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Chalky halibut investigations, 1997 to 1999

by

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Contents

Abstract

At the request of the Pacific halibut fishing industry, the International Pacific Halibut Commission (IPHC) has conducted three years of investigation into the occurrence of chalkiness in Pacific halibut landings. During 1997 and 1998, industry surveys determined the incidence of chalky halibut at about a half percent in Alaska, one percent in Canada, and up to ten percent in waters off Washington and Oregon, with a trend for increased chalkiness during the warmer late-summer and early-fall months. In 1999, the IPHC conducted an experiment to determine the effects of post-capture handling, particularly stunning and bleeding, on the development of chalkiness. This experiment shows no relationship between these handling methods and chalkiness. There was a strong relationship between chalkiness and both fishing ground and sex.

Chalky halibut investigations, 1997 to 1999

Stephen M. Kaimmer

Introduction

While the first records of chalky halibut investigations date from the 1950s (Bell 1950), the first published studies into chalky halibut are from the mid-1960s with reports from joint studies by the International Pacific Halibut Commission (IPHC), the U.S. Bureau of Commercial Fisheries in Seattle, WA., and the Pacific Biological Station in Nanaimo, B.C. (Patashnik 1966, Patashnik and Groninger 1964, Tomlinson et al. 1964, 1965, 1966a, 1966b, and Tarr 1966, 1968). Additional information is contained in unpublished reports from the period (Patashnik 1965, Myhre 1968). In 1985, Alaska Sea Grant summarized the older reports, but added no new information (Kramer and Paust 1985).

The flesh of chalky halibut is a dull, 'chalky' opaque white contrasting with the shiny and semi-translucent flesh of non-chalky halibut. The visual indications of chalkiness develop post-mortem, and may take up to 7 days to become obvious in fish held on ice. The condition may develop after thawing in fish that have been frozen. Chalkiness can vary in degree, both between fish and within a single fish. The flesh of chalky halibut is more acidic. Fish with flesh pH above 6.2 are never chalky, while those with pH below 6.0 are always chalky. Between pH 6.0 and 6.2, halibut can be chalky, not chalky, or partially chalky. Chalkiness may develop more quickly or to a greater degree in fish held at higher temperatures. The lowered pH results in the denaturation of muscle proteins, which in turn is associated with lowered protein solubility and less water holding capacity (drip loss increasing from 1-2% in non-chalky flesh to 4-9% in chalky flesh). Less water means that chalky fish are equal or superior to non-chalky fish *nutritionally,* with higher percent oil and protein content. The visual appearance of chalky fish is caused by this change in the state of muscle proteins. The cooked meat of chalky halibut may be drier and tougher than non-chalky flesh, but is otherwise acceptable as a food product.

The drop in muscle pH is associated with the pre-death metabolic breakdown of glycogen and the formation of lactic acid in the muscle tissue (for more detail see Appendix). Lactic acid is one byproduct of the conversion of glycogen into energy. During normal activity levels, less lactic acid is produced, and that which is produced can be broken down and removed from the body. During periods of high energy need, more lactic acid is produced than can be removed, and it accumulates in the body. The buildup of lactic acid is associated with fatigue, a condition that inhibits muscle contraction. A fish that dies in a state of fatigue has a high amount of lactic acid in the blood and tissues. This lactic acid is directly responsible for the acidic denaturation of muscle proteins, and the change in visual appearance of the tissue.

Rest or periods of lesser activity result in decreases in lactic acid levels, and the recovery from 'fatigue'. Possible causes of the increased lactic acid concentrations in landed halibut include death occurring while the fish is stressed or exhausted, or possibly feeding differences resulting in high muscle glycogen reserves at time of capture. A fish that dies immediately after a highly active period will develop high levels of lactic acid (low pH) and is likely to be chalky. Chalkiness is more frequent in trawl caught fish.

Halibut evade trawls by swimming ahead of the footrope. Halibut are caught by trawls when the they drop back across the footrope, exhausted. These fish would have been subject to extreme stress and exhaustion. Halibut caught by trawls still alive, allowed to recover in a holding tank for 10 to 13 hours, and then killed and dressed, had a lower percentage of chalkiness than fish which were not allowed a recovery time after capture. Fish caught on setlines alternate periods of intense swimming activity with periods of rest, the duration of the rest periods increasing as the fish presumably approach exhaustion (Kaimmer 1999). Setline-caught halibut that have had a sufficient rest period before gear retrieval could have lower lactic acid levels and less chalkiness. Well-fed fish would have high reserves of energy (glycogen). These fish may exercise more strongly at capture, producing higher lactic acid levels. It could take longer to recover the tissue acid-balance in these fish, making them more likely to be chalky.

Industry Surveys

The current IPHC chalky halibut investigation was started with mail surveys of the industry in 1997 and 1998. These surveys determined the extent and distribution of reported chalkiness in overall halibut landings during the years 1996 through 1998. Reports on specific instances of chalky halibut occurence were solicited from halibut processors for the years 1997 and 1998. The information from the chalky incidence reports was not very useful, documenting only 53 incidents in 1997 and nine in 1998. Almost three-quarters of the 53 incident reports received during 1997 were from two processors, and were limited in the times and areas represented. The year-summary surveys were more useful. Twenty-two surveys were received for 1996, 13 for 1997, and 27 for 1998 (Table 1), representing from 43 to 67 percent of the halibut production in those years. Responses were spread across all areas, with only Area 2A being poorly represented. A phone survey was then directed at halibut buyers in Area 2A during 1998. The surveys reported some chalkiness from all areas, and during all months of the 2A fisheries.

Table 1. Summarized results of industry surveys conducted during 1997 and 1998.

	1996	**1997**	**1998**
Number of reports	22	14	27
Total pounds of chalky fish reported	58,000	124,000	375,000
Percent identifying chalky fish as a "problem"	59%	43%	67%
Total landings represented (millions of pounds)	11.8	17.0	57.8
Total fishery landings (millions of pounds)	43.9	47.3	65.0
% of total fishery landings represented in survey	26.9%	35.9%	88.9%
Where chalky fish were identified[1]			
During landing by fishers	23%	8%	11%
During processing	55%	31%	48%
By later claims from buyers	46%	46%	56%
Percent chalky by region			
Washington and Oregon (Area 2A)	n/a	-[2]	2.5%[2]
British Columbia (Area 2B)	n/a	1.0%	0.9%
Alaska (Areas 2C, 3 and 4)	n/a	0.5%	0.4%

[1] Respondents were allowed to check none, or more than one box for this question, letting totals across categories total more or less than 100%.

[2] There were few survey responses from Area 2A buyers. The value for 1998 comes from a phone survey conducted during the fall of that year.

Survey biases

There are a number of possible biases in the surveys. Chalky fish is not often detected when the fish are first sold. While it may take up to a week for fillets to go white and opaque, many commercial vessels sell their catch after only a few days. Further, chalkiness is often not noticed until fish are cut into either fillets or steaks. Many fish, probably more than half of the entire production, are not cut at the buying plant beyond removal of the head. The whole fish are either shipped fresh to wholesale buyers or frozen for the same market. The surveys reported that most of the chalky fish was recognized through claims by these subsequent buyers. An alternate detection method could be through measuring the muscle pH of each fish when it is offloaded from the catching vessel, but the reported 30 second or so time delay for each reading with currently available meters may make this impractical for many plants (personal communication. Blake Tipton, S.M. Products Ltd., Delta, B.C.). All of these factors complicate effective screening for chalkiness in whole fish landings, and could cause a general under-reporting of chalkiness. It is also possible that chalky fish goes purposely unreported, in an effort to downplay the problem, or over-reported in an effort to get a reduction or rebate on the price paid for the fish. We have no way of determining whether either of these biases in fact exists, and, if so, the degree to which survey results are effected.

Survey results

The surveys indicated overall incidences of chalky halibut at about a half percent in the combined Alaska Areas 4, 3, and 2C, one percent in Area 2B, and up to ten percent in Area 2A (Fig. 1). More detail on these surveys and survey results can be found in Kaimmer (1997, 1998). From the 1997 and 1998 incidence reports, and from anecdotal data, there is a pattern in area and time of chalky fish occurrence, with chalkiness more common during the hot months of late summer and early fall. Chalkiness is common throughout the mid-summer fisheries in Area 2A. Chalkiness is generally first seen in Canada in the waters outside of Vancouver Island during mid-August and over a period of a few weeks becomes evident to the north in the waters of Hecate Strait (personal communication Blake Tipton, S.M. Products Ltd., Delta, B.C.). A similar pattern is seen in Area 3A, where first

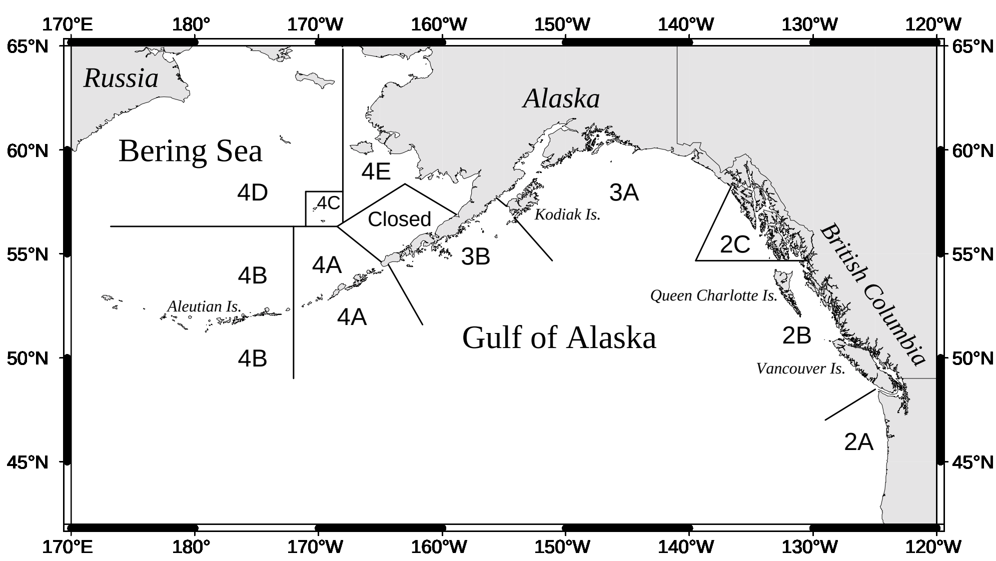

Figure 1. IPHC regulatory areas.

reports are often seen around the southern end of Kodiak Island in early September, then moving north and east into the waters of Cook Inlet and Prince William sound (personal communication Brad Faulkner, Alaska Custom Seafoods, Homer, AK).

Post-capture Handling

During 1999 the IPHC conducted a study suggested by industry on the effects of stunning and/or bleeding on the development of the chalky condition. A core team of industry members commented on project design and helped track evidence of chalky halibut during the 1999-fishing season. Chalky halibut was expected to be most evident in the late summer or early fall, and the field experiments were timed to coincide with these time periods.

Methods

Pilot study, tag type, and tag placement

A pilot study during a 1999 IPHC grid-fishing charter determined a tag type and developed the methodologies for tag attachment and body-temperature measurement. During the pilot study, approximately 100 fish were tagged with both t-bar tags and metal strap tags (Floy Tag Co., Seattle, WA; tag styles TD-68B anchor tags and 10045-49 monel strap tags), and marked with a length of surveyor’s tape tied around the mouth, through the opercular flap. Tags were attached to maximize holding power while minimizing any high profiles that might result in tags being torn off during handling. Strap tags were attached across the underside of the white-side pectoral fin, going through the thickest region close to the base of the fin. The t-bar tags were attached into the knobby area underneath the white-side pectoral fin, with the body of the tag lying under the fin. Once sold, all marked fish were tallied to determine tag loss. Both tag types had low and similar tag-loss rates. Difficulties in attaching the t-bar tags and in maintaining the t-bar tag applicators resulted in choosing the strap tag for the main study. A relatively inexpensive digital stem thermometer (Accu-Tuff #12710, Atkins technical, Inc., FL, USA) was assessed for usability during the pilot project. This thermometer was not waterproof, and was determined to be unsuitable for the main study.

Design and analysis

Experiments were conducted in Area 2B and in Area 3A. Each experiment was limited to catching not more than 50,000 pounds of legal-sized halibut. Eighteen to twenty sets of gear were estimated to be necessary for the analysis, and fishers were instructed to avoid fishing locations where catches would exceed 2,000 pounds per set. Four skates of IPHC standard gear[1] were fished at each set. Trips were designed to re-create fishing conditions experienced by commercial fishers, with set and soak times left to the discretion of the chartered vessels. Each experiment was conducted as a randomized block design, testing the two factors stunning and bleeding. A 2´2 factorial on the factors gave four treatment groups; stunning, bleeding, stunning and bleeding, and no treatment. As fish were caught, each fish was tagged and randomly assigned to one of four treatment groups. Each set was considered to be an experimental block. The experimental design requires equal replication

[1] IPHC adjusts fishing effort to an equivalent 1800-foot skate of gear with 16/0 circle hooks at 18-foot hook spacing. Most IPHC experimental fishing uses this gear.

within sets (blocks) and allows proportional replication between sets; sets could vary in the overall number of fish caught, as long as within each set the number in each treatment group was the same. Fish were randomly assigned to the treatments in groups of four, maintaining the proportion of fish assigned to each group in each set for every four fish caught.

The IPHC awarded two vessel charters following a bid procedure, one to the *F/V Angela Lynn* in Area 3, and one to the *F/V StarWars II* in Area 2B. Prior sale arrangements with New West Fisheries (Bellingham, WA) and S. M. Products facilitated checking for chalkiness after landing, the former to buy Area 3 fish in Homer and the latter to buy the Area 2B fish. These processors also advised on times and areas where we would be most likely to experience chalky halibut. Area 3 fish were shipped to Bellingham, WA, for processing, while the Area 2B fish were shipped to Ladner, B.C.

It was expected that as many as three observations would have to be randomly removed from each set to achieve the required equal replication within sets. This procedure was further complicated by tag losses between initial tagging and fish examination at the processing locations, which in some cases required some additional removals of observations from individual blocks. In all, 85 of the Alaskan observations were randomly deleted from individual treatment groups prior to ANOVA procedures. Tag loss and chalky reporting problems with the Area 2B data set precluded using an ANOVA procedure on that data.

Shipboard handling and data recording

One of the four treatment groups (stunning, bleeding, stunning and bleeding, or no treatment) was assigned immediately after tagging. Core body temperatures were taken from a 12-fish sample at the start of each gear retrieval to estimate a typical capture temperature for all fish in a set. A digital stem thermometer (Hanna HI9063, Hanna Instruments, Italy) was used for all body temperature measurements. After making a small cut through the skin midway between the eye and the dorsal fin, the thermometer probe was inserted about one inch into the flesh. Temperatures were read and recorded to the nearest 0.1 ºC.

Time of capture and whether fish were moribund or extremely active was also recorded. About 1/4 to 1/3 of fish caught and tagged were set aside for up to three hours prior to dressing. After dressing and prior to each fish being iced for storage, fish length, sex, maturity, core body temperature, and time of icing were recorded

Shore handling

After sale, fish were held on ice from two to four days to allow chalkiness to fully develop. This was facilitated by the transit time necessary to ship fish from the point of sale to processing locations. As many fish as practical were checked for chalkiness at the processing locations. This was either through a visual inspection of a cut made about mid-body and just below the dorsal fin (Fig. 2), or inspecting fillets or steaks cut from tagged fish (Fig. 3). Records were kept on all fish with tag number and comments including time and day of processing and location and degree of chalkiness. Some fish were sent out whole to retail buyers. Chalkiness on these fish was to be determined by subsequent claims.

Results

Fishing success

Three fishing trips were completed, two in Canada and one in Alaska (Table 2). The *Star Wars II* completed two trips in the Hecate Strait region of Area 2B, fishing from

Figure 2. Location of cut just below dorsal fin to visually determine chalkiness.

Figure 3. Chalky fillet (right) and non-chalky fillet (left). The chalkiness in the fillet on the right is fully developed throughout the entire fillet.

August 24-29 on the first trip and from August 31 through September 1, 1999 on the second. The first trip was delivered in Port Edward, B.C. These fish were then trucked to Ladner, B.C. and processed on September 1. On September 3, the second trip was delivered in Port Hardy, B.C. These fish were processed in Ladner on September 7. From both trips, the *Star Wars II* completed 46 sets, tagging 1,427 fish.

The *Angela Lynn* completed one trip, fishing from September 6-12, mostly in the Semidi Island region of Area 3B. Although we had expected to fish in Area 3A, few chalky fish had been seen in this area prior to the start of the charter. The fish were delivered to Homer, AK on September 13. Fishing was conducted in three areas; off Chiginagok Bay west of the southern end of Kodiak Island, off the southeastern corner of the Semidi Islands, and off Seldovia in outer Kachemak Bay. Chalky halibut had been reported from the first two areas. The Chiginagok area was abandoned

Table 2. Summary by fishing ground of fishing success and incidence of chalkiness.

Alaska data *F/V Angela Lynn*	**Alaska Peninsula**	**Semidi Islands**	**Kachemak Bay**	**Total**
Number of sets	4	13	5[1]	22
Pounds sold	-	-	-	41,656
Number of halibut tagged	287	962	66	1,315
Number of tags lost	20	50	7	77
Number of halibut in final dataset[2]	267	912	59	1,238
Fishing depth (min-max)	70-99	40-108	37-60	37-108
Bottom temp	4.7	5.1-5.9	10.0	4.7-10.0
Elapsed days capture to processing	10	7-8	4	4-10
% Chalky overall	7.2%	8.6%	10.3%	8.4%
Observed number male/female	100/164	135/769	4/55	239/987
% male chalky	16.2%	27.4%	50.0%	23.1%
% female chalky	1.8%	5.3%	7.4%	4.9%

Canada data *F/V Star Wars II*	**Ramsey Ground (Trip 1)**	**S and E of Ramsey Ground (Trip 2)**	**Total**
Number of sets	33	13	46
Pounds sold	34,907	17,053	51,960
Number of halibut tagged	850	577	1,427
Number of halibut observed in plant	264	217	481
Number of tags lost from observed fish	33	27	60
Number of halibut in final dataset[2]	231	190	421
Fishing depth (min-max)	66-153	63-78	63-153
Bottom temp	6.7-6.8	6.7-6.8	6.7-6.8
Elapsed days capture to processing	3-8	6-7	3-8
% Chalky overall	15.8%	11.6%	13.8%
Observed number male/female	30/197	39/157	69/354
% male chalky	16.7%	12.8%	13.5%
% female chalky	15.7%	11.5%	13.8%

[1]Only the first of these five sets tagged more than 20 halibut, a criteria of the randomized block design.
[2]Number of halibut in final dataset includes only those fish which retained their tags through final processing and for which chalky determinations were recorded.

when catch rates exceeded design criteria for the experiment. Deteriorating weather near the Semidi Islands resulted in the third area being fished at the end of the experiment. Fish were processed in Bellingham on September 16 and 17. The *Angela Lynn* completed 22 sets, and tagged 1,315 fish.

Shore processing and overall incidence of chalkiness

Fish from Area 2B were initially sorted into market categories by individual fish weight in pounds. About one third of the fish from each Area 2B delivery were either filleted or steaked at the plant. Generally, this was about 25% of the 10-20's and 50% of the 20-40 and 40-60's. All other fish were sent out whole. From the first trip, 43 (16%) of 264 filleted fish were chalky and 33 (13%) of the filleted fish had lost the strap tag. From the second trip, 22 (11%) of 200 filleted fish and 3 (18%) of 17 steaked fish were chalky, and

27 (14%) of the filleted or steaked fish had lost the strap tag. From the fish sent out whole, one chalky claim was received from the first trip and three from the second.

A total of 1,315 fish from the Alaskan trip were headed and washed, with 79 Number 2 fish[2] set aside into totes. The remaining fish were cut just below the dorsal fin to determine chalkiness. One hundred and fourteen of these fish (9.3%) were chalky and set aside, and remaining fish were sorted by market size. All of the Number 2 fish, as well as all of the chalky fish, were then filleted. Chalkiness in the Alaskan fish was especially dramatic, with the wholly chalky fillets in striking contrast to non-chalky fillets (Fig. 3). The differences in fillets from the Canadian fishing were less dramatic, and the assigning of fish into chalky or non-chalky groups was more subjective. During filleting of the Alaskan fish, five of the Number 2s (6%) were determined to be chalky, one entirely and four partially. Of the 114 fish initially determined as chalky, filleting revealed that one fish was not chalky, 95 fish were fully chalky, and 18 fish were partially chalky. Seventy-seven fish (6%) had lost the strap tag. A total of 1,238 halibut from the Alaskan fishing had retained their strap tags and was tracked from capture through processing.

Plant observations on chalkiness from the Canadian fishing demonstrated chalky rates of over 10 percent, while the fish sent out whole received almost no chalky claims. The fish filleted in the plant were chosen randomly from the group as a whole, and the most likely explanation for the difference in rates is non-reporting of chalkiness in the whole fish. A decision was made not to use the data from the fish sent out whole in calculating rates of chalkiness for the Canadian experiment, using only those determinations which were confirmed by direct visual examination by IPHC staff. The exclusion of these fish,

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[2] Many halibut buyers separate fish which have handling marks, scars, or other surface defects into a separate purchasing category, commonly described as ‘number 2’. The purchase price for these fish is usually discounted by some amount to reflect the more limited market into which they may be sold.

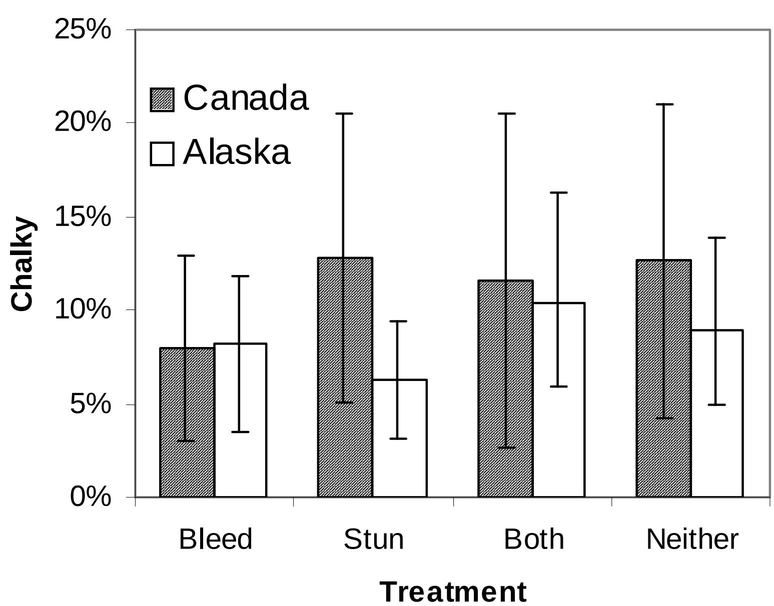

Figure 4. Percent chalkiness by treatment. Error bars indicate 95% confidence intervals about each estimate.

combined with the higher than expected rate of tag loss in the Canadian fish, results in only 421 usable data from the Area 2B experiment. In terms of equal application of treatments within sets, and proportional application of treatments across sets, the data are essentially unusable for the randomized block analysis. Results from the Area 2B fishing are presented and discussed when they appear to differ from, or support trends documented in, the Area 3 data.

Fish handling and other factors affecting chalkiness

There is no relationship between chalkiness and any of the four treatments tested in this study (Alaskan data, df = 17, F = 0.75, p = 0.59). Estimates of relative incidence of chalkiness within the four treatment groups were within percentage points of any of the others for the same area, with broadly overlapping confidence intervals (Fig. 4).

An interesting result in the Alaskan data was the very strong relationship between sex and chalkiness. Males had a rate of chalkiness four times that seen in females (Table 2). Within females, immature and spent females were much less chalky than mature females (Table 3). Aside from considerations of maturity, forklength alone also seems to be a factor in chalkiness (Fig. 5). For both males and females, chalkiness appears to be more prevalent at smaller lengths in the Alaskan fish.

There were also different rates of chalkiness seen among the three fishing grounds in the Alaskan study. The relative rates of chalkiness among males and females are consistent across these areas (Table 3). The reason for the differences by area is unclear. The area with the highest percentage of chalky fish is also the one with by far the fewest data points (58 compared to 263 and 904). The Kachemak area also had the shallowest depths and the warmest bottom temperature. The distributions of the depth and bottom temperature data make these less suitable for testing as factors in chalky incidence. Depths ranged from 37 to 108 fathoms during the Alaskan fishing, with an average depth overall of 95 fathoms. The fishing in Kachemak Bay ranged from 37 to 60 fathoms. Bottom temperatures were only recorded once a day, for a total of seven measurements, and ranged from 4.7 to 5.9 ºC from the Alaska Peninsula and Semidi Islands locations, to a single measurement of 10.0 ºC at the Kachemak Bay location.

Measured core temperatures when fish were brought aboard the vessel ranged from 5.4 to 11.8 ºC. Plotting average core temperature at landing against measured bottom temperature shows good correlation (Fig. 6, $r^2 = 0.62$). There is a complication with using a sample of core temperatures to represent all fish in a set. The gear depth for any one set

Table 3. Chalky halibut (number chalky/total observed) and percent chalky by fishing ground, sex, and maturity from Alaska data. Note that numbers do not include one female with unknown maturity and one immature male.

		Fishing ground			
Sex	**Maturity**	**Alaska Peninsula**	**Semidi Islands**	**Kachemak Bay**	**Combined**
Male	*all mature*	16/99 (16.2%)	37/135 (27.4%)	2/4 (50.0%)	55/238 (23.1%)
Female	*Immature*	0/60 (0.0%)	6/258 (2.3%)	2/27 (7.4%)	8/345 (2.3%)
	Mature	3/92 (3.3%)	33/462 (7.1%)	2/27 (7.4%)	38/581 6.5%)
	spent	0/12 (0.0%)	2/49 (4.1%)	0/0 (-)	2/61 (3.3%)
	Total female	3/164 (1.8%)	41/769 (5.3%)	4/54 (7.4%)	48/987 (4.9%)

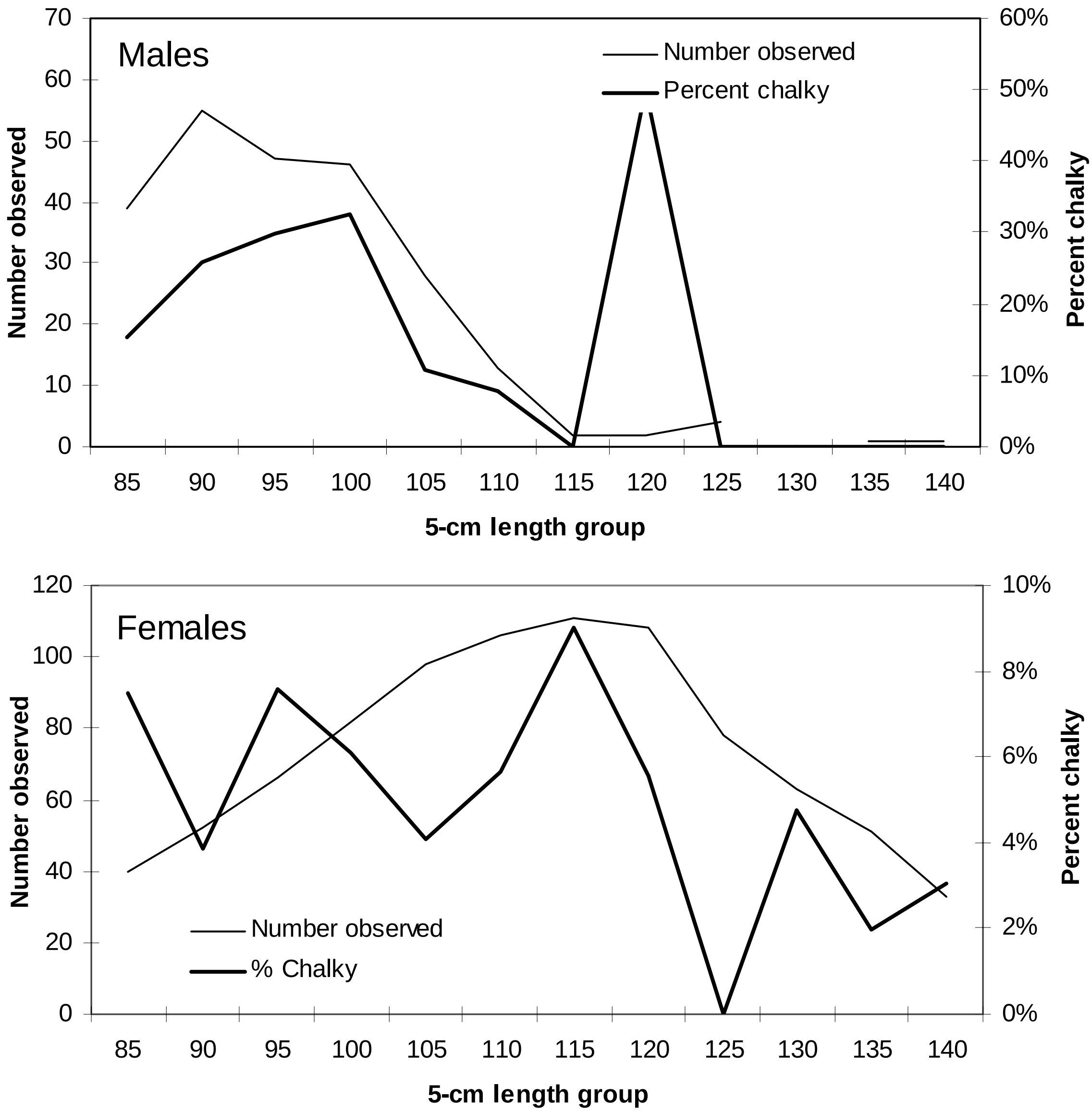

Figure 5. Percent chalkiness by length and sex-maturity group for Alaskan data.

varied from as little as one to as much as 61 fathoms, with an average within-set range of 28 fathoms. We deployed a WADAR device (Water and depth recorder Mod. TL; TSKA, North Bend, WA) tied on to one end of a gear set to record bottom temperature. In two deployments (the fifth and sixth data points in Fig. 6), the WADAR was at the far end of the string as it was being retrieved, and the WADAR depth was much greater than the depth at the first end where the core temperature sample was selected. For these points, the bottom temperature was recorded at 40 and 56 fm, while the core temperature sample was taken from the other end of the sets, which were in much deeper (98 and 99 fathoms, respectively) and presumably colder water. These two data points have the lowest core temperatures, as well as the lowest ratio of core to bottom temperature. Removing the data points from these two sets, the predictive relationship between core body temperature and bottom temperature is improved (r^2 = 0.82). Both of these correlations are significantly

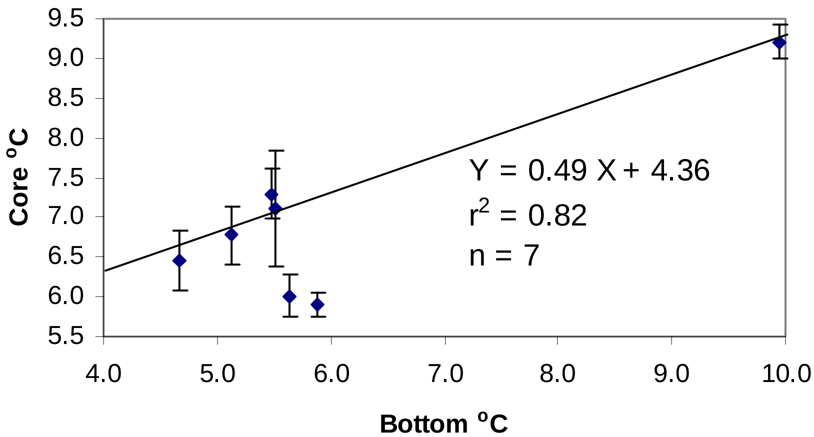

Figure 6. Core body temperature when fish is landed and measured bottom temperature. Error bars represent ± 1 standard deviation. Regression line is excluding data from the fifth and sixth points.

effected by the observation at 10 ºC. This lone point, so far removed from the cluster of points between 4.5 and 5.5 ºC, exerts a strong effect on the resulting regression lines. Core temperatures at the lower bottom temperatures appear to be 1.5 to 2.0 ºC higher than bottom temperature. This could be the result of the fish core warming during the hauling process as the gear is brought up through the thermocline and into warmer surface waters. There is no relationship between chalkiness and landing core temperature for the 294 fish for which landing temperature was directly measured.

A portion of the fish was purposely left on deck for one to three hours before dressing. The core temperatures of these fish warmed as much as 7.6 ºC (average change 2.3 ºC) during this holding (Fig. 7). The lack of a strong relationship between holding time and temperature change is not surprising, as fish are piled into deck bins two or three feet

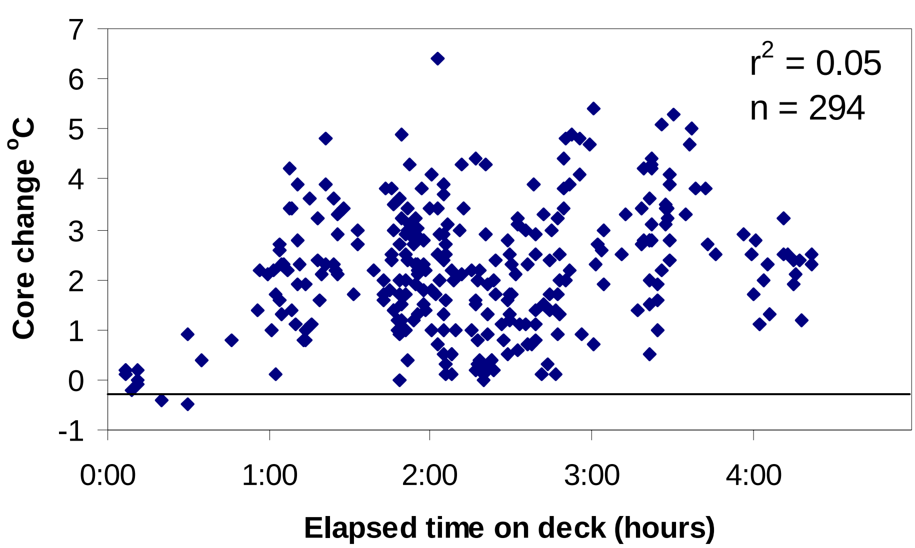

Figure 7. Change in measured core body temperature and elapsed time from landing to dressing.

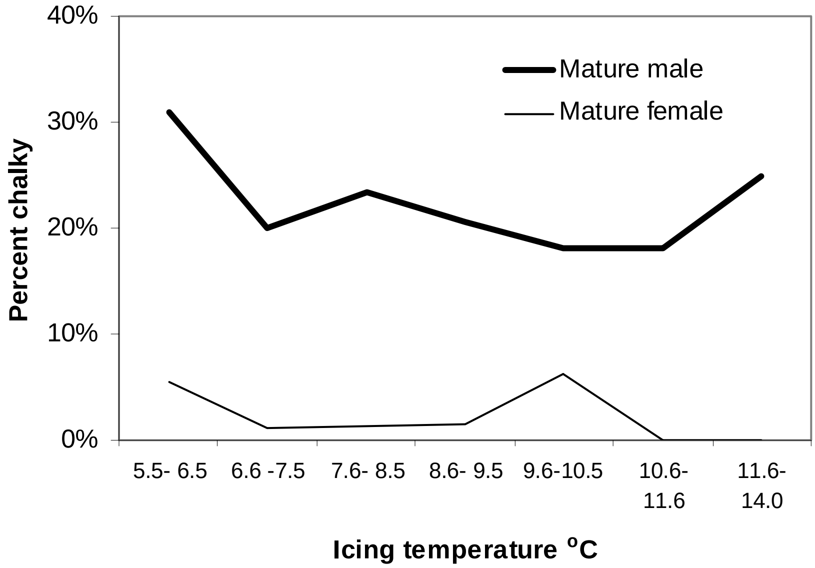

Figure 8. Percent chalky by icing temperature and sex-maturity group for Alaskan data.

deep. Fish in the middle or bottom of a pile might be expected to be well-insulated from effects of air temperature and humidity, while fish on top would be expected to have temperature changes which reflected the ambient environment. There was no relationship between time left on deck or absolute temperature at icing and chalkiness (Figs. 8 and 9).

Soak time ranged from just over five to twelve hours with almost 88% of individual fish caught on sets with soak times between five and nine hours. There was no obvious relationship between soak time and chalkiness (Fig. 10).

Most fish had normal activity at capture, with only 27 fish 'moribund' and 114 'active' (Table 4). This gives small samples to compare to the 1,085 'normal' fish, and chalkiness estimates from smaller groups are probably not as accurate. By sex, chalkiness was much higher for moribund females and normal males were twice as chalky as moribund or active males. Normal and active males were two to four times chalkier than normal and active females, while moribund females are almost three times chalkier than moribund males. Within the current data there is no clear relationship that can be applied across both groups and sexes.

Table 4. Chalky halibut (number chalky/total observed) and percent chalky by activity at landing, sex, and maturity from Alaska data.

		Activity			
Sex	**Maturity**	**Moribund**	**Normal**	**Active**	**Combined**
Male	*all mature*	1/9 (11%)	52/215 (24%)	2/14 (14%)	55/238 (23%)
Female	*Immature*	3/8 (38%)	5/296 (2%)	0/40 (0%)	8/345 (2%)
	Mature	1/8 (13%)	34/518 (7%)	3/55 (6%)	38/581 (7%)
	spent	1/2 (50%)	1/54 (2%)	0/5 (0%)	2/61 (3%)
	Total female	5/18 (28%)	40/869 (5%)	4/100 (3%)	48/987 (5%)
Total		6/27 (22%)	92/1,084 (9%)	6/114 (4%)	104/1225 (8%)

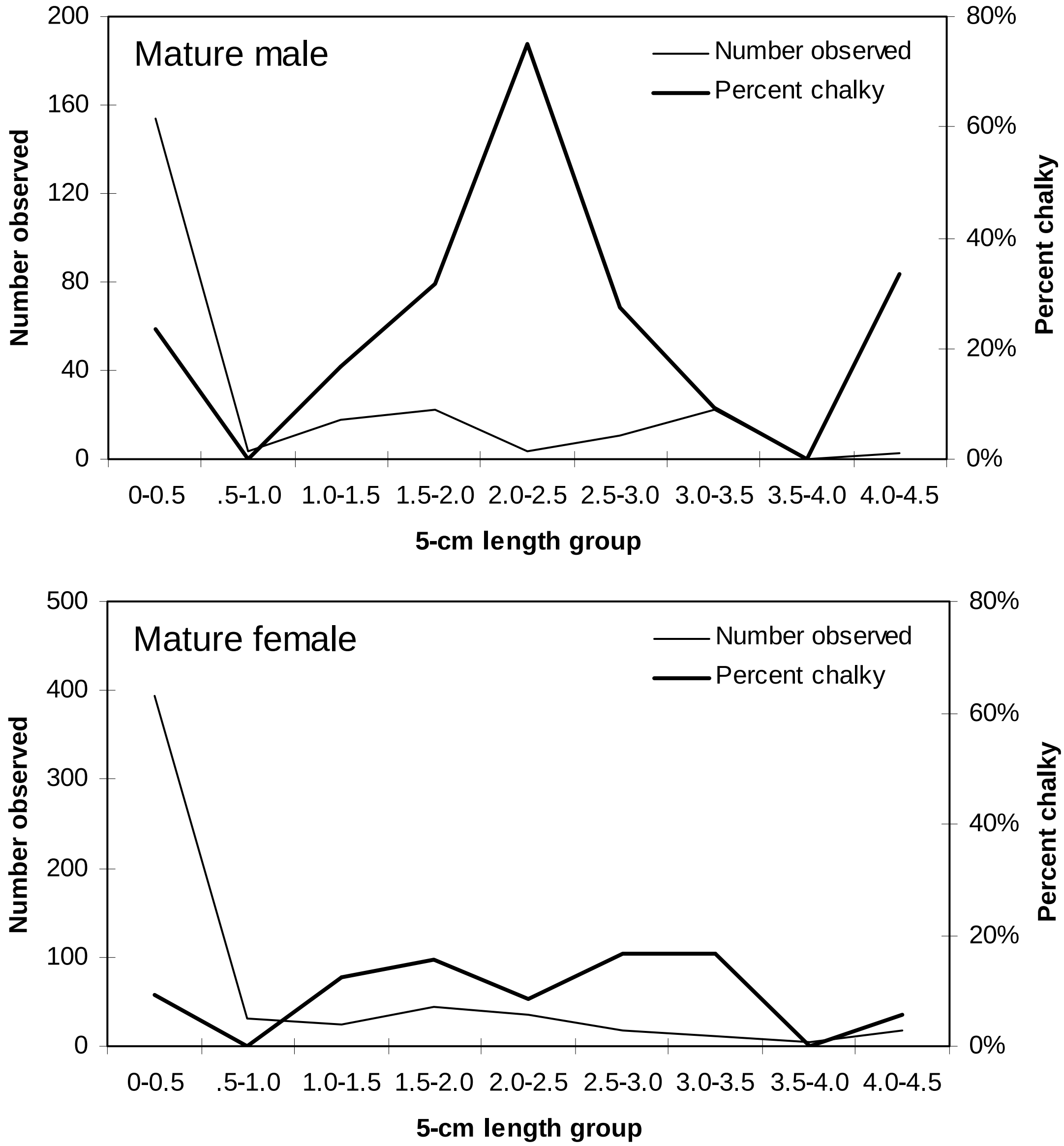

Figure 9. Percent chalky by elapsed time between landing and dressing and sex and maturity group (Alaska data).

Summary

When applied to total landing figures, an overall incidence of one-half to one percent could represent three to six hundred thousand pounds of chalky fish being sent to market. It is possible that increased diligence by fishers can reduce the occurrence of chalky fish. For the most part, fishers now are very aware of procedures to maximize quality of landed product (stunning, bleeding, and rapid chilling), and our studies have not yet suggested any additions to these procedures which would minimize chalkiness. While the literature suggests that proper handling of setline halibut can reduce the development of chalkiness, in no case is there any indication that fish handling can stop or reverse the development of

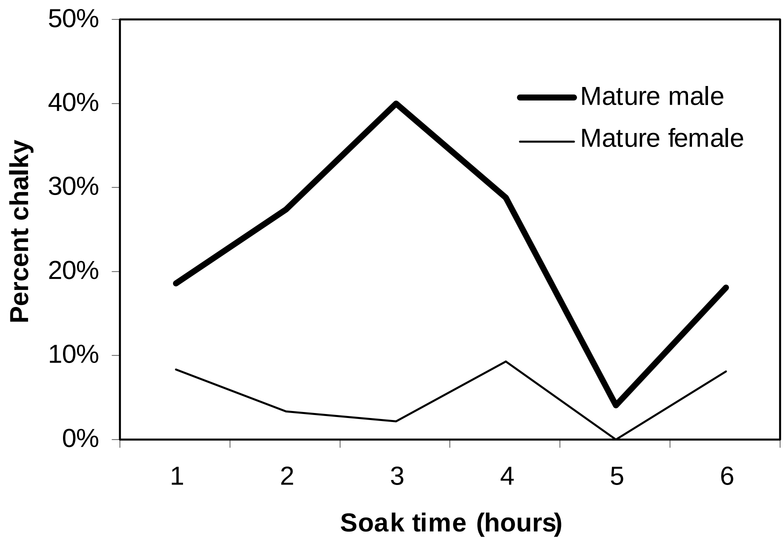

Figure 10. Percent chalkiness by soak time and sex-maturity group for Alaskan data.

chalkiness once the fish dies with flesh pH below 6.0. It is possible that chalkiness endemic to the fishery, even when fish are handled as well as possible.

Neither stunning nor bleeding had an effect on chalkiness. While they are good practice, and undoubtedly improve the appearance and shelf life for Pacific halibut, these techniques do not have an effect on chalkiness. Similarly, neither the soak time nor the time the fish was left on deck before cleaning was significant. The factors that were significant in the fish-handling study are those particular to the fish prior to capture. The most significant effect came from the sex of the fish, suggesting a physiological or behavioral bias for some fish to be chalky. Sex effects, along with effects of area, and possibly bottom temperature and depth, are more important than fish handling within the limits of the generally good handling associated with this experiment.

Although chalkiness may occur in up to a half-million pounds of halibut annually, the biggest problem may come from the difficulty in detecting the condition before it reaches the retail market. Intermediate buyers suffer financial loss due to returned or rejected product, and some members of the industry might forgo purchases of halibut from some areas or during certain periods of the fishery. Consumers who buy chalky halibut may form a poor impression of halibut. Detecting chalky halibut as it is landed would allow the chalky product to be diverted into a different marketing program, reducing the dollar loss from chalky landings. There is a direct causal relationship between flesh pH and the development of chalkiness. Currently, inexpensive portable pH meters are available which can measure flesh pH which a frequency of about two readings per minute and an accuracy of 0.01 pH unit. This reading frequency is impractical for scanning a load of fish to identify those that are, or will go, chalky. A reading frequency of five to ten readings per minute could be practical. While an investigation into the physiology of chalkiness would be interesting, of immediate benefit to the industry would be development of a usable methodology for chalky detection that could be applied quickly and easily to fish as they are offloaded from the vessel. This would allow the dockside buyer to pay less for this portion of the delivery, reducing dollar loss from product rejection or return by retail buyers. This would also allow chalky product to be diverted into secondary markets and away from the fresh-fish retail sector.

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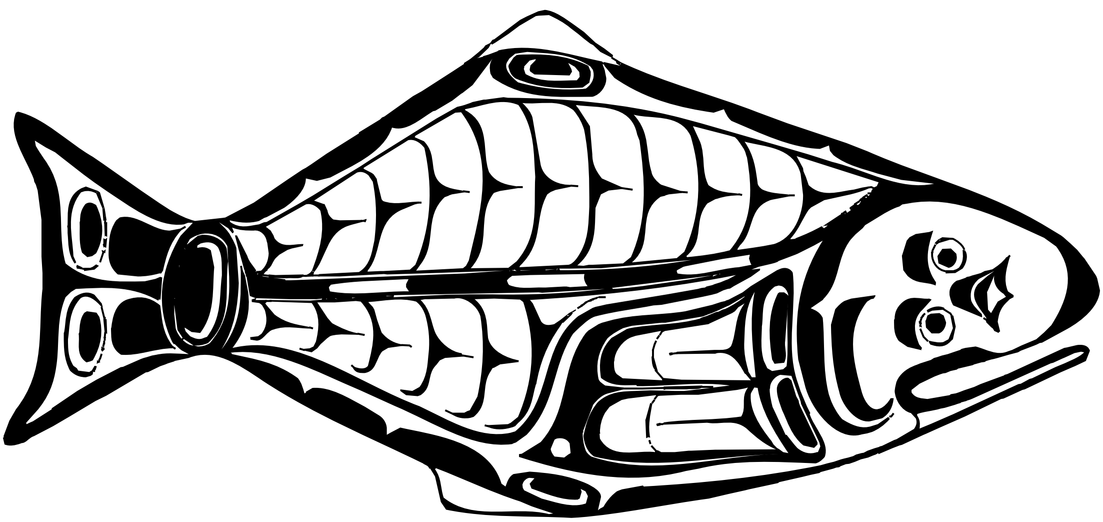
Appendix: Fish fatigue, lactic acid, and chalkiness

Muscle tissue stores energy in the form of long glucose chains called glycogen. Energy is released from glycogen by the process of glycolysis. This is the energy that fuels muscle contraction, and all other cellular energy-dependant functions. In the first stage of glycolysis, energy is produced when glycogen is converted from six-carbon molecules into three-carbon molecules called pyruvic acid, or pyruvate. Under conditions of normal activity, all the pyruvate produced is shuttled into mitochondria within the muscle tissue where oxidative breakdown produces further energy. This is the normal metabolic path for pyruvate, producing the most energy for the tissue.

Mitochondrial energy production consumes oxygen, and during periods of high-energy need the amount of oxygen available to the cell determines how much or how fast energy may be produced. When mitochondrial capacity is exceeded, energy production may continue at a lower level by allowing the first step of glycolysis to produce pyruvate faster than it can be metabolized aerobically. Extra energy can thus be made available for brief periods of high activity, like swimming away from a predator, or struggling against capture on a hook. This additional pyruvate is converted anaerobically to lactic acid, or lactate, a temporary dead end in the energy yielding process. If fish could not allow temporary accumulations of lactic acid, their ability to perform brief high intensity exercise would be almost eliminated. The cost to the fish in the short term lies in the accumulation of lactic acid, and this lactic acid must eventually be converted back to pyruvate and subsequently metabolized in the normal aerobic manner.

When the rate of conversion of lactic acid cannot keep up with its production or appearance in the blood, it accumulates and pH is lowered, which inhibits muscle contraction. The fish is therefore fatigued and muscle efficiency is reduced dramatically. A rest period following fatigue gives an opportunity for the aerobic removal of lactic acid from the system. Over time, lactic acid will diffuse from the muscle tissue into blood capillaries, and eventually to the highly aerobic heart, liver, or kidneys or into inactive muscles with higher oxygen reserves. At these locations lactic acid is converted back to pyruvic acid and metabolized by mitochondria or used by the liver as a building block to re-synthesize glucose.

A fish that dies in a state of fatigue has a high amount of stored lactic acid. The increase in lactic acid in the tissue, and corresponding decrease in pH, occurs shortly after death and takes place over a period of 12 to 24 hours or less. This lactic acid is directly responsible for the acidic denaturation of muscle proteins, and the change in visual appearance of the tissue. The denaturation of the proteins, and corresponding visual indications of chalkiness, take place over a period of a few days to a week.



HALIBUT CREST - adapted from designs used by Tlingit, Tsimshian and Haida Indians