2-thiobarbituric acid tests run on both treated and untreated samples showed that ascorbic acid retarded the development of rancidity in the frozen fillets.

INTRODUCTION

Fresh-water white bass (*Roccus chrysops*) are caught primarily in Lake Erie and Lake Ontario; relatively few are present in other Great Lakes and in the Mississippi Drainage System. They are marketed almost exclusively as fresh fish, either as a "pan-ready" (headed and gutted) item or as fillets. Some processors, however, freeze the whole fish and hold them until periods of slack production, at which time they are thawed, processed, and sold on the fresh market.

White bass are not usually marketed as a frozen product, mainly because of its relatively short shelf life when frozen. Commercial processors report that white bass, frozen in-the-round, cannot be held beyond 6 or 8 months at 0° F. because off-flavors develop in the thawed, cooked product. In agreement with the estimates of commercial processors, Lane (1964) found that whole white bass held at 0° F. had a shelf life of from 5 to 9 months, but he did not report the reasons for this limited shelf life. These findings applied to whole white bass only. No information was found concerning the shelf life of other frozen white bass products, such as fillets. Yet, since the surface that is exposed to air in fillets is large relative to the weight of flesh, fillets normally are more susceptible to oxidative rancidity than whole fish are. So, theoretically at least, frozen white bass fillets should have a shorter shelf life than white bass frozen in-the-round.

Greig, Emerson, and Fliehman (1967) reported that ascorbic acid was effective in retarding the development of rancidity in several species of frozen fresh-water fish other than white bass. The purpose of the work reported here therefore was to determine whether chemical pretreatment would be effective in extending the frozen shelf life of white bass fillets. This pretreatment involved the use of ascorbic acid. It also involved the use of ascorbic acid plus citric acid to show whether citric acid would act synergistically and thereby increase the effectiveness of the ascorbic acid.

Author: R. A. Greig, *Chemist*, Bureau of Commercial Fisheries Technological Laboratory, Ann Arbor, Michigan 48103

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I. MATERIALS AND METHODS

A. PREPARATION OF SAMPLES

The white bass fillets used in this study were obtained from a commercial source. The fillets (skin-on) had been cut from white bass that had been caught in a trap net in the central basin of Lake Erie and held on ice for 1 day. They were obtained on the day they were cut from the fish and were randomly divided, on that same day, into three groups. The fillets in the first group were dipped in a 3-percent ascorbic acid solution for 45 seconds; those in the second group were treated in the same manner with a solution containing 3 percent of ascorbic acid plus 1 percent of citric acid. Those in the third group were left untreated. All the fillets were individually quick frozen on a plate freezer, sealed in 3-mil polyethylene bags (3 fillets to a bag), and stored at $-5° \pm 3°$ F.

B. EVALUATION OF SAMPLES

The fillets were examined by means of sensory and chemical tests.

A taste panel composed of six laboratory workers provided the sensory data. The frozen samples were breaded and deep-fat fried for presentation to the taste panel. The taste panel rated the samples on a 5-point scale:

5 — No detectable rancid off-flavors or off-odors.

4 — Barely detectable rancid off-flavors and off-odors.

3 — Slightly rancid off-flavors and off-odors.

2 — Moderately rancid off-flavors and off-odors.

1 — Strongly rancid off-flavors and off-odors.

A score of less than 3 was taken as evidence of objectionable rancidity.

A 2-thiobarbituric acid (TBA) test was used to reveal objectively the development of rancidity in the samples. The procedure of Tarladgis, Watts, Younathan, and Dugan (1960) was used with the following exceptions: (1) 5-gram instead of 10-gram samples were used and (2) the TBA reagent was dissolved in triply distilled water instead of in glacial acetic acid. The size of sample was cut in half because of the excessively high absorbance readings obtained in the later stages of oxidation with the use of 10-gram samples. (This finding is unpublished data obtained on other fresh-water fish.) The different solvent for the TBA reagent was used because of more recent work by Tarladgis, Pearson, and Dugan (1964), which showed that there was less chance of side reactions with the water solvent than with the acetic acid solvent. The results of the TBA test are reported as TBA "values" —the absorbance (at 536 millimicrons) obtained from 5 milliliters of TBA reagent and 5 milliliters of sample distillate.

Ascorbic acid concentrations were determined on the samples used for the TBA test. The procedure (obtained from the Hoffman LaRoche Company, Patterson, New Jersey) was as follows: 10 grams of ground fish was blended for 1 minute in 150 milliliters of 4 percent metaphosphoric acid. The entire contents were transferred quantitatively to a 250-milliliter volumetric flask and diluted to volume with distilled water. This mixture was filtered, and 10-milliliter aliquots of the filtrate were titrated with a solution of 2, 6 dichlorobenzenoneindophenol that had been standardized against pure ascorbic acid dissolved in metaphosphoric acid.

II. RESULTS AND DISCUSSION

Sensory data (Figure 1) indicated that the untreated control product was not objectionably rancid until it had been stored for 7 months; however, several panelists rated certain of these fillets as having rancid off-flavors as early as the 3-month test. Fillets treated with either ascorbic acid or ascorbic acid plus citric acid did not develop rancid off-flavors

throughout the entire 13 months of storage. Samples treated with ascorbic-citric acid, however, had a fairly strong, objectionable lemonlike flavor. Also, a few of the fillets that had been treated with ascorbic acid alone had a moderate lemonlike flavor. These samples, which were in the minority, may have absorbed more acid than the others.

TBA values supported the findings of the taste panel as to the development of rancidity in the various samples. After the fillets had been stored for 3 months, the TBA values in the nontreated samples increased appreciably; TBA values in the chemically treated samples, on the other hand, did not increase appreciably. These data indicate that the development of rancidity in the white bass fillets was effectively retarded by the chemical treatments.

The concentration of ascorbic acid (Table 1) varied considerably between samples, but it remained relatively constant as a function of storage time.

Table 1.—Ascorbic acid concentration in the fillets

Storage time at −5° F.	Concentration of ascorbic acid	
	Sample 1[1]	Sample 2[2]
Months	*Percent*	*Percent*
0	0.30	0.27
1	0.26	0.22
2	0.25	0.27
3	0.28	0.26
4	0.36	0.25
5	--	--
6	--	--
7	0.31	0.29
8	--	--
9	0.34	0.32
10	--	--
11	0.30	0.28
12	0.25	0.26
13	0.25	0.27

[1] Fillets dipped in 3-percent ascorbic acid for 45 seconds prior to being frozen.

[2] Fillets dipped in 3-percent ascorbic acid plus 1-percent citric acid for 45 seconds prior to being frozen.

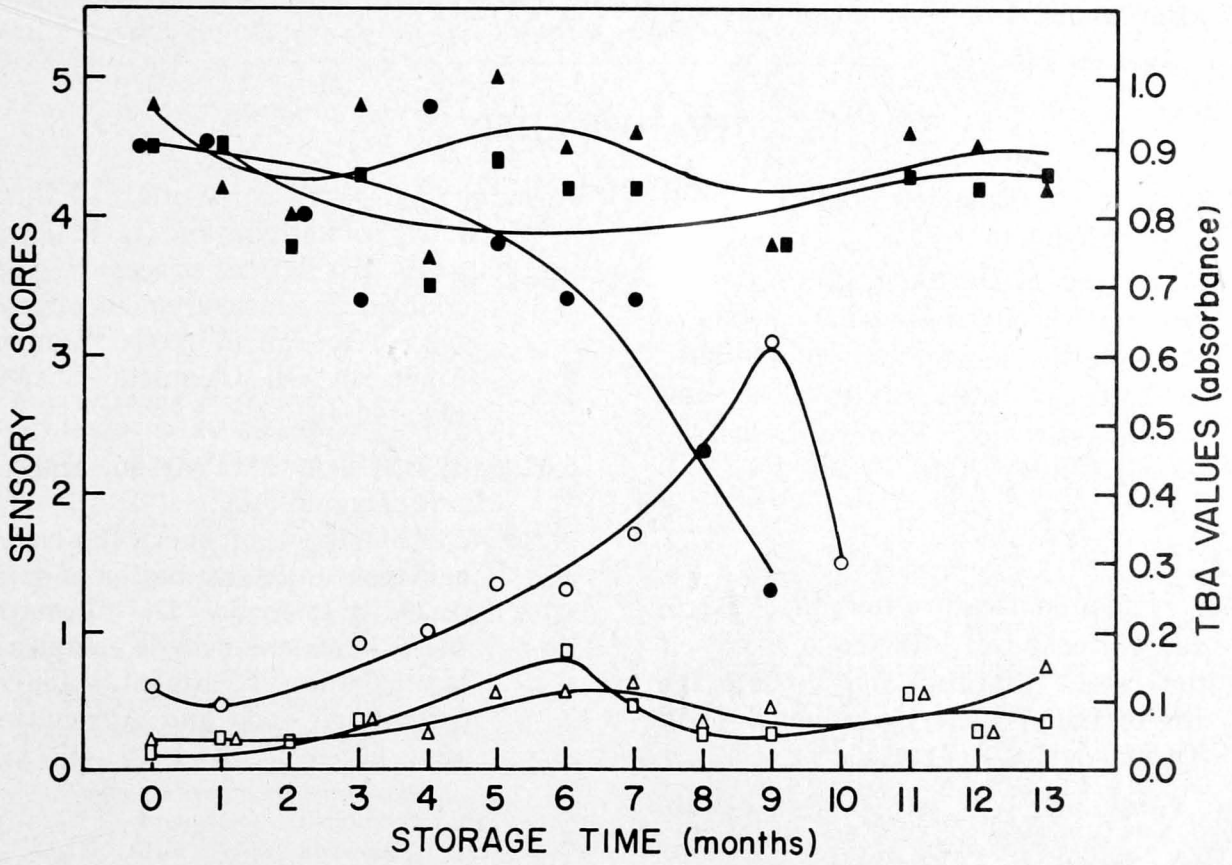

Figure 1.—Results of sensory and TBA tests on white bass fillets held at −5° F.

CONCLUSIONS

Ascorbic acid retards the development of rancidity in stored, frozen, white bass fillets. Fillets treated with a 3-percent solution of ascorbic acid should have about twice the shelf life (at 0° F.) of corresponding nontreated fillets, though some of them may develop a moderate lemonlike flavor. The ascorbic-citric acid combination gave no improvement over the ascorbic acid in retarding the development of rancidity in white bass fillets.

SUMMARY

Chemically treated and untreated white bass fillets were studied throughout 13 months of frozen storage. The treated fillets were dipped in a solution containing either 3-percent ascorbic acid or 3-percent ascorbic acid plus 1-percent citric acid before being frozen and stored. The frozen products were periodically subjected to sensory and TBA tests.

Sensory data showed that untreated white bass fillets developed objectionably rancid off-flavors after about 7 months of storage at −5° F. but that fillets treated with either ascorbic acid or ascorbic-citric acid did not develop rancid off-flavors even after 13 months of storage. In general, the TBA data supported the sensory ratings.

All fillets treated with ascorbic acid plus citric acid and a few fillets treated with ascorbic acid alone had a sour, lemonlike flavor at every stage of testing. Most ascorbic-acid treated fillets, however, developed no off-flavors at all.

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MS #1712

RELATIVE CATCHING EFFICIENCY OF A 70-FOOT SEMIBALLOON SHRIMP TRAWL AND A 94-FOOT EASTERN FISH TRAWL

by

Walter T. Pereyra, Hiromu Heyamoto, and Robert R. Simpson

ABSTRACT

The purpose of the experiment was to equate the relative catching efficiencies of a 94-foot Eastern fish trawl and a 70-foot semiballoon shrimp trawl. With the limitations that were imposed on experimental work by practical considerations, a simple, precise equation relating the catch efficiencies of the two trawls could not be developed. Nevertheless, the work yielded results by which one can make a more objective comparison of shallow- and deep-water trawl data.

CONTENTS

Authors: Walter T. Pereyra and Hiromu Heyamoto, *Fishery Biologists (General)*, Bureau of Commercial Fisheries Exploratory Fishing and Gear Research Base, Seattle, Washington 98102; and Robert R. Simpson, *Assistant Regional Director*, Bureau of Commercial Fisheries Regional Office, Juneau, Alaska 99801.

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INTRODUCTION

The work reported here — comparing the efficiencies of two dissimilar trawls — is an offshoot of a larger, more comprehensive study. This larger study has been in progress since 1961, at which time the Bureau of Commercial Fisheries and the Atomic Energy Commission began a cooperative investigation of the demersal fishes and invertebrates in the area southwest of the mouth of the Columbia River. Among the aims of this long-term joint investigation are to determine how various species of fishes and invertebrates are distributed on the outer Continental Shelf and on the Continental Slope to depths of from 50 to 1,050 fathoms and how the distributions vary by season and year.

In carrying out this work, we would have preferred to sample the entire bathymetric range with a 94-foot, 400-mesh, commercial Eastern otter trawl, since we have used this gear in other demersal surveys. This trawl is normally towed on a double warp (Figure 1). To fish the gear in 1,050 fathoms using the double-warp towing arrangement would call for a vessel equipped with at least 3,600 fathoms of ½-inch cable equally divided on two drums. Herein lay the difficulty: each of the vessels being used to pull the trawl was equipped with a combination winch that contained only 1,000 fathoms of cable on each drum. If the standard double-warp arrangement was used, the cable would be too short relative to the depth fished, and thus sampling would be unreliable. Yet, to adapt the vessels so that they could handle the Eastern otter trawl at the depths to be sampled would be inordinately expensive.

Instead of using the double-warp configuration with the commercial Eastern otter trawl (hereafter called "fish trawl"), we developed a system for towing a bridle-rigged, 70-foot, semiballoon shrimp trawl (hereafter called "shrimp trawl") on a single warp (Figure 2) in an attempt to avoid expensive adaptation of the vessels. In addition to being fished differently, the shrimp trawl had a shorter footrope (70-foot rather than 94-foot) than the fish trawl had, and the wings and body of the net were constructed of smaller meshes (1½-inch rather than 4-inch) than were the wings and body of the fish trawl.

Since two dissimilar gears were used to sample the trackline (94-foot fish trawl at depths less than 500 fathoms and 70-foot

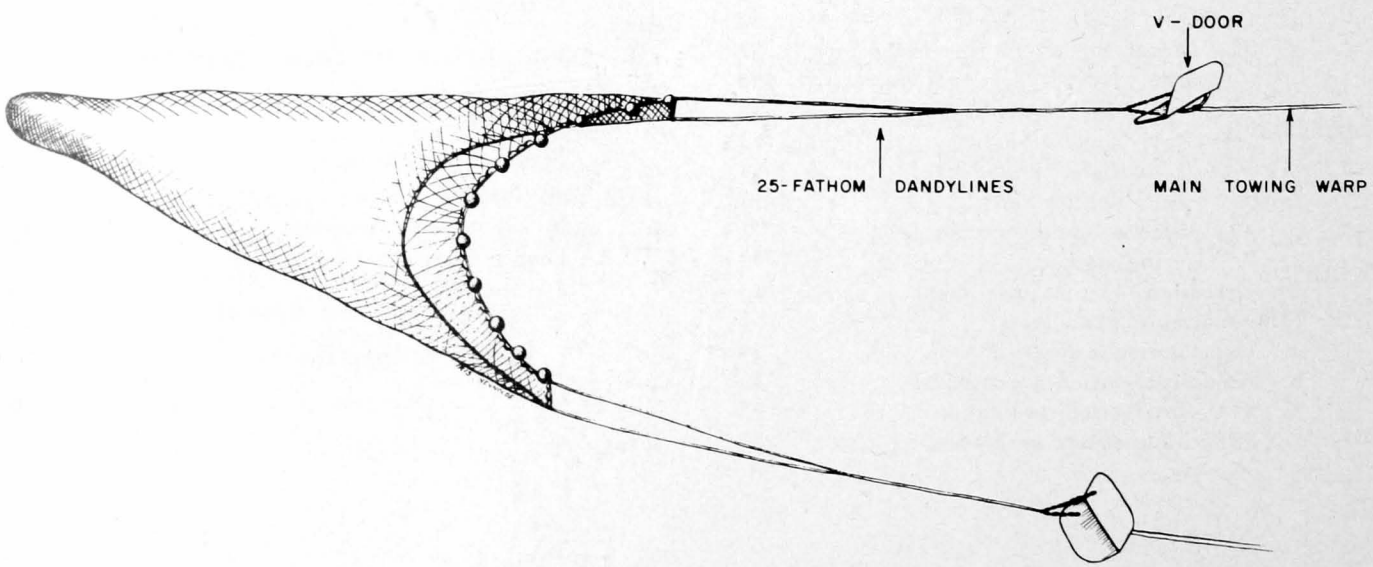

Figure 1.—Double-warp trawling arrangement used with the fish trawl.

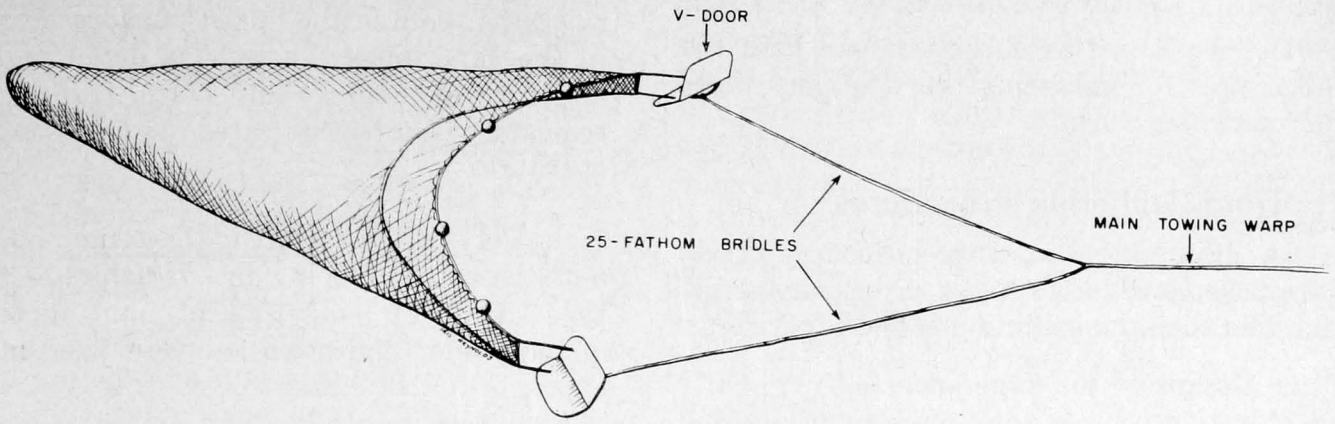

Figure 2.—Single-warp trawling arrangement used with the shrimp trawl.

shrimp trawl at depth equal to 500 fathoms or greater), a meaningful equation relating the catching efficiencies of the two trawls needed to be developed to equate objectively the shrimp-trawl and fish-trawl data. The purpose of this study therefore is to describe the method and results of our attempt to equate these two trawls.

One of the easier methods of obtaining an equation between two trawls would be to fish both trawls at depths where the fish trawl and the shrimp trawl were effective, derive a relation between the catching efficiency of the two, and extrapolate for those depths where the use of the fish trawl was not practicable. Initially, to make such an equation, we had hoped to make a series of paired hauls during which two vessels, each fishing one of the two trawls being compared, would fish in the same place and at the same time but would switch the trawls regularly to avoid bias introduced by the particular vessel used. Since the ultimate aim of the equation is to be able eventually to compare the deep- and shallow-water components of the demersal community realistically, the two-vessel comparisons would have to be made at a number of depths to determine the differences, if any, in the trawl-catch relation with depth. However, since only the *Commando*, a 65-foot purse-seine-type vessel (chartered from the College of Fisheries, University of Washington) was available for the projected study, we had to abandon the two-vessel design.

The best alternative approach to obtaining the data needed to develop the desired equation seemed to be through the use of one vessel to tow both gear types over a short period of time during which no change in population is assumed. With such a scheme, we could account not only for the variations caused by the type of gear but for those caused by tidal currents, diel[1] fluctuations in the availability of different species to capture, changes in the fish and invertebrate populations during the experiment, and differences due to depth.

To understand the relation of the catching efficiency of the two trawls, we also needed, in addition to catch-rate equations, a knowledge of their relative gear selectivities, since catch rate and gear selectivity are closely interrelated. Accordingly, to accomplish our specific purpose, we carried out a factorially designed experiment that allowed us to compare (1) the catch rates of the two trawls and (2) the gear selectivities of the two trawls.

[1] An ecological term derived from the Latin word (dies) for day. It refers to the 24-hour period that usually includes a day and the succeeding night.

I. COMPARISON OF CATCH RATES

A. PROCEDURES

Described in this subsection are both the procedures for gathering the data and those for analyzing them.

1. Data-Gathering Procedures

In discussing our data-gathering procedures, we consider first the experimental design and then the execution of the experiment.

a. Design of the experiment.—To permit an objective comparison of the relative catch rates of the shrimp trawl and the fish trawl, we developed the 2^5 factorial design shown in Figure 3. The design resulted from a consideration both of the "fixed" factors involved in the experiment — such as depth of haul and time of haul — and of the safety and economic factors associated with a trawling operation.

(1) Fixed factors in the design.—From a statistical standpoint, five variables — gear type, depth of haul, time of haul, direction of haul, and replication — were fixed in the experimental design.

(a) *Gear type.*—The fish trawl was similar to the one described by Greenwood

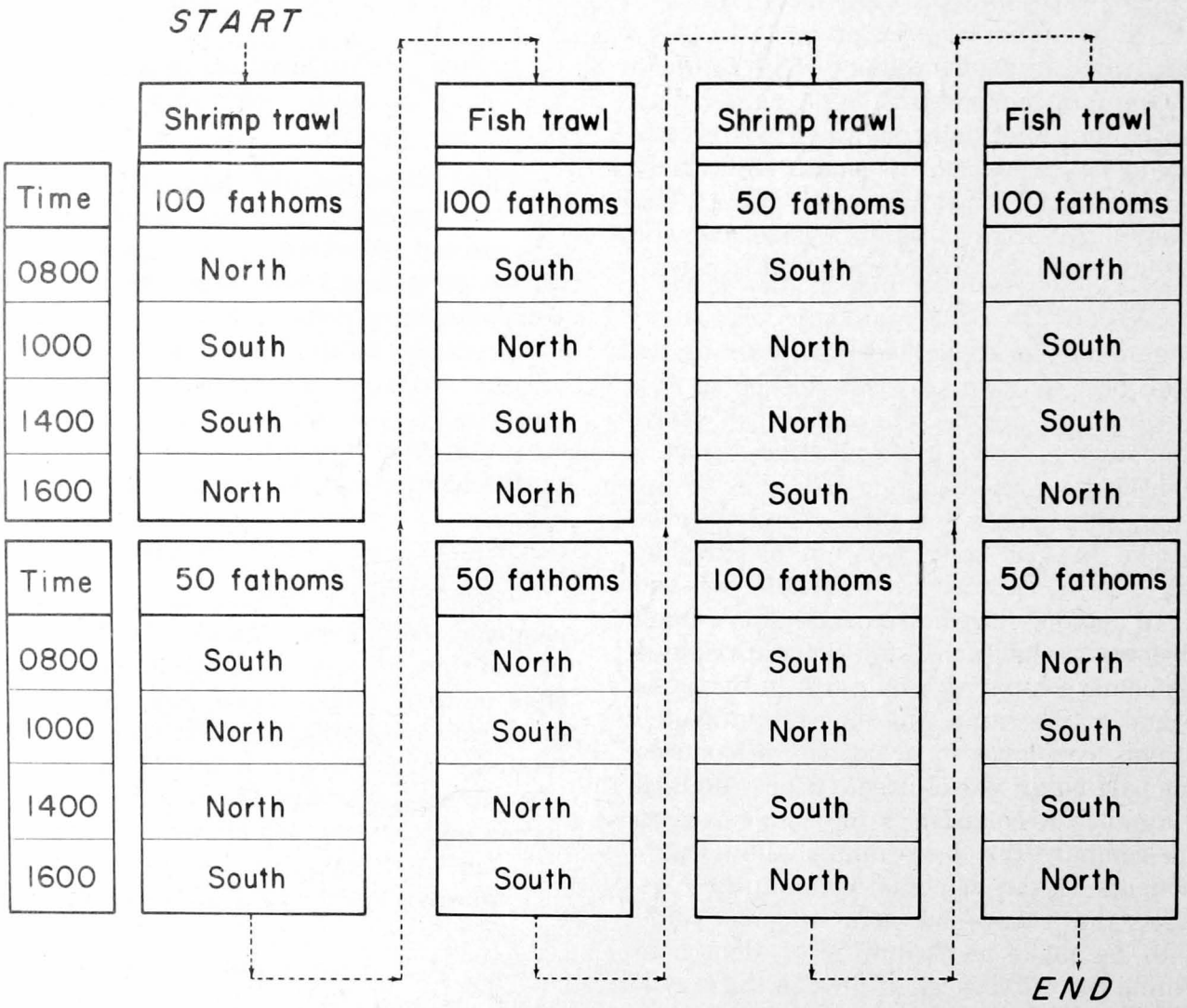

Figure 3.—Design of 2^5 factorial experiment. North and south denote the direction in which the haul was made. Time is the hour (PST) at which the haul was begun.

(1958) except that all webbing was nylon and that 4-inch instead of 4¼-inch mesh was used in the wings, square, and belly of the net. The intermediate section and cod end were constructed of 3½-inch mesh. This trawl had 11 aluminum floats, 8 inches in diameter, equally spaced on the headrope, and a 1½-inch-mesh liner in the cod end. The shrimp trawl (Greenwood, 1959) was constructed of 1½-inch nylon mesh throughout; it had 4 aluminum floats, 8 inches in diameter, equally spaced on the headrope.

(b) *Depth of haul.* — Trawling depths of 50 and 100 fathoms, respectively, were selected for hauls at two fixed stations, one located at Latitude 46°09′ North, Longitude 124°13′ West and the other at Latitude 46°04′ North, Longitude 124°39′ West. Positions were determined by means of loran and echo sounder.

(c) *Time of haul.*—Because some species of fishes move vertically in diel cycles, it is quite possible that early morning or late afternoon hauls might be made at a time when the fishes are not in their daytime habitat. Four hauls were therefore spaced during the day so that this possible effect could be taken into consideration in the analysis.

(d) *Direction of haul.*—Hauls were made in a northerly and southerly direction so that the possible effects of tidal currents on the catch could be evaluated. Although currents in the study area vary daily in both intensity and direction, the net transport of surface water is to the southwest.

(e) *Replication.* — The experiment was repeated once to allow us to determine if any significant changes in population occurred with time at the two sampling stations. Thus, the "replication" is just a repeat of the experiment in a different block of time and not a true replication, since we allow a block difference in addition to random variation.

(2) Safety and economic factors in the design.—For reasons of safety, the gear could not be changed at sea. We therefore felt that we should make at least eight hauls before changing gear so as to minimize the time of running to and from port. Because of these considerations and because we had only enough charter time to make 32 hauls, we decided to make four hauls with each of the two gears at each of the depths and then replicate the experiment. Within each of the four-haul series, there would be one northerly and one southerly haul during the morning (at 0800 and 1000) and one northerly and one southerly haul during the afternoon (at 1400 and 1600). Within the physical limits of the design, the paired sequential arrangement of gear, depth of haul, and direction of haul was decided randomly. This partial randomization resulted in the design shown in Figure 3.

b. Execution of the experiment.—The field work was done between September 5 and September 14, 1964.

We handled the fish trawl in the standard manner now used on West Coast combination vessels equipped with a net reel. We used two ½-inch towing warps; metal, V-type, otter boards measuring 4½ x 6½ feet and weighted to 850 pounds each; and 25-fathom dandylines (Figure 1).

For the reasons discussed earlier, we handled the shrimp trawl differently. We towed it on a single ½-inch cable and used 25-fathom bridles connected to a triangular plate with ball-bearing swivels to prevent the bridles from winding together (Figure 4). We attached the wings of the net directly to the same kind of V-type otter boards that we used with the fish trawl (Figure 2).

The drags were made at a scope ratio of 3:1 (that is, the length of the cable was three times the depth of the trawl) and at a vessel speed of about 2.8 knots. All drags were ½ hour in duration. Trawling time was considered as that time elapsing from the moment the desired amount of cable was out until the moment that the retrieval of the cable was begun.

The fish and invertebrate species in each of the 32 hauls were usually counted and were usually weighed. When large catches were made, the weights of the dominant species were estimated from total counts and average weights.

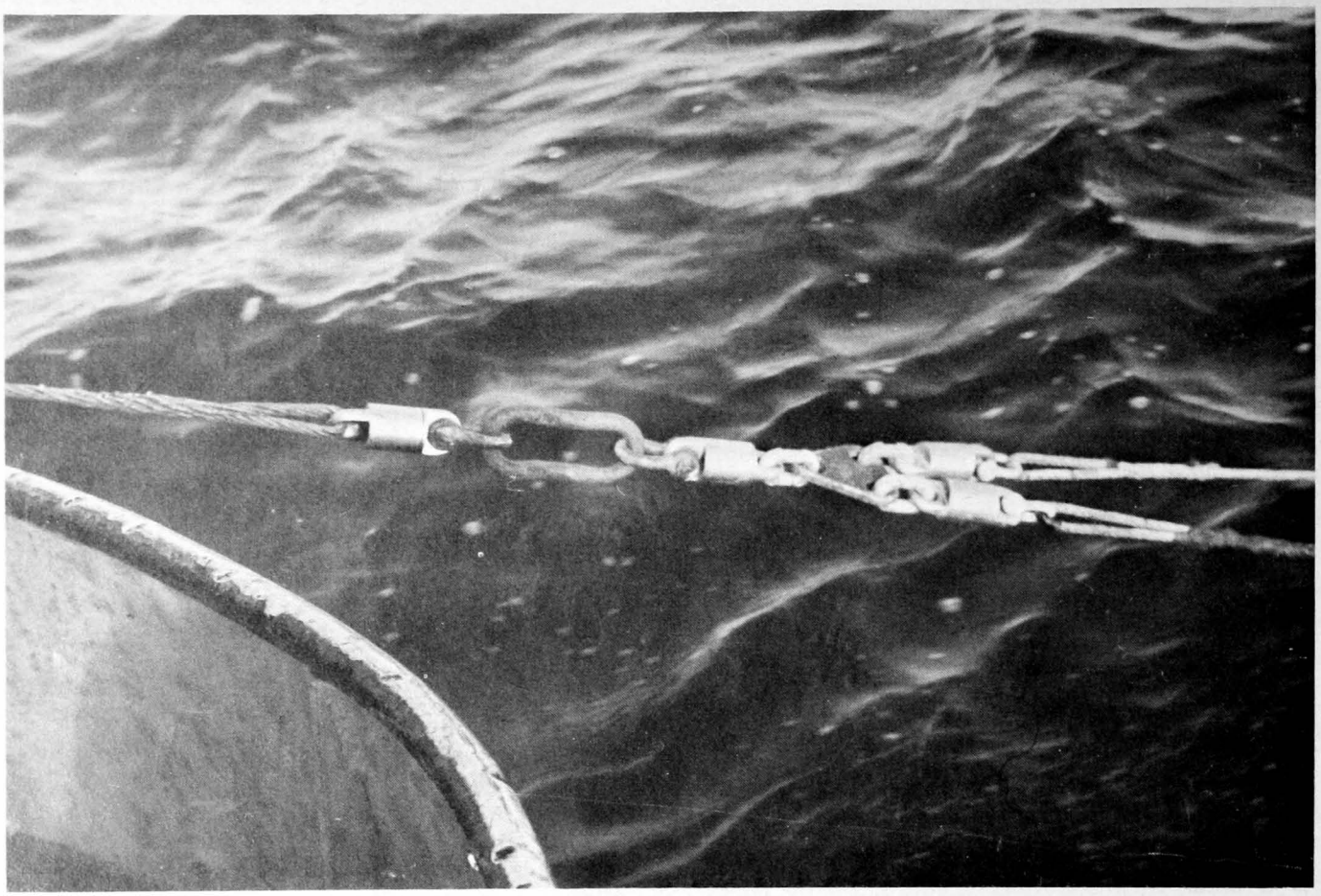

Figure 4.—Arrangement for connecting the towing-warp and the bridles used with the shrimp trawl. This arrangement utilizes a triangular plate and four ball-bearing swivels, three of which are attached to the plate.

2. Data-Analyzing Procedures

The data were tested by analysis-of-variance using the BMD 02V program developed by the Biomedical Department of the University of California at Los Angeles. From an understanding of the significance of the main effects and their interactions, it was then possible to estimate the relative differences in catch rates between the gears by using the ratio of their catch rates.

a. Data normalization.—Moyle and Lound (1960), Roessler (1965), and Taylor (1953) showed that the number of individuals of a species in a series of catches follows a skewed distribution — namely, the negative binomial distribution. Owing to the small number of tows in our study, the type of distribution could not be determined. Nevertheless, we had no reason to suspect the occurrence of a different type, so we assumed the negative binomial distribution in this experiment.

Moyle and Lound, Roessler, and Taylor counted the individuals in the catch; whereas, depending upon the circumstances, we counted and weighed the individuals. The weight should vary proportionately with the count, provided that the size distributions of the species do not vary markedly between catches — that is, provided the same population is always sampled. Since we made replicate tows over a short period of time and in the same area, we felt that any change in population was negligible. Furthermore, inspection of length data for the dominant species from replicate tows did not reveal any noticeable differences in length composition of the catches. Therefore, we assumed the negative biomial distribution for the weights of species in the repetitive hauls and applied the logarithmic

transformation

$$Y = \log (x + 1)$$

to our data to normalize them before testing them by analysis-of-variance.

b. Analysis-of-variance procedures.—The analysis-of-variance was carried out on all the species of fishes and invertebrates that were taken in sufficient numbers to make the results of the analysis meaningful. In addition, we analyzed the following catch categories: total catch, total fishes, cartilaginous fishes, flatfishes, roundfishes (excluding rockfishes),[2] rockfishes, and total invertebrates.

(1) Interaction evaluation.—An overall error term to test the first-order interactions was calculated by adding the sums of squares of all interaction terms greater than the first order to the sums of squares of the residual error term. First-order interactions were tested at the 25-percent level of probability with 1 and 16 degrees of freedom.

(2) Main-effects evaluation.—The five main effects of gear type, depth of haul, time of haul, direction of haul, and replication were tested for significance at the 5-percent and 1-percent levels of probability. To get the overall error term with which to test these main effects, we added all nonsignificant interactions within a category to the preceding error term (residual).

c. Procedure used to calculate the ratio estimators. — The ratio between the catch rate of the fish trawl and that of the shrimp trawl was used as a measure of the difference in catch rates between the two trawls. Because ratios of this type were to be used in equating untransformed catch data, all calculations of ratios were based on untransformed data.

Both the arithmetic-mean (parametric) and the median (nonparametric) methods of evaluating the ratios were used. The arithmetic-mean approach involved calculating the mean of both the numerator and the denominator and getting the ratio of the two calculated means. The median approach involved arranging both the numerator and the denominator in ascending order, taking the central value in the numerator and the central value in the denominator, and calculating the ratio of these medians. When two central terms occurred, the mean of the two was used as the median. The median method was included because of (1) the assumed negative binomial distribution, (2) the small sample size, and (3) the wide variation in the catches. Under these conditions, the median is generally more descriptive of average conditions than is the mean and has a narrower range of error associated with it (Moyle and Lound, 1960).

Originally, we had hoped that an overall ratio estimator — with its corresponding confidence interval — of the average catch rate of the fish trawl to that of the shrimp trawl could be calculated for all the dominant species and major categories of the catch. This estimation then would be a good measure of the catching-efficiency relations between the two trawls; but, because the percentage of trawl-replication and trawl-depth interactions was high (as will be shown), this approach was not feasible. So, instead of using this approach, we divided the 32 hauls into 4 sets of 8 hauls each, taking into consideration the 2 replications and 2 depths. Thus each replication-depth combination had a discrete set of eight hauls — four with the fish trawl and four with the shrimp trawl.

B. RESULTS AND DISCUSSION

1. Results

The 32 drags caught almost 50,000 pounds (Tables 1A, 1B, 1C, and 2). The catch taken by the fish trawl was considerably more than that taken by the shrimp trawl. Fish accounted for more than 95 percent of the overall weight in the combined catch of both gears at both depths (Table 3).

The rates of catch differed considerably between gears. They also differed considerably within each gear among the crossed factors of depth, time of day, direction, and replication (Tables 1-3). The analyses of var-

[2] Even though the rockfishes constitute a subgrouping of the roundfishes, they are analyzed and discussed separately, owing to their individual distinctness as a group. Therefore, whenever the term "roundfishes" is used, we are referring to the roundfishes exclusive of the rockfishes.

Table 1A.—Catches made with fish and

Categories and species	Catch with fish trawl								
	Drag 13 9/9/64 P.M. North	Drag 14 9/9/64 A.M. South	Drag 15 9/9/64 P.M. North	Drag 16 9/9/64 P.M. South	Drag 29 9/14/64 A.M. North	Drag 30 9/14/64 A.M. South	Drag 31 9/14/64 P.M. South	Drag 32 9/14/64 P.M. North	Total catch
FISHES	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Cartilaginous fishes:									
Polistotrema spp.	--	--	--	--	--	--	--	--	--
Squalus acanthias	--	--	--	--	3.0	--	--	--	3.0
Raja kincaidii	0.2	5.0	10.0	5.0	3.0	7.0	12.0	25.0	67.2
Raja rhina	30.0	40.0	85.0	10.0	5.0	50.0	60.0	100.0	380.0
Total	30.2	45.0	95.0	15.0	11.0	57.0	72.0	125.0	450.2
Flatfishes:									
Citharichthys sordidus	--	--	3.0	0.2	--	--	--	--	3.2
Atheresthes stomias	150.0	--	50.0	100.0	200.0	300.0	300.0	400.0	1,500.0
Eopsetta jordani	--	20.0	--	5.0	6.0	10.0	10.0	65.0	116.0
Glyptocephalus zachirus	150.0	125.0	500.0	200.0	100.0	100.0	250.0	300.0	1,725.0
Lyopsetta exilis	20.0	15.0	--	5.0	50.0	20.0	5.0	50.0	165.0
Microstomus pacificus	150.0	200.0	2,100.0	135.0	400.0	300.0	450.0	600.0	4,335.0
Parophrys vetulus	10.0	20.0	50.0	8.0	2.0	1.0	2.0	20.0	113.0
Total	480.0	380.0	2,703.0	453.2	758.0	731.0	1,017.0	1,435.0	7,957.2
Roundfishes:									
Engraulis mordax	--	--	--	--	--	--	--	--	--
Hypomesus pretiosus	--	--	--	--	--	--	--	--	--
Thaleichthys pacificus	--	--	--	--	--	--	--	--	--
Merluccius productus	2,000.0	3,000.0	4,000.0	2,990.0	4,000.0	4,500.0	2,000.0	450.0	22,940.0
Anoplopoma fimbria	1,600.0	120.0	600.0	85.0	400.0	1,500.0	1,000.0	1,500.0	6,805.0
Ophiodon elongatus	--	--	--	--	2.0	--	--	--	2.0
Radulinus asprellus	--	--	--	--	--	--	--	--	--
Agonid, unidentified	--	--	--	--	--	--	--	--	--
Anarrhichthys ocellatus	--	--	--	--	--	5.0	--	--	5.0
Delolepis gigantea	--	--	--	--	--	--	--	--	--
Lyconectes aleutensis	--	--	--	--	--	--	--	--	--
Lycodopsis pacifica	0.2	1.0	--	--	1.0	1.0	1.0	1.0	5.2
Total	3,600.2	3,121.0	4,600.0	3,075.0	4,403.0	6,006.0	3,001.0	1,951.0	29,757.2
Rockfishes:									
Sebastodes elongatus	--	1.0	--	--	--	--	--	--	1.0
Sebastodes entomelas	2.0	2.0	2.0	--	--	0.2	--	--	6.2
Sebastodes flavidus	--	--	3.0	--	4.0	6.0	--	--	13.0
Sebastodes paucispinis	--	--	--	--	8.0	--	--	--	8.0
Sebastodes pinniger	10.0	10.0	3.0	--	--	--	--	--	23.0
Sebastodes sp.	--	--	--	--	--	--	--	--	--
Total	12.0	13.0	8.0	--	12.0	6.2	--	--	51.2
Total fishes	4,122.4	3,559.0	7,406.0	3,543.2	5,184.0	6,800.2	4,090.0	3,511.0	38,215.8
INVERTEBRATES									
Sea pens, unidentified	0.2	--	0.2	1.0	0.2	0.2	0.2	0.2	2.2
Metridium fimbriatum	10.0	2.0	0.2	4.0	--	0.2	5.0	1.0	22.4
Other anemones	0.2	--	--	--	--	--	--	--	0.2
Pandalus jordani	10.0	0.2	0.2	10.0	2.0	0.2	0.2	0.2	23.0
Pandalus platyceros	0.2	--	--	--	--	--	--	--	0.2
Hippolytid shrimp	--	--	--	--	--	--	--	--	--
Cragonid shrimp	--	--	--	--	--	--	--	--	--
Cancer magister	50.0	80.0	75.0	13.0	15.0	40.0	60.0	80.0	413.0
Polinices pallidus	--	--	--	--	--	--	--	--	--
Colus halidonus	--	--	--	--	--	--	--	--	--
Patinopecten caurinus	1.0	2.0	4.0	2.0	0.2	1.0	12.0	1.0	23.2
Octopus sp.	--	--	--	--	0.2	0.2	--	--	0.4
Rossia pacifica	--	--	--	--	0.2	0.2	--	--	0.4
Pyconopodia helianthoides	--	--	--	--	--	--	--	--	--
Pseudarcharster parelii	--	--	--	--	--	--	--	--	--
Luidia foliata	1.0	2.0	2.0	1.0	0.2	1.0	1.0	1.0	9.2
Dermasterias imbricata	1.0	--	--	--	--	--	--	--	1.0
Brisaster townsendi	--	--	--	--	--	--	--	--	--
Gorgonecephalus caryi	0.2	0.2	0.2	--	--	--	--	--	0.6
Asteronyx sp.	--	--	--	--	--	--	0.2	--	0.2
Ophiura sp.	--	--	--	0.2	--	--	--	--	0.2
Nemertine worm	--	--	--	--	--	--	--	--	--
Echiuroid worm	--	--	--	--	--	--	--	--	--
Total invertebrates	73.8	86.4	81.8	31.2	18.0	43.0	78.6	83.4	496.2
TOTAL CATCH	4,196.2	3,645.4	7,487.8	3,574.4	5,202.0	6,843.2	4,168.6	3,594.4	38,712.0

shrimp trawls at 50 fathoms, September 1964

Categories and species	Catch with shrimp trawl								
	Drag 5 9/6/64 P.M. South	Drag 6 9/6/64 P.M. North	Drag 7 9/7/64 A.M. North	Drag 8 9/7/64 A.M. South	Drag 17 9/10/64 A.M. South	Drag 18 9/10/64 A.M. North	Drag 19 9/10/64 P.M. North	Drag 20 9/10/64 P.M. South	Total catch
FISHES	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Cartilaginous fishes:									
Polistotrema spp.	2.0	5.0	2.0	2.0	2.0	2.0	3.0	3.0	21.0
Squalus acanthias	--	--	--	--	--	--	--	--	--
Raja kincaidii	--	--	--	--	--	--	--	--	--
Raja rhina	--	--	--	--	--	1.0	2.0	--	3.0
Total	2.0	5.0	2.0	2.0	2.0	3.0	5.0	3.0	24.0
Flatfishes:									
Citharichthys sordidus	--	--	--	--	--	--	--	--	--
Atheresthes stomias	10.0	--	10.0	15.0	5.0	2.0	2.0	10.0	54.0
Eopsetta jordani	--	--	--	--	0.2	--	--	--	0.2
Glyptocephalus zachirus	0.2	0.2	2.0	5.0	1.0	0.2	1.0	1.0	10.6
Lyopsetta exilis	0.2	0.2	--	0.2	0.2	0.2	--	--	1.0
Microstomus pacificus	--	0.2	1.0	3.0	--	1.0	--	--	5.2
Parophrys vetulus	--	2.0	1.0	1.0	--	--	--	--	4.0
Total	10.4	2.6	14.0	24.2	6.4	3.4	3.0	11.0	75.0
Roundfishes:									
Engraulis mordax	--	--	0.2	--	--	--	--	--	0.2
Hypomesus pretiosus	1.0	1.0	0.2	0.2	0.2	1.0	0.2	0.2	4.0
Thaleichthys pacificus	--	--	--	--	0.2	--	--	--	0.2
Merluccius productus	100.0	100.0	50.0	50.0	100.0	165.0	200.0	200.0	965.0
Anoplopoma fimbria	--	--	2.0	--	30.0	2.0	50.0	100.0	184.0
Ophiodon elongatus	--	--	--	--	--	--	--	--	--
Radulinus asprellus	0.2	0.2	--	0.2	--	--	--	--	0.6
Agonid, unidentified	--	--	--	--	0.2	--	--	--	0.2
Anarrhichthys ocellatus	--	--	--	--	--	--	--	--	--
Delolepsis gigantea	--	--	0.2	--	--	--	--	--	0.2
Lyconectes aleutensis	--	0.2	--	--	0.2	--	--	--	0.6
Lycodopsis pacifica	0.2	--	--	--	0.2	0.2	--	--	0.6
Total	101.4	101.4	52.6	50.4	131.0	168.2	250.2	300.2	1,155.4
Rockfishes:									
Sebastodes elongatus	--	--	--	--	--	--	--	--	--
Sebastodes entomelas	--	--	--	--	--	--	--	--	--
Sebastodes flavidus	--	0.5	--	--	--	--	3.0	--	8.0
Sebastodes paucispinis	--	--	--	--	--	--	--	--	--
Sebastodes pinniger	--	--	6.0	--	--	--	--	--	6.0
Sebastodes sp.	--	--	0.2	0.2	--	--	--	--	0.4
Total	--	5.0	6.2	0.2	--	--	3.0	--	14.4
Total fishes	113.8	114.0	74.8	76.8	139.4	174.6	261.2	314.2	1.268.8
INVERTEBRATES									
Sea pens, unidentified	0.2	--	0.2	0.2	0.2	--	--	0.2	1.0
Metridium fimbriatum	0.2	--	1.0	1.0	1.0	1.0	1.0	1.0	6.2
Other anemones	--	0.2	1.0	--	1.0	2.0	--	2.0	6.2
Pandalus jordani	50.0	50.0	60.0	90.0	30.0	10.0	15.0	20.0	325.0
Pandalus platyceros	--	--	--	--	--	--	--	--	--
Hippolytid shrimp	--	--	--	0.2	--	--	--	--	0.2
Cragonid shrimp	--	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.4
Cancer magister	1.0	--	1.0	2.0	3.0	--	--	1.0	8.0
Polinices pallidus	--	--	--	0.2	--	--	--	0.2	0.4
Colus halidonus	0.2	--	0.2	--	--	--	--	--	0.4
Patinopecten caurinus	1.0	--	--	0.2	0.2	--	--	--	1.4
Octopus sp.	--	--	0.2	0.2	--	0.2	--	--	0.6
Rossia pacifica	0.2	--	0.2	0.2	--	--	--	--	0.6
Pycnopodia helianthoides	--	2.0	--	--	--	--	--	--	2.0
Pseudarcharster parelii	0.2	--	--	--	--	--	--	--	0.2
Luidia foliata	1.0	3.0	1.0	0.2	1.0	1.0	1.0	2.0	10.2
Dermasterias imbricata	--	--	--	--	--	--	--	--	--
Brisaster townsendi	0.2	0.2	0.2	1.0	0.2	0.2	0.2	0.2	2.4
Gorgonecephalus caryi	--	--	--	--	--	--	--	--	--
Asteronyx sp.	--	--	--	--	--	--	--	--	--
Ophiura sp.	--	--	0.2	0.2	0.2	--	--	--	0.6
Nemertine worm	--	--	0.2	--	--	--	--	--	0.2
Echiuroid worm	--	--	0.2	--	--	--	--	--	0.2
Total invertebrates	54.2	55.6	65.8	95.8	37.0	14.6	17.4	26.8	367.2
TOTAL CATCH	168.0	169.6	140.6	172.6	176.4	189.2	278.6	341.0	1,636.0

Table 1B.—Catches made with fish and

Categories and species	Catch with fish trawl								
	Drag 9 9/8/64 A.M. South	Drag 10 9/8/64 A.M. North	Drag 11 9/8/64 P.M. South	Drag 12 9/8/64 P.M. North	Drag 25 9/13/64 A.M. North	Drag 26 9/13/64 A.M. South	Drag 27 9/13/64 P.M. South	Drag 28 9/13/64 P.M. North	Total catch
FISHES	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Cartilaginous fishes:									
Polistotrema spp.	--	--	--	--	0.2	--	--	--	0.2
Squalus acanthias	5.0	--	10.0	2.0	3.0	3.0	8.0	15.0	46.0
Raja kincaidii	3.0	--	5.0	5.0	8.0	70.0	3.0	10.0	104.0
Raja rhina	10.0	--	30.0	75.0	65.0	20.0	30.0	350.0	580.0
Hydrolagus colliei	--	3.0	3.0	5.0	--	10.0	4.0	3.0	28.0
Total	18.0	3.0	48.0	87.0	76.2	103.0	45.0	378.0	758.2
Flatfishes:									
Citharichthys sordidus	--	--	--	--	--	--	0.2	--	0.2
Atheresthes stomias	50.0	25.0	75.0	85.0	100.0	75.0	35.0	75.0	520.0
Eopsetta jordani	--	--	--	--	0.2	5.0	0.2	0.2	5.6
Glyptocephalus zachirus	50.0	10.0	500.0	40.0	400.0	15.0	125.0	300.0	1,440.0
Lyopsetta exilis	20.0	7.0	75.0	20.0	40.0	5.0	15.0	50.0	232.0
Microstomus pacificus	450.0	50.0	300.0	130.0	300.0	300.0	300.0	400.0	2,230.0
Total	570.0	92.0	950.0	275.0	840.2	400.0	475.4	825.2	4,427.8
Roundfishes:									
Thaleichthys pacificus	0.2	--	--	--	0.2	0.2	--	--	0.6
Gadus macrocephalus	15.0	--	--	--	5.0	--	3.0	2.0	25.0
Merluccius productus	20.0	60.0	85.0	--	1.0	10.0	2.0	--	178.0
Anoplopoma fimbria	50.0	3.0	50.0	7.0	80.0	50.0	35.0	65.0	340.0
Ophiodon elongatus	10.0	--	15.0	--	5.0	--	--	--	30.0
Cottod, unidentified	--	--	--	--	--	0.2	--	--	0.2
Radulinus asprellus	--	--	--	0.2	--	--	--	--	0.2
Agonid, unidentified	--	--	--	--	--	1.0	0.2	0.2	1.4
Xeneretmus latifrons	0.2	0.2	0.2	1.0	--	--	--	--	1.6
Aprodon cortezianus	--	--	--	--	--	--	--	--	--
Bothrocara sp.	--	--	--	--	--	2.0	--	--	2.0
Lycodopsis pacifica	0.2	1.0	2.0	1.0	2.0	1.0	2.0	2.0	11.2
Brosmophycis marginata	--	--	--	--	--	--	--	--	--
Total	95.6	64.2	152.2	9.2	93.2	64.4	42.2	69.2	590.2
Rockfishes:									
Sebastodes alutas	20.0	150.0	100.0	150.0	25.0	150.0	300.0	175.0	1,070.0
Sebastodes brevispinis	--	--	--	35.0	--	--	--	--	35.0
Sebastodes crameri	--	2.0	2.0	15.0	1.0	200.0	1.0	1.0	222.0
Sebastodes diploproa	--	0.2	--	--	--	--	--	--	0.2
Sebastodes elongatus	20.0	4.0	8.0	50.0	18.0	10.0	25.0	2.0	137.0
Sebastodes entomelas	--	--	--	--	--	--	--	--	--
Sebastodes flavidus	3.0	--	--	--	--	--	--	--	3.0
Sebastodes helvomaculutus	1.0	--	--	5.0	--	1.0	--	--	7.0
Sebastodes paucispinis	--	--	--	100.0	--	--	7.0	--	107.0
Sebastodes pinniger	5.0	--	--	3.0	--	--	--	3.0	11.0
Sebastodes proriger	10.0	--	--	--	--	--	--	0.2	10.2
Sebastodes ruberrimus	--	--	--	3.0	--	--	--	--	3.0
Sebastodes rubrivinctus	--	--	--	5.0	7.0	0.2	--	--	12.2
Sebastodes saxicola	60.0	40.0	50.0	10.0	15.0	3.0	75.0	40.0	293.0
Sebastodes zacentrus	25.0	0.2	--	75.0	--	1.0	--	--	101.0
Sebastodes sp.	--	--	--	--	--	--	--	--	--
Sebastolobus alascanus	5.0	5.0	5.0	15.0	35.0	25.0	7.0	35.0	132.0
Total	149.0	201.4	165.0	466.0	101.0	390.2	415.0	256.2	2,143.8
Total fishes	832.6	360.6	1,315.2	837.2	1,110.6	957.6	977.6	1,528.6	7,920.0
INVERTEBRATES									
Sea pens, unidentified	0.2	0.2	0.2	0.4	0.2	1.0	0.4	0.2	2.8
Metridium fimbriatum	--	--	--	--	1.0	1.0	--	--	2.0
Aphroditid worm	--	--	--	--	0.2	--	--	--	0.2
Travisia sp.	--	--	--	--	--	--	--	--	--
Bristle worm	--	--	--	--	--	--	--	--	--
Pandalus jordani	0.2	0.2	5.0	2.0	10.0	10.0	5.0	5.0	37.4
Eualus macropthalma	--	--	--	--	--	--	--	--	--
Cragonid shrimp	--	--	--	--	--	--	--	--	--
Chorilia longipes	--	--	--	--	--	0.2	--	--	0.2
Pagurus sp.	0.2	--	--	--	0.2	--	0.2	--	0.6
Lopholithodes foraminatus	--	--	--	--	--	--	--	--	--
Natica clausa	--	--	--	0.2	--	--	--	--	0.2
Colus halidonus	0.2	0.2	0.2	0.2	--	--	--	--	0.8
Antiplanes perversa	--	--	--	0.2	--	--	--	--	0.2
Fusitriton oregonensis	--	--	--	--	--	--	--	--	--
Pelecypod, unidentified	--	--	--	--	--	--	--	--	--
Solemya, agassizi	--	--	--	--	--	--	--	--	--
Octopus sp.	0.2	--	--	--	0.2	0.2	--	--	0.6
Rossia pacifica	0.2	--	0.2	0.2	0.2	0.2	--	--	1.0
Starfish, unidentified	--	--	--	--	--	--	--	--	--
Rathbunaster californicus	--	3.0	1.0	2.0	4.0	3.0	3.0	4.0	20.0
Stylasterias forreri	--	--	--	0.2	--	0.2	0.2	--	0.6
Poraniopsis inflata	--	--	--	--	--	--	--	--	--
Pseudarchaster parelii	0.2	0.2	0.2	1.0	0.2	0.2	0.2	0.2	2.4
Luidia foliata	0.2	--	0.2	1.0	2.0	1.0	0.2	0.2	4.8
Henricia sp.	--	--	--	--	--	--	--	--	--
Pteraster tesselatus arcuatus	--	--	--	--	--	--	--	--	--
Allocentrotus fragilis	20.0	1.0	200.0	10.0	200.0	0.2	1.0	150.0	582.0
Brisaster townsendi	5.0	--	--	0.2	5.0	--	--	5.0	15.2
Asteronyx sp.	--	0.2	--	--	--	--	--	--	0.2

shrimp trawls at 100 fathoms, September 1964

Categories and species	Catch with shrimp trawl								
	Drag 1 9/5/65 P.M. North	Drag 2 9/5/65 P.M. South	Drag 3 9/6/64 A.M. South	Drag 4 9/6/64 A.M. North	Drag 21 9/11/64 A.M. South	Drag 22 9/11/64 A.M. North	Drag 23 9/11/64 P.M. South	Drag 24 9/11/64 P.M. North	Total catch
FISHES	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Cartilaginous fishes:									
Polistotrema spp.	0.2	--	--	--	--	--	--	1.0	1.2
Squalus acanthias	--	--	--	--	1.0	--	--	--	1.0
Raja kincaidii	3.0	2.0	--	--	--	1.0	--	--	1.0
Raja rhina	--	--	--	--	3.0	--	--	--	3.0
Hydrolagus colliei	--	--	--	--	0.2	--	--	--	0.2
Total	3.2	2.0	--	--	4.2	1.0	--	1.0	11.4
Flatfishes:									
Citharichthys sordidus	--	--	--	--	--	--	--	--	--
Atheresthes stomias	1.0	--	1.0	2.0	3.0	10.0	5.0	2.0	24.0
Eopsetta jordani	--	--	--	--	--	--	--	--	--
Glyptocephalus zachirus	5.0	5.0	1.0	10.0	--	0.2	--	2.0	23.2
Lyopsetta exilis	1.0	5.0	1.0	5.0	0.2	0.2	0.2	1.0	13.6
Microstomus pacificus	10.0	25.0	--	10.0	0.2	--	1.0	4.0	50.2
Total	17.0	35.0	3.0	27.0	3.4	10.4	6.2	9.0	111.0
Roundfishes:									
Thaleichthys pacificus	0.2	0.2	1.0	10.0	8.0	4.0	0.2	--	23.6
Gadus macrocephalus	--	--	--	--	--	--	--	--	--
Merluccius productus	3.0	5.0	6.0	5.0	2.0	2.0	5.0	--	28.0
Anoplopoma fimbria	--	2.0	--	--	10.0	15.0	8.0	2.0	37.0
Ophiodon elongatus	--	--	--	--	--	--	--	--	--
Cottid, unidentified	--	--	--	--	--	--	--	--	--
Radulinus asprellas	--	0.2	--	0.2	--	--	--	--	0.4
Agonid, unidentified	--	0.2	0.2	--	0.2	--	--	0.2	0.8
Xeneretmus latifrons	1.0	0.2	0.2	0.2	--	--	--	--	1.6
Aprodon cortezianus	0.2	--	--	--	--	--	--	--	0.2
Bothrocara sp.	--	--	--	--	--	--	--	--	--
Lycodopsis pacifica	0.2	0.2	0.2	0.2	--	--	--	0.2	1.0
Brosmophycis marginata	--	--	--	0.2	--	--	--	--	0.2
Total	4.6	8.0	7.6	15.8	20.2	21.0	13.2	2.4	92.8
Rockfishes:									
Sebastodes alutus	50.0	5.0	10.0	25.0	20.0	15.0	5.0	20.0	150.0
Sebastodes brevispinis	--	--	--	--	--	--	--	--	--
Sebastodes crameri	5.0	1.0	--	5.0	2.0	5.0	15.0	0.2	33.2
Sebastodes diploproa	--	--	--	--	--	--	0.2	--	0.2
Sebastodes elongatus	--	--	--	--	--	--	2.0	--	2.0
Sebastodes entomelas	--	--	10.0	--	--	2.0	--	--	12.0
Sebastodes flavidus	--	--	3.0	--	--	--	--	--	3.0
Sebastodes helvomaculatus	--	--	--	--	0.2	--	--	--	0.2
Sebastodes paucispinis	--	--	--	--	--	--	--	--	--
Sebastodes pinniger	--	--	--	--	--	--	--	--	--
Sebastodes proriger	--	--	--	--	--	--	--	--	--
Sebastodes ruberrimus	--	--	--	--	--	--	--	--	--
Sebastodes rubrivinctus	--	--	--	--	--	--	--	--	--
Sebastodes saxicola	--	3.0	10.0	20.0	2.0	10.0	1.0	3.0	49.0
Sebastodes zacentrus	--	--	--	--	3.0	5.0	5.0	1.0	14.0
Sebastodes sp.	1.0	0.2	--	--	0.2	--	0.2	0.2	1.8
Sebastolobus alascanus	--	10.0	--	--	--	0.2	--	1.0	11.2
Total	56.0	19.2	33.0	50.0	27.4	37.2	28.4	25.4	276.6
Total fishes	80.8	64.2	43.6	92.8	55.2	69.6	47.8	37.8	491.8
INVERTEBRATES									
Sea pens, unidentified	0.2	--	0.2	0.2	0.2	--	--	0.2	1.0
Metridium fimbriatum	--	--	--	--	--	--	--	--	--
Aphrotitid worm	1.0	1.0	0.2	0.2	0.2	1.0	1.0	0.2	4.8
Travisia sp.	--	--	--	--	--	--	0.2	--	0.2
Bristle worm	--	--	--	--	--	0.2	--	0.2	0.4
Pandalus jordani	30.0	15.0	5.0	0.2	10.0	20.0	10.0	3.0	93.2
Eualus macropthalma	--	--	--	--	0.2	--	--	0.2	0.4
Cragonid shrimp	--	--	--	--	--	--	0.2	--	0.2
Chorilia longipes	--	--	--	--	--	--	--	--	--
Pagurus sp.	--	--	--	0.2	0.2	--	0.2	--	0.6
Lopholithodes foraminatus	--	--	--	1.0	--	--	--	--	1.0
Natica clausa	0.2	--	--	--	--	--	--	--	0.2
Colus halidonus	0.2	1.0	0.2	0.2	0.2	0.2	0.2	0.2	2.4
Antiplanes perversa	0.2	0.2	--	--	--	0.2	--	--	0.6
Fusitriton oregonensis	--	--	--	0.2	0.2	--	--	--	0.4
Pelecypod, unidentified	--	--	0.2	--	--	--	--	--	0.2
Solemya agassizi	--	--	--	0.2	--	--	--	--	0.2
Octopus sp.	0.2	--	--	0.2	--	--	0.2	0.2	0.8
Rossia pacifica	0.2	0.2	0.2	--	0.2	0.2	0.2	0.2	1.4
Starfish, unidentified	--	--	0.2	--	--	--	--	--	0.2
Rathbunaster californicus	1.0	0.2	0.2	1.0	2.0	2.0	3.0	2.0	11.4
Stylasterias forneri	--	--	--	0.2	0.2	--	--	--	0.4
Poraniopsis inflata	--	--	--	--	--	0.2	0.2	--	0.4
Pseudarchaster parelii	0.2	0.2	0.2	0.2	0.2	0.2	0.2	--	1.4
Luidia foliata	--	1.0	1.0	0.2	0.2	--	--	--	2.4
Henricia sp.	--	--	0.2	--	--	--	--	--	0.2
Pteraster tesselatus arcuatus	--	--	--	--	0.2	--	--	--	0.2
Allocentrotus fragilis	1.0	15.0	3.0	120.0	1.0	--	1.0	15.0	156.0
Brisaster townsendi	3.0	15.0	6.0	45.0	15.0	--	15.0	10.0	109.0
Asteronyx sp.	--	--	--	--	--	--	--	--	--

Categories and species	Catch with fish trawl								
	Drag 9 9/8/64 A.M. South	Drag 10 9/8/64 A.M. North	Drag 11 9/8/64 P.M. South	Drag 12 9/8/64 P.M. North	Drag 25 9/13/64 A.M. North	Drag 26 9/13/64 A.M. South	Drag 27 9/13/64 P.M. South	Drag 28 9/13/64 P.M. North	T ca
INVERTEBRATES—Con.	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	Po
Ophiura sp.	--	--	--	0.2	0.2	--	--	--	
Ophiopholis sp.	--	--	--	--	--	--	--	--	
Parastichopus californica	1.0	--	1.0	1.0	1.0	8.0	6.0	3.0	
Molpadia intermedia	--	--	--	--	--	--	--	--	
Pentamera pseudocalcigera	--	--	--	--	--	--	--	--	
Psolus squamatus	--	--	--	--	--	--	--	--	
Sponge	--	--	--	--	--	--	--	--	
Branchiopod	--	--	--	--	--	--	--	--	
Tunicate	--	--	--	0.2	--	--	--	--	
Total invertebrates	27.6	5.0	208.0	19.0	224.4	25.2	16.2	167.6	
TOTAL CATCH	860.2	365.6	1,523.2	856.2	1,335.0	982.8	993.8	1,696.2	8,

Table 1C.—Scientific name and common name or phyletic category for all identified species in Tables 1A and 1B

Scientific name	Common name or phyletic category
Cartilaginous fishes:	
Polistotrema spp.	Hagfish
Squalus acanthias	Dogfish
Raja kincaidii	Black skate
Raja rhina	Longnose skate
Hydrolagus colliei	Ratfish
Flatfishes:	
Citharichthys sordidus	Pacific sanddab
Atheresthes stomias	Arrowtooth flounder
Eopsetta jordani	Petrale sole
Glyptocephalus zachirus	Rex sole
Lyopsetta exilis	Slender sole
Microstomus pacificus	Dover sole
Parophrys vetulus	English sole
Roundfishes:	
Engraulis mordax	Northern anchovy
Thaleichthys pacificus	Eulachon
Hypomesus pretiosus	Surf smelt
Gadus macrocephalus	Pacific cod
Merluccius productus	Pacific hake
Anoplopoma fimbria	Sablefish
Ophiodon elongatus	Lingcod
Radulinus asprellus	Slim sculpin
Xeneretmus latifrons	Blacktip poacher
Aprodon cortezianus	Bigfin eelpout
Bothrocara sp.	Eelpout
Lycodopsis pacifica	Blackbelly eelpout
Anarrhichthys ocellatus	Wolf-eel
Brosmophycis marginata	Red brotula
Delolepsis gigantea	Giant wrymouth
Lyconectes aleutensis	Dwarf wrymouth
Rockfishes:	
Sebastodes alutus	Pacific ocean perch
Sebastodes brevispinis	Silvergray rockfish
Sebastodes crameri	Blackmouth rockfish
Sebastodes diploproa	Splitnose rockfish
Sebastodes elongatus	Greenstriped rockfish
Sebastodes entomelas	Widow rockfish
Sebastodes flavidus	Yellowtail rockfish
Sebastodes helvomaculatus	Rosethorn rockfish
Sebastodes paucispinis	Bocaccio
Sebastodes pinniger	Canary rockfish
Sebastodes proriger	Redstripe rockfish
Sebastodes ruberrimus	Rasphead rockfish
Sebastodes saxicola	Stripetail rockfish
Sebastodes zacentrus	Sharpchin rockfish
Sebastolobus alascanus	Shortspine channel rockfish
Invertebrates:	
Metridium fimbriatum	Sea anemone
Travisia sp.	Polychaete worm
Pandalus jordani	Pink shrimp
Pandalus platyceros	Spot shrimp
Eualus macropthalma	Hippolytid shrimp
Cancer magister	Dungeness crab
Chorilia longipes	Spider crab
Pagurus sp.	Hermit crab
Lopholithodes foraminatus	Box crab
Natica clausa	Gastropod (snail)
Polinices pallidus	Gastropod (snail)
Colus halidonus	Gastropod (snail)
Antiplanes perversa	Gastropod (snail)
Fusitriton oregonensis	Gastropod (snail)
Patinopecten caurinus	Weathervane scallop
Solemya agassizi	Pelecypod (clam)
Octopus sp.	Octopus
Rossia pacifica	Squid
Pycnopodia helianthoides	Sun star
Rathbunaster californicus	Sea star
Stylasterias forreri	Sea star
Poraniopsis inflata	Sea star
Psuedarchaster parelli	Sea star
Luidia foliata	Sea star
Henricia sp.	Sea star
Dermasterias imbricata	Sea star
Pteraster tesselatus arcuatus	Sea star
Allocentrotus fragilis	Sea urchin
Brisaster townsendi	Sea urchin
Gorgonecephalus caryi	Basketstar
Asteronyx sp.	Brittlestar
Ophiura sp.	Brittlestar
Ophiopholis sp.	Brittlestar
Parastichopus californica	Sea cucumber
Molpadia intermedia	Sea cucumber
Pentamera pseudocalcigera	Sea cucumber
Psolus squamatus	Sea cucumber

s and species	Catch with shrimp trawl								
	Drag 1 9/5/64 P.M. North	Drag 2 9/5/64 P.M. South	Drag 3 9/6/64 A.M. South	Drag 4 9/6/64 A.M. North	Drag 21 9/11/64 A.M. South	Drag 22 9/11/64 A.M. North	Drag 23 9/11/64 P.M. South	Drag 24 9/11/64 P.M. North	Total catch
EBRATES—Con.	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
.....	0.2	--	--	--	0.2	--	--	0.2	0.6
sp.	--	--	--	--	--	0.2	--	--	0.2
californica ...	1.0	3.0	7.0	0.2	4.0	6.0	--	4.0	25.2
termedia	0.2	0.2	0.2	0.2	0.2	0.2	0.2	--	1.4
seudocalcigera ..	0.2	0.2	0.2	0.2	--	0.2	0.2	0.2	1.4
matus	--	--	--	--	--	0.2	--	--	0.2
.....	--	--	--	--	0.2	1.0	0.2	--	1.4
.....	--	--	0.2	--	0.2	--	--	--	0.4
.....	--	--	--	--	--	--	--	--	--
ertebrates	39.0	52.2	24.4	169.8	35.0	32.0	32.2	35.8	420.4
CATCH	119.8	116.4	68.0	262.6	90.2	101.6	80.0	73.6	912.2

Table 2.—Catch, by weight

Major categories	Catch at:				Total catch
	50 fathoms in:		100 fathoms in:		
	Fish trawl	Shrimp trawl	Fish trawl	Shrimp trawl	
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
FISHES:					
Cartilaginous fishes	450.2	24.0	758.2	11.4	1,243.8
Flatfishes	7,957.2	75.0	4,427.8	111.0	12,571.0
Roundfishes:					
Rockfishes	51.2	14.4	2,143.8	276.6	2,486.0
Other roundfishes	29,757.2	1,155.4	590.2	92.8	31,595.6
Total fishes	38,215.8	1,268.8	7,920.0	491.8	47,896.4
INVERTEBRATES	496.2	367.2	693.0	420.4	1,976.8
TOTAL CATCH	38,712.0	1,636.0	8,613.0	912.2	49,873.2

Table 3.—Catch, by percentage of weight

Major categories	Catch at:				Total catch
	50 fathoms		100 fathoms		
	Fish trawl	Shrimp trawl	Fish trawl	Shrimp trawl	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
FISHES:					
Cartilaginous fishes	1.2	1.5	8.8	1.2	2.5
Flatfishes	20.6	4.6	51.4	12.2	25.2
Roundfishes:					
Rockfishes	0.1	0.8	24.9	30.3	5.0
Other roundfishes	76.9	70.6	6.9	10.2	63.3
Total fishes	98.8	77.5	92.0	53.9	96.0
INVERTEBRATES	1.2	22.5	8.0	46.1	4.0
TOTAL CATCH	100.0	100.0	100.0	100.0	100.0

iance made to test these differences showed significant first-order interactions for all major catch categories and dominant species (Table 4). In view of the diversity of the faunas sampled, the most significant interactions were displayed by gear type with replication and by gear type with depth.

As was expected, differences between the trawls were highly significant for most species and catch categories (Table 5). On the other hand, the differences attributed to time of day and direction of haul effects were mostly not significant. Some differences were significant for the two other main variables.

Because of the trawl-depth and trawl-replication interactions, the data were divided into four groups. Ratios of the means and medians of the four fish-trawl and shrimp-trawl hauls within each of these sets are presented in Table 6. Although the ratios within any major category or dominant species cover a fairly broad range, a general pattern emerges. Of the five categories, flatfishes show the highest ratios, followed by roundfishes (other than rockfishes), cartilaginous fishes, rockfishes, and invertebrates. With the exception of the rockfish species, the species within any category generally had a greater range in ratios than their particular categories had.

2. Discussion

The degree of interaction in the experiment was high, making interpretation of the results difficult. The significant trawl-depth interactions indicate that the relative differences in catches between trawls changed with depth. This fact makes the extrapolation of the results from this experiment into deep-water risky at best. The trawl-depth interactions appear to be a function of changes in the reactivity of the fishes to the trawls with depth, as will be discussed later. No explanation is offered for the large number of trawl-replication interactions.

Since the degree of interaction in the experiment was high, we do not know whether the significant differences observed for main variables, other than gear and depth, were real

Table 4.—Significance of first-order interactions

Major categories and dominant species	Trawl X replication	Trawl X depth	Trawl X time	Trawl X direction	Replication X depth	Replication X time	Replication X direction	Depth X time	Depth X direction	Direction X time
Categories:										
Total catch	–	*	–	–	–	–	–	–	–	–
Total fishes	–	*	–	–	*	*	–	–	–	–
Cartilaginous fishes	*	*	*	–	*	*	–	–	–	*
Flatfishes	*	*	–	–	–	–	–	–	–	–
Roundfishes:										
Rockfishes	–	*	*	*	*	–	*	*	*	*
Other roundfishes	*	*	–	–	–	–	–	*	–	*
Total invertebrates	*	–	–	–	*	–	–	–	–	–
Species:										
Turbot	–	–	*	–	–	–	–	–	–	–
Slendor sole	*	–	–	–	*	–	*	*	–	–
Dover sole	*	*	–	–	–	–	–	–	–	–
Rex sole	*	*	*	–	–	–	*	–	–	–
Sablefish	*	–	–	–	–	–	–	–	–	–
Hake	*	*	*	*	*	–	–	*	*	*
Ocean perch	–	[1]	*	*	[1]	–	*	[1]	[1]	–
Sebastodes crameri	–	[1]	–	–	[1]	*	*	[1]	[1]	–
Sebastodes saxicola	–	[1]	*	*	[1]	*	*	[1]	[1]	*
Pink shrimp	–	*	–	–	*	*	–	*	–	–
Dungeness crab	–	[2]	–	*	[2]	*	*	[2]	[2]	*
Rathbunaster californicus	–	[1]	–	*	[1]	–	*	[1]	[1]	*
Luidia foliata	*	[2]	–	–	[2]	–	*	[2]	[2]	–
Allocentrotus fragilis	–	[1]	–	–	[1]	–	*	[1]	[1]	–
Parastichopus californicus	*	[1]	–	–	[1]	–	–	[1]	[1]	*

* = Significance at the 25-percent level of probability with 1 and 16 degrees of freedom.
– = No significance.
[1] = No depth interaction, as this species was taken only at 100 fathoms.
[2] = No depth interaction, as this species was taken only at 50 fathoms.

Table 5.—Significance of main effects

Major categories and dominant species	Degrees of freedom	Significance of:				
		Trawl	Depth	Time	Direction	Replication
Categories:						
Total catch	1,25	**	**	–	–	–
Total fishes	1,23	**	**	–	–	–
Cartilaginous fishes	1,20	**	–	*	–	*
Flatfishes	1,24	**	–	–	–	–
Roundfishes:						
Rockfishes	1,18	**	**	–	*	–
Other roundfishes	1,22	**	**	–	–	–
Total invertebrates	1,24	–	–	–	–	–
Species:						
Turbot	1,25	**	–	–	–	*
Slender sole	1,22	**	*	–	–	–
Dover sole	1,24	**	–	–	–	–
Rex sole	1,22	**	–	–	–	–
Sablefish	1,25	**	**	–	–	**
Hake	1,18	**	**	–	*	–
Ocean perch	1,9	**	[1]	–	–	–
Sebastodes crameri	1,8	–	[1]	–	–	–
Sebastodes saxicola	1,6	**	[1]	–	–	–
Pink shrimp	1,22	**	–	–	–	–
Dungeness crab	1,7	**	[2]	–	–	–
Rathbunaster californicus	1,8	**	[1]	–	**	**
Luidia foliata	1,9	–	[2]	–	–	–
Allocentrotus fragilis	1,10	–	[1]	–	–	–
Parastichopus californicus	1,9	–	[1]	–	–	–

* = Significant at the 5-percent level of probability.
** = Significant at the 1-percent level of probability.
– = Not significant.
[1] = No depth effect, as species was taken only at 100 fathoms.
[2] = No depth effect, as species was taken only at 50 fathoms.

Table 6.—Ratio of fish-trawl to shrimp-trawl catches

Major categories and dominant species	Catch ratio of fish-trawl to shrimp-trawl									
	50-fathom catches				100-fathom catches				Range of ratios	
	Replication 1		Replication 2		Replication 1		Replication 2			
	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Categories:										
Total catch	29.1	23.2	20.1	20.0	6.4	7.3	14.5	13.7	6.4 - 29.1	7.3 - 23.2
Total fishes	49.7	40.3	22.0	21.3	11.9	11.5	21.7	20.3	11.9 - 49.1	11.5 - 40.3
Cartilaginous fishes	16.8	18.8	20.4	21.5	30.0	33.0	97.1	89.6	16.8 - 97.1	18.8 - 89.6
Flatfishes	78.4	38.3	165.6	181.1	23.0	19.2	87.6	85.6	23.0 - 165.6	19.2 - 181.1
Roundfishes:										
Rockfishes	2.9	3.9	6.1	[1]	6.2	4.4	9.8	11.6	2.9 - 9.8	3.9 - 11.6[2]
Other roundfishes	47.1	43.6	18.1	17.7	8.9	10.2	4.7	4.0	4.7 - 47.1	4.0 - 43.6
Total invertebrates	1.0	1.2	2.3	2.8	0.9	0.5	3.2	2.9	0.9 - 3.2	0.5 - 2.9
Species:										
Turbot	8.6	7.5	63.2	85.7	58.8	62.5	14.3	18.8	8.6 - 63.2	7.5 - 85.7
Slender sole	66.7	50.0	312.5	350.0	10.2	6.7	68.8	137.5	10.2 - 312.5	6.7 - 350.0
Dover sole	615.5	291.7	1750.0	[1]	20.7	21.5	250.0	500.0	20.7 - 1750.0	21.5 - 500.0[2]
Rex sole	131.8	159.1	234.5	175.0	28.6	6.0	381.8	2125.0	28.6 - 381.8	6.0 - 2125.0
Sablefish	1202.5	[1]	24.2	31.3	55.0	[1]	6.6	6.4	6.6 - 1202.5	6.4 & 31.3[2]
Hake	40.0	39.9	16.5	164.4	8.7	8.0	1.4	0.8	1.4 - 40.0	0.8 - 164.4
Ocean perch	[3]	[3]	[3]	[3]	4.7	7.1	10.8	9.3	4.7 & 10.8	7.1 & 9.3
Sebastodes crameri	[3]	[3]	[3]	[3]	1.7	0.7	9.1	0.3	1.7 & 9.1	0.3 & 0.7
Sebastodes saxicola	[3]	[3]	[3]	[3]	4.9	6.9	8.3	11.0	4.9 & 8.3	6.9 & 11.0
Pink shrimp	0.08	0.09	0.04	0.01	0.15	0.11	0.70	1.2	0.04 - 0.70	0.01 - 1.2
Dungeness crab	54.5	62.5	48.8	100.0	[4]	[4]	[4]	[4]	48.8 & 54.5	62.5 & 100.0
Rathbunaster californicus	[3]	[3]	[3]	[3]	2.5	2.5	1.6	1.8	1.6 & 2.5	1.8 & 2.5
Luidia foliata	1.2	1.5	0.6	1.0	[4]	[4]	[4]	[4]	0.6 & 1.2	1.0 & 1.5
Allocentrotus fragilis	[3]	[3]	[3]	[3]	1.7	1.7	20.7	75.5	1.7 & 20.7	1.7 & 75.5
Parastichopus californicus	[3]	[3]	[3]	[3]	0.3	0.5	1.3	1.1	0.3 & 1.3	0.5 & 1.1

[1] Three of the four catches with the shrimp trawl were zero; hence there was no median value.
[2] Some of the median values for this category or species are missing as indicated by [1].
[3] This species was taken only at 100 fathoms.
[4] This species was taken only at 50 fathoms.

or fictitious. The differences in results between depths were probably real, since the abundance of fishes and invertebrates is known to change with depth. As for the gear differences, Margetts (1949) and Parrish (1949 and 1951) have shown that size and method of operation, alone or in combination, can influence both the absolute and the relative catching efficiency of fishing gear, so that the observed differences are to be expected.

Selectivity factors aside, the catches of the two trawls should be in direct proportion to the size of the trawls. SCUBA-equipped divers estimated the average spread of the shrimp trawl, as rigged and fished in this experiment, to be 22 feet (wing tip to wing tip), with an average vertical opening of about 6 feet. As for the spread and vertical opening of the fish trawl, Alverson, Pruter, and Ronholt (1964) gave values of 40 and 6 feet, respectively. Thus, the horizontal spread of the fish trawl is about 1.8 times that of the shrimp trawl. Since the vertical openings of the trawls are nearly the same, their mouth areas should be proportional to their horizontal openings (1.8 to 1). Yet, owing to differences in the shape of the two nets, the mouth opening of the fish trawl is nearer to 2 or 2½ times that of the shrimp trawl.

The catch ratios of certain benthic invertebrate species, such as the two starfish species *Luidia foliata* and *Rathbunaster californicus*, were in direct proportion to the horizontal spread of the trawls. This proportionality might be expected, since both species are relatively immobile and are of sufficient size to prevent the smaller meshes of the shrimp trawl from having a selective advantage over the larger meshes of the fish trawl.

The catch ratios of other invertebrate species, such as the pink shrimp (*Pandalus jordani*) and the Dungeness crab (*Cancer magister*), however, varied markedly from the expected ratio of 1.8. Pink shrimp passed readily through the large meshes of the wings and body of the fish trawl, thereby giving the shrimp trawl a decided advantage in catching ability for this species. The reverse was true for Dungeness crab — the fish trawl had a decided advantage.

The catch ratios for the rockfish species tended to be slightly higher than 1.8 — nearer the range reflected by the ratio of the area of the mouth openings of the two trawls. Considering the differences in the geometrical configuration of the two trawls as well as the size, off bottom distribution, and known passive behavior of rockfishes, we would expect these ratios in the absence of gear selectivity.

The catch ratios of roundfish (excluding rockfish) and flatfish species, especially of flatfish, departed widely from the expected — the catch of all species of roundfishes and flatfishes by the fish trawl was considerably higher than the catch of these species by the shrimp trawl.

Why should the fish trawl be so superior in catching roundfishes and flatfishes when the difference between the mouth areas of the two trawls is probably not much greater than 2? The explanation lies in the way the two trawls were rigged, together with the manner in which these two groups of fishes reacted to the configurations.

The wings of the shrimp trawl were attached directly to the doors, and the trawl was towed on a single cable, with 25-fathom bridles connecting the doors to the end of the towing cable. The two bridles made a V of the wire in front of the trawl.

The fish trawl, on the other hand, had 25-fathom dandylines connecting the wings to the doors; it was towed with two warps, one attached to each door. Unlike the shrimp-trawl arrangement, the fish-trawl arrangement left the area in front of the trawl clear. In addition, the arrangement of the dandylines positioned the doors considerably outboard from the trawl during towing, thereby increasing its effective sweeping area.

From an experiment to test the effect of placing a length of wire between the door and the net wing (the Vigneron-Dahl modification of the otter trawl), Bagenal (1958) concluded that fish "feel" vibrations from the wire as it passes through the water and over the bottom and that they react in such a manner as to avoid these tactile stimuli. Blaxter and Parrish (1966), using tank tests, also observed that fish avoid moving netting and other parts

of the fishing gear; however, they discounted the significance of tactile stimuli in herding and suggested that visual stimuli are more important. Yet, regardless of the type(s) of stimulation involved, if the flatfishes and roundfishes in our experiment had reacted negatively to the dandylines and doors, they would be repulsed from the path of the shrimp trawl by the wire V of the bridles; in contrast, they would be herded into the path of the fish trawl by the spread dandylines and doors. Such reactions would decrease the effectiveness of the shrimp trawl and increase that of the fish trawl. The magnitude of the fish-trawl-to-shrimp-trawl catch ratio would thus reflect, at least in part, the intensity of reaction of the fishes. Hence, both the repulsion by the wire V in front of the mouth of the shrimp trawl and the herding by the outboard doors and dandylines of the fish trawl would appreciably affect the fish-trawl-to-shrimp-trawl catch ratio. We therefore have to be cautious in ascribing the differences in catch ratios solely to the manner in which one or the other of the trawls was rigged.

The catch results indicate that flatfishes react more negatively than roundfishes do and that rockfishes react least of all. Observations by divers in areas where rockfishes are abundant tend to support this hypothesis — at least in regard to the rockfishes. The high reactivity displayed by flatfishes in the experiments of Blaxter and Parrish (1966) also substantiate our results. The fact that both the flatfishes and the gear are in contact with the bottom could partially explain the apparently greater reactivity of the flatfishes.

Besides being useful in explaining the herding or repulsing effects of the trawl configurations, the results of experiments by Blaxter and Parrish (1966) offer a plausible explanation of trawl-depth interactions. In their experiments, they found that herding decreased markedly at low intensities of light. Thus, with the difference in light intensities to be expected between the 50- and 100-fathom depths in our study, the herding effects should differ. This fact could account for the differences in the relative advantage of the fish trawl over the shrimp trawl with depth. The catch ratios were generally higher at 50 fathoms than at 100 fathoms (Table 6). King and Iversen (1962) and Pearcy and Laurs (1966) have shown by analysis of size data from day and night midwater trawl catches that larger organisms are captured at night, suggesting greater avoidance of the gear during the day. This conclusion of higher avoidance under conditions of greater light intensity are also in agreement with our conclusions.

II. COMPARSON OF GEAR SELECTIVITIES

A. EXPERIMENTAL APPROACH

To permit evaluation of size selectivities, length data were taken for the dominant species in the catches of both gears at both depths. All length measurements are total length from the front of the snout to the end of the tail.

B. FINDINGS

The selective capacity of a trawl can be adduced both from the variety and from the size of the fishes in its catches. Thus, to compare the selectivity of the two gears, we compared the composition of their catches in terms both of species and of length-frequency distributions.

1. Species Composition

Differences in the species composition of the two trawls can best be evaluated by considering the number and type of species caught and their relative dominance in the catches.

a. Species caught.—Almost 100 species of fishes and invertebrates were caught (Table 7). Eleven species of fishes and six species of invertebrates caught by the fish trawl were not caught by the shrimp trawl (Table 8). On the other hand, 6 species of fishes and 22 species of invertebrates caught by the shrimp trawl were not caught by the fish trawl. Although the species that were exclusive to one gear made up nearly half the total number of

Table 7.—Number of species taken by both the fish trawl and the shrimp trawl

Major categories	Species caught at:								
	50 fathoms			100 fathoms			Both depths combined		
	Fish trawl	Shrimp trawl	Total	Fish trawl	Shrimp trawl	Total	Fish trawl	Shrimp trawl	Total
FISHES:	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Cartilaginous fishes	3	2	4	5	5	5	5	5	5
Flatfishes	7	6	7	6	4	6	7	6	7
Roundfishes:									
Rockfishes	5	3	5	15	11	16	16	11	16
Other roundfishes	5	10	12	11	9	13	12	13	18
Total fishes	20	21	28	37	29	38	40	35	46
INVERTEBRATES	14	19	23	21	34	39	29	46	51
Total catch	34	40	51	58	63	77	69	81	97

Table 8.—Species taken exclusively by the shrimp trawl or by the fish trawl

Species taken exclusively by the shrimp trawl		Species taken exclusively by the fish trawl	
Names	Number of occurrences	Names	Number of occurrences
Fishes:		Fishes:	
Brosmophycis marginatus	1	*Citharichthys sordidus*	3
Engraulis mordax	1	*Anarrhichthys ocellatus*	1
Hypomesus pretiosus	8	*Gadus macrocephalus*	4
Lyconectes aleutensis	2	*Ophiodon elongatus*	4
Delolepsis gigantea	1	*Bothrocara* sp.	1
Aprodon cortezianus	1	Unidentified cottid	1
		Sebastodes brevispinis	1
		Sebastodes paucispinis	3
		Sebastodes proriger	2
		Sebastodes ruberrimus	1
		Sebastodes rubrivinctus	3
Invertebrates:		Invertebrates:	
Travisia sp.	1	*Pandalus platyceros*	1
Bristle worm	2	*Chorilia longipes*	1
Unidentified hippolytid shrimp	1	*Dermasterias imbricata*	1
Eualus macropthalma	2	*Gorgonocephalus caryi*	3
Unidentified cragonid shrimp	8	*Asteronyx* sp.	2
Lopholithodes foraminatus	1	Unidentified tunicate	1
Polinices pallidus	2		
Fusitriton oregonensis	2		
Unidentified pelecypod	1		
Solemya agassizi	1		
Pycnopodia helianthodes	1		
Poraniopsis inflata	2		
Henricia sp.	1		
Pteraster tesselatus arcuatus	1		
Ophiopholis sp.	1		
Molpadia intermedia	7		
Pentamera pseudocalcigera	7		
Psolus squamatus	1		
Unidentified sponge	3		
Unidentified nemertine worm	1		
Unidentified echiuroid worm	1		
Unidentified brachiopod	2		

species caught, their frequency of occurrence and their abundance relative to the total catch were usually not great (Table 1). Thus, their occurrence in one gear and not in the other could possibly be attributed to chance alone rather than to the physical makeup of the gear.

Major exceptions to the generalization that frequency of occurrence and abundance of the "exclusive" species were not great were evident in catches of Pacific cod (*Gadus macrocephalus*), lingcod (*Ophiodon elongatus*), and bocaccio (*Sebastodes paucispinis*) in the fish

trawl and of surf smelt (*Hypomesus pretiosus*), an unidentified cragonid shrimp, and sea cucumbers (*Molpadia intermedia* and *Pentamera pseudocalcigera*) in the shrimp trawl. Each of these species was taken either in a high percentage of the drags or in quantity in individual drags.

The smaller size of mesh is undoubtedly the major cause of the selective advantage of the shrimp trawl. Because all of the species of fishes and most of the species of invertebrates that were exclusive to the shrimp trawl were quite small, they would be retained by the small mesh of the shrimp trawl but not by the larger mesh of the fish trawl. Even though the fish trawl was fitted with a small-mesh (1½-inch) liner in the cod end, this modification was not completely effective in increasing the species-catching efficiency of this gear. The small forms apparently escaped through the larger meshes in the wings and in the intermediate section of the net before they reached the cod end, where they could be retained.

The ability of the fish trawl to capture Pacific cod, lingcod, and several species of rockfishes exclusively and repeatedly can be attributed partially to its configuration. The large size and the greater amount of headrope overhang of the fish trawl could account for its advantage in taking the larger, faster-swimming fishes (Pacific cod, lingcod, and bocaccio) and in taking the rockfish species, which tend to be off-bottom. Another explanation might be that the larger meshes of the fish trawl do not build up as repelling a "wall of water" in front of the gear during towing as do the smaller meshes of the shrimp trawl. No explanation, other than chance occurrence, is offered for the exclusive capture of several invertebrates by this gear.

b. Dominance patterns.—The particular species that dominated the catch of a given category changed with depth. At 50 fathoms, roundfishes were dominant in the catch of fishes taken by both types of trawls. At 100 fathoms, flatfishes were dominant in the catch of fishes by the fish trawl, and rockfishes in the catch of fishes by the shrimp trawl.

The dominance patterns of species, without regard to category, varied more dramatically as a result of changes in depth and gear than did the patterns of the categories themselves (Tables 1 and 9).

At 50 fathoms, Pacific hake (*Merluccius productus*) was the dominant species taken by both gears; the relative numbers of other species varied radically. Shrimp, which ranked second in the shrimp-trawl catches, were taken in too few numbers by the fish trawl to be placed in the rankings. Dover sole (*Microstomus pacificus*) ranked high in the fish-trawl catches but were virtually unrepresented in the shrimp-trawl catches. The extreme in variation was shown by hagfish (*Polistotrema* spp.) —it was fifth in dominance in the shrimp-trawl catches at the 50-fathom depth but was not even taken with the fish trawl.

At 100 fathoms, flatfishes dominated the fish-trawl catches, whereas invertebrates, especially the sea urchins *Allocentrotus fragilis* and *Brisaster townsendi*, dominated the shrimp-trawl catches. Pacific ocean perch (*Sebastodes alutus*) was moderately represented in the catches of both gears at this depth.

A number of factors operating together probably caused the observed dominance patterns. Undoubtedly, the small size of mesh and the nonfish-catching design of the shrimp trawl contributed substantially to its ability to

Table 9.—Dominant species caught, in decreasing order of weight of catch

Species caught at 50 fathoms in:		Species caught at 100 fathoms in:	
Fish trawl	Shrimp trawl	Fish trawl	Shrimp trawl
Pacific hake	Pacific hake	Dover sole	Sea urchin *(Allocentrotus)*
Sablefish	Pink shrimp	Rex sole	Pacific ocean perch
Dover sole	Sablefish	Pacific ocean perch	Sea urchin *(Brisaster)*
Rex sole	Arrowtooth flounder	Sea urchin *(Allocentrotus)*	Pink shrimp
Arrowtooth flounder	Pacific hagfish	*Raja rhina*	Dover sole
Dungeness crab	Rex sole	Arrowtooth flounder	*Sebastodes saxicola*

take more of the smaller invertebrate forms than of the other forms abundant in the area being studied. In contrast, the fish trawl's larger mesh size and its fish-catching design made the fish trawl more effective at taking fishes. This effectiveness varied, as previously shown, with species.

2. Length-Frequency Distribution

Because the ability of the shrimp trawl to catch fishes was limited, only three species were taken in sufficient quantities by both gears at any one depth to permit a meaningful comparison of their fish-size selectivities. These three species were sablefish (*Anoplopoma fimbria*) and Pacific hake at 50 fathoms and Pacific ocean perch at 100 fathoms.

a. Sablefish.—Analysis of the length-frequency distribution of sablefish taken at 50 fathoms shows that both gears caught sablefish up to 53 centimeters long in about the same proportion (Figure 5), but the fish trawl also took sablefish of greater length. Despite this apparent inability of the shrimp trawl to catch the larger fishes, the mean lengths of the sablefish taken by the two gears were not significantly different (Table 10).

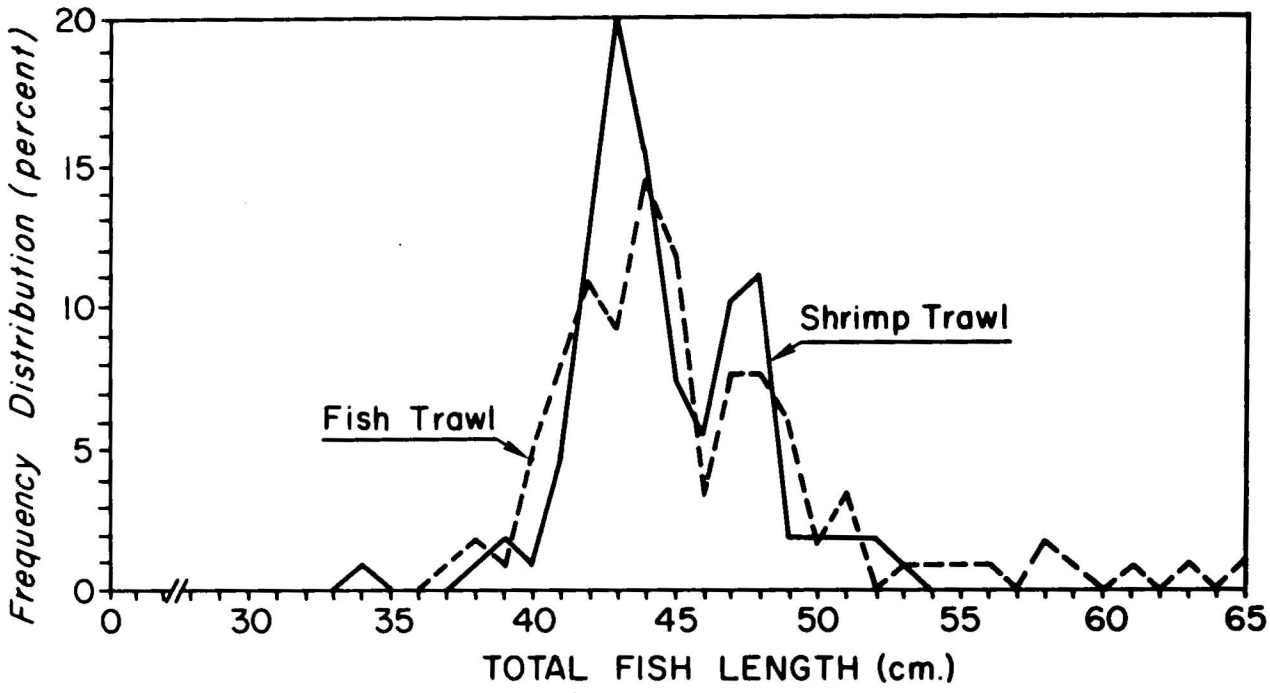

Figure 5.—Sablefish length-frequency distribution at 50 fathoms.

Table 10.—t-test analyses of the mean lengths of three species of fishes that were taken in quantity by the two gears at one depth

Species	Depth	Gear	Number of fish measured	Mean length	Variance[1]	t-value	Significance[2]
	Fathoms			*Cm.*			
Sablefish	50	FT	119	45.5	24.85	1.586	n.s.
		ST	109	44.6	9.58		
Hake	50	FT	173	54.0	7.21	2.140	*
		ST	321	53.4	8.88		
Pacific ocean perch	100	FT	140	34.8	24.62	5.753	**
		ST	150	30.8	45.93		

FT = fish trawl
ST = shrimp trawl
[1] The variances were tested for homogeneity prior to each t-test.
[2] n.s. = not significant at the 5-percent probability level; * = significant at the 5-percent probability level; ** = significant at the 1-percent probability level.

b. Pacific hake.—The length-frequency distribution for Pacific hake taken at 50 fathoms shows that those taken by the fish trawl were slightly longer than those taken by the shrimp trawl (Figure 6). The statistical validity of this difference is supported by the significant difference between the means of the respective samples (Table 10).

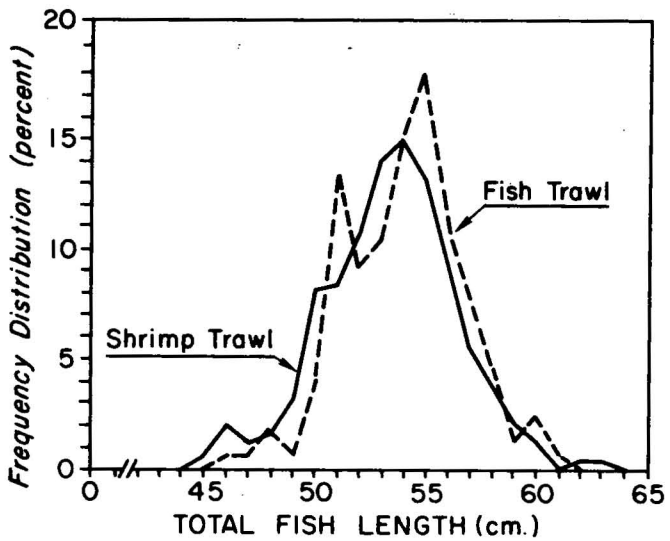

Figure 6.—Pacific hake length-frequency distribution at 50 fathoms.

c. Pacific ocean perch.—Whereas the length-frequency distributions of sablefish and Pacific hake approached normality, those of Pacific ocean perch did not (Figure 7). The multiplicity of sizes sampled resulted in high variances (Table 10). Both gears caught fishes over most of the ranges of length found, but the fish trawl caught a higher percentage of larger fishes (greater than 31 centimeters), and the shrimp trawl caught a higher percentage of smaller fishes (31 centimeters and less). Paradoxically, the shrimp trawl took the largest as well as the smallest fish in the samples. The validity of the differences in selectivity was supported by the results of t-tests (Table 10). These results show that the difference between the mean lengths of fishes taken by the two gears is highly significant.

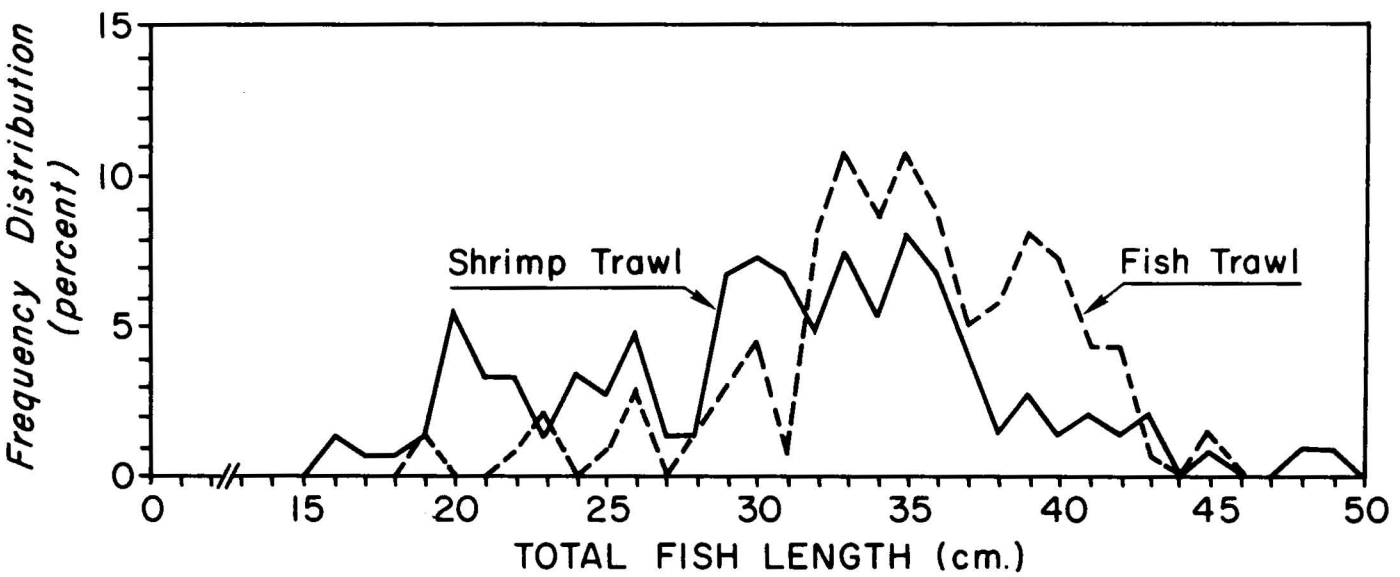

Figure 7.—Pacific ocean perch length-frequency distribution at 100 fathoms.

CONCLUSIONS

This experiment has demonstrated that a precise equation for the relative catching efficiency of the fish trawl and the shrimp trawl cannot be derived from a simple ratio of their catch rates. The failure of such a solution is attributable to the following: (1) the inherent, contiguous nature of the distributions of species in space results in large within-species variability in catch rates and makes the estimated ratios unreliable; (2) the interactions of trawl with depth and of trawl with replication distort the extrapolations in time and space of calculated ratios; and (3) the catch selectivity of the two trawls is highly disparate. The effect that the systematic error associated with the contiguous nature of the distributions of species has on the ratios can be partially corrected for by applying the proper transformation to the data. But very little can be done to correct for the trawl interactions or the differences in catch composition because these two factors vary with the species involved.

From the results, it is apparent that faunal-comparison studies in which large areas or several depths are to be examined should be so designed that one gear at least will be used to sample all areas or depths. As a minimum requiremnt, two of the gears should overlap in their coverage of a study area or depth.

Because the ratios of the catch rates are unreliable as a measure of the differences in the catching efficiency of the two trawls, they can be used only for gross comparisons of orders of magnitude. Even then, caution must be exercised if correction factors are used, since (1) as we have shown, the ratio estimators and selectivity factors for the individual species within any catch category vary widely from one depth to another, owing to the trawl-depth interactions, and (2) the demersal community changes radically with depth.

SUMMARY

Before the catch data that were collected during an investigation made at the mouth of the Columbia River could be evaluated, the relative catching efficiencies of the two sampling gears used — a 94-foot Eastern fish trawl and a 70-foot semiballoon shrimp trawl — needed to be determined. The catching efficiencies of the two trawls were to be equated by a comparison of their catch rates and their gear selectivities.

In an attempted development of this equation, thirty-two ½-hour drags were made during which both gears and one vessel were used in a 2^5 factorially designed experiment. Five experimental factors were taken into consideration. These were gear type, depth of haul, time of haul, direction of haul, and replication.

Statistical analyses of the catch data disclosed a number of significant interactions, especially those of gear type with replication and gear type with depth. Most of the observed differences in catch rates can be attributed to the gear effects. Time of day and the direction of hauls in this experiment apparently did not contribute significantly to the differences in catch rates. Inspection of various ratios of the catch rates of the fish trawl to those of the shrimp trawl showed that, with the exception of ratios for most invertebrate species, these ratios tended to be higher than one would expect from a consideration of the physical dimensions of the trawls alone. This disparity was greatest for flatfish species. Apparently the manner in which the trawls were rigged greatly influenced the observed results.

Comparison of the selectivities of the two gears disclosed that the species composition, dominance patterns, and size selectivities of the two gears differed widely. These differences were also ascribed to differences in the trawls, particularly to their configurations. A small-mesh liner in the cod end of a trawl did not ensure the retention of the smaller forms encountered.

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