Biological Research

Deployment of a water column profiler from a halibut longliner during IPHC survey operations

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Abstract

A water column profiler was purchased and deployed successfully aboard a typical halibut longliner chartered to conduct IPHC stock assessment survey operations. A total of 130 stations was fished by the vessel; conductivity-temperature-depth profiles were successful at 120 of the stations. If outside grant money can be secured, the profiler program can be expanded to become an integral part of the annual IPHC survey.

Introduction

Since the expansion of its survey operations in 1996, the IPHC has annually conducted fishing operations at more than 1000 stations from Oregon to the Bering Sea (Fig. 1). These stations are located on the continental shelf in depths between 35 and 500 meters on an equidistant 10 nautical mile grid. As such, the IPHC operates the largest consistent sampling program of any research agency in the north Pacific. Recently, the IPHC has sought proposals on how this sampling program could be used for other scientific investigations without affecting the core survey activities. One obvious project is the collection of oceanographic data. The IPHC already records bottom temperature at one quarter to one third of the survey stations using a Water Data Recorder (WaDaR), however the potential exists to sample the entire water column. This document describes the selection, modification and deployment of a water profiler (conductivity, temperature, depth (CTD) recorder) from an IPHC survey vessel.

To better understand the factors driving fluctuations in growth and recruitment of fish populations, increasing attention is being paid to climatic and oceanic conditions. Primary and secondary productivity are directly driven by variations in water temperature, salinity, mixing, and light penetration, among other factors. Most of this production takes place in the mixed layer, between 20 and 100 meters deep. Spring and early summer are peak periods of production. Waters over the continental shelf are, naturally, most important to the groundfish species that constitute much of the fish production of the northeast Pacific. The IPHC survey is ideally situated to capture a snapshot of upper ocean conditions during the most productive time of the year. Observations of ocean conditions are important both to understand variability in time and space as well as to provide necessary data for modeling production. Satellites sample the ocean surface and free drifting arrays of mid-ocean profilers provide data on mid-latitude ocean conditions. However, there is a great lack of observational data for most of the nearshore northeast Pacific.

To collect more than bottom temperatures it is necessary to utilize a water column profiler of some sort. Though profiler technology has greatly improved over time, even the most basic profilers are still fairly large, expensive and somewhat delicate, temperamental instruments. There are several challenges to deploying a profiler from the type of vessel generally used on the IPHC assess-

ment surveys. These include physical deployment without use of a crane/winch, preventing the profiler from crashing onto the ocean floor, and concerns over the time required to deploy and retrieve the instrument during normal survey operations.

Methods

The profiler purchased for this pilot project was a SeaBird SBE 19 "Personal CTD" (Fig. 2). This profiler can sample at a programmable rate up to two scans per second allowing it to "characterize the water column with high accuracy and half second resolution" (quote from operations manual). We purchased a standard SBE 19 unit with the exception that we opted for the aluminum housing which is rated for depths to 3400 meters. The unit weighs 9.2 kg in air and 5.2 kg in water. For protective purposes, a stainless steel cage, 96 cm tall and specially designed for this profiler, was also purchased. A water pump is often deployed with the SBE 19 but our method of deployment – as described below – negated the need for the pump. The unit comes with 1024K bytes of CMOS static RAM – enough memory for approximately 100 casts. Power for the unit is supplied by nine D-size alkaline cells which provide about 40 hours of operation of the basic CTD sensors. Software for downloading and displaying the data is provided. Communication between the profiler and a computer is accomplished via a RS-232 port. To set up the profiler, deploy it, and then retrieve the data these steps are followed:

1. Connect the profiler to a computer, check instrument status, and select sampling parameters using menu-driven software.
2. Switch the profiler ON just before lowering into the water (cast number, time, and date are automatically recorded).
3. When the cast is complete, switch the profiler OFF. Up to 100 casts can be recorded (within limit of available memory) before uploading to computer.
4. After recovery, connect profiler to the computer and transfer the stored CTD data (plus any auxiliary sensor data) to floppy or hard disk files.
5. Run graphing/plotting program to convert to engineering units and/or display the data.

The profiler was deployed from the *F/V Bold Pursuit*, a 65-ft vessel which had been contracted to survey the Sitka, Fairweather and Yakutat stations of the 2000 Standardized Stock Assessment (SSA) survey. Operations were conducted from June 1 to July 23, 2000. The profiler and associated gear were transported north to Ketchikan as personal gear by the lead IPHC sampler aboard the *F/V Bold Pursuit*. A sturdy box to transport the profiler was supplied by Seabird. Total weight of the profiler, box and miscellaneous gear was 100 pounds. In addition, an IBM-compatible laptop was taken along to download data from the profiler while at sea, which was sent to Seattle (on a floppy disk) following each trip. The software runs on a 386 CPU, thus a relatively inexpensive laptop is adequate for the purpose. A 50-foot long RS-232 serial cable was also provided. This allowed the laptop to be kept inside while the profiler remained outside during data transmission.

To adapt the profiler for deployment from a halibut fishing vessel, we designed a system using weights and floats that permitted the profiler to descend rapidly enough through the water column to collect valid data, but also insured that the unit would not crash into, or become permanently attached, to the ocean bottom. A sustained descent rate of 1-2 m/sec is generally ideal for CTD

sensors. However, aboard scientific research vessels, CTDs are usually deployed from winches and descend more slowly. This is the reason that a pump is often used with profilers – they ensure good water flow no matter the speed of descent. We preferred to avoid using a pump both for the cost and the added complexity. The weight of the profiler and cage in the water are sufficient that if the unit is allowed to freefall the target descent rate would be achieved.

We attached a 15-meter anchor rope to the bottom of the CTD cage using a section of gangion line as a weak link (in case the anchor became attached to the bottom). A 40-pound halibut anchor was attached to the end of the 15-meter rope. To the top of the cage we attached two floats that effectively offset the weight of the anchor in water. The floats were attached to standard halibut buoyline which is almost neutrally buoyant. To deploy the unit the anchor was lowered into the water followed by the profiler and cage and then the buoys. After a few minutes of acclimation in the water, the rope was released and the full set allowed to freefall. Once the anchor hit the bottom the remainder of the unit came to rest shortly afterward due to the strong positive buoyancy of the floats compared to the weight of the profiler and cage. Comparing recorded bottom depths with profiler measured depth, it appears that the unit descended approximately five meters after the anchor hit bottom and therefore was never in danger of crashing. On board the vessel it was immediately obvious when the anchor hit bottom by a noticeable slackening of the rope. At this time, the rope was coiled around the gurney and the profiler immediately hauled back up. The conductivity cell was quickly rinsed with distilled water, anchor and buoy ropes removed from the attaching carabiners and the unit secured to the side of the vessel with bungee cords. Once the methodology was established, deployment and retrieval could be achieved in ten minutes.

Results

The *F/V Bold Pursuit* fished 130 stations and the profiler was successfully deployed and casts obtained at 120 of the stations (Fig. 3). The profiler was not deployed at nine stations and was not turned on before deployment at one station. The reasons for non-deployment of the profiler included: concern over bottom "stickiness", rough weather, strong currents, and lack of time. Nevertheless, a success rate of 92% should be considered remarkable given the novelty of the project and its goals. The region surveyed by the *F/V Bold Pursuit* included stations from inside waters to 70 nautical miles offshore. There was considerable diversity in the CTD profiles as can be seen in Figure 4, contrasting a station in Yakutat Bay (No. 4079) which has high fresh water runoff with an offshore station (No. 3111) that shows much less variability in salinity and a considerably deeper mixed layer. The full set of casts have been handed over to personnel at NOAA's Pacific Marine Environmental Laboratory (PMEL) for further processing.

Discussion

The purpose of this project was to demonstrate that a water profiler could be successfully deployed from a fishing vessel without substantially affecting normal survey operations. As a "proof of concept", this pilot project was completely successful. Upon completion of the project and initial processing of the data, a meeting was arranged with PMEL oceanographers to discuss the results, potential improvements and, most importantly, future collaboration in seeking grant

money to expand the profiler program within IPHC SSA survey operations. Specific suggestions and discussion points included:

1) Add a pump to the profiler. While the freefall arrangement does insure adequate flow of water through the conductivity cell, it is still preferable to have a known constant amount pumped through the cell. A pump, approximately $800 cost, will be purchased for the unit.
2) Add a chlorophyll fluorometer. A fluorometer measures chlorophyll *a*, which is the generally utilized measurement of primary productivity. Of all biological measurements, this is the most crucial for modeling productivity dynamics in shelf waters. The fluorometer bolts onto the profiler and fits inside the cage. The unit costs $3000, however, and it may be worth waiting until outside funding is found before purchasing one.
3) Loan the profiler to NOAA so it can be deployed side by side with a more robust and technologically advanced profiler. This comparison will allow reliable calibration of our data. We have already agreed to loan the profiler for a NOAA cruise in January 2001.
4) Seek external funding to expand the program. The IPHC SSA survey presents a unique opportunity to measure water column dynamics over virtually the entire Alaska continental shelf for the next several years. A number of funding opportunities are newly available for observational programs such as is envisioned here. The IPHC and PMEL reached verbal agreement to cooperatively write grant proposals to place profilers on as many as a dozen vessels in the next few years. We would seek monies for replacement profilers, technician time to process the data, and programmer time to make the final data available through the PMEL data web site.

Acknowledgments

I wish to acknowledge the significant contributions of Dan Randolph and Andy Vatter in designing the deployment system used for the profiler. Greatest kudos to Reisa LaTorra, the lead sampler aboard the *F/V Bold Pursuit,* who cheerfully accepted the added duties and performed them flawlessly.

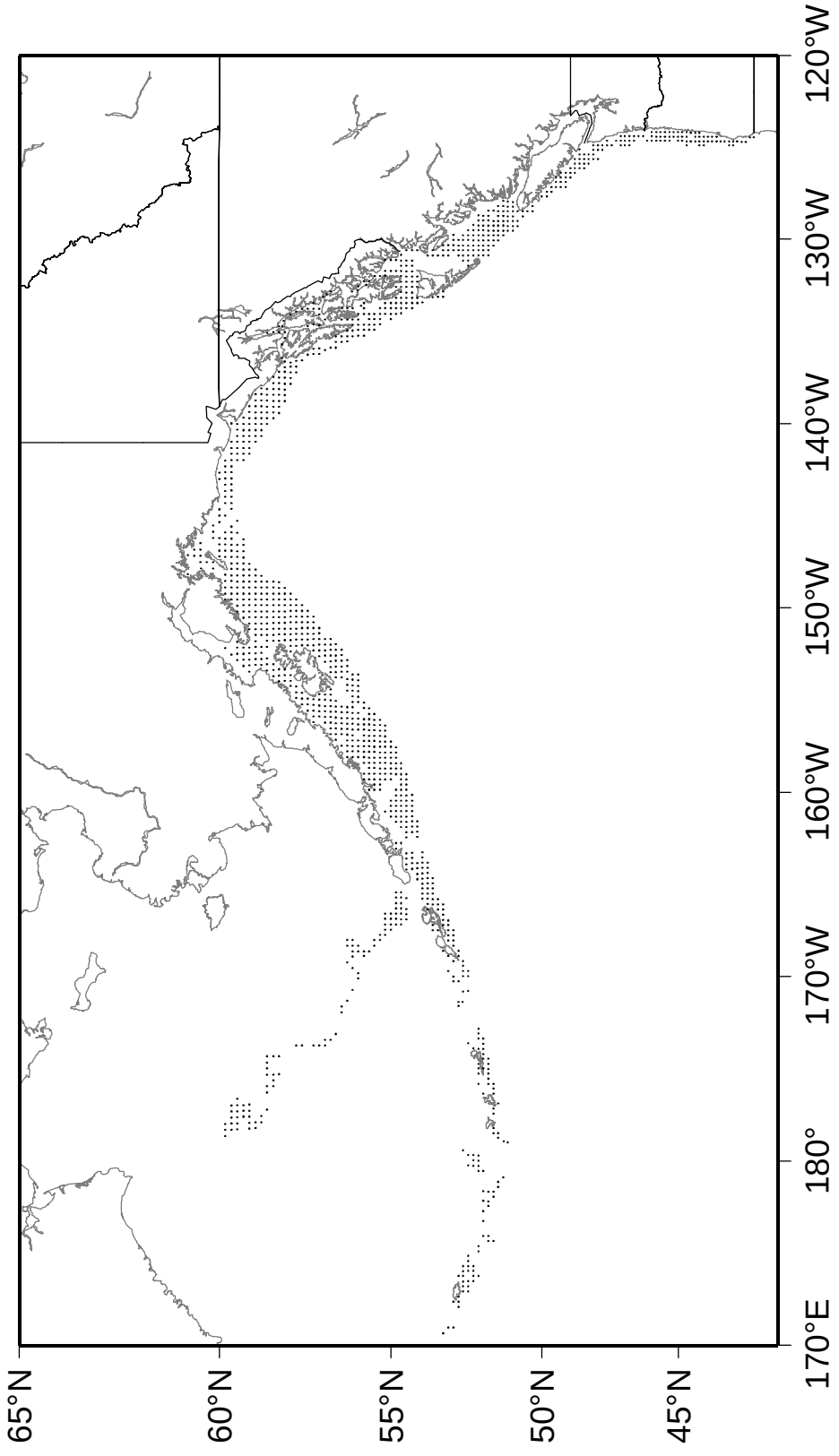

Figure 1. Station locations for the IPHC standardized stock assessment survey.

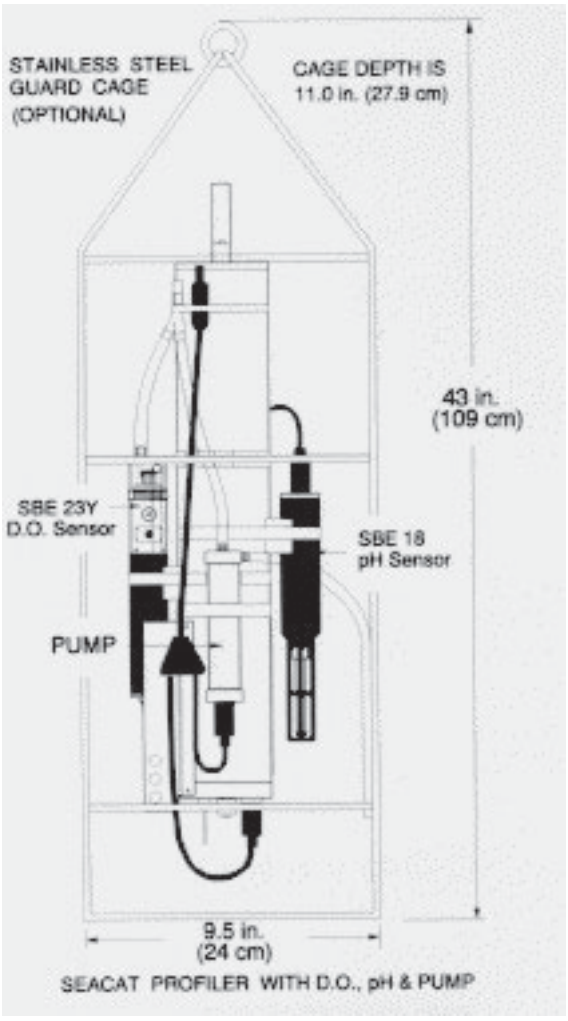

Figure 2. A SeaBird SBE-19 CTD profiler. This unit is shown with the optional water pump and dissolved oxygen and pH sensors; these were not used with the IPHC profiler.

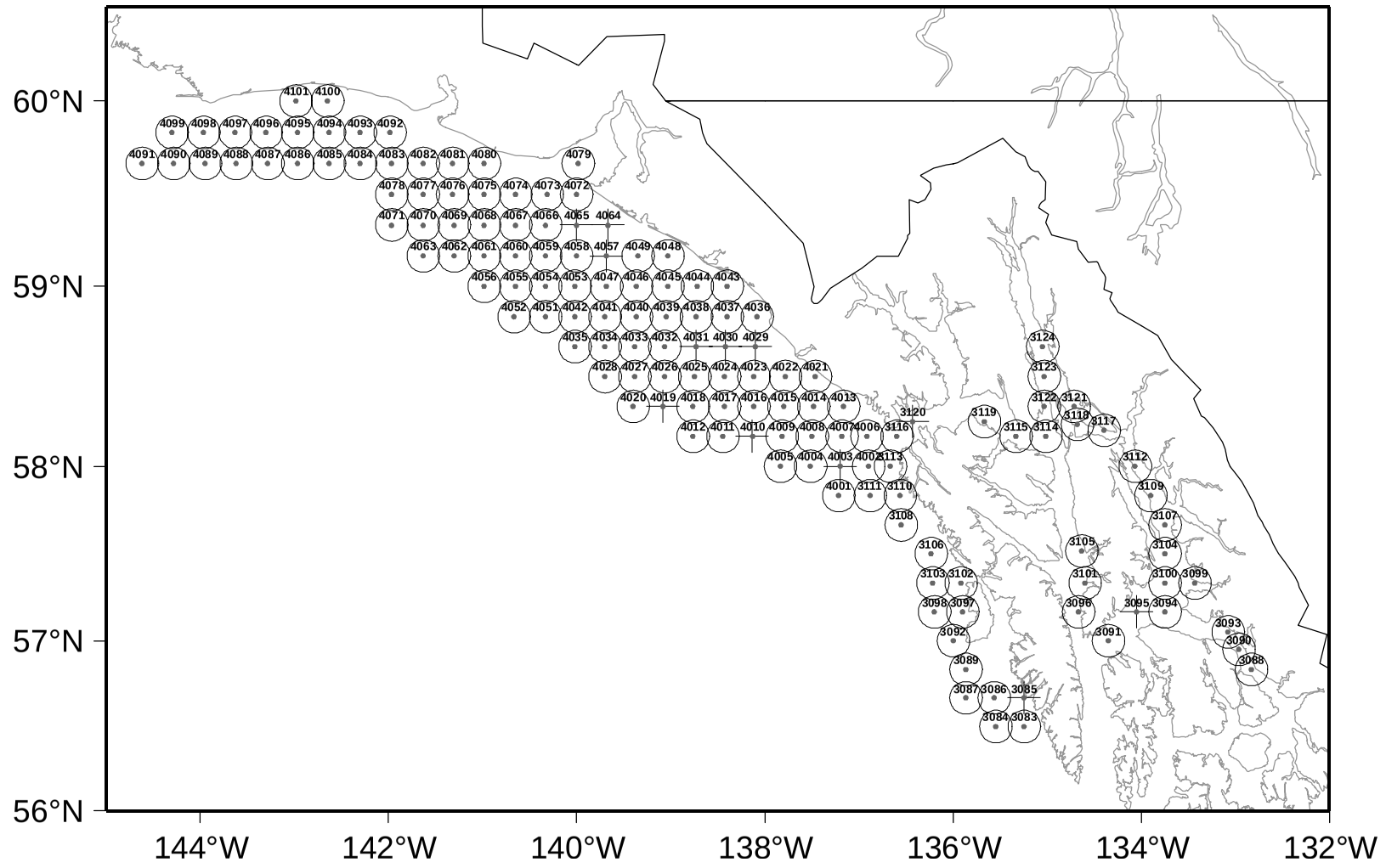

Figure 3. The 130 stations fished by the *F/V Bold Pursuit* in 2000. Stations where deployment of the profiler yielded usable data are circled; stations with a cross indicate non-deployment or unsuccessful cast.

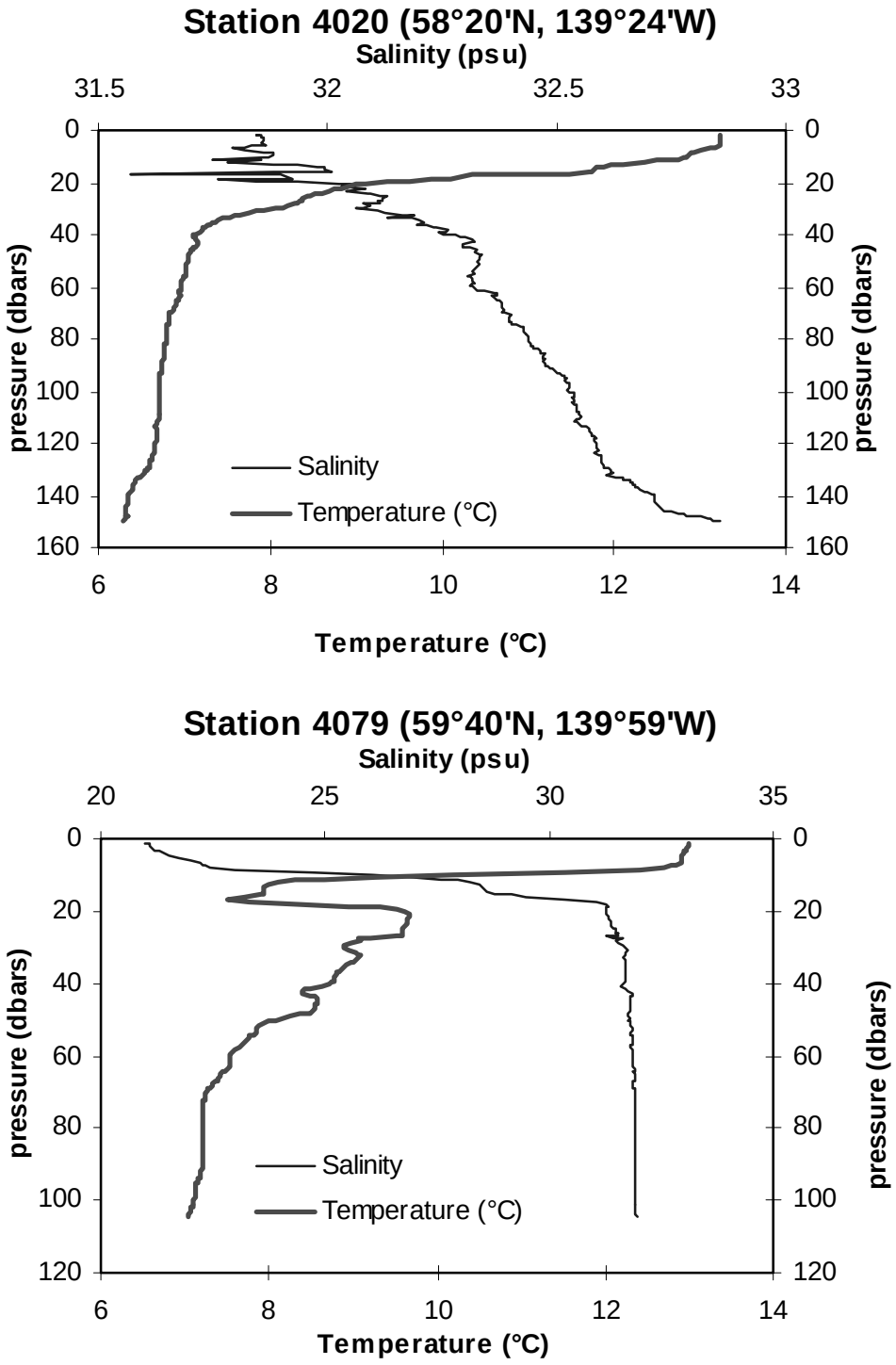

Figure 4. Two illustrative CTD casts taken aboard the *F/V Bold Pursuit*. Station 4020 is located about 70 miles offshore from Cape Spencer. Station 4079 is in the middle of Yakutat Bay.

Evaluation of differences in otolith edge growth interpretation as a source of aging error

Joan E. Forsberg

Abstract

Otolith edge codes associated with age determinations were recorded and entered into IPHC age data tables. Between-reader differences in edge interpretation for double-aged otoliths were evaluated as a cause of aging error.

Background

Otoliths, found in the inner ear of bony fishes, are widely used by biologists for determining the age of fish. Each year, alternating opaque (summer) and translucent (winter) rings are deposited on the otolith. A year's growth consists of both an opaque and translucent zone. Since halibut are spawned in the winter and have an arbitrary January 1 "birth date", the translucent or winter zones are counted to determine the age of the fish in years. The winter growth zones are also referred to as annuli (singular: annulus).

The International Pacific Halibut Commission (IPHC) collects large numbers of halibut otoliths each year for age determination. Over half of the commercial ("market") samples and over a third of the survey ("general series") otoliths are collected March through June, and often during this time, the translucent winter zone has not yet been deposited, or is still in the process of forming on the otolith edge. There is a problem of deciding whether edge growth on a particular otolith is new (from the current spring or summer) or from the previous summer. Some fisheries agencies have readers record an *annulus count* and an edge code rather than an *interpreted age*. IPHC readers record interpreted ages. For example, an otolith collected in February with 12 annuli and a full opaque zone on the edge would have an interpreted age of 13, whereas the annulus count for the same otolith would be 12.

As a general rule, for otoliths collected through June, IPHC readers have included the edge in the annulus count if the edge growth is greater than half the width of the previous opaque (summer) zone in fish older than 10 years, or almost the same width as the previous opaque zone in fish younger than 10 years. The edge is not counted in younger fish unless it is about the same width as the previous year's growth because young halibut start their growth season earlier in the year when compared with older fish, and may already have close to half the previous year's width of new growth by late May or early June. Sometimes fish collected in fall or even late summer may have a translucent zone on the edge. In this case, we believe the fish has started laying down the coming winter's annulus early rather than assuming the annulus was from the previous winter, which would imply zero summer growth. In any case, differences in edge growth interpretation between readers could be a source of aging error.

IPHC age readers have noted whether edge growth is included in the annulus count for each age since 1990. If two readers examine the same otolith and both get the same annulus count but

one includes the edge while the other does not, there would be a one-year difference in the two ages. Most between-reader discrepancies in halibut ages are in fact within one year. In an attempt to evaluate how many one-year age discrepancies are due to the edge interpretation difference described above, we began entering edge codes into the age tables in 1999.

The following are the codes used by IPHC readers for both market sample and general series otoliths:

1 = the edge (last summer's opaque growth) is included in the annulus count for age
2 = there is a translucent zone on the edge and no new opaque growth
3 = there is new opaque growth that is not included in the age
4 = there is a translucent zone on the edge that is not included in the age

Results & discussion

Subsets of otoliths from both the market samples and general series are aged twice by two different readers. This second, independent (i.e., second reader doesn't have knowledge of the first reader's ages) reading is called the *quality control* or "QC" reading. Initial and QC ages and edge codes were compared for 1999 age data. Table 1 shows the results of the comparison. Of the ages that differed by one year, only a small proportion of those differences was explained by edge interpretation (5% for all samples combined). A fairly large proportion (79% for all samples) of these age differences was definitely not due to edge interpretation. In these cases, the assigned ages were one year different, but the edge codes were equal, indicating that the differences were due to annulus rather than edge interpretation.

Otolith edge growth does not occur evenly. Often one can find three edge code types on a single otolith in different regions of the otolith. The edge code recorded depends on edge type observed in the transect the reader examines to determine the age. Also, determining the start or finish of an annulus is quite subjective, and could account for smearing between edge types 1 and 2 or between types 2 and 3.

The proportions of age differences explained by or not explained by edge interpretation differed between market sample and general series data (Table 1). These differences could be due in part to the fact that greater numbers of QC market sample otoliths were collected prior to July and we would expect age differences due to edge interpretation to occur earlier in the year. In fact, 71% of the QC market sample otoliths were collected before July, while 66% of the QC general series otoliths were collected July through August.

Conclusion

Although results from the 1999 data do not implicate edge interpretation as a major source of aging error, we will probably enter the edge data from 1990 through 1998 before discontinuing edge code assignment or entry. Age staff may also consider adopting more descriptive edge codes.

Table 1. Differences in edge interpretation and one-year discrepancies in assigned age for 1999 market sample (MS) and general series (GS) otoliths.

	MS		GS	
	No.	%	No.	%
Total number of ages that differ by 1 year	318	---	267	---
Age difference of 1 year due to edge interpretation	29	9	0	0
Age difference of 1 year not due to edge interpretation (i.e., edge codes are equal)	208	65	256	95

Recent changes in production age determination protocol at the IPHC

Joan E. Forsberg, Calvin L. Blood and Thomas M. Kong

Abstract

Recent changes in production aging at IPHC include shifted deadlines and sample priorities, increased numbers of break and burn age determinations and new readers.

Introduction

The International Pacific Halibut Commission (IPHC) age staff currently reads between 25,000 and 30,000 otoliths per year. Halibut otoliths are collected from the commercial catch (market samples), surveys (general series) and recaptured tagged fish. All otoliths are surface-aged; otoliths that meet certain criteria are read a second time in cross-section using the "break and burn" technique. Both techniques are standard methods of fish age determination. Additionally, a subset of halibut otoliths is selected for replicate, independent or "quality control" (QC) readings. Initial and QC readings are made by different readers and discrepancies in ages are evaluated.

This document discusses recent changes in production aging at IPHC. Changes include shifted deadlines and sample priorities, increased rates of break and burn age determinations, and new readers.

Changes in sample priorities and deadlines

For over 15 years, current year market sample age data had an October deadline (for use in stock assessment). Fishing seasons during that period consisted of several short "openings" of one to several days in duration and were held between April and September, with an occasional "clean-up" opening in early October. When quota systems and longer seasons came into effect for Area 2B in 1991 and Alaska in 1995, the goal was to age as many market sample otoliths as possible by the deadline. Usually between 92 and 98% of the total number collected were aged by the deadline. Survey or general series otoliths were aged after the market samples, and completed in the spring of the following year.

There was a shift in priorities and deadlines in 1999; survey otoliths from Regulatory Areas 2B, 2C and 3A were read first, with a deadline of October 15. The assessment model was modified in 1999 to incorporate current year survey ages and this was the reason for the shift in the survey age deadline. Market sample otoliths from the same areas were given second priority. As a result, only 83% of the market samples collected by mid-October were aged before the end of October. In 2000, Regulatory Area 3B was added to the priority list for both market sample and general series ages. In 2000, only 73% of the market samples collected through October were aged before the

assessment deadline. While 94% of market samples from Areas 2B, 2C, 3A and 3B were aged by the end of October, only 29% of otoliths from Area 4 had been aged.

The advanced deadline for this portion of the survey ages redistributes the age staff's workload as full time aging now begins a month earlier (August instead of September).

Break and burn changes

The proportion of break and burn readings has increased in recent years. Table 1 shows the numbers and percentages of otoliths broken and burned by year since 1993. Numbers of burns are quite low for 1993 and 1994 because during those years, only the QC reader performed break and burns, and only on those otoliths for which the initial and QC surface age disagreed by more than 2 years. Table 1 also shows that the percentages of break and burns for both market sample and general series otoliths increased the most in 1999 and 2000. Figure 1 shows the total number of general series otoliths broken and burned by surface age between 1998 and 2000.

Table 2 lists numbers and percentages of break and burns by regulatory area and year for market sample (MS) otoliths. Percentages of break and burns increased for all areas between 1997 and 2000. Areas 3A, 4A and 4C showed rather large increases in 2000 from the previous year. Readers have noticed that market sample otoliths seem to be getting more difficult to read, especially those from Area 3A, and more so than 3A general series (GS) otoliths, for which break and burn rates remained at about 20% for 1999 and 2000. The difference in "difficulty" (i.e., annulus patterns less distinct, otoliths thicker) between MS and GS otoliths collected in Area 3A could be due to changes in fishing practices or grounds being fished by sampled commercial vessels.

The overall increases in break and burn rates over the last few years could be due to increased difficulty in annulus patterns on the otoliths and/or between-reader differences or changes in application of *break and burn criteria*. These are the criteria used by an ager to decide whether to break and burn a given otolith. Current criteria include thick or steep otolith, difficult annulus pattern, closely spaced annuli (especially near the edge), a cloudy or opaque surface, high surface age or lack of confidence in surface age for some other reason. The break and burn rate increase over time may also be partly explained by increased experience with and confidence in break and burn interpretation. Reader effects on break and burn rates are discussed in the next section.

Personnel changes

There has been some turnover in IPHC age readers since 1994. In that time, there have been seven different agers. Currently IPHC has four agers who have between three and eighteen years of aging experience. The percentages of otoliths broken and burned by reader and year for MS and GS otoliths are shown in Table 3. While there are differences in rates of break and burn between readers, all four current agers show an increase in individual rates of break and burn over time, particularly in the last two years. Differences between readers could be due to differences in application of criteria, but are also affected by the method of capture or regulatory area of origin of the otoliths read. As shown in Table 2, some areas have relatively low rates of break and burn, either because more of the otoliths collected are from younger fish or annulus patterns are more distinct in those areas. For example, Reader 4 has relatively low break and burn rates, but has aged the trawl

survey otoliths for the past three years. Trawl survey halibut tend to be young fish whose otoliths are less likely to require breaking and burning.

Table 4 shows differences in application of one type of break and burn criteria: high surface age. For example, 97 to 99% of one reader's burns are made on otoliths that had a surface age of 15 or higher. Lower numbers for other readers show that they performed break and burns on higher numbers of younger otoliths.

One proposal being considered is an amendment to our current break and burn criteria whereby all otoliths with a surface age over 14 years will be burned. This proposal is based on results of an earlier surface - break and burn age comparison. Only about 60% of otoliths surface-aged at 15 and over were broken and burnt in 1999. Burning all otoliths with a surface age greater than 14 would add 1.5 to 3 months to the age staff's workload.

Table 1. Numbers and percentages of otoliths broken and burned by year.

	Market Sample (MS)				General Series (GS)		
Year	# Otoliths	Number Break/burn ages	Percent Break/burn ages		# Otoliths	Number Break/burn ages	Percent Break/burn ages
1993	13,747	358	2.2		3,383	146	4.3
1994	13,311	271	2.0		3,377	216	6.4
1995	12,297	733	6.0		4,948	161	3.3
1996	13,452	697	5.2		10,885	1,122	10.3
1997	15,501	2,458	15.9		15,614	1,806	11.6
1998	14,395	1,594	11.1		9,556	924	9.7
1999	12,796	2,383	18.6		14,475	2,061	14.2
2000	9,691	2,289	23.6		7,872	1,459	18.5

Table 2. Percentage of Market Sample otoliths broken and burned by year and regulatory area, 1997 through 2000.

Regulatory Area	Year	# Break/burn ages	Total aged	% Break/burn
2A	1997	23	770	3
	1998	45	1,261	4
	1999	41	588	7
	2000	53	692	8
2B	1997	465	2,830	16
	1998	271	1,834	15
	1999	286	1,594	18
	2000	347	1,987	18
2C	1997	255	1,888	14
	1998	289	2,294	13
	1999	386	2,022	19
	2000	359	1,833	20
3A	1997	385	2,009	19
	1998	270	1,848	15
	1999	515	2,319	22
	2000	681	2,105	32
3B	1997	469	2,646	18
	1998	249	1,748	14
	1999	475	1,944	24
	2000	537	1,826	29
4A	1997	282	1,935	15
	1998	113	1,819	6
	1999	194	1,468	13
	2000	185	636	29
4B	1997	380	1,773	21
	1998	234	1,684	14
	1999	289	1,056	27
	2000	57	160	36
4C	1997	53	663	8
	1998	12	783	2
	1999	49	752	7
	2000	42	277	15
4D	1997	146	987	15
	1998	111	1,124	10
	1999	148	1,053	14
	2000	28	175	16

Table 3. Percentage of otoliths broken and burned by reader and year for market sample (MS) and general series (GS).

Reader	Year	Percent Break & Burn (MS)	Percent Break & Burn (GS)
1	1995	7.8	3.4
1	1996	2.8	4.6
1	1997	10.4	10.5
1	1998	9.1	7.5
1	1999	15.2	16.0
1	2000	22.0	22.5
2	1996	9.4	17.2
2	1997	20.6	15.5
2	1998	18.1	14.4
2	1999	25.9	22.0
2	2000	32.7	28.2
3	1995	18.8	n/a
3	1997	22.5	n/a
3	1999	19.0	17.4
3	2000	22.7	20.1
4	1998	n/a	4.1
4	1999	n/a	5.0
4	2000	n/a	5.7
5	1997	13.4	8.2
5	1998	6.4	11.9

Table 4. Percentage of break and burn readings made on otoliths with surface age of 15 or greater by reader (1999 and 2000 data).

	Percent break/burn where surface age=15	
Reader	MS	GS
1	78	75
2	64	41
3	97	99
4	n/a	62

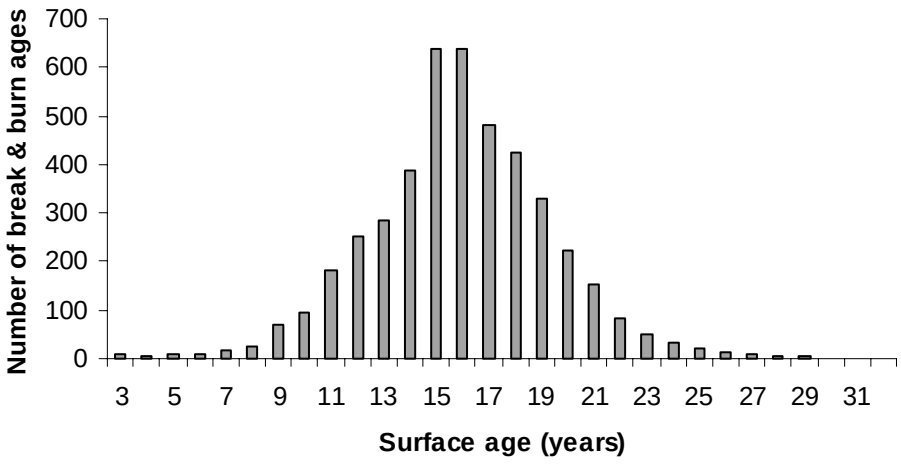

Figure 1. Number of otoliths broken and burned by surface age (from GS data, 1998-2000).

Tagging studies

Tracee O. Geernaert

Abstract

The IPHC has been tagging halibut since 1925 and has released over 380,000 and recovered over 46,000 tags. Halibut are tagged to study migration, utilization, age, growth and mortality. The last major tagging project took place in 1995 as part of a study on halibut mortality in the trawl fishery. In 2000 a total of 140 tags were released and 92 were recovered. The majority of tag recoveries occurred in Area 3A where the most recent tagging experiments have taken place. The longest distance traveled was by two tagged fish who moved from Newport, Oregon to the southern Queen Charlotte Islands. Recovery rates from the most recent experiments vary from three to 47 percent.

Tag releases

Tag releases in 2000 totaled 140, all of which occurred in the sport fishery. The Ninilchik and Homer halibut derbies were the only IPHC sponsored tag release programs and they released 50 and 90 tags, respectively. The sport charter voluntary catch and release program is slowly being phased out and will not be reported on in this document.

Tag recoveries

Tag recoveries in 2000 dropped significantly from numbers seen in 1999 (Table 1). There were 92 tags redeemed this year compared to 153 recoveries in 1999. The most recoveries were turned into the port of Kodiak where 40 tags were redeemed by the IPHC sampler. Seward was the only port to show an increase in 2000 with 21 tags recovered compared with 20 in 1999. Juneau was staffed this year for the first time and we were able to redeem five tags from this port. Recoveries by regulatory area show the largest number of tags in Area 3A where the most recent tag experiments have taken place (Table 2).

Tagged fish are usually recovered in or near their area of release (numbers in bold in Table 2). The longest distance between release and recovery in 2000 was with two fish released in 1989 as part of the Central Oregon tagging project. They were both recovered off Cape St. James in the southern Queen Charlotte Islands. Most of the tagged fish recovered in 2000 were from the 1993-94 longline mortality study, and many of them were caught close to their release site. Two of the 2000 recoveries were at large for 16 years. Both tagged fish were released in 1984 by the *F/V Pacific Harvester*. One fish was tagged off Rose Spit and recovered in the same area and the other fish was released near Unimak Island and recovered on Portlock Bank.

Overall, recovery rates from the most recent experiments vary from three to 47 percent (Table 3). The highest rates occurred in the older experiments where fish have been available for capture the longest. Nearly half the tagged fish released in the 1988 Sitka Spot experiment have now been recovered. The 1989 central Oregon study, with 626 recoveries, has a recovery rate of 30%. The longline mortality experiments in 1993 and 1994 have recovery rates of eight and nine percent, respectively. The most recent project was the 1995 trawl mortality experiment aboard the *F/V Forum Star*. To date, the recovery rate for this experiment is only three percent.

Table 1. Tag recoveries by port.

Primary Ports	1998	1999	2000
Seattle	0	0	0
Bellingham/Blaine	4	6	6
Vancouver	5	4	1
Port Hardy	4	2	1
Prince Rupert	12	4	1
Sitka	2	4	1
Juneau	0	0	5
Hoonah	8	5	0
Seward	15	20	21
Homer	43	31	14
Kodiak	95	66	40
Dutch Harbor	1	4	1
Misc. Ports	12	6	1
Total	201	153	92

Table 2. Distribution of 2000 tag recoveries by Regulatory Areas.

		Recovery Area							
		Area 2A	Area 2B	Area 2C	Area 3A	Area 3B	Area 4	Unknown	Total
Release Area	Area 2A		2						2
	Area 2B		**1**						1
	Area 2C			**4**					4
	Area 3A			3	**60**	3		5	71
	Area 3B				2	**8**		1	11
	Area 4				2		**1**		3
	Total		3	7	64	11	1	6	92

Table 3. Recovery rates for the most recent experiments.

Experiment	Release year	Number recovered	Number released	Recovery rate
Sitka Spot	1988	1246	2652	47%
Central Oregon	1989	626	2118	30%
Longline mortality	1993	281	3800	8%
“	1994	876	9296	9%
Trawl mortality	1995	139	4852	3%

Field test of robust pH meter

Stephen M. Kaimmer

Abstract

During 2000, the International Pacific Halibut Commission investigated the use of pH meters to determine flesh pH of Pacific halibut in field situations. We found that pH meters could be very appropriate tools for quickly screening halibut for the pH indicators which would associate with the development of the chalky condition.

Introduction

The International Pacific Halibut Commission has been studying the incidence and occurrence of chalky halibut in commercial landings since 1997 (Kaimmer, 2000). Early in this study, we recognized the need for detecting chalky halibut when landed and sold by the fishers. The detection technique currently used involves a visual inspection of the flesh through a cut either into the tail or dorsal area of the fish. The flesh of chalky halibut is an opaque white, contrasting with a more translucent appearance in non-chalky fish. The visual inspection method does not detect all the chalky fish, since in some cases the visual indications of chalkiness may take three to seven days to develop after the fish is killed. The process by which halibut turns chalky was well described by four reports published in the 1960s (Tomlinson et al 1965, 1966a and 1966b, and Patashnik 1966). Normally, the pH of halibut flesh is above 6.2. In fish where the chalky condition develops, the flesh pH is lower than 6.2 (lower pH = more acidic). Fish with pH between 6.0 and 6.2 are sometimes chalky. Fish with pH below 6.0 are always chalky. The visual indications of chalkiness are the direct result of the flesh pH, and the time period associated with the appearance of visual indications are probably affected by both the holding temperature and the degree of acidity in the flesh. The change in flesh pH appears to develop within the first one or two days after death, as the result of lactic acid stored in the muscle tissue prior to death. During 2000, we contacted a number of manufacturers of pH meters. We requested to borrow pH meters and probes for a field test of their effectiveness in screening halibut for flesh pH. Three manufacturers agreed to loan us meters for testing. We received the following meters: HI 9023C meter with FC230B probe from Hanna Instruments, USA; IQ150 meter with PH07-SS probe from Cole-Parmer Instrument Company, IL; and Argus meter 5000-0001 and 2074-008 probe from Sentron, Inc., WA. The Hanna probe was a conventional glass probe and the probes from Cole-Parmer and Sentron were ISFET[1] probes. The ISFET probes were much smaller in diameter than the glass probe, and the Sentron probe had a piercing tip that most easily penetrated the halibut skin. We determined to perform the field test using the Sentron probe.

[1] ISFET (Ion-Sensitive Field Effect Transistor) meters and probes use a durable membrane on the tip of the probe as a pH sensor, as opposed to conventional pH probes which use a more fragile glass bulb at the tip. This allows the ISFET probes to be smaller in diameter and to have shaped or sharpened tips, which can penetrate skin and membranes easily

Methods

IPHC staff visited New West Fisheries in Bellingham, Washington to field-test pH meters for use in scanning for halibut chalkiness. The plant had already started processing a load of fish that had been shipped in totes from Alaska. The fish were at least four days old when tested, since the shipping takes three days. Video and still images of the testing process were also obtained.

The meter/probe was an "Argus" Part #5000-0001 with LanceFet probe Part #2074- 008 (Figure 1), supplied by Sentron, Inc.of Gig Harbor, Washington. The retail value on the probe and meter is $890. The probe has a sharpened stainless-steel tip designed for meat penetration.

Fish had already been visually screened for chalkiness by plant personnel, using a small cut on the dark side of the fish just below the dorsal fin. The pH probe was inserted into this same cut, to avoid further marking of the fish. However, we also probed directly into a small number of fish which had been set-aside as Number 2, and the probe penetrated the skin and flesh without problem or delay.

Results and discussion

We tested 33 fish, 22 that had been screened as Not Chalky, and 11 that had been screened as Chalky (Table 1). The relationship between pH range and chalkiness agreed completely with previously published data. It is interesting to note that the pH meter was in complete agreement with the visual checker on all fish with pH either less than or equal to 6.0, or greater than pH 6.2. Had these fish been screened when they were initially offloaded from the catcher vessel, we would have expected to pH readings to have been about the same on individual fish, and with less obvious visual indications of the chalky condition. These readings also suggest that some fish graded visually as Not Chalky might develop chalkiness prior to marketing.

The meter was robust and very easy to use. Readings could be obtained in a matter of seconds. The probe has a both a thermister (for temperature) and a pH-sensitive membrane, and the meter we tested automatically compensates for changes in temperature. When the probe was inserted into the first fish, it took 60 seconds for the temperature reading to stabilize from the outside ambient temperature of 11.2 °C to 2.2 °C, the temperature of the iced flesh. The pH reading is almost instantaneous, but changes as the probe temperature stabilizes to the flesh temperature. As the temperature of the probe drops, the internal system compensation results in an increase in pH reading. For the example here, the pH reading changed from 6.36 to 6.41 as the temperature stabilized. Therefore, it is only for fish with pH readings below 6.2 on initial insertion for which temperature compensation is important to accurate classification. From an operational perspective, temperature compensation is not a major issue. Once the probe was at the flesh temperature, it could be rinsed and inserted into another fish very quickly. Between fish, the probe temperature did not have time to rise from the flesh temperature, and the pH reading on subsequent fish was accurate within seconds following probe insertion. We were able to easily make readings on different fish about every six seconds. Further testing is necessary to determine the time sequence of post-mortem pH changes in halibut muscle, and their relationship to the development of the visual indications of chalkiness.

Acknowledgements

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Patashnik, M. 1966. New approaches to quality changes in fresh chilled halibut. Comm. Fish. Rev. 28: 1-7.

Table 1. Number of observations and percent of fish either visually determined to be either chalky or not chalky by range of flesh pH.

Range of measured pH	*Result of visual screening*			
	Not chalky		Chalky	
5.70-6.00	0	0%	8	100%
6.07-6.11	2	40%	3	60%
6.20-6.70	20	100%	0	0%

Figure 1. Sentron probe used in pH meter field test. The stabbing portion of the probe is 5 cm in length, with the last 1.7 cm tapering to a sharp point. The sensing membrane is contained in the tapered point.

Summary of 1960's investigations of chalky halibut

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 U. S. Bureau of Commercial Fisheries in Seattle, WA and the Fisheries Research Board of Canada in Vancouver, B.C. (Patashnik and Groninger 1964, Tomlinson et al. 1964, 1965, 1966a, 1966b, and Tarr 1966, 1968). These were not the first papers to mention chalkiness in halibut, but they represented a coordinated research effort to investigate the problem. 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).

When the studies were initiated, the cause of chalkiness was unknown, and it was not known whether the condition was present in the flesh when the fish were caught or whether it developed post-mortem. The condition had been previously described as having higher oil and protein content and lower water content, but these quantitative differences were thought to be results of, rather than the causes of, the chalky condition. The chalky condition was described as one where the flesh was dull and opaque, in contrast to the shiny, semi-translucence of normal raw flesh. In addition, chalky halibut was described as softer and 'flabbier' than normal, and the myomeres of chalky flesh would tend to separate from each other more readily than in non-chalky flesh.

A series of four reports, three published by Tomlinson, Geiger, and Dollinger in 1965 and 1966 and one published by Patashnik in 1966, gave a thorough groundwork for understanding the chalky condition in halibut. The first three authors worked at the Technological Research Laboratory of the Fisheries Research Board in Vancouver, B.C., while Patashnik was at the Technological Laboratory of the U.S. Bureau of Commercial Fisheries in Seattle. While these reports are old and copies are difficult to obtain, they remain definitive works describing the development and causes of chalkiness in Pacific halibut. This paper will detail the findings of those reports in order to make these findings more readily available. In many cases, the data or text from the reports will be reproduced exactly as it appears in the source document. Due to the nature if this paper, and the number of times exact text will be quoted, quotations will not be used on these inclusions.

Tomlinson N., Geiger, S.E., and E. Dollinger. 1965. Chalkiness in halibut in relation to muscle pH and protein denaturation.

Summary

Trawl caught halibut and some longline halibut were examined for muscle pH, lactic acid and protein concentrations. These results were compared with visual indications of chalkiness. The authors found that chalky fish caught by either method had opaque flesh, lower pH, higher lactic acid concentrations, and lowered protein solubility than non-chalky fish. All of these indicators developed post-mortem, taking as long as three to seven days to be evident. The authors conclude

that chalkiness is most likely the result of a change in muscle proteins, developing post-mortem. The change to the chalky condition was shown to be dependent on the pH of the muscle, taking place only if it fell to about 6.0 or lower. The "cooked" appearance of the chalky muscle is related to the loss in protein solubility. They further state that the quantity of lactic acid found in fish muscle post mortem and consequently the pH is related to the glycogen content of the muscle of the fish at hooking or netting, and is in turn related to the state of nutrition of the fish. They would expect well-fed fish to be more likely to become chalky. The further surmise that while both trawl and longline-caught fish undergo struggling and exhaustion during capture, that longline fish would have the opportunity to recover from this exhaustion while "resting" on the hook. This would reduce the lactic acid content prior to gear retrieval.

Methods

Halibut were caught by trawl. For contrast, additional samples of longline-caught fish were obtained after being held on ice for from two to three weeks. Trawls were from one to three hours duration. Once onboard, a large cut was made for visual determination of chalkiness and a similar determination was made after landing six days later. Fish were classified as being normal, moderately chalky, chalky, or very chalky. Muscle samples were taken both when the fish was caught and when the fish was fletched. In some cases, additional muscle samples were taken at periods of up to seven hours after catching and before fish were iced. Once taken, all muscle samples were frozen on dry ice and then held at -30 °C until analyses could be carried out. Flesh pH and lactic acid, protein nitrogen, and soluble protein concentrations were determined in the laboratory. After capture, fish were held on ice for 6 days and then landed. Since the chalky condition appeared to develop post-mortem and since the change in appearance seemed to be the result of some change in the muscle protein, the extractability of these proteins was investigated. Since the pH of the flesh was expected to exert an influence on the state of muscle proteins, pH and lactic acid content were also determined.

Results

Visual screening for chalkiness

In a pilot experiment, over 2000 halibut were visually examined during three fishing trips to determine whether chalkiness was a post-mortem development. None of the fish were visually chalky at the time of catching, but from 35-70 % of the fish were judged to be chalky when landed 5-10 days later. A number of fish found to be not chalky after being held on deck for 1 to 7 hr before being examined and iced, became chalky before being landed six days later.

Extractability of muscle proteins

Twenty fish were randomly selected for laboratory analyses. On being landed, 12 of the fish were normal and eight chalky. Samples were taken from individual fish when they were caught, and then when they were landed six days later. There was a pronounced decrease in the extractability of muscle protein in fish that were chalky. The authors present representative data from this part of the study (summarized in Table 1). The percentage of protein that is extractable in flesh taken just after capture was 90.3 and 90.8 percent in normal and chalky fish, respectively. When the fish were landed, those percents dropped to 86.0 for normal fish, and 51.0 for chalky fish (59.7% for moderately chalky fish and 45.6% for very chalky fish).

Flesh pH

The flesh of the chalky fish had a pH below 6.0 when landed, while the flesh of normal fish was 6.0 or higher. The lower pH was related to a higher concentration of lactic acid. There was also a tendency for a greater increase in the dry weight of chalky muscle than seen in normal muscle during storage of the fish in ice. The flesh pH between fish that would be chalky and normal fish did not differ when the fish was caught.

Comparison of samples following thawing

Since the flesh of normal and potentially chalky halibut was indistinguishable at catching insofar as appearance, pH, and protein extractability of samples frozen at capture were concerned, but became apparent within a few days storage on ice, a comparison of thawed samples from normal and chalky fish was made. Samples were examined while they were still frozen, immediately after being thawed, and after a further two hours storage at 20 degrees C (Table 2). Samples frozen at catching were semi-translucent when thawed. The sample from the chalky fish became opaque within two hours, while the sample from the normal fish was partly cloudy. The marked change in appearance of the sample from the chalky fish frozen at catching was accompanied by a marked decrease in pH and in extractability of muscle proteins.

Examination of fish caught by longline

Samples of six normal and six chalky fish caught by longline were obtained when the fish were landed in ice, two to three weeks after catching. The chalky samples were analyzed for soluble protein both before being frozen and again after freezing. Muscle protein and pH were determined in all fish. A marked difference between normal and chalky fish in protein extractability and muscle pH was obvious, similar in magnitude to that found between chalky and normal trawled fish (Table 3). All of the trawl samples had been frozen prior to analysis. The longline fish were tested both before and after freezing to determine whether the freezing had an effect on results. From Table 3, by far the greatest loss in protein solubility took place prior to freezing.

Tomlinson N., Geiger, S.E., and E. Dollinger. 1966a. Free drip, flesh pH, and chalkiness in halibut.

Summary

The authors investigated the relationship between free drip, flesh pH, and chalkiness in halibut. Free drip was found to increase continuously with decreasing pH in the range pH 6.8-5.7. Flesh pH varied somewhat with location in the body, being higher near the head. The minimum flesh pH was reached within 24-48 hours of death and increased slowly thereafter.

All fish with a flesh pH below 6.0 were chalky, those with a pH above 6.2 non-chalky, while in the pH range between 6.0 and 6.2 there was an intermingling of chalky, borderline chalky, and nonchalky.

Methods

Trawl caught halibut were stunned, eviscerated and held on ice for 11 days. Measurement of pH was by insertion of a pH electrode into small incisions on the flesh at various locations around the body. Free drip was determined from skinned fillets as a percentage of the initial weight of the

sample. Degree of chalkiness was determined by visual examination of the surface of a cut made across the wide portion of the body. Fish were rated chalky when the flesh was white, opaque, and dull in appearance, borderline when white, nearly opaque, but shiny in appearance, and not chalky when translucent and shiny in appearance. The fish examined were mostly small and medium in size (10-20 and 20-60 lb, respectively) with only a very few large (60-100 lb) fish examined.

Results

Variation of pH within the flesh

Eleven locations across the halibut body were sampled in seven different halibut (Figure 1). There was a tendency for the pH to be higher near the head of the fish and lower near the center of the body (Table 4). Maximum variations in pH encountered between any two positions were on the order of 0.3.

Change in flesh pH with time

In general, the minimum pH was reached within the first or second day of storage (Figure 2). Flesh pH was determined when the fish were caught, and on day one, two, eight, and thirteen after capture. Flesh pH values dropped about 0.2 to 0.4 between the first and the third day. There was a tendency for the pH to increase slowly after the initial decrease, although these increases never returned to the starting value.

Relation between flesh pH, free drip, and chalkiness

One hundred and twenty-two halibut were examined for flesh pH, free drip, and chalkiness (Figure 3). While there was a good deal of scatter in the free drip values observed, it is clear that there was a trend toward higher free drip values with decreasing pH, and that this trend was continuous within the pH range encountered. On average, after 11 days storage in ice, free drip from chalky fish (8.5%) was a little more than double that from nonchalky (3.8%), with that from borderline fish occupying an intermediate position (6.2%).

Patashnik, M. 1966. New approaches to quality changes in fresh chilled halibut.

Summary

This study focused on defining the initial quality of landed fresh halibut in subjective and objective terms, and to relate these to the time-temperature rate of change in quality of the frozen product. The author describes both chemical and physical methods of determination. Product was held for up to 30 days, and was also submitted to a taste panel. Most of this paper discusses tests for product deterioration, particularly with respect to bacteriological growth. I will only summarize those results specific to chalkiness.

Methods

A hydraulic shear was used to test toughness in halibut that was cooked after two and fifteen days in iced storage. A greater shear force represents a higher textural resistance, or toughness, in

the halibut sample. The author also determined pH of the interior flesh of halibut and related this to halibut weight.

Results

Toughness

There was a small but detectable difference in toughness resulting from time in storage. There was also an almost two-fold increase in toughness between high pH and low pH flesh. The author concludes that the pH is of greater significance in determining flesh toughness than storage time. He states that it is known that pH is related to the degree of struggling prior to death, and suggests that stunning a fish as it is landed to limit struggling on deck would result in a higher flesh pH.

Chalkiness and fish weight

The author observed the pH of halibut to decrease with fish weight, with a corresponding increase in chalkiness (Figure 4).

Chalky condition

The chalky condition is described. Normal halibut is described as semitransparent. Chalky halibut is described as having a flat-chalky-white opaque color, a low pH, and a great tendency to lose water from cut tissue. Further, chalky halibut is described as having lower protein solubility and a lower protein content in the free drip. The cooked meat of chalky halibut is described as dry or tough. The causes of the chalky condition are described as involving (1) feeding halibut with high glycogen energy reserves, (2) death occurring in a frenzy of activity or a state of extreme exhaustion, with a resulting accumulation of fatigue-produced lactic acid in the muscle, (3) the inability to get rid of the lactic acid accumulation, and (4) high holding temperatures - the higher the holding temperature, the quicker the development of the chalky condition. Based on these preliminary observations, the author advises fishermen to kill or stun halibut immediately to stop all physical activity and to chill halibut immediately.

Tomlinson N., Geiger, S.E., and E. Dollinger. 1966b. Influence of fishing methods on the incidence of chalkiness in halibut.

Summary

The earlier studies found a much higher degree of chalkiness in trawl caught fish than in longline caught fish. The author's suggested that this was either the result of the trawl catching heavily fed fish which might not be a susceptible to longlines, or that the longline allowed the fish a more or less lengthy recovery period following capture and prior to death. Three experiments using trawl caught halibut investigated the second hypothesis. The authors demonstrated that a recovery period following capture of trawl caught halibut resulted in an increase in postmortem flesh pH and a decrease in postmortem chalkiness.

Methods

After removal from the trawl net, halibut were either immediately killed, eviscerated, and iced, or placed into a seawater tank for various lengths of time prior to being killed, dressed, and iced.

After an 11-day storage, flesh pH was measured and fish were examined for chalkiness. Fish were classified as chalky, borderline, or nonchalky.

Results

Results for the first two experiments are given in Table 5. In each of these experiments, the mean flesh pH was higher, and the incidence of chalkiness lower, in the group allowed the period of recovery than in the corresponding group killed at once. A lower overall flesh pH was seen in experiment one (6.06) than in experiment two (6.35) This corresponded to a higher overall chalkiness rate in experiment one. The change in mean flesh pH with the recovery period was of about the same magnitude in both experiments. Data from the third experiment are not presented, but the authors describe it's results as being essentially the same as those of experiment two. Results were not significant in the first experiment ($p=0.2$) but were significant in the second and third experiments ($p=0.01$). Combining results across all three experiments gave significant results at $p=0.01$.

The authors view the results as evidence that the time that elapses between capture and killing in effect allows longline caught fish to recover from the exhaustion of the capture process.

Discussion

The authors of these papers expected that chalkiness would be more prevalent in fish that were well fed, with higher glycogen reserves. This has not been demonstrated, either in the experiments during the 1960s, or in subsequent experiments or observations. The authors further demonstrate an increase in chalkiness with fish size. The 1999 IPHC chalky experiment found the opposite, that chalkiness was more prevalent in small fish.

The papers summarized in this report give a clear description of the chalky condition. In short summary, the flesh of chalky halibut is a dull, 'chalky' opaque white. Non-chalky flesh is shiny and semi-translucent. The condition is usually not apparent when the fish is first caught, and may take up to seven days to become obvious. Chalky fillets have lower protein solubility and higher drip-loss, from four to as high as nine percent compared to one to two percent in non-chalky flesh. The cooked meat of chalky halibut may be dry and tough compared to non-chalky flesh, but is otherwise acceptable as a food product. The flesh of chalky halibut is more acidic. Fish with 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. The visual and pH indicators of chalkiness develop post-mortem.

The metabolic basis for the chalky condition is also clear. 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.

The ultimate causes of pH change in Pacific halibut are less clear. Possible causes of the lowered pH include death occurring while the fish is exhausted with resultant high lactic acid concentrations, feeding differences resulting in high muscle glycogen reserves at time of capture, as well as high ambient or holding temperatures. The postmortem pH of halibut muscle can be raised by simply allowing a rest period before death. The increase in pH is accompanied by a reduction in incidence of chalkiness. This provides support for the view that chalkiness is caused by low flesh pH and not by some unknown pathogen or abnormal condition. Two general area/time patterns for chalky occurences in Canada and Alaska have been observed. 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 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). Although both patterns are associated with warmer summer months, it is not known if additional ecological factors such as a change in feeding patterns also play a role in these patterns.

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Table 1. Relation between pH, lactic acid and protein solubility (mg/gram muscle), and dry weight (% of wet weight) of halibut muscle and appearance of chalkiness (fish taken in trawls).

Condition when landed	No. of fish	At catching					On landing 6 days later				
		pH	Lactic acid	Protein N Tot.	Protein N Sol.	Dry wght	pH	Lactic acid	Protein N Tot.	Protein N Sol.	Dry wght
Normal	12	6.28	6.0	27.8	25.1	21.9	6.17	6.9	28.4	24.4	22.5
Mod. Chalky	3	6.16	7.1	27.0	24.9	21.8	5.90	7.8	29.8	17.8	23.6
Very chalky	5	6.22	5.8	27.3	24.0	21.7	5.76	8.3	29.2	13.3	23.7
Combined chalky	*8*	*6.19*	*6.3*	*27.2*	*24.4*	*21.7*	*5.81*	*8.1*	*29.4*	*15.0*	*23.7*

Table 2. Changes in pH and in extractable protein (mg/gram muscle) in frozen normal and chalky halibut muscle on thawing.

Condition at extraction	Frozen at catching			Frozen on landing		
	pH	Protein N soluble in NaCl solution	Protein N soluble in KCl Solution	pH	Protein N soluble in NaCl solution	Protein N soluble in KCl Solution
Normal fish						
Frozen	6.31	26.8	5.2	6.25	25.3	4.4
Thawed (8 min, 20°C)	6.32	25.1	5.1	6.28	26.7	4.4
Thawed (2 hr, 20°C)	6.33	23.0	4.8	6.24	24.3	4.1
Chalky fish						
Frozen	6.18	25.2	6.0	5.74	13.4	2.6
Thawed (8 min, 20°C)	6.13	25.7	5.4	5.74	13.2	2.5
Thawed (2 hr, 20°C)	5.79	12.2	4.0	5.70	10.3	2.7

Table 3. Soluble protein nitrogen and pH of normal and chalky muscle from halibut caught by longline.

	Number of fish	pH	Protein N				
			Before freezing			After freezing	
			Total	Soluble	% Sol.	Soluble	% Sol.
Normal fish	6	6.46	27.9	25.1	90	-	-
Chalky fish	6	5.91	29.3	13.5	47	10.8	40

Table 4. Variation in flesh pH in halibut with location of the measurement site. Each value is the mean for seven fish.

Position No.	Mean pH	Mean deviation from mean pH for all positions
1	6.05	+0.09
2	6.03	+0.07
3	5.96	0.00
4	5.97	+0.01
5	5.96	0.00
6	5.89	-0.07
7	5.85	-0.11
8	6.04	+0.08
9	5.96	0.00
10	5.96	0.00
11	5.87	-0.09

Table 5. The influence of a recovery period between the catching and killing of halibut on flesh pH postmortem and on incidence of chalkiness.

	Fish killed	
	Immediately after being caught	After a period of recovery
Experiment 1		
Recovery period	-	10 hr
Number of fish	13	13
Mean flesh pH	5.98	6.14
Range of flesh pH	5.74-6.45	5.78-6.66
Percentage of fish chalky or borderline	77	46
Experiment 2		
Recovery period	-	9-13 hr
Number of fish	21	21
Mean flesh pH	6.23	6.47
Range of flesh pH	5.90-6.64	6.25-6.85
Percentage of fish chalky or borderline	33	0

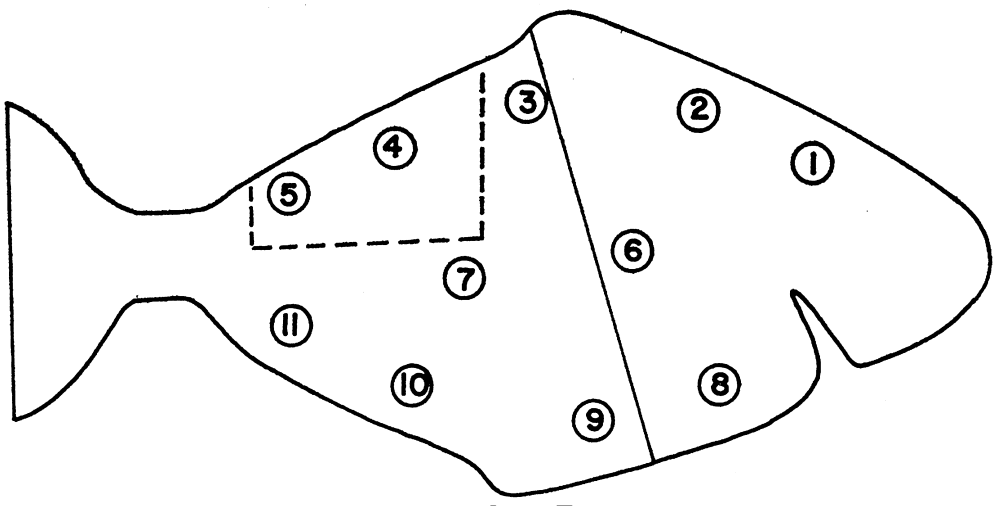

Figure 1. Outline sketch of a halibut showing the sites at which pH measurements were made (numbered 1-11), the position of the cut made to enable visual examination of the flesh (solid line anterior to "3" and "9"), and the location of the position from which samples were taken for drip determinations (area enclosed by broken lines).

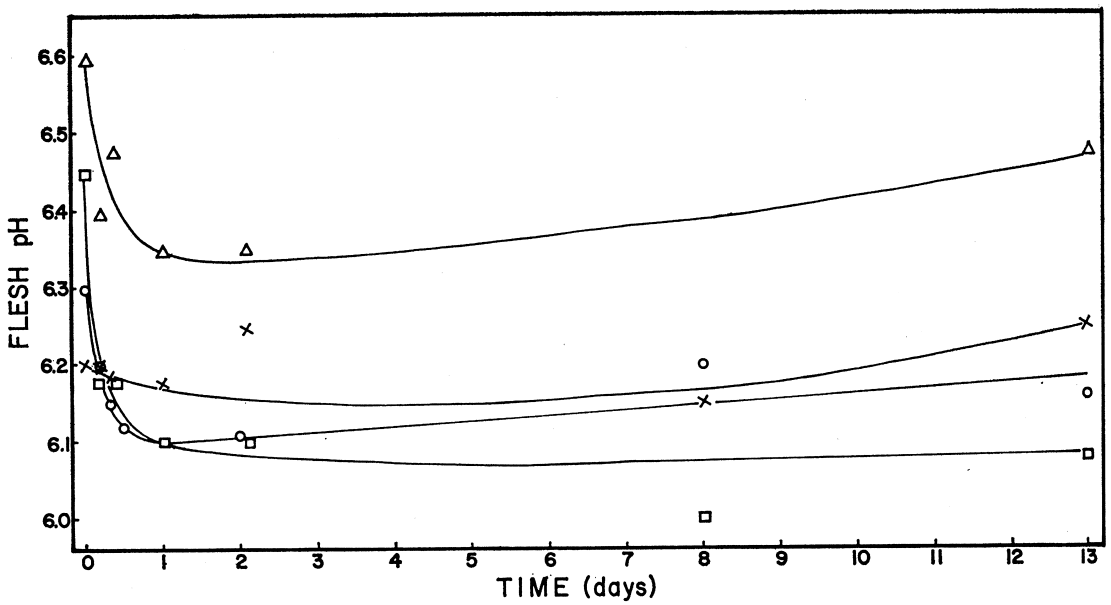

Figure 2. Changes in halibut flesh pH with time of storage in ice. Each measurement was made in a separate, fresh incision in an area surrounding position "3", Fig. 1. The temperature of the flesh of these fish was 9-10 °C when they were killed, and 0-1 °C 4 hr after they were iced. The two small fish were in rigor within 4 hr of being killed, the medium fish within 8 hr. Small fish Δ and ❑ , medium fish ❍ and X.

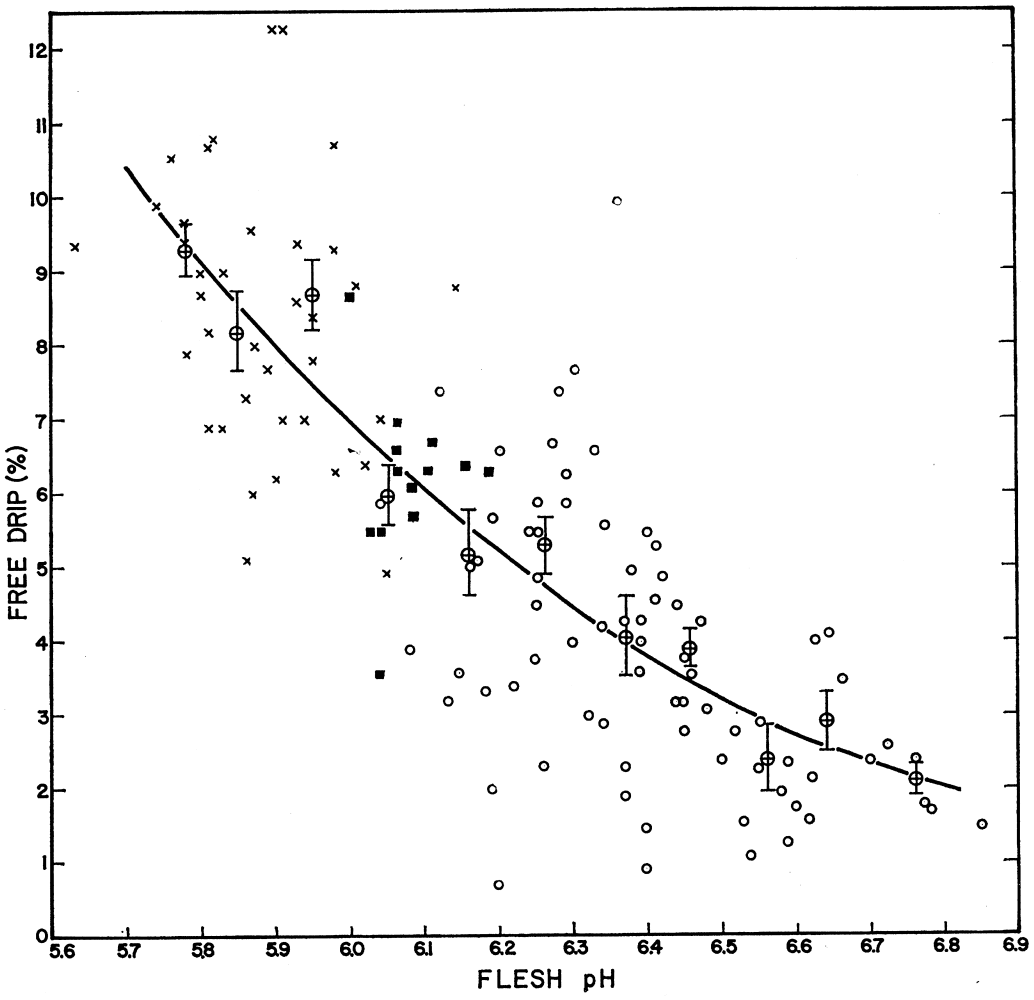

Figure 3. Relation between free drip, flesh pH, and chalkiness in halibut. Free drip and flesh pH (position "3", Fig. 1) measurements made after the fish had been stored 11 days in ice. Chalky fish, X; borderline chalky, ❑ ; nonchalky, ❍ . Mean value within each 0.1 pH unit interval, and the standard error of the mean, are indicated by Å and the vertical line drawn through that symbol, respectively.

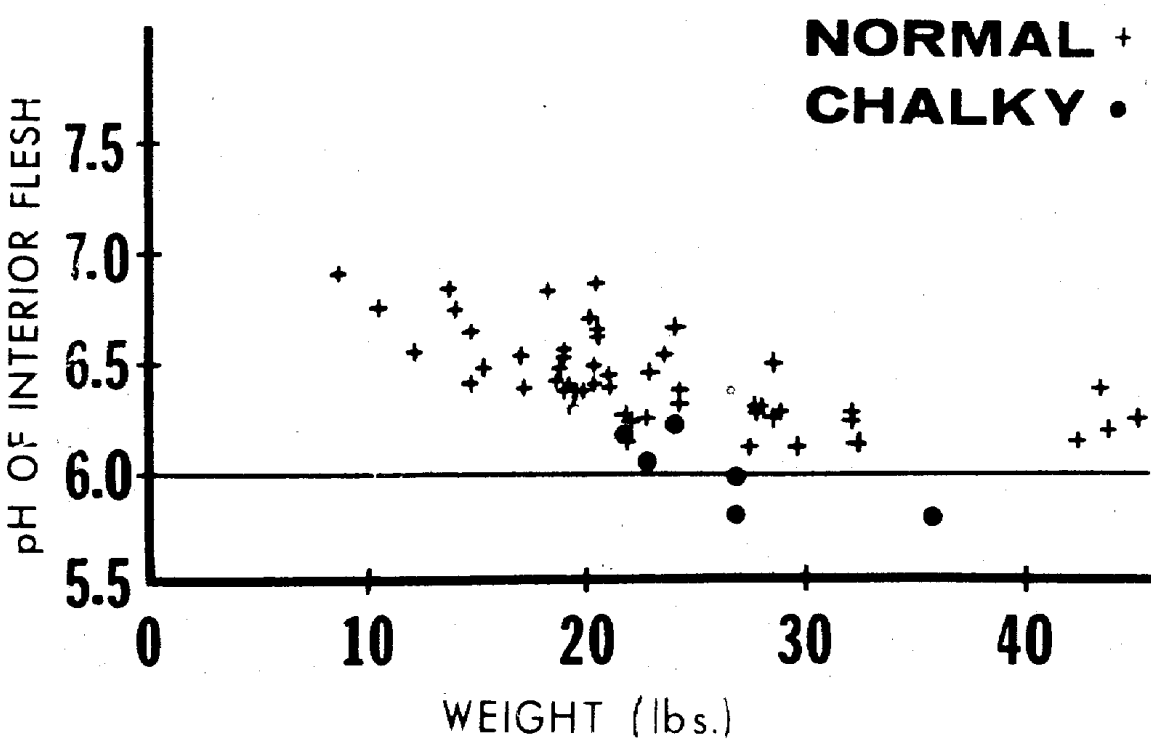

Figure 4. Variation of interior meat pH with weight of the halibut, head on and eviscerated.