FACTORS AFFECTING COOKED TEXTURE QUALITY OF PACIFIC WHITING, *MERLUCCIUS PRODUCTUS*, FILLETS WITH PARTICULAR EMPHASIS ON THE EFFECTS OF INFECTION BY THE MYXOSPOREANS *KUDOA PANIFORMIS* AND *K. THYRSITIS*

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ABSTRACT

Pacific whiting is known to have abnormal cooked texture induced by enzymes of the Myxosporean parasites *Kudoa*. An extensive United States-Canadian joint research project was initiated to explore the correlation between texture quality and intensity of *Kudoa* infection. Enumeration of white and black pseudocysts and identification of the *Kudoa* species present was done by the Canadian team while texture quality was determined by the U.S. team. Data analysis showed that 1) white pseudocysts were more closely correlated with cooked texture quality than were black pseudocysts; 2) *K. paniformis* and mixed infections correlated well with sensory texture while *K. thyrsitis* infections correlated poorly; 3) Pacific whiting from southern fishing areas had higher white pseudocyst counts of *K. paniformis* and more soft abnormal texture than Pacific whiting from northern fishing areas; 4) nape and dorsal areas of fish had higher intensities of *Kudoa* infections and greater incidences of abnormal texture; 5) body length correlated weakly with texture quality, but there was no relationship between sex and sensory texture. Results of experimental evaluations indicate that the visual culling method may have some potential for use in sorting Pacific whiting with white and/or black pseudocysts. However, the white pseudocysts require careful examination to be detected. Therefore, a visual culling method may be too time consuming to be practical for use on a production line.

Between 1982 and 1984, the annual catch of Pacific whiting[2], also known as Pacific hake, *Merluccius productus*, harvested by American and foreign fishing fleets in the territorial waters off the Pacific coast of the United States, ranged between 80,000 and 100,000 t. Of this amount, between 67,000 and 79,000 t were annually harvested by a joint venture fishery with the Soviet Union. The catch by other foreign countries, mainly Poland and Bulgaria, operating in the directed fisheries, ranged from 7,000 to 14,000 t[3]. Although the Pacific whiting resource has been estimated to vary between 445,000 and 3,440,000 t (Dark 1985), its domestic use has been limited because of soft texture associated with the presence of a parasitic Myxosporea of the genus *Kudoa*. Patashnik et al. (1982) and Tsuyuki et al. (1982) established that the flesh deterioration of infected Pacific whiting was due to an enzyme-induced proteolysis. However, the correlation between the degree of infection and the condition of the flesh was not entirely clear. Sometimes Pacific whiting heavily infected with the protozoan parasite appeared, when cooked, not to be affected, i.e., soft-textured, while lightly infected fish had very poor textures. The discovery by Kabata and Whitaker (1981) that Pacific whiting is infected by two different species of *Kudoa* (Fig. 1) explained some of these discrepancies. Tsuyuki et al. (1982) found that these species, *Kudoa paniformis* (Kabata and Whitaker 1981) and *Kudoa thyrsitis* (Gilchrist 1924), differ from each other in their enzyme activity, i.e., enzyme-induced proteolysis. Because Pacific whiting can be infected with one or both species of *Kudoa*, the final condition of the flesh might be determined by the type of *Kudoa* since *K. paniformis* is capable of producing much heavier infections than *K. thyrsitis* (Kabata and Whitaker 1981).

From a public health standpoint, no protozoan diseases of fish have been known to have man as host (Oppenheimer 1962) and myxosporea per se have never been reported to cause illness in humans (Konagaya 1982; Nagahisa et al. 1983). Nonetheless, infection with *Kudoa* continues to

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[2]The U.S. Food and Drug Administration has ruled that this species can be marketed as Pacific whiting (Robins et al. 1980).

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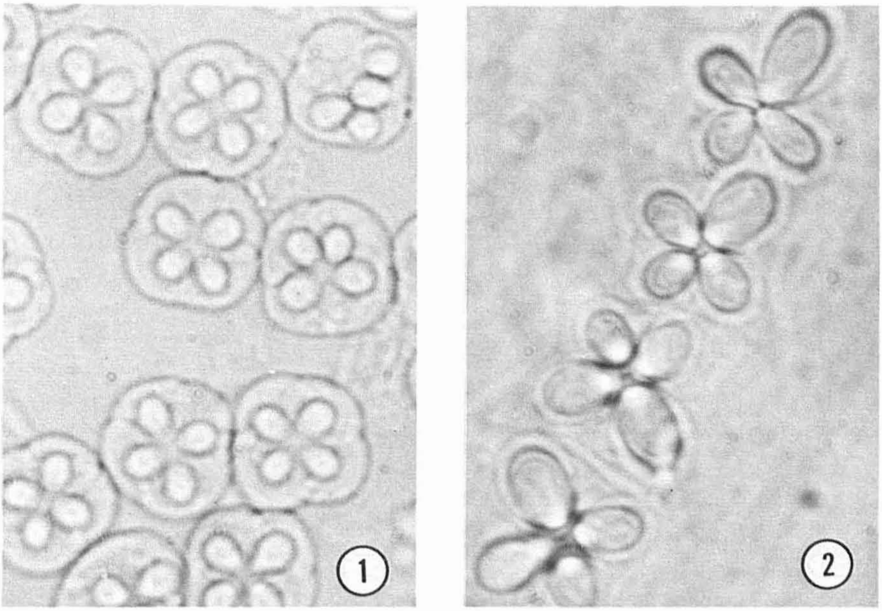

FIGURE 1.—Unstained spores at ×2400, (1) *Kudoa paniformis* (approximately 8 μm in size) and (2) *Kudoa thyrsitis* (about 15 μm in size), found in the muscle of Pacific whiting. *Photo by Carla Stehr.*

be a serious limiting factor in the Pacific whiting fishery.

A joint U.S.-Canadian project aimed at taking the full measure of these problems was initiated in 1983. The purpose of this paper is to report on the results of investigations into cooked flesh texture and its relationship to the intensity and type of *Kudoa* infection. The paper also correlates subjective sensory texture values with objective instrumental readings and establishes texture quality profiles of fish taken in different geographic areas along the distribution range of the Pacific whiting. Other factors, such as sex, body size, and location of infection within the various parts of the fish (i.e., anterior, posterior, dorsal, ventral) which might influence texture quality, were also examined. Finally, visual culling was evaluated to determine if sorting Pacific whiting infected with pseudocysts from the pack was practical.

MATERIALS AND METHODS

The sample used in this investigation consisted of 579 Pacific whiting collected by National Marine Fisheries Service personnel aboard the chartered MV *Nordfjord* in 37 hauls off the Pacific coast of North America, between lat. 37°18′N (near San Francisco) and 48°54′N (west coast of Vancouver Island) in the four International North Pacific Fisheries Commission (INPFC) areas (Fig. 2). The fish were caught between 16 July and 28 September 1983, in 30-min tows at depths ranging from 34 to 164 fathoms. Water temperatures at the cod end ranged between 7.5° and 10.5°C, while surface temperature ranged between 12.1° and 18.8°C. These temperatures were somewhat warmer than those in previous years, due to the 1982-83 El Niño effect (Weinberg et al. 1984). The Pacific whiting catch varied from 7 to 2,053 kg in the total catch of 20 to 2,488 kg per haul (Weinberg et al. 1984). A 32 mm (1 1/4″) stretched mesh size cod end liner was used to retain small fish. Each fish was measured and sexed, individually numbered, and frozen aboard the vessel. The fish samples were taken to the Utilization Research Division (URD) laboratory of the Northwest and Alaska Fisheries Center (NWAFC) in Seattle where they were sectioned longitudinally and each half labeled accordingly. One half of each fish was shipped to the Pacific Biological Station in Nanaimo, B.C., Canada, for parasitological examination, and the other retained by the URD laboratory for determination of flesh quality.

The parasitological methods used by the Pacific Biological Station are described elsewhere (Kabata and Whitaker 1986). Intensity of infec-

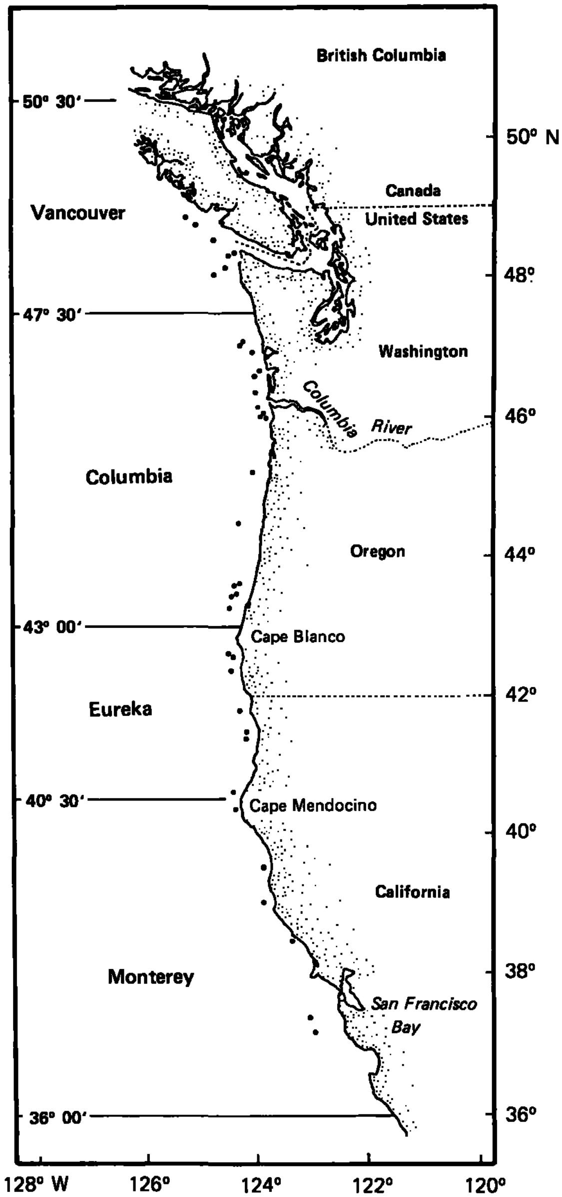

FIGURE 2.—Locations of the 37 hauls (black dots) of Pacific whiting made by MV *Nordfjord* and the International North Pacific Fisheries Commission (INPFC) areas surveyed in the summer of 1983.

tion with *Kudoa* was measured in each fillet, which were divided into six inspection areas (Fig. 3) as numbers of pseudocysts (i.e., infected muscle fibers) per gram of tissue. Separate counts were taken for each species of *Kudoa* and for white (young) and black (old) pseudocysts.

The flesh texture was determined in two ways: 1) by a sensory technique developed especially for Pacific whiting and 2) by mechanical shear press. The sensory texture evaluations were made by two project personnel experienced with Pacific whiting texture. Normal taste panel methods could not be used in this study because each sample fillet was divided into six areas for sequential evaluation, similar to the method described by Patashnik et al. (1982). The project personnel used a combination of taste and touch techniques to determine hardness sensation. The touch technique consisted of estimating hardness or resistance by pressing on the sample with the tip of the index finger. Taste texture was determined by the subjective force required to bite through the sample with the molar teeth.

Texture ratings were based on a 9-point hedonic scale (Table 1) where scores of 9 to 5 described normal textures ranging from the firmness of rockfish to the tenderness of typical Pacific whiting, 4 to 3 as the softness of sole, and 2 to 1 as an abnormal or mushy to liquefied texture.

Prior to measuring sensory textures, the frozen Pacific whiting halves were placed on racks in trays, tempered at ambient temperature for approximately 2 hours or until semifrozen, covered with aluminum foil, and then, depending on the

TABLE 1.—Sensory texture category based on a 9-point hedonic scale.

Category	Scale	Description
Normal	9	Very firm and flaky as in rockfish
	8	Very firm and flaky as in rockfish
	7	Firm and flaky as in true cod
	6	Tender and slightly flaky as in typical Pacific whiting
	5	Tender and slightly flaky as in typical Pacific whiting
Soft	4	Soft as in sole and flounder
	3	Soft as in sole and flounder
Abnormally soft[1]	2	Mushy
	1	Liquefied

[1]Considered organoleptically unacceptable as previously described by Patashnik et al. (1982) and Nelson et al. (1985).

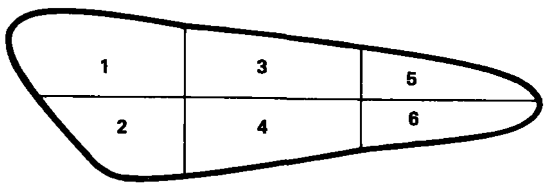

FIGURE 3.—Selected Pacific whiting fillet areas examined for cooked texture and pseudocyst intensity.

thickness, cooked in an oven at 375°F for 20 to 50 minutes. The texture of the fish was then determined organoleptically.

Mechanical texture was determined on 180 randomly selected fish, in which duplicate shear press readings were taken on 15 g of muscle tissue removed from the dorsal portions of the fish samples to correlate with the portions taken for sensory evaluations. The successful use of mechanical texture analysis to correlate with the sensory texture of Pacific whiting was previously reported by Nelson et al. (1985). The tissues were teased into flakes which were leveled to a height of 8 mm in a Kramer shear-compression cell which was reduced in size to 29 mm wide, 71 mm long, and 64 mm deep to accommodate the sample. The assembly, consisting of four blades, was similar to the one described by Bilinski et al. (1977) and used by Tsuyuki et al. (1982) to evaluate objectively the texture of Pacific whiting. The cell operated in conjunction with the Food Technology Corporation FTA 3000 transducer[4], TP-4 Texturepress, and the TR-5 Texturecorder. A plot was made of the force required to drive the blades through the sample at a ram speed of 1 cm per minute and at a set recorder range. The peak force in pounds per 15 g tissue was calculated from the plot (Bourne 1982).

Culling was performed on partially thawed halves of fish. Pseudocysts are visible as white or black threads of varying intensities imbedded longitudinally along the muscle fibers. The culling categories were modeled after the scheme of Patashnik et al. (1982) for both white and black pseudocysts as none, light (<20%), moderate (20 to 30%), and heavy (>30%) as determined visually, based on the percent area of fillet affected.

Only fish over 27 cm were used for all analyses, since in commercial operations fish smaller than 27 cm would not likely be taken because domestic and foreign fishermen use 50 mm (2 in) to 100 mm (4 in) cod end mesh size as regulated by the Pacific Coast Groundfish Fishery Management Plan.[5]

Data representing sensory textures and *Kudoa* pseudocyst counts (made on a total of 562 fish exclusive of fish under 27 cm) were analyzed on the NWAFC Burroughs 7800 computer system using the SPSS software package described by Nie et al. (1970) and SPSS Update 7-9 (Hull and Nie 1981).

Fitted regression curves between cooked texture values and white and black pseudocyst counts were drawn using robust locally weighted regression analyses described by Cleveland (1979). The method was used to smooth scatterplots by calculating a polynomial fit to data using weighted least squares.

RESULTS AND DISCUSSION

Relationship Between Sensory Texture Ratings and Shear Press Values

Since any nonsensory evaluations of a fishery product must ultimately relate to the products' intrinsic organoleptic properties, emphasis in this study was placed upon taste tests despite the inherent fatigue factor associated with testing large numbers of samples. No consumer-type panel was carried out to test the accuracy of the texture evaluation, because fish with abnormal

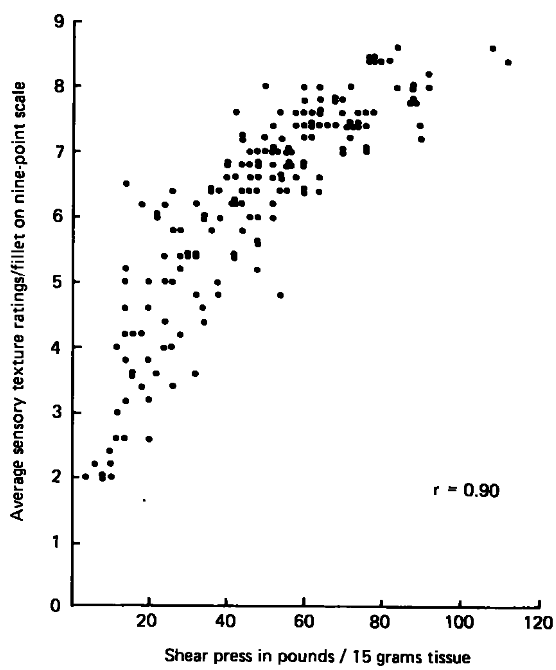

FIGURE 4.—Scatterplot and Spearman correlation coefficient (r) between sensory texture rating and shear press force of cooked flesh of Pacific whiting fillets.

[4]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

[5]J. Wall, REFM Division, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., BIN C15700, Seattle, WA 98115, pers. commun. March 1985.

texture were purposely included in the present study to determine the extent of the problem. On randomly selected samples, shear press measurements were run concurrently as an objective support for the sensory data.

A scatterplot and the Spearman correlation coefficient (nonparametric) determined for the sensory texture ratings and shear press values shown in Figure 4 was produced by the SPSS software. The high degree of correlation (r = 0.90 at P = 0.001) was found to support the credibility of sensory texture evaluation in this study.

Effect of White and Black Pseudocysts and *Kudoa* Species Upon Sensory Texture

Fitted regression curves for sensory texture values and white pseudocyst counts are shown in Figure 5A. Mixed infections include both *K. paniformis* and *K. thyrsitis* pseudocysts in the same fish. The curve representing the white mixed infection shown superimposed on that of the white *K. paniformis* curve suggests that most of the white mixed pseudocysts consisted of *K. pani-*

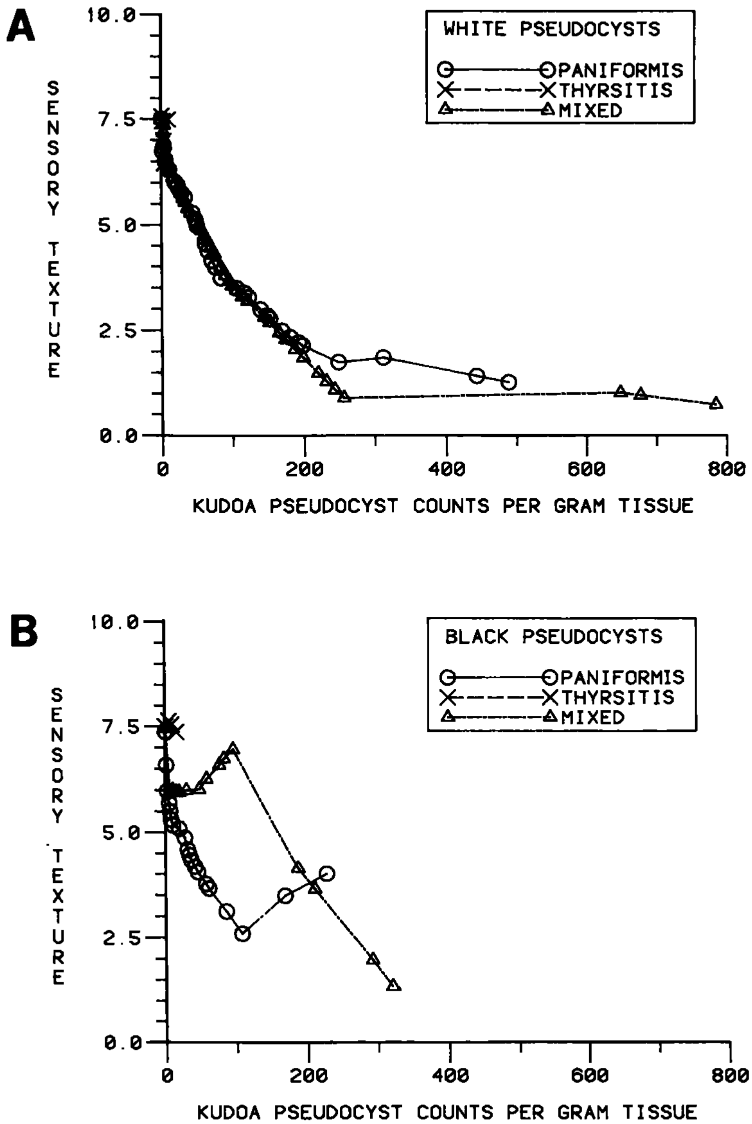

FIGURE 5.—Fitted regression curves between cooked texture of Pacific whiting and intensity of (A) white *Kudoa* pseudocysts and (B) black pseudocysts.

formis. Correlation values for these two curves were $r = -0.79$ and -0.80, respectively (Table 2). Pseudocyst counts of white *K. thyrsitis* were <10 and did not appear to adversely affect the texture of the Pacific whiting (Table 3A). The low count is thought by Kabata and Whitaker (1981) to be the result of an evolutionary development of defense mechanisms in the host fish. The correlation coefficient representing sensory textures and white *K. thyrsitis* infection was 0.12. This suggests that *K. thyrsitis* plays an insignificant role in the texture quality of Pacific whiting, a view also held by Kabata and Whitaker (1981).

Fitted regression curves between sensory textures and black pseudocyst counts are shown in Figure 5B. Mixed black pseudocyst counts did not follow the pattern for black *K. paniformis* counts, as observed with the white mixed and *K. paniformis* infections. This suggests that the black pseudocyst counts cannot be used as a reliable predictor of sensory texture. Magnitudes of black *K. paniformis* counts and black mixed counts were <320, while counts were <16 for black *K. thyrsitis*. Like those infected with white *K. thyrsitis*, fish infected with black *K. thyrsitis* parasites had normal, firm cooked textures (Table 3A). The absolute value of the Spearman correlation coefficient (Table 2) between texture quality and black pseudocyst intensity was lower (−0.38) than that of the coefficient for texture quality and white pseudocyst intensity (−0.74), both at significance level of 0.001.

TABLE 2.—Spearman correlation coefficient between sensory texture rating and *Kudoa* pseudocysts in Pacific whiting caught during the summer of 1983.

Sensory texture with:	Sample size	Correlation coefficient	Significance
White pseudocysts			
total population	562	−0.74	0.001
Black pseudocysts			
total population	562	−0.38	0.001
K. paniformis			
white pseudocysts	201	−0.80	0.001
black pseudocysts	201	−0.66	0.001
K. thyrsitis			
white pseudocysts	191	−0.12	0.05
black pseudocysts	191	0.07	0.15
Mixed infection			
white pseudocysts	259	−0.79	0.001
black pseudocysts	259	−0.49	0.001

TABLE 3.—Percentage of sensory texture ratings for (A) each *Kudoa* species, (B) fork length, and (C) sex composition for Pacific whiting caught during the summer of 1983.

Description	Sample size	Sensory texture rating (%)			
		Normal	Soft	Abnormal	Total
(A) *Kudoa* species					
K. paniformis	144	17	5	3	26
K. thyrsitis	125	22	0	0	22
Mixed infection	190	23	7	4	34
None	103	18	0	0	18
Total	562	80	12	7	100
(B) Fork length composition of whiting					
Small (27-39 cm)	144	93	5	2	100
Medium (40-49 cm)	172	79	17	4	100
Medium large (50-59 cm)	170	74	14	12	100
Large (60-80 cm)	76	72	15	13	100
All lengths	562	80	13	7	100
(C) Sex composition of whiting					
Female	332	81	12	6	100
Male	227	79	13	8	100
Total	559	80	13	7	100

From the correlation coefficients for the white and black pseudocyst counts of both species, the square of the coefficients (coefficient of determination) was calculated to compare their relative importance in terms of differences in their magnitude with respect to one another. Fifty-five percent of the observed variability in all sensory texture ratings can be accounted for (predicted) by the observed variability in the white pseudocyst counts, while only 14% can be accounted for by the observed variability in the black pseudocysts counts. However, infections do not occur in Pacific whiting as only white or black pseudocysts; they also occur as a mixture of the two. Thus, when the quantitative effects of the white or black pseudocyst counts on sensory texture were evaluated by multiple regression analysis, we found that only 1.5% of the variability in sensory texture rating was accounted for by black pseudocyst counts, and 45% accounted for by white pseudocyst counts. These figures represent partial coefficients of determination which indicate the relationship between two variables while controlling the effects of one or more other variables and are consistent with the findings of Patashnik et al. (1982) and Tsuyuki et al. (1982).

Intensity of White and Black Pseudocyst Infection in Relation to Sensory Texture Ratings

The magnitude of white and black pseudocyst counts in relation to their corresponding sensory texture scores are shown in Tables 4 and 5.

A total of 214 fish, 38% of the fish examined, did not have white pseudocysts. Table 4 shows that texture scores for this group of fish range from 4 to 9 with 97% of the scores in the range of

6 to 8. Fish infected with white pseudocysts to the degree of 26 to 50 counts (average for the six areas in each fish tested) resulted in 1 out of 50 fish tested with a sensory texture score of 2. Thus, 2% of the fish in this category must be regarded as too soft and are organoleptically unacceptable (Table 1). In the sample of 562 fish, 25 specimens were found with white pseudocyst counts ranging between 51 and 75, none of which were judged to have a texture score of 2 or lower. However, note that 11 of 25 (44%) fish samples were soft textured. When the white pseudocyst counts were 76 or higher, nearly all of the fish were soft or abnormally soft textured.

The frequency distribution of sensory texture scores vs. black pseudocyst counts (Table 5) does not show the same relationship that intensity of white pseudocyst infection had on sensory texture (Table 4). This becomes evident after examining sensory texture scores for fish with black pseudocyst counts of 1 to 25 (Table 5) when the entire range of texture scores is represented.

Note, however, that the observed distributions of white and black pseudocysts differ. For example, of the 98 fish with pseudocyst counts exceeding 50, 81 had white pseudocysts but only 17 had black pseudocysts. Also, for Pacific whiting with counts >100, 37 of 45 (82%) with white pseudo-

TABLE 4.—Frequency distribution of fish in each sensory texture score category and intensity of white pseudocyst infection in Pacific whiting over 27 cm. n = 562.

White pseudocyst count (ave./fillet)	Number of fish in each sensory texture score category									Row total	Percent of n
	9	8	7	6	5	4	3	2	1		
0	5	131	69	7	1	1				214	38.1
1-10	2	49	59	24	14	2	1			151	26.9
11-25	1	5	15	23	11	9	2			66	11.7
26-50		3	5	18	14	5	4	1		50	8.9
51-75			2	3	9	10	1	0		25	4.4
76-100			0	1	2	3	3	0	2	11	2.0
101-125		1	0	1	1	1	4	5	1	14	2.5
126-150						1	1	1	0	3	0.5
151-200						2	3	9	2	16	2.8
201-300							1	1	4	6	1.1
301-400						1	0	0	0	1	0.2
401-800								1	4	5	0.9
Total of infected fish	3	58	81	70	51	34	20	18	13	348	
Percent of n	0.5	10.3	14.4	12.5	9.1	6.0	3.6	3.2	2.3	61.9	100.0

TABLE 5.—Frequency distribution of fish in each sensory texture score category and intensity of black pseudocyst infection in Pacific whiting over 27 cm. n = 562.

Black pseudocyst count (ave./fillet)	Number of fish in each sensory texture score category									Row total	Percent of n
	9	8	7	6	5	4	3	2	1		
0	2	97	72	15	9	4	3	2	0	204	36.3
1-10	5	74	62	42	31	21	8	6	4	253	45.0
11-25	1	14	10	9	8	5	4	5	2	58	10.3
26-50		4	3	7	4	4	1	4	3	30	5.3
51-75			1	2	0	0	2	0	0	5	0.9
76-100			2	0	0	0	1	0	1	4	0.7
101-125					0	1	0	0	1	2	0.4
126-150					0	0	0	0	0	0	0
151-200				1	0	0	0	0	1	2	0.4
201-300				1	0	0	1	1	0	3	0.5
301-400									1	1	0.2
401-800										0	0
Total of infected fish	6	92	78	62	43	31	17	16	13	358	
Percent of n	1.1	16.4	13.9	11.0	7.7	5.5	3.0	2.8	2.3	63.7	100.0

cyst counts and 5 of 8 (63%) with black pseudocyst counts fell in the 1 to 3 texture category. Although the data are limited, this may suggest that for lower counts black pseudocysts are not related to poor texture, whereas for higher counts, they are ($r = -0.38$ at $P = 0.001$).

In this study, 459 out of 562 fish were infected with the myxosporean parasite *Kudoa*. However, knowing that only white pseudocysts contain the parasites that produce the proteolytic enzymes that adversely affect texture (Tsuyuki et al. 1982), the assessment of the effect of pseudocyst infections on texture was necessarily confined to white pseudocyst counts only. Therefore, in order to determine the most likely white pseudocyst count which, when exceeded, would produce an abnormal texture in the cooked fish, the following analysis was made. On the scale of firmness in Table 1, the minimum acceptable texture value was defined as 3. Only 20 fish were rated 3. Their mean intensity of infection was 94.9 pseudocyst counts and median intensity was 88. Consequently, fish with median intensity ≥88 pseudocyst counts were hypothesized to be abnormally textured. On a qualitative scale this level of infection was considered heavy. To test this hypothesis, all fish having infection intensities ≥88 white pseudocyst counts were computer selected. There were 50 such fish. These included 90.3% of all the fish with abnormal textures (sensory rating of 1 to 2), but also included 3.9% of all the normal or soft-textured fish (sensory rating of 3 to 9). Next, fish with average sensory textures (5) were selected to determine the white pseudocyst counts below which sensory textures would most likely be normal. The median pseudocyst count for these fish was 23. Counts below 23 were considered indications of a light infection. The level of infection between these two counts (23 to 88) was considered to be moderate.

Because black pseudocyst counts correlated poorly with sensory texture in this study, the degree of black pseudocyst infection had to be arrived at from cullability figures using the culling techniques described previously. The cullability categories were determined visually and, like the white pseudocysts, described as light, moderate, and heavy. Confidence limits for black pseudocyst counts for each cullability category were statistically determined and the midpoint between the high end of one confidence limit and the low end of the adjoining confidence limits was taken as the dividing point. The following range of black pseudocyst counts was arrived at for each category: none (0); light (1 to 28); moderate (29 to 79); heavy (80 or more).

Effect of Geographical Areas

Data in Figure 6A shows the percentage of the catch from the various survey areas sampled in this study and their related sensory textures. Based on results of our sensory evaluations, 13% of the Pacific whiting harvested from the Monterey-Eureka, CA, sampling areas had abnormal textures, whereas only 1 to 3% of the Pacific whiting caught between the Columbia River and Vancouver Island had abnormal textures. The correlation coefficient between survey area and sensory texture rating was 0.20 at $P = 0.001$.

Similarly, the incidence of heavy white pseudocyst infection (>88 pseudocyst counts) was about threefold greater in the Pacific whiting from the Monterey-Eureka, CA, corridor (Fig. 6B) than in whiting caught between the Columbia River and Vancouver Island, i.e., 16 to 11% vs. 5 to 4%. The percentage of no white pseudocyst found in the fish samples from all survey areas ranged from 25 to 34%.

The trend in black pseudocyst counts (Fig. 6C) was similar to the trend in white pseudocyst counts in that more heavy (>80) black pseudocyst counts were observed in Pacific whiting caught between Monterey-Eureka, CA, and the Columbia River than in Pacific whiting from the Vancouver Island area. Two to three percent of the Pacific whiting sampled from the area between Monterey, CA, and the Columbia River were heavily infected with black pseudocysts, whereas no heavy black pseudocyst infections were found in the Pacific whiting caught from Vancouver Island area. Infections of black pseudocysts in Pacific whiting from the Vancouver Island area were primarily light (1 to 29), the category into which 84% of the infected fish fell, and moderate infections (29 to 79), the category in which 4% of the infected fish fell.

Table 6A shows the prevalence of the *Kudoa* species found in Pacific whiting caught between Monterey, CA, and Vancouver Island, Canada. *Kudoa paniformis* was the predominant species (average 36 to 37%) found in the Pacific whiting taken in the Monterey-Eureka area, whereas *K. thyrsitis* was the predominant species (29 to 40%) in the fish caught north of the Columbia River. Mixed infections averaged 34% for the combined survey areas.

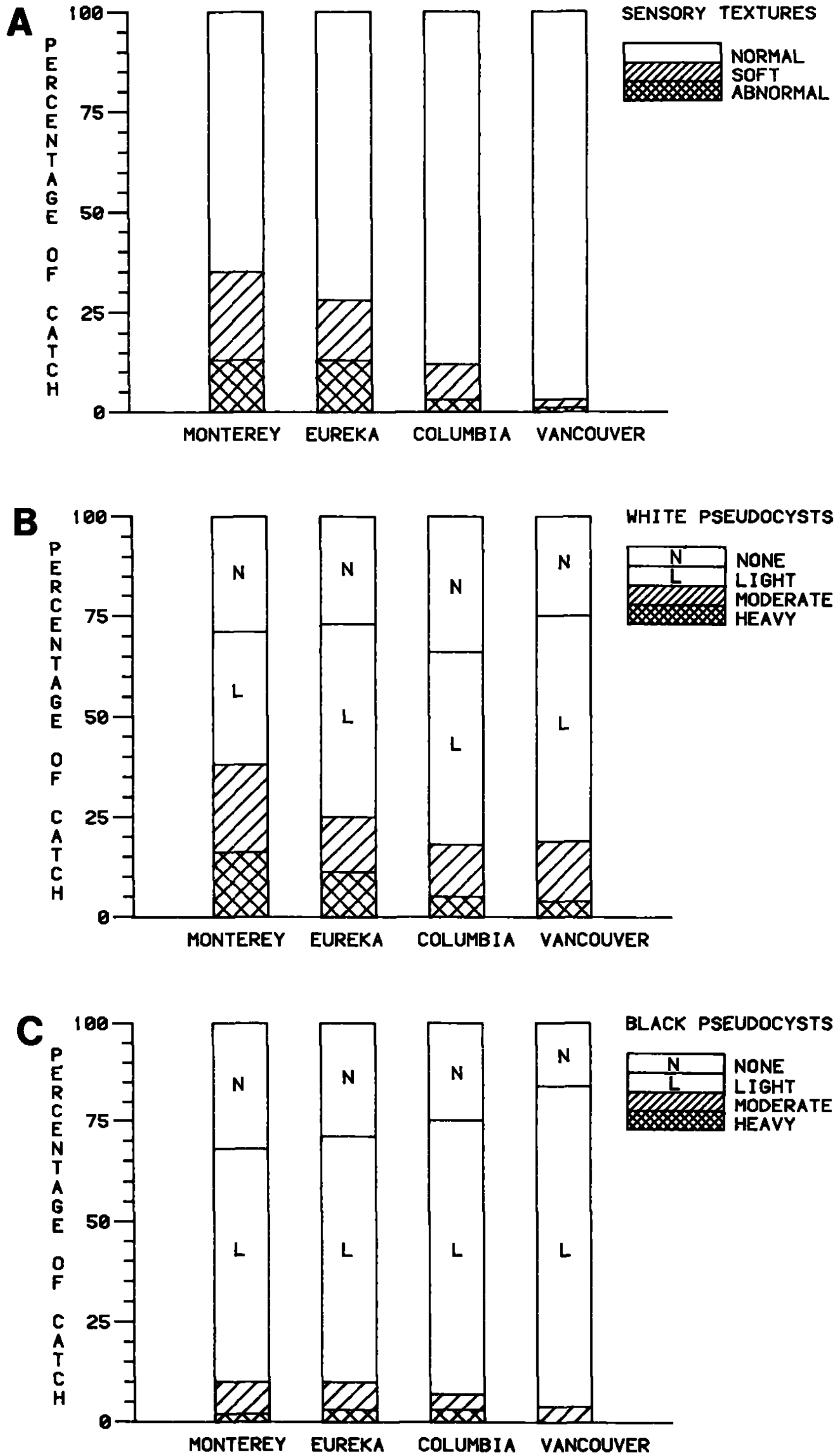

FIGURE 6.—Occurrence (%) of (A) sensory texture categories, (B) degree of white pseudocyst infection, and (C) degree of black pseudocyst infection of Pacific whiting, by INFPC areas.

TABLE 6.—(A) Prevalence of *Kudoa* species, (B) fork length composition (%), and (C) sex ratio of Pacific whiting samples in the INPFC catch survey area.

Description	INPFC survey area				
	Monterey	Eureka	Columbia	Vancouver	All areas
Sample size (fishes)	136	117	234	75	562
(A) *Kudoa* species (%)					
K. paniformis	36	37	18	15	26
K. thyrsitis	7	15	29	40	22
Mixed infection	35	27	35	39	34
None	22	21	19	7	18
(B) Fork length composition (%)					
Small (27-39 cm)	30	33	26	7	26
Medium (40-49 cm)	31	29	31	32	31
Medium large (50-59 cm)	27	28	30	40	30
Large (60-80 cm)	13	10	13	21	14
(C) Ratio of female/male	1.2	1.3	1.6	2.2	1.5

Effect of Biological Factors on Sensory Texture

Biological data showing sex composition, the ratio of females to males, and representative fork lengths (FL) and their relationship to corresponding sensory textures and survey areas are given in Tables 3B, 3C, 6B, and 6C, respectively. The ratio of females to males nearly doubled as fishing activities in this study moved from south to north along the Pacific coast. Concurrently, the fork length of the fish increased as well. About 60% of the largest fish (60 to 80 cm FL) were caught between the Columbia River and Vancouver Island. More abnormal textures were oberved in the larger fish than in the smaller fish (Table 3B). Based on the total number of specimens examined, however, the correlation coefficient for the relationship between fork length and sensory texture was low ($r = -0.21$ at $P = 0.001$).

Sensory texture was not found to be related to the sex of the fish ($r = 0.04$ at $P = 0.181$, Table 3C). The percentage of abnormal textures in the female and male fish was about the same, i.e., 6 and 8%, respectively, confirming the reports of Kabata and Whitaker (1981). Similarly, males and females were evenly distributed (approximately 12%) in the soft-texture category.

The Relationship of Pseudocyst Counts to Location of Infection in a Fillet Area to Texture

Results of analyses to determine the relationship of intensity of infection in a fillet area (Fig. 3) to texture quality are shown in Table 7. Pseudocyst infections were found throughout the fillet areas. The highest percentage (11 to 12%) of heavy infections of white pseudocysts were located in the nape area, whereas the lowest incidence (8%) was located in the tail ($r = 0.89$ at

TABLE 7.—Percentage of degree of *Kudoa* pseudocyst infection and corresponding sensory textures found in preselected examination areas of Pacific whiting fillets.

	Fillet area examined					
	Nape		Middle		Tail	
	Dorsal	Ventral	Dorsal	Ventral	Dorsal	Ventral
Degree of white pseudocyst infection (%)/examination area						
None	38	41	41	43	46	46
Light (1-22)[1]	32	34	33	37	32	34
Moderate (23-87)[1]	18	15	17	13	15	13
Heavy (88 and over)[1]	12	11	9	8	8	8
Degree of black pseudocyst infection (%)/examination area						
None	41	34	43	40	44	41
Light (1-28)[1]	51	55	51	52	50	54
Moderate (29-79)[1]	6	8	4	6	5	3
Heavy (80 and over)[1]	2	3	2	2	1	2
Sensory texture(s) (%)/examination area						
Normal	77	82	81	85	85	87
Soft	12	10	11	10	10	10
Abnormal	11	8	8	5	5	4
Sample size	502	548	562	556	560	551

[1]Pseudocyst counts.

$P = 0.008$). Incidences of heavy infections of black pseudocysts were 2 to 3% at the nape and about 1 to 2% at the tail ($r = 0.71$ at $P = 0.06$). In general, there tend to be more black and/or white pseudocysts in the nape than in the tail area, although the correlation of white pseudocysts in the dorsal to ventral direction was rather low ($r = -0.21$ at $P = 0.035$).

Sensory texture profiles shown in Table 7 indicated that more abnormal textures were found in the nape area (11 to 8%) than in the tail area (5 to 4%) of the fish examined ($r = 0.48$ at $P = 0.16$).

Effect of Culling

At the present time, there is no accepted method or methods for efficiently detecting and culling Pacific whiting infected with white or black pseudocysts. Ultraviolet light and back lighting with white light have been tried on occasion, but these techniques have not been developed enough to be effective for use in Pacific whiting production. This leaves visual detection as the only on-site method for detecting and removing suspect Pacific whiting from the production line. However, as there are no reliable data available concerning the effectiveness of visual culling, an attempt was made in this study to estimate its potential usefulness.

Criteria for culling (Patashnik et al. 1982) in this study was described in a previous section. Of the 562 fish examined, 34 were visually culled on the basis of a moderate to heavy degree of white and black pseudocyst infection. Of these, 10 fillets were moderately to heavily infected with white pseudocysts, 7 with both black and white pseudocysts, and 17 with only black pseudocysts. Based on the criteria developed by Patashnik et al. (1982), these results suggest that culling fillets that are moderately or heavily infected with pseudocysts appears possible. However, since culling has not been successfully demonstrated in a commercial setting, the technique may prove to be too difficult and time consuming to be practical.

CONCLUSIONS

Overall, 18% of the Pacific whiting samples collected for this study were uninfected with *Kudoa*. Furthermore 65% had counts of <10 white pseudocysts, and only 10% had counts over 100 white pseudocysts. By comparison, 81% of the fish samples had <10 black pseudocysts counted and only 1% were infected with over 100 black pseudocysts counted.

When both the white and black pseudocyst counts were considered collectively, the variation in white pseudocysts explained 55% of the variation in sensory texture, whereas black pseudocysts accounted for 14%. However, when the effect of the white pseudocysts was mathematically removed from the fish samples having both, the black pseudocysts were found to explain only 1.5% of the variation in sensory texture.

Infections of white *K. paniformis* and white mixed infections correlated ($r = 0.80$ and 0.79, respectively) with the variations in sensory texture better than the black *K. paniformis* or black mixed infections (0.66 and 0.49, respectively). Neither the white nor the black *K. thyrsitis* pseudocyst counts correlated well with sensory textures. Although common in the Pacific whiting samples examined in this study, *K. thyrsitis* consistently were found in low numbers. On the other hand, *K. paniformis* were identified in 26% of the sample, and mixed infections were observed in 34% of the fish examined.

The heaviest infections of white and black *Kudoa* sp. pseudocysts were found in the Pacific whiting caught off the coast of California. The highest percentage of abnormal sensory textures were also observed in the fish harvested off the California coast.

Generally, in this study, we found that the larger the fish the greater the incidence of abnormal textures. Sex of the fish had no apparent effect on the quality of sensory texture.

Anatomically, the nape and dorsal areas of the Pacific whiting samples examined tended to have higher counts of white pseudocysts, and therefore more abnormal textures, than the other areas of the fish examined. The occurrence of heavy white pseudocyst infections in the nape, middle, and tail sections of the fish samples averaged 11.5%, 8.5%, and 8%, respectively. Heavy black pseudocyst infections were 2.5%, 2%, and 1.5% for nape, middle, and tail sections. Overall, abnormal textures were found 9.5% of the time in the nape, 6.5% in the middle, and 4.5% in the tail. Differences in the number of white pseudocyst counts found between the dorsal and ventral sides of the fish were small. The occurrence of abnormal texture was 30% greater for the dorsal side of the fish than the ventral side.

Results of visual culling in this study suggest that the method may have some potential, but that the technique has yet to be successfully demonstrated under commercial conditions.

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