Biological Research

General

Deployment of the Seacat water column profiler in 2001

Steven R. Hare

Abstract

A Seacat SBE-19 water column profiler was successfully deployed for a second year aboard vessels participating in the annual stock assessment survey. Usable salinity-temperature-depth profiles were obtained at 100 stations around Kodiak Island between June 1 and August 24, 2001.

Introduction

In 2000, a Seacat SBE-19 water column profiler was purchased and deployed aboard a commercial halibut longliner chartered for the annual stock assessment survey (Hare 2000). For the initial deployment in 2000, an experienced vessel and sampler were selected without concern about the area the vessel would be fishing. The focus was also on the process, as we expected there to be a number of logistical difficulties to resolve. For this year, the objectives were slightly modified. A pump was added as recommended in Hare (2000) to attempt to stabilize the salinity profiles.

Methods

The profiler was deployed in the same manner as described in Hare (2000). The vessels selected to carry the profiler this year were those scheduled to conduct the stock assessment survey work around Kodiak Island. The reason for this selection was that NOAA was conducting a great deal of fishery-marine mammal interaction work around Kodiak Island, and physical oceanographic measurements might contribute to the research.

Results

The profiler was aboard the *F/V Viking Star* for two trips and aboard *F/V Kristiana* for seven trips. A total of 126 stations were fished during the combined nine trips. A total of 100 usable salinity-temperature-depth profiles were made, for a success rate of 79%, somewhat lower than the 92% rate obtained in 2000. The principal reason for this was that one entire cruise was missed as problems arose with the sampler power supply. Removing this cruise increases the success rate to 89%.

Discussion

After two successful years of deployment, the intent for the 2002 field season is to increase the number of profilers deployed during the survey field season. Collaboration with Pacific Marine Environmental Lab of NOAA is being pursued as are a number of funding opportunities.

Acknowledgments

I wish to acknowledge the work of sea samplers, Darcie Hook and Kelly Attridge, (aboard the *F/V Viking Spirit*) and Bruce Biffard and Art Dodds (aboard the *F/V Kristiana*).

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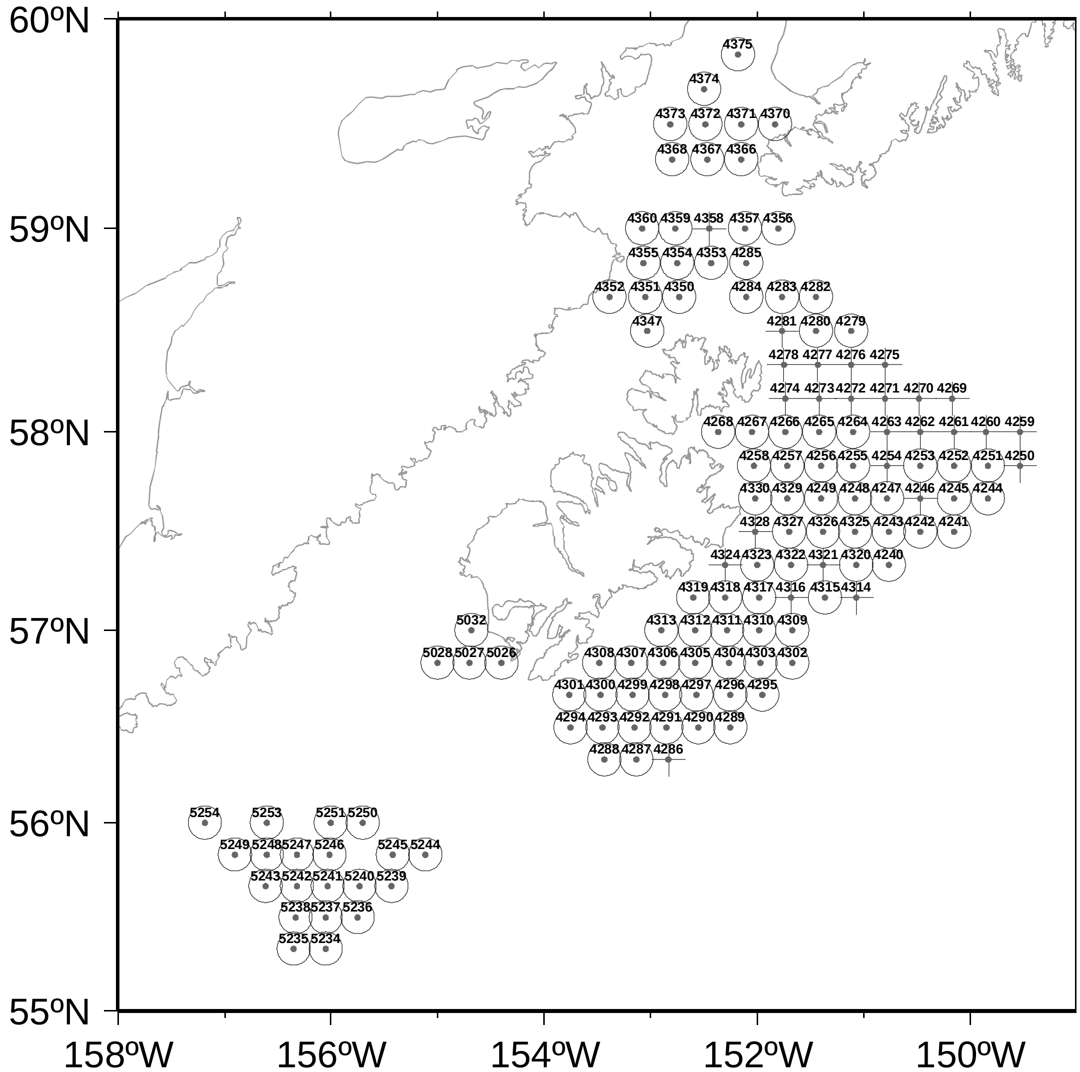

Figure 1. The 126 stations fished by the *F/Vs Viking Spirit and Kristiana* while the profiler was on board in 2001. Stations where deployment of the profiler yielded usable data are circled; stations with a cross indicate non-deployment or unsuccessful cast.

Chalky halibut investigations in 2001

Stephen M. Kaimmer

Abstract

Chalky halibut investigations in 2001 included the purchase and use of pH meters by some buying stations to screen chalky halibut. During the early fall, the IPHC conducted a charter to collect halibut and track changes in pH and chalkiness over a five-day period. Our observations on these fish indicate that pH screening should be very useful when conducted 24 hours or more after the fish are caught and killed.

Introduction

The Halibut Association of North America (HANA) entered into an agreement with Sentron, Inc, to make a bulk purchase of the Argus X pH meters at a wholesale price, and several HANA members used these meters during 2001 to screen landings for chalky halibut. These users were surveyed at the beginning and the end of the 2001 season as to the utility and performance of the pH meters. Also, a few of these buyers have made specific season-end data available to IPHC regarding pH observations taken during the season, including landing-by-landing chalky occurrence at their facilities. Post-season interview data regarding pH meter use, as well as summaries of some of the processor data will be prepared for the IPHC Bluebook. Associated with the pH meter testing, the IPHC conducted a study in the fall that followed the changes in pH and chalkiness in 32 halibut, which were purposely caught in a high chalk area near Homer. Data from this study is summarized in this report.

One problem with chalky halibut marketing is having a clear definition of chalky halibut. I am opening with some criteria for nomenclature regarding chalky fish from the U.S. and Canadian governments.

Every year, our understanding of the changes which take place in chalky halibut is increased. In the discussion, some information on the interplay of rigor and post-mortem metabolism are presented as they effect flesh pH.

United States fish grades as applied to chalky halibut

According to the United States Food and Drug Administration (FDA) standard for grades of whole or dressed fish[1], "chalky" is considered an abnormal condition where the physical and/or chemical structure of the fish flesh has been sufficiently altered so that the usability and/or desirability of the fillet is adversely affected. Specifically, "chalky" refers to a fillet which is partially or

[1] http://seafood.nmfs.noaa.gov/261SubpartA.htm

wholly characterized by a dry, chalky, granular appearance and fiberless structure. Abnormal conditions are further characterized as moderate, or excessive (Table 1).

The Canadian Food Inspection Agency defines chalky as "Chalky Texture: Dry and powdery, leaving the sensation of a chalky solution in the mouth. (texture crayeuse)"[2].

Use of pH meters at halibut buying stations by members of the industry

During 2001, a total of 14 meters were purchased by six different companies, for use at seven locations in the U.S. and Canada. A survey was sent out early in the season asking about ease of use and satisfaction with the product. There were three replies to this early survey. Respondents generally agreed that the meters were easy to calibrate and use, and gave quick and accurate readings of flesh pH. However, one respondent felt that there was not always a good correlation between the flesh pH ranges earlier published by the IPHC (Kaimmer 2001a) and chalkiness in the fillet (pH < 6.0, always chalky; pH between 6.0 and 6.2, may be chalky; and pH > 6.2, never chalky).

Results of the second, season-end, survey will be made available in the Bluebook, as well as summaries of some of the data collected by meter users.

Progression of pH and chalkiness changes in a sample of halibut

Design and methods

The 44-foot *F/V Americanus* was chartered from October 11-13, 2001 to collect up to 100 Pacific halibut from an area near Homer which had recently produced chalky halibut. Brad Faulkner, of Alaska Custom Seafoods in Homer, directed us to locations where chalky fish had recently been encountered. Fish were caught on 16/0 hooks using snap gear from the area near the Barren Islands. Poor weather hampered the collection, and only 32 fish were collected.

All pH and temperature measurements were made using one of two Argus X pH meters with LanceFet probes that were loaned by Sentron, Inc. This is an upgraded version of the meter used in trials last year by the IPHC (Kaimmer 2001b). Although the probe design allows stabbing into meat products, we used a knife to make a small cut through the skin for easier probe insertion. All pH and chalky observations were made on the white side of the fish. This was for our convenience, but also mirrors the industry practice of storing iced halibut on vessels or in fish plants with the white side up. The probe was allowed to stabilize to flesh temperature for all pH readings. Flesh temperatures at capture were around 11°C while temperatures in iced fish were all around one °C. It could take one or two minutes for the probe to equilibrate from a cold room temperature to the temperature of the fish stored on ice, but once the probe was at fish temperature, it could be rinsed and inserted into another fish without noticeable change in the probe temperature. This allowed multiple readings from the meter as quickly as we were able to change fish. Visual observations of chalkiness were made through the same cut. Chalkiness was assigned one of four values; none, slight, moderate, and excessive (Table 2). The moderate and excessive categories were chosen to coincide with the U.S. FDA definitions (Table 1). In most cases, a non-chalky reference fish was

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[2] http://inspection.gc.ca/english/anima/fispoi/manman/samnem/define.shtml

used to provide a contrast to fish being examined for chalkiness, and determination of slight and moderate grades was very subjective.

One set of longline gear was made on the first fishing day. This fishing produced 30 halibut, ranging in size from 77 to 119 cm. Initial observations of flesh temperature, pH, and chalkiness were made through a transverse cut across the top of the tail as soon as each fish was landed. Sex and landing time were also recorded. Fish were eviscerated and cleaned soon after capture and held in an insulated fish tote until the set was completed. A second set produced one halibut, which was handled as above. The second day started with tail observations on all iced fish. One additional set was made on the second day, which resulted in the catch of one halibut. Severe weather precluded any additional fishing, and the vessel returned to Homer. On the evening of the second day, temperature, pH, and chalky observations were recorded at the tail for all fish, and fish were offloaded and iced into an insulated tote. All subsequent observations were conducted indoors in space donated by the Fish Factory, Homer, AK.

Once fish were ashore, observations were obtained from three locations during each reading; tail, dorsal, and pectoral. The dorsal observation was made through a cut just below and behind the anterior insertion of the dorsal fin, while the pectoral cut was made just beside the pectoral fin. These cuts were enlarged as necessary when determining visual signs of chalkiness. On the second through the fifth days, observations were taken twice a day, once in the early morning and again in the early evening. On the sixth day, only one set of observations was made, in the late morning. When all observations were complete, remaining food-quality fish (about 200 pounds) was filleted, vacupacked, and donated to the Homer Food Bank. The Fish Factory and Alaska Custom Seafoods donated filleting and vacupacking services.

Results

Overall, eleven of the 32 fish showed some signs of chalkiness, ten in the tail area, nine in the dorsal area, and nine in the pectoral area. Nine fish were chalky in all three areas, one fish was chalky in the tail and dorsal only, and one fish was chalky in the dorsal only. Of the ten fish that were chalky in the tail, I only gave a “slight” code to three fish. One of these later developed into moderately chalky. Seven fish were first coded as moderately chalky. Five of these were later coded as excessively chalky.

In the following discussion of changes over time, data from the single fish collected on the second day will not be used. It did not go chalky, and being collected almost 24 hours after the first group, the time sequence on observations for that fish is seriously out of phase with the other 31 series. From the first 31 fish collected, a total of 372 paired pH and chalky determinations were made at the tail. The range of pH observed was 5.89 to 7.36 (Figure 1).

For all fish, the highest pH was seen immediately after capture, and pH generally decreased over the first 24-36 hours to a low about 0.5 to 1.0 pH units below the initial reading. There was a major difference in this progression between fish that eventually went chalky and fish which did not go chalky. In fish which did not go chalky, after a pH decrease in the first 1-2 hours, there was a pH increase seen in the third reading, taken the morning following icing, at about seven hours post mortem. Although this rise in pH was seen in some fish from all chalky categories (Figure 1), it was most dramatic in those fish which did not go chalky. The downward slope and eventual flattening of the pH curves was similar for all groups after this third (or sometimes fourth) reading, but the magnitude of the pH rise in the non-chalky group resulted in a much higher ending pH (lower acidity) for this group as a whole. Figure 2 shows the same information, but is plotting the average tail pH by chalky group at each reading interval, rather than the individual readings. Plotted on this figure are 95% confidence intervals for those series where that can be calculated. Even with the small group sizes in this study, there is a clear distinction between pH ranges for non-chalky fish and chalky fish after about 24 hours. A t-test on these values (Table 3) supports this observation, non-chalky fish having highly significant differences in pH from each of the chalky groups. However, although there are pH differences suggested between chalky groups in Figure 2, these differences are not significant with our group sizes.

Chalkiness was not noted in any fish until at least 18 hours after death, and in some cases not until 3 days of observation (Table 4 and Figure 3). Most chalky fish showed some signs of chalkiness within the first 24-36 hours. Five fish were moderately chalky within 24 hours. The earliest appearance of severe chalkiness was not until after 72 hours post-mortem, and for two fish this severe chalkiness was not apparent until the fifth day of observation. Lines on Figure 3 indicate changes from one chalky classification to the next for individual fish. In all cases, the transition from one chalky stage to the next took 2-3 days. There does not seem to be a relationship between tail pH and how long it took to develop the moderate chalky condition, two fish with the lowest pH (highest acidity) taking three times as long to develop a moderate chalky condition as four fish with higher pH values.

The other two locations on the fish which were tracked for pH and chalkiness changes were the area below the dorsal fin ("dorsal"), and the area just above and behind the pectoral fin ("pectoral"). Paired with the tail observations, seven sets of pH and chalkiness data were collected when the fish were in iced storage on shore. Over all 224 observations, the average tail, dorsal, and pectoral pH values varied less than $1/10^{th}$ of a pH unit (Table 5). Within individual fish, the largest difference within any set of readings was ¼ to 1/3 above or below any other reading in the set. The time series for the dorsal and pectoral readings started at about 40 hours, when the fish were landed. By this time, most of the fish that were going to show tail chalk had already started to show visual signs of chalkiness. There was a tendency towards later, and less severe, chalkiness in the pectoral region, with fairly equal occurrence and intensity between the tail and dorsal regions.

Discussion

Every year we learn a little more about the development of chalkiness in Pacific halibut. Probably the major accomplishment this year has been the field demonstration of the pH meter, and its development as a tool to detect fish at the point of sale which are likely to go chalky. We have clearly demonstrated the need to test fish at least 24 hours after capture and killing. Unfortunately, the exact relationship between pH and eventual stages of chalkiness is not clear-cut, and pH meter-users will have to excercise judgement as to what pH levels to use for chalky classifications. The data from our 2001 experiment suggest that the 6.0 and 6.2 pH levels are reasonable starting points for these classifications. Certainly, fish with a pH of over 6.3 should have little incidence of chalkiness, and readings in the 6.0 to 6.1 range are often chalky.

Some literature has recently become available to IPHC staff which discusses changes in quality of fresh fish (Huss 1995), with particular reference to pH and rigor mortis. This has particular bearing on the chalky halibut problem. After death, fish metabolism continues for some time. When the blood is removed from the body of the slaughtered animal, removal of waste products from the muscle is stopped, and homeostatic mechanisms attempt to maintain a physiological balance in the internal environment. This results in the anaeorbic metabolism that produces lactic acid, and is most likely the direct cause of the immediate drop in pH in post-mortem flesh. This drop in pH is the direct cause of loss of protein solubility, higher drip loss, and protein denaturation. Rigor mortis is the post-mortem condition where ATP stores are insufficient for muscle filaments to release their contracted states. The following is an excerpt from Huss (1995):

> "Immediately after death the muscle is totally relaxed and the limp elastic texture usually persists for some hours, whereafter the muscle will contract. When it becomes hard and stiff the whole body becomes inflexible and the fish is in rigor mortis. This condition usually lasts for a day or more and then rigor resolves. The resolution of rigor mortis makes the muscle relax again and it becomes limp, but no longer as elastic as before rigor. The rate in onset and resolution of rigor varies from species to species and is affected by temperature, handling, size and physical condition of the fish. The effect of temperature on rigor is not uniform. In the case of cod, high temperatures give a fast onset and a very strong rigor mortis. This should be avoided as strong rigor tensions may cause gaping, i.e., weakening of the connective tissue and rupture of the fillet."

Many meat industries "hang" meat during rigor to reduce the extent of the rigor phase. Stress prior to death can exacerbate the post-mortem changes. Capture stress and struggling on the hook undoubtably demand more energy than aerobic rerspiration can provide, resulting in the activation of anaerobic metabolism. This can generate lactic acid prior to death. Temperatures outside the normal range experienced by the species can also provide a non-lethal stress.

The "bump" in pH at 6-8 hours after death which I saw in most of the non-chalky fish may be able to be explained by someone with a better understanding of post-mortem changes in metabolism, and could provide a major clue to undestanding the temporal and spacial occurences of chalky halibut in our fishery.

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Huss, H. H. 1995. Quality and quality changes in fresh fish. FAO Fisheries Technical Paper No. 248. Food and Agriculture Org. of the United Nations, Rome.

Table 1. United States standard for grades of flounder and sole fillets criteria for degree of abnormal conditions in fish fillets.

Criteria	U.S. F.D.A. definition
moderate	The condition is conspicuously noticeable but does not seriously affect the appearance, desirability, and/or eating quality of the fillets.
Excessive	The condition is both distinctly noticeable and seriously objectionable.

Table 2. Categories used in this study for assigning chalkiness by visual inspection of fillet flesh.

Degree of chalkiness	Criteria
None	No signs of chalkiness, flesh transparent, bluish sheen obvious on surface of fillet when skin is pulled away.
Slight	Whitening between myotomes.
Moderate	General whitening, particularly when viewed alongside non-chalky flesh. No sheen on surface of fillet.
Excessive	Flesh totally opaque, in advanced stages there may be gaping fissures between myotomes.

Table 3. P-values from t-tests of average tail pH values over time by degree of final chalkiness.

Chalkiness	Slight	Moderate	Excessive
None	< 0.001*	< 0.001*	< 0.001*
Slight		0.58	0.57
Moderate			0.15

Table 4. Time and tail pH reading for first occurrence of each degree of chalky condition. Not all fish were first noted as "slight" chalky. A total of eleven fish showed at least one of the chalky conditions.

Chalkiness	Number	Hours post-mortem Average (range)	pH Average (range)
Slight	3	47 (22-78)	6.15 (6.03-6.21)
Moderate	8	33 (15-77)	6.19 (5.97-6.47)
Excessive	5	98 (77-112)	6.07 (5.99-6.23)

Table 5. Differences in pH readings between different areas in individual halibut. Readings are averaged over all fish grouped by a final chalky classification for each fish. Numbers in parentheses are the standard deviation about each average.

		Average change in pH in readings		
Chalky classification	Number	From tail to dorsal	From tail to pectoral	From dorsal to pectoral
Slight	21	0.01(±0.06)	-0.07(±0.11)	-0.08(±0.10)
Moderate	14	0.07(±0.08)	0.00(±0.14)	-0.07(±0.10)
Excessive	35	-0.01(±0.10)	-0.13(±0.16)	-0.12(±0.14)
None	154	0.01(±0.11)	-0.05(±0.11)	-0.06(±0.11)
Total	224	0.01(±0.11)	-0.06(±0.12)	-0.07(±0.12)

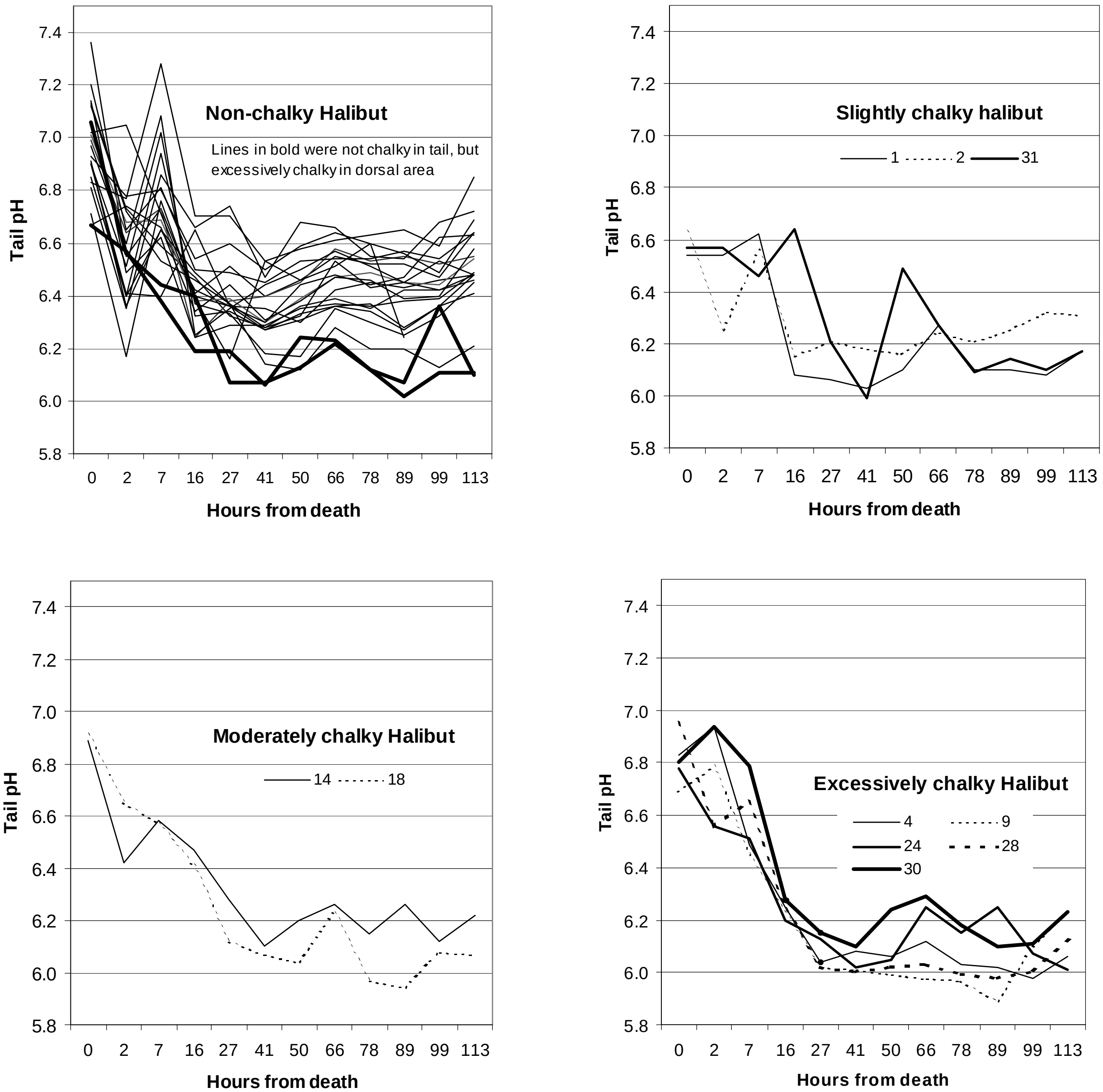

Figure 1. Tail pH values plotted as a function of time from death for halibut. Data are categorized by final degree of chalkiness in tail at end of observation period. The two bold lines in the first figure are fish which did not go chalky in the tail, but did go chalky elsewhere in the body. In the other figures, the lines are identified by tag number.

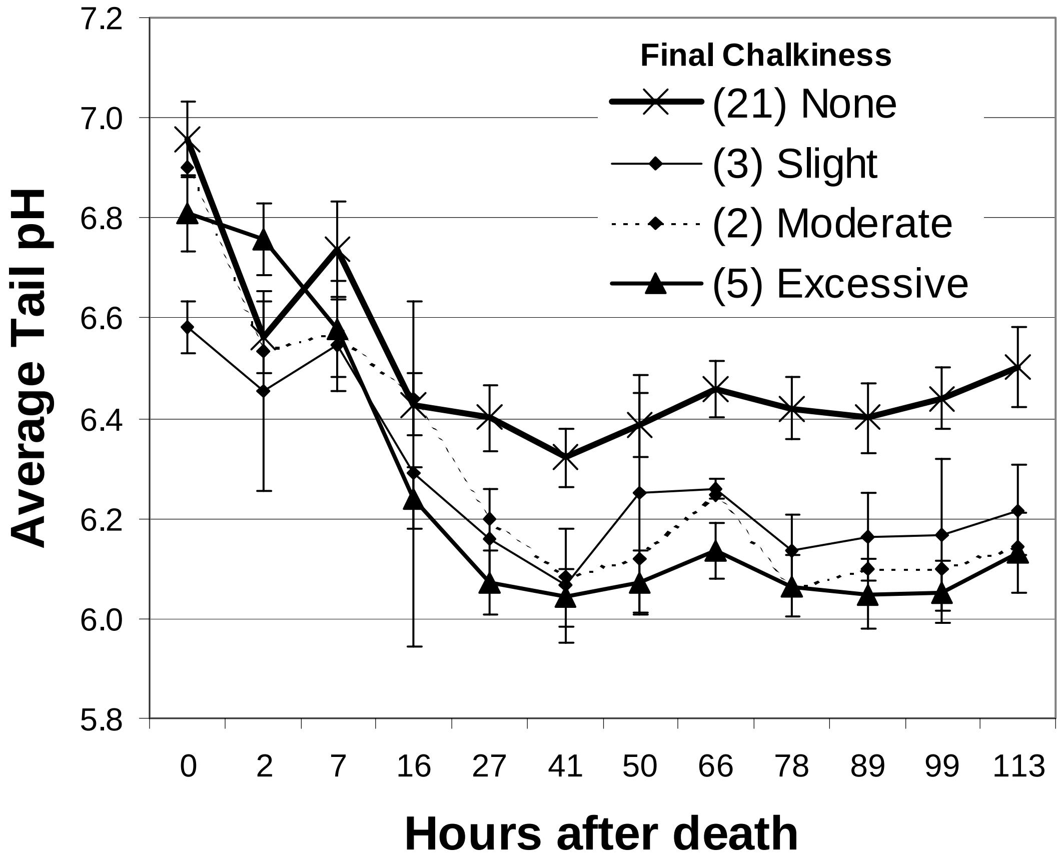

Figure 2. Average tail pH values for each of four groups of Pacific halibut. Groups are defined by final chalkiness determination of each fish. Vertical bars indicate 95% confidence intervals about the averages. Numbers in parenthesis indicate number of fish in each group. A confidence interval could not be calculated for the 'slight' category, which only had two members.

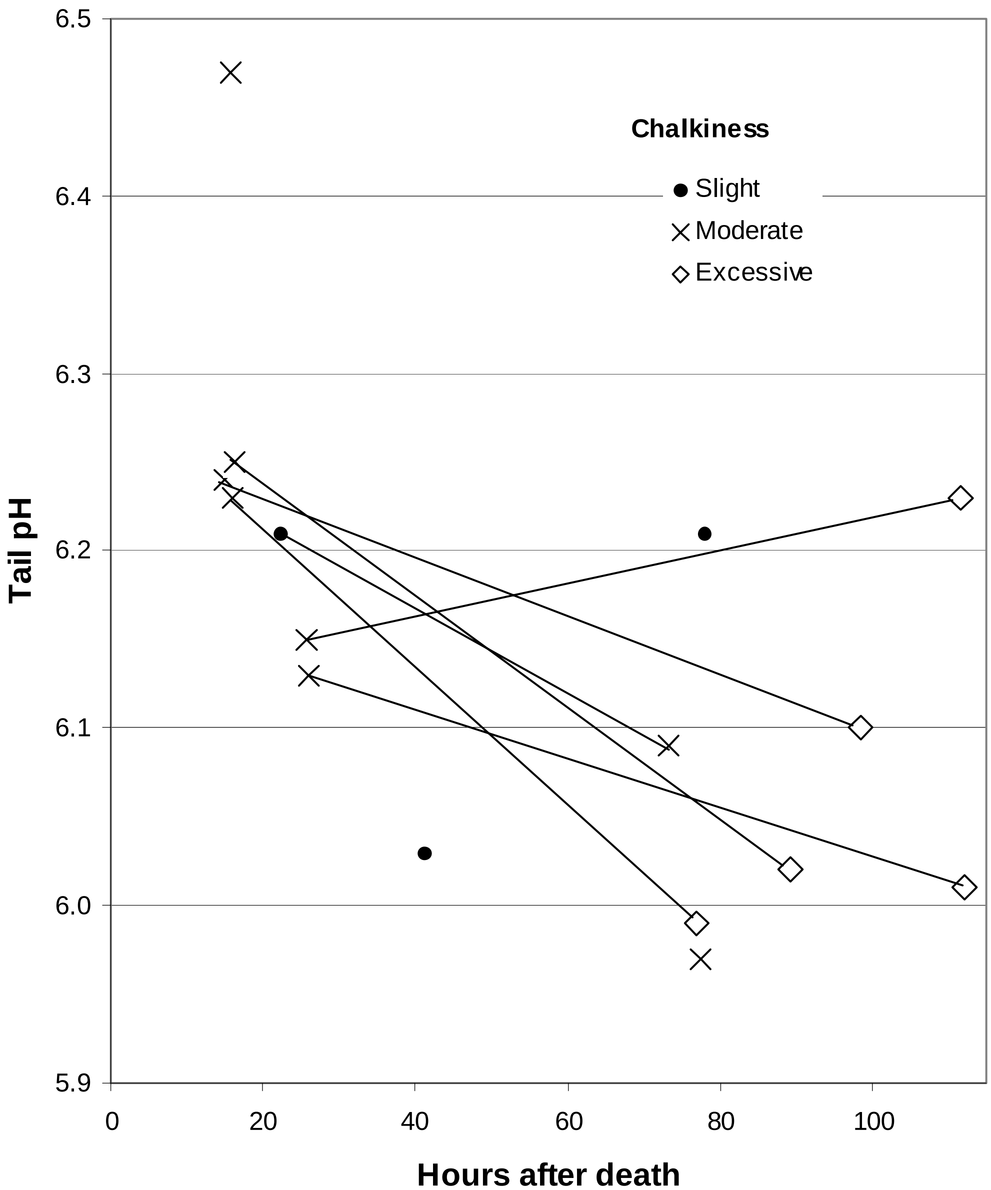

Figure 3. Time and tail pH when first classified as slightly, moderately, or excessively chalky. Changes in chalky classification on individual fish are indicated by lines connecting data points.

Variance comparison for surface and break-and-burn ages

Joan E. Forsberg, Din Chen, and Thomas M. Kong

Abstract

Results of a 1995 comparison of the variance of replicate break-and-burn ages with the variance of surface ages indicated that between-reader burn ages were more variable. In a similar comparison performed in 2000, with replicate readings of both surface and burn ages for the same set of otoliths, variance between the paired burn readings was lower than that of surface ages. A simulation study further indicates that the variance from burn aging is significantly lower than the variance from surface aging from age 11 years and up. Implications the new findings have on current aging criteria are discussed.

Introduction

Age readers at the International Pacific Halibut Commission (IPHC) began routinely using the break-and-burn method of age determination in 1992. The break-and-burn method enables readers to view growth zones that are hidden from view on the surface due to the nature of the otolith's growth. At the IPHC, all otoliths are surface-aged and those meeting certain criteria (i.e., cases where the reader believes growth zones are hidden from surface view) are then broken and burnt. The break-and-burn method is preferred over surface-aging by most agencies aging west coast groundfish (Committee of Age Reading Experts (CARE)[1]).

In the early 1990s, IPHC aging practices went through a series of changes in terms of number of otoliths aged and number of readings per otolith. Since break-and-burn ages are assumed to be more accurate, breaking and burning of all halibut otoliths was considered in 1995 (percentage of otoliths broken and burnt under current protocol has ranged between four and 25% since 1992). In an unpublished study, Clark (W.G. Clark, PO Box 95009, Seattle, WA 98145-2009, unpublished data) evaluated the variance of a set of paired burn ages. The between-reader variance for the burn ages was found to be considerably higher than variance between surface ages and the switch to 100% break-and-burn was abandoned.

However, the readers were relatively inexperienced in the technique of break-and-burn at the time of Clark's study. For this reason, the variance comparison was repeated in 2000 on another set of otoliths. In the current study, paired readings were made of both surfaces and burnt sections.

[1] http://www.psmfc.org/care/

Methods

The 543 otoliths used in the 1995 study were collected on a longline survey in IPHC Regulatory Area 2B between July 3 and July 14, 1995. The 520 otoliths used in the current study were also part of a longline survey collection from Area 3B and were collected between June 17 and August 11, 1999. For the 1995 study, surface age was not recorded. Each burnt otolith section was aged "blind" by two readers (i.e., the second reader did not have access to the first reader's ages). The readers in the 1995 study had less than one full year of experience at burnt-section age determination.

The otoliths used in the current study were surface-aged twice, then broken and burnt, then the two readers each read the burnt sections (all readings made without knowledge of the other reader's ages). The two readers examining the 1999 otoliths (one of whom had also participated in the 1995 study) both had over 5 years experience at reading burnt sections.

Ages for the 1999 otoliths were entered and analyzed as follows:

Variance model

A model from Richards et al. (1992) is used for this comparison. The variance of age readings at a true age of *b* years is modeled in the following form for surface and break-and-burn readings with different parameters for each age-reading method:

$$\sigma(b;\sigma_1,\sigma_A,\alpha)=\begin{cases}\sigma_A+(\sigma_A-\sigma_1)\dfrac{1-e^{-\alpha(b-1)}}{1-e^{-\alpha(A-1)}} & \alpha\neq 0\\ \sigma_A+(\sigma_A-\sigma_1)\dfrac{b-1}{\mathrm{A}-1} & \alpha=0\end{cases} \qquad (1)$$

where A is the estimated maximum age from the readings. σ_1, the standard deviation for age 1 readings, and $\sigma_{A,}$ the standard deviation for the maximum age A, provide lower and upper bounds to $\sigma(b)$ defined in equation (1) for ages b = 1 and b = A, respectively. Therefore $\sigma(1)=\sigma_1$ and $\sigma(A)=\sigma_A$. The parameter α indicates non-linearity for the variance structure in equation (1).

Results and discussion

The maximum likelihood estimation is used to estimate the associated parameters from both aging methods.

First, we fit the model with six parameters (three each for surface/break-and-burn). We found that parameter σ_1 for both readings is not significantly different from zero (p-value > 50%), which is consistent with both the expectation and actuality of insignificant error in reading age 1 fish. We then refit the model fixing σ_1=0. Table 1 summarizes the estimated parameters and the associated variance-covariance matrix. Therefore, the estimated variance structures for both surface and break-and-burn readings can be constructed using equation 1 (see Fig. 1).

The variance for burn ages levels off after age 15 (Fig. 1). In general, the surface reading is subject to larger variance than the burn reading. Therefore the break-and-burn technique appears to be the better method for aging halibut. However, we cannot conclude from Figure 1 the age at which the burn reading is significantly better than the surface reading.

In order to do that, the probability distributions are needed for the variance structures from these two methods, which is not straightforward since equation (1) is not linearly dependent on the parameters. Therefore, we used a simulation approach for this purpose. The following steps were used for the simulation:

Step 1: randomly draw a sample from the multivariate normal distribution MVN(μ, Σ) for parameter vector $\left(\sigma_A^B, \alpha^B, \sigma_A^S, \alpha^S\right)$. This is based on the theory of maximum likelihood estimation that the parameter vector is asymptotically distributed as a multivariate normal distribution as MVN(μ, Σ), where μ and Σ are given by Table 1.

Step 2: calculate the variances for both aging methods using equation (1) as:

$$V^B(b) = \left[\sigma\left(b;0,\sigma_A^B,\alpha^B\right)\right]^2 \text{ and } V^S(b) = \left[\sigma\left(b;0,\sigma_A^S,\alpha^S\right)\right]^2;$$

Step 3: calculate the difference: $d(b) = V^S(b) - V^B(b)$

Step 4: loop over Step (1) to (3) ten thousand times, which gives 10,000 $d(b)$ for each age. The 95% confidence interval for the variance difference can then be constructed by the 2.5% and 97.5% quantiles for each age.

Figure 2 is the resultant sampling distribution for the variance difference at each age. We can see that the sampling variance for the difference increases with age. This is logically consistent since the aging error increases with age.

The 95% confidence interval for the difference is constructed by the percentile (Figure 3). It can be seen from Figure 3 that there is a statistically significant difference between surface and break-burn readings from age 12 years on.

For comparison, we ran the break-and-burn age data from the 1995 study in the model and plotted the standard deviation of the readings in Figure 4. In 1995, break-and-burn ages were more variable than surface ages. Since surface ages were not recorded for the 1995 study otoliths, the standard deviations of the 1999 surface ages are used for comparison.

In addition to surface and burn age, several other observations were recorded for each otolith in the 1999 data set. These other items included edge type, a code indicating the level of confidence the reader had in the age reading, and whether or not the reader would normally break and burn the otolith. These data will be analyzed further at a later date, but a preliminary examination of percent agreement between readers shows that surface ages of otoliths the readers would not normally break and burn had similar agreement and coefficient of variation (CV) to the paired burn ages (Table 2). Although percent agreement and CV were similar, the surface ages had a stronger bias between readers. Percent agreement, CV, and average percent error (APE) were calculated as described in Kimura and Lyons (1991) and Beamish and Fournier (1981).

Conclusions

Results of this study indicate a change to current break-and-burn criteria, i.e., breaking and burning all otoliths over a surface age of 10 years, should be considered. A surface/break-and-burn comparison by Blood (C.L. Blood, PO Box 95009 Seattle, WA 98145-2009, unpublished data) contrasts somewhat to these conclusions, as he found that surface and burn readings diverge at a surface age of around 7 years.

IPHC age readers have observed regional differences in pattern difficulty in halibut otoliths. Some otolith surfaces are very clear, even up to the age of 20 years. Further analysis of the 1999 otolith data set as well as an examination of regional differences in surface/burn agreement may lead to different recommendations in the future.

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Table 1. Estimated parameters and the associated standard errors (in brackets).

Aging Method	Parm.	Estimate	Estimated variance-covariance matrix
Break-burn	σ_A^B	0.650	$$\begin{pmatrix} 0.003728357, & -0.002718658, & 0.000086309, & -0.000029331 \\ -0.002718658, & 0.002190148, & -0.000215928, & 0.000046444 \\ 0.000086309, & -0.000215928, & 0.054029245, & -0.006313589 \\ -0.000029331, & 0.000046444, & -0.006313589, & 0.000772049 \end{pmatrix}$$
	α^B	0.155	
Surface	σ_A^S	1.312	
	α^S	0.038	

Table 2. Percent agreement, coefficient of variation (CV), average percent error (APE), and between-reader bias for different sets of paired age estimates.

Description of age data	% agreement	CV	APE	% -bias	% +bias
1995 burn 1 vs burn 2	33.8	6.7	4.7	23.4	42.7
1999 burn 1 vs burn 2	58.8	2.8	2.0	16.9	24.2
1999 surface 1 vs surface 2	47.4	4.4	3.1	10.9	41.7
1999 burn 1 vs burn 2 where bb reason code=N[1]	64.6	2.6	1.9	17.5	17.9
1999 surf. 1 vs surf. 2 where bb reason code= N[1]	64.3	2.8	1.9	7.8	27.9

[1] "bb reason code N" was assigned to otoliths the reader would not normally break and burn.

Figure 1. Estimated variance structure for surface and break-burn readings.

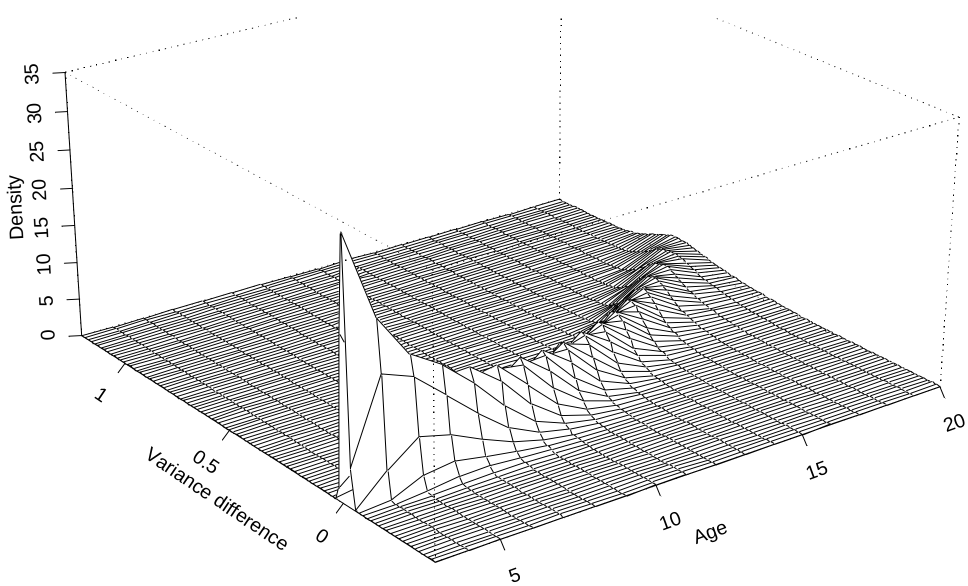

Figure 2. Sample distribution for the variance difference of surface and break-and-burn age estimates.

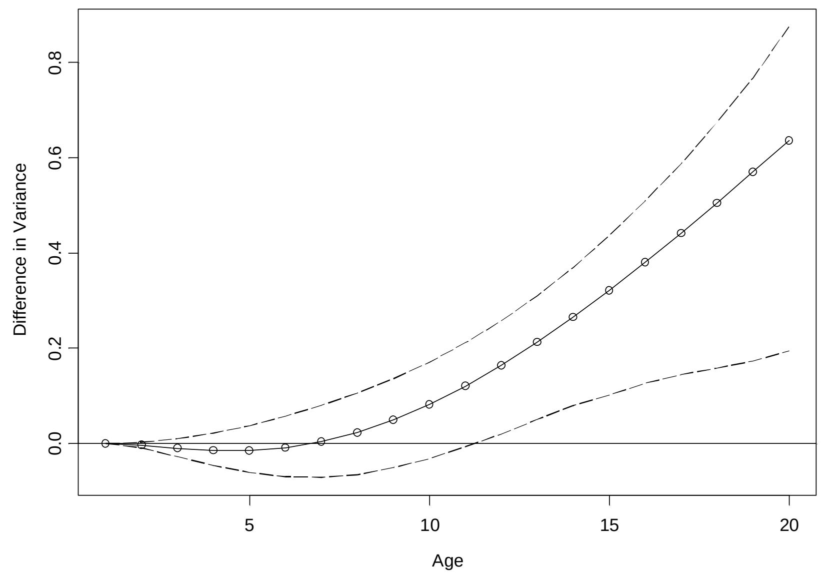

Figure 3. The estimated variance difference of surface and break-and-burn age estimates (solid line with dots) and the associated confidence interval (dashed line).

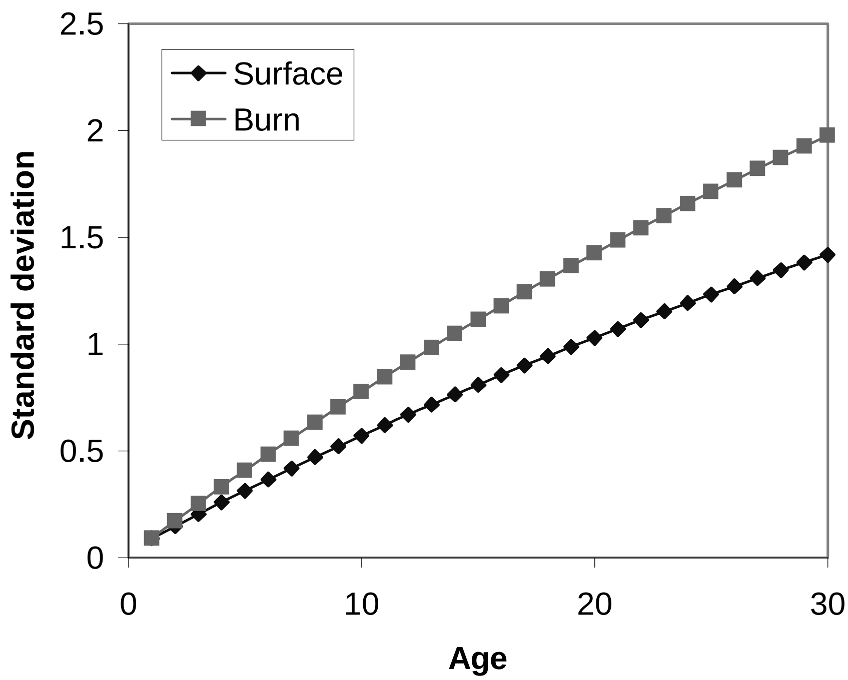

Figure 4. Standard deviation for 1995 break-and-burn readings compared with that of surface readings of the 2000 study set.

Seabird interactions with halibut longline gear: Sources of variation in abundance and behavior

Kendra Holt

Abstract

Due to increasing awareness of the incidental mortality of seabirds by north Pacific longline fisheries and the occurrence of the endangered short-tailed albatross (*Phoebastria albatrus*) on some halibut fishing grounds, the International Pacific Halibut Commission (IPHC) is interested in exploring gear and operational changes that would decrease seabird bycatch. The goal of this study was to examine species-specific interactions with halibut longline gear and assess the vulnerability of individual species. In addition, the effects of weather and time of day were examined to determine what conditions increased the risk of incidental capture.

Data were collected from IPHC Regulatory Area 4A near Unalaska Island, Alaska. Bird counts were conducted during both gear setting and hauling operations and the abundance and feeding behavior of each bird species was quantified.

While northern fulmars (*Fulmarus glacialis*) were the most abundant species present during setting (51%), they displayed little feeding activity, seldom taking strikes at the gear, and are considered to be at a relatively low risk of incidental capture. Laysan albatross (*Phoebastria immutabilis*) were moderately abundant (27%); however, they were the most aggressive species taking 86% of the observed strikes at the gear. The Laysan albatross were shown to be the most vulnerable species to incidental capture. Both black-footed albatross (*P. nigripes*) and shearwaters (*Puffinus* spp.) were observed at low abundance during setting operations (6% and 2%, respectively).

Weather conditions at the time of setting influenced both the abundance and behavior of ship-following seabirds. All four species observed feeding on baited hooks were more vulnerable to capture in rougher weather conditions; however, the effect of weather on abundance varied by species. This variation could have been a result of inter-species competition and dominance, or observer bias.

Contradictory to previous studies, the time of day at which the gear was set did not appear to have an effect on abundance or behavior. While it is possible that time of day does not affect the feeding activity of seabirds in this area, it seems more likely that the lack of a trend is due to the failure of the study design to account for variations in light levels between days.

Introduction

Over the past decade there have been increasing concerns regarding the incidental mortality of seabirds by worldwide commercial longline fisheries. (Brothers 1991; Murray et al. 1993; Ashford et al. 1994; Moloney et al. 1994; Prince et al. 1994; Cherel et al. 1996). Many species of seabirds forage for food in the waters frequented by commercial fishing vessels and are attracted to individual vessels. Food is believed to be the main factor causing this attraction and some species have become ship-followers, scavenging on the large amounts of fish and offal discarded into the water

(Wahl and Heinemann 1979; Griffiths 1982; Ryan and Moloney 1988; Garthe and Huppop 1994). The concentration of seabirds around vessels is of particular concern to the longline fishery. Problems arise when birds forage on the baited hooks while the gear is being set. During setting, the mainline may float at the surface for a short period of time before sinking. Seabirds taking bait are liable to become hooked and drown as the line sinks. Brothers (1991) classified the first 50 m behind the vessel as the most vulnerable area for birds to become hooked. The use of Bird Avoidance Devices (BADs), such as tori lines and towed objects, is required by most fisheries and discourages birds from entering this area. Birds may also become hooked on the line while the gear is being hauled; however, this is a less common occurrence.

While many different species of seabirds may be caught on longline gear, including albatross, petrels, shearwaters, and gulls, the incidental capture of albatross has gained the most attention (Brothers 1991; Bergin 1997; Gales 1998). Mortality associated with longline fishing activities is considered the most serious threat to albatross populations throughout the world. Population declines of several species in the Southern Hemisphere, including the wandering albatross (*Diomedea exulans*) and the black-browed albatross (*D. melanophris*), have been linked to longline fisheries in the southern oceans (Prince et al. 1994; Moloney et al. 1994; Gales 1998).

While much bycatch research has focused on the southern oceans, in particular the southern tuna (*Thunnus* spp.) and Patagonian toothfish (*Dissostichus eleginoides*) fisheries, there has been a growing awareness that northern fisheries, including the north Pacific halibut fishery, are also responsible for the incidental mortality of seabirds (Ludwig et al. 1998). In the north Pacific, northern fulmars, shearwaters, Laysan albatross, and black-footed albatross are the seabirds most frequently taken by longline vessels (Stehn et al. 2001). The co-occurrence of the endangered short-tailed albatross in halibut fishing grounds off Alaska has further increased pressure to reduce bycatch. The International Pacific Halibut Commission (IPHC) is currently evaluating alterations to longline fishing practices and gear that could decrease incidental mortality of seabirds (Trumble and Geernaert 2001).

In order to reduce seabird catch rates the number of interactions between seabirds and baited hooks must be reduced. To do this we must first develop a strong understanding of the factors that affect the frequency of seabird interactions with longline gear. Numerous studies in the Southern Hemisphere have reported higher rates of seabird bycatch in daylight hours than nighttime hours (Ashford et al. 1994; Cherel et al. 1996) and night setting is a commonly used method to reduce incidental mortality. Within nighttime hours, a full moon has been shown to increase catch rates (Duckworth 1995), indicating that higher levels of light increase feeding activity. Strong wind conditions have also been shown to increase the frequency of bait taking (Brothers 1991). Several other factors have also been shown to affect seabird catch rates, including season, species complex present, fishing practices, and the use of BADs (Garthe and Huppop 1994; Bergin 1997; Lokkeborg 1998). The effects and magnitude of these factors are specific to each seabird species and can vary greatly among fishing areas (Murray et al. 1993). Results obtained from studies conducted on the southern oceans are not necessarily applicable to seabirds in the north Pacific.

The goal of this study was to examine species-specific interactions with halibut longline gear and determine which species are at the highest risk of incidental mortality. In addition, the effects of weather conditions and time of day on the abundance and behavior of individual species were evaluated. The objectives of this study were to 1) describe the species composition and behavior of ship-following birds during both gear setting and hauling operations, 2) determine the effect of weather conditions on the abundance and behavior of ship-following seabirds while the gear is being set, and 3) determine the effect of the time of day on the behavior and abundance of ship-following seabirds while the gear is being set.

Methods

Survey design

The data used in this study were collected aboard the *F/V Pacific Sun*, in conjunction with the 2001 IPHC standardized stock assessment survey of Regulatory Area 4A near Unalaska Island, Alaska (IPHC 2001). The area surveyed was between 52° 30' and 54° 10' N Lat and 163° 48' and 171° 35' W Lon.

A total of 66 stations were set for the stock assessment survey between May 30 and June 18, 2001. Three or four stations were set and hauled each day. Of the 66 stations, bird transects were conducted at 41 stations during setting (Fig. 1). The first station set each morning, at 0500 h, was excluded from the study due to darkness. Limited visibility in the dark prevented accurate bird counts. In addition a bird count was conducted once a day while the gear was being hauled.

All bird transects conducted while the gear was being set took place near dawn, between 0600 h and 1000 h Alaska Local Time (ALT). During each set a 300 m wide transect was observed from the stern of the ship. The rectangular transect band, consisting of 150 m distance on both sides of the observer, was continuously scanned for seabirds during the first 10 min of each set. The surveys conducted while the gear was being hauled took place during daylight, between 1100 h and 1830 h. A spot survey was conducted from the bridge for a period of 10 min. The survey area was a circle with a 300 m radius around the observer.

Fishing gear

Each set consisted of five 1,800 ft skates. The hook spacing between gangions was 18 ft, for a total of 100 hooks per skate and 500 hooks per set. Gangions were 24 in long after tying. A three to ten lb groundline weight was attached to the line between each skate. Number 3 (16/0) circle hooks were used with 0.25 lb pieces of chum salmon baited on each hook. The vessel speed during setting ranged from 7.6 to 8.5 kt.

In compliance with IPHC chartered vessel protocol, BADs were deployed during all daylight sets to discourage seabirds from feeding on the baited hooks. A 100 m tori line was attached to a crane at the stern of the ship and a towed object was dragged on the surface at the end of the tori line. The tori line did not hang directly over the gear. It was positioned to the port side of the vessel.

Data recording and analysis

Observations were made during both setting and hauling. All birds sitting on the water or passing through the survey area were included in the counts. During setting the abundance and the number of times an individual attempted to take a baited hook (hereafter referred to as a "strike") was tallied for each species present. During hauling the abundance of birds was recorded. The transect start time and weather conditions were recorded for each set. The weather was characterized using Beaufort sea-state descriptions (Table 1).

In order to study variations in feeding behavior during setting, a ratio of the total number of strikes to abundance was used as a measure of behavior. Abundance and behavior were grouped by weather and the time of day to determine if either of these factors had an effect on the feeding activity of the birds.

Although the weather conditions experienced during the transect surveys ranged from force one to force seven (Table 1), conditions lower than force two and higher than force three were rare. For this reason only force two and three conditions were considered when analyzing the effect of weather on feeding behavior.

Results

Abundance and species composition

A total of 3390 birds were counted, of which 3257 were classified into 10 taxonomic groups. Of these groups, seven were identified to the species level, two to the genus level, and one to the family level. On average, there were 34 seabirds around the vessel during setting operations and 120 during hauling operations.

The main ship-following species present during setting were the northern fulmar (51 % of counts), the Laysan albatross (27 %), shearwaters (6%), and the black-footed albatross (2%) (Table 2). Tufted puffins (*Lunda cirrhata*) were frequently present in transects located near the shore (4% of total counts); however, they did not appear to be following the ship. Only one short-tailed albatross was observed during setting (<1%).

Northern fulmars were more predominant in the species composition during hauling than setting (81% of the counts; Table 2). Other ship-following species present during hauling were the Laysan albatross (11 %), and the black-footed albatross (2%). Shearwaters and short-tailed albatross were only present at low relative abundances (<1% each). Once again, tufted puffins were present (2% of counts), but did not appear to be responding to the ship.

Feeding behavior

There was no incidental mortality of seabirds observed during the 18 days that surveys were conducted. During the setting of longline gear a total of 361 attempts to take bait were observed from four different species: Laysan albatross (86% of strikes), shearwaters (6%) northern fulmars (4%), and black-footed albatross (4%). The one short-tailed albatross observed during setting was not observed attempting to take bait directly from the line. The tufted puffins did not attempt to feed on the bait and flew straight through the transect band. No birds attempted to take bait from the hooks while the vessel was hauling gear.

For the majority of the set time the birds remained in flight searching for food. When a bird attempted to take a piece of bait it first landed on the water and then dove beneath the surface. While the presence of BADs did deter birds from feeding in the most vulnerable area, within 50 m of the ship, birds were observed diving past the end of the 100 m tori line. Although the success rate of the birds at obtaining bait was not recorded, the birds were seen feeding on pieces of bait still attached to the gangion on several occasions. While the longline gear was being hauled, the birds would sit on the surface and feed on scraps of fish discarded by the vessel.

Behavioral differences were observed among species during setting (Table 3). Of the four species observed feeding on bait during setting, Laysan albatross displayed the highest average ratio of strikes to abundance, indicating that they were the most active feeders during setting. Although northern fulmars were the most abundant of the ship-following species, they seldom took strikes at the gear and displayed one of the lowest ratios of strikes to abundance. When present, the black-footed albatross and shearwaters were more likely to attempt to take bait than the northern fulmars.

Observations of inter-species relationships during feeding showed that several birds shared the success of one individual. When one bird obtained a piece of bait from the gear, several birds joined in feeding and tore pieces of the bait from its beak. The one short-tailed albatross observed during setting did not attempt to take bait directly from the gear; however, it did tear pieces of bait already taken from the gear by a Laysan albatross. Northern fulmars were also observed attempting to feed on pieces of bait from the beaks of other species. Laysan albatross were the most aggressive species present. On several occasions Laysan albatross displayed kleptoparasitism, stealing the whole bait from the beaks of other species. No other species were observed to display this behavior.

Weather conditions

Weather conditions during setting were found to have an effect on the abundance of ship-following birds; however, the effect varied by species (Fig. 2). Both northern fulmars and shearwaters were, on average, more abundant in force two than force three conditions. The reverse trend was observed for the Laysan albatross, which were more abundant in force three conditions. Black-footed albatross were also more abundant in force three conditions; however the difference was small.

Weather conditions during setting were found to also have an effect on behavior. All four species observed feeding on the baits were more likely to take a strike at the gear in force three weather than in force two weather (Fig. 3). Laysan albatross appeared to be most heavily influenced by weather with a fourfold increase in the ratio of strikes to abundance in force three. This difference was found to be significant (two tailed *t* test; $p = 0.01$). Although increases in the ratio of strikes to abundance in force three conditions were seen in black-footed albatross, shearwaters, and northern fulmars, the differences were not significant.

Time of day

Field observations suggested that, on a given morning, the abundance of ship-following birds increased with each set throughout the morning; however, data analysis indicated that the time of day (0605 h to 0943 h) did not have an effect on seabird abundance or behavior (Tables 4 and 5). Grouping the time data by weather did not reveal any additional trends in abundance or behavior.

Discussion

Species abundance and behavior

Although northern fulmars were the most abundant species around the boat during both setting and hauling operations, they were shown to have a relatively low risk of being caught on baited hooks. While northern fulmars were attracted to the vessel during setting, they were rarely observed attempting to take bait from the line. Instead, they more commonly fed on the pieces of fish and offal discarded overboard during hauling, as evidenced by their increased relative abundance during hauling and general observations. Feeding on discards from fishing vessels may be hazardous to seabirds, regardless of the vessel activity, because it promotes ship-following behavior. However, birds feeding on discards during hauling are less vulnerable to incidental mortality than those feeding on baited hooks during setting.

While Laysan albatross were present at a lower abundance than northern fulmars during both setting and hauling, they appeared to be at a higher risk of being caught on hooks. The Laysan albatross were more abundant during setting than hauling and took 86% of the total strikes observed on baited hooks. Laysan albatross demonstrated the highest ratio of strikes to abundance for all species studied, indicating that individuals of this species were more likely to attempt to take bait than the other birds. In addition, the aggressive nature displayed by Laysan albatross may enhance their vulnerability. By stealing whole pieces of bait attached to hooks from smaller species, albatross increase their risk of becoming hooked (Brothers 1991). In the past the species has been relatively resilient to fishing activities and Laysan albatross populations are considered to be relatively secure; however, two large breeding populations are currently declining (Gales 1998). Longlining fishery operations are, at present, the most significant cause of mortality (Ludwig et al. 1998).

Although black-footed albatross were only observed at a low abundance during setting and hauling, when present they exhibited a high ratio of strikes to abundance. The low abundance observed indicates that the incidental capture of black-footed would be small within the study area; however, it may be larger on other halibut fishing grounds where black-footed albatross are more abundant. The species has been slow to recover from excessive hunting at the turn of the century and at present all major populations are either decreasing or of unknown status (Gales 1998). As with the Laysan albatross, longline fishery operations are the largest threat to the persistence of the species.

Shearwaters were present at low abundance during both setting and hauling operations. When individuals were present during setting they had a moderate ratio of strikes to abundance, indicating that they are relatively vulnerable to capture. Shearwaters are able to dive to deeper depths than the larger albatross and this has been suggested to increase their vulnerability by increasing their success at obtaining baited hooks from the groundline (Brothers 1991, Cherel et al. 1996).

Reflective of the endangered status of short-tailed albatross, only two individuals were observed during surveys: one during setting activities and one during hauling activities. While numbers were not large enough to base conclusions on, observations of feeding behaviors during setting suggest that individuals foraging in waters frequented by halibut longline vessels could be at risk. Short-tail albatross populations are slowly recovering from near extinction during the mid 1900's. There are currently only 170 breeding pairs confined to two breeding locations (Gales 1998). The small population size and limited breeding areas make conservation difficult and the loss of any individuals to incidental capture is a serious concern. Reported captures of short-tailed albatross by the halibut industry have been low, with only one individual taken since 1987 (Geernaert et al. 2001); however, as the population increases bycatch rates may also increase.

Despite the behaviors observed in this study, nothern fulmars have the highest catch rates of any seabird species taken by groundfish longline fisheries (excluding halibut) in Alaska: between 1993 and 1997 they comprised 66% of the incidental catch of seabirds by these fisheries (Stehn et al. 2001). Laysan and black-footed albatross accounted for only 5% and 6% respectively. These values likely reflect the relative abundance of species throughout Alaskan waters more so than the susceptibility to capture of each species.

Weather conditions

Variations of the effect of weather on species abundance could possibly be explained by interactions among species. Competition for space and discards around fishing vessels can be strong and dominance is based largely on size (Bartle 1974). The success of smaller species, such as northern fulmars and shearwaters, at obtaining food is often dependent on the species composition of other birds present (Garthe and Huppop 1994). Larger species, such as albatross, get preference to any food made available. As a result, smaller species may have been discouraged from following the vessel when albatross were abundant. This would explain the increased abundance of northern fulmars and shearwaters during force two weather conditions when Laysan albatross were less abundant. However, if this were the case we would also expect to see increased feeding behavior by northern fulmars and shearwaters in force two weather and this was not observed.

Another plausible explanation for the varying effects of weather on species abundance is observer bias. Rough weather and increased wave heights can greatly decrease the visibility of small, dark birds, such as northern fulmars and shearwaters (Tasker et al. 1984). This may have caused the abundance of these species to be underestimated during force three weather conditions. The large white Laysan albatross would still be easily visible in force three conditions.

While a significant difference was found only for Laysan albatross, all species observed feeding on the gear showed an increased ratio of strikes to abundance in force three weather conditions. This indicates that ship-following birds are more vulnerable to incidental mortality when wind conditions are stronger. Brothers (1991) found that on days when the wind speed was less than force two the frequency of bait taking was significantly reduced. He suggested that the increased feeding in rougher winds was a result of increased ocean turbulence from wind and the ship's propeller returning baits to the surface and making them more accessible to seabirds. Another possible explanation for increased feeding activity in stronger weather conditions is the decreased effectiveness of the tori line. Lokkeborg (1998) observed that strong winds can blow the streamers out from their intended position and prevent them from hanging directly over the groundline.

Time of day

Analysis revealed that the time of morning at which the gear was set did not have an effect on bird abundance or feeding behavior. Previous studies have reported higher rates of seabird bycatch in daylight hours (Ashford et al. 1994; Cherel et al. 1996) and in accordance with these observations one would expect the abundance and feeding activity of ship-following seabirds to increase throughout the dawn as light levels increased. Although no upward trends in abundance and feeding behavior were detected in our data, there may have been an undetected difference between daylight and darkness. As data were only collected from dawn onward, when there was sufficient daylight to observe the birds, these trends would not have been evident.

The impression from field observations that, on a given day, the abundance of ship-following birds increased with each set throughout the morning suggested that time of day may affect abundance. This difference between apparent trends and those shown by analysis may be due to variation in light levels between days, which was not included in the study design. Although weather conditions were measured on the Beaufort scale, which is a measure of wind speed, the actual light levels were not measured. The amount of cloud cover on a given morning clearly influenced the amount of light present. Light levels would be expected to be lower at 0600 on an overcast day than 0600 on a sunny day. The failure of this study design to accurately quantify light levels and incorporate them into the analysis may account for this study's inability to detect short-term temporal trends in abundance and feeding behavior.

Future studies attempting to detect differences in abundance and behavior with time of day should seek to include levels of light, as well as time, into the study design. Furthermore, by including both night sets (before dawn) and daylight sets in the study one could gain valuable insight into the influence of light on the activity of ship-following seabirds.

Conclusions

Of the 10 species of seabirds observed around the vessel, only four (northern fulmars, shearwaters, Laysan and black-footed albatross) were observed attempting to take baited hooks from longlines, making them vulnerable to incidental capture. Northern fulmars were the most abundant species around the vessel during both setting and hauling operations; however, they rarely attempted to take bait from the line during setting and were considered to be at a relatively low risk. The two albatross species observed feeding on baited hooks were shown to be more vulnerable to capture than both the northern fulmars and the shearwaters. Laysan albatross had the most aggressive feeding behaviors, placing them at the highest risk. Although less abundant than the northern fulmars, Laysan albatross comprised 86% of the total number of strikes observed on the gear. The Laysan albatross further increased their chances of becoming hooked by stealing baited hooks from other species.

Weather conditions were found to influence both the abundance and behavior of ship-following seabirds. The effect of weather on abundance varied by species. Whereas Laysan albatross were more abundant in force three than in force two conditions, northern fulmars and shearwaters were more abundant in force two conditions. Factors that could account for this variation include interactions among the species, in which a high abundance of the more aggressive Laysan albatross discourages other species from following the vessel, as well as observer bias. The feeding activity of all four species was greater in force three than in force two weather conditions. This effect was most likely a result of the increased ocean turbulence returning baits back up to the surface and the decreased efficiency of the tori line in stronger winds.

The time of day at which the groundline was set did not appear to have an effect on abundance or behavior. These results were contradictory to what would be expected based on results from other studies. While it is possible that time of day does not have an effect on seabirds in the area this study was conducted, it seems more likely that the scope of the study was not wide enough to account for variations in light levels between days. Furthermore, as bird counts were not conducted in the dark for logistical reasons, differences in abundance and behavior between night and day could not be measured.

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Table 1. Beaufort sea-state descriptions.

Code	Wind speed (knots)	Air	Sea description
0	0	Calm	Sea like a mirror.
1	1-3	Light air	Ripples with the appearance of scales are formed, without foam crests.
2	4 - 6	Light breeze	Small wavelets, still short, but more pronounced, crests have a glassy appearance but do not break.
3	7	Gentle wind	Large wavelets; crests begin to break; foam of glassy appearance; perhaps scattered white horses (white caps).
4	1	Mod	Small waves, becoming longer; fairly frequent white horses.
5	1	Fresh	Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray).
6	22 - 27	Strong wind	Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray).
7	2	Near	Sea heaps up and white foam from breaking waves begins to be blown in streaks the direction of the wind.
8	34 - 40	Gale	Moderately high waves of greater length; edges of crests begin to break into the spindrift; the foam is blown in well-marked streaks along the direction of the wind.
9	41 - 47	Strong gale	High waves; dense streaks of foam along the direction of the wind; crests of waves begin to topple, tumble, and roll over; spray may affect visibility.
10	48 - 55	Storm	Very high waves with long overhanging crests; the resulting foam, in great patches, is blown in dense white streaks along the direction of the wind; on the whole, the sea surface takes a white appearance; the tumbling of the sea becomes heavy and shock-like; visibility affected.
11	56 - 63	Violent storm	Exceptionally high waves (small and medium-sized ships might be lost to view for time behind the waves); the sea is completely covered with long white patches of foam lying along the direction of the wind; everywhere the edges of the wave crests are blown into froth; visibility affected.
12	64+	Hurricane	The air is filled with foam and spray; sea completely white with driving sprays; visibility very seriously affected.

Table 2. Species composition of ship-following seabirds during the setting and hauling of longline gear aboard the *F/V Pacific Sun* in May-June, 2001.

Species	Sets				Hauls			
	Min	Max	Mean	Relative abundance	Min	Max	Mean	Relative abundance
Northern fulmar	3	152	17.46	0.51	32	300	99.56	0.83
Laysan albatross	0	24	9.05	0.27	0	35	13.06	0.11
Black-footed albatross	0	2	0.59	0.02	0	25	3.38	0.3
Short-tailed albatross	0	1	0.02	< 0.01	0	1	0.06	<0.01
Shearwater	0	11	1.83	0.06	0	3	0.56	<0.01
Tufted Puffin	0	30	1.54	0.04	0	22	1.88	0.02
Others	0	70	3.54	0.10	0	6	1.19	0.01

Table 3. Behavior of ship-following seabirds during setting, measured as the ratio of number of strikes observed to abundance.

Species	Relative no. of strikes (%)	Average strikes:abundance
Northern fulmar	0.04	0.03
Laysan albatross	0.86	0.66
Black-footed albatross	0.04	0.50
Shearwaters	0.06	0.29

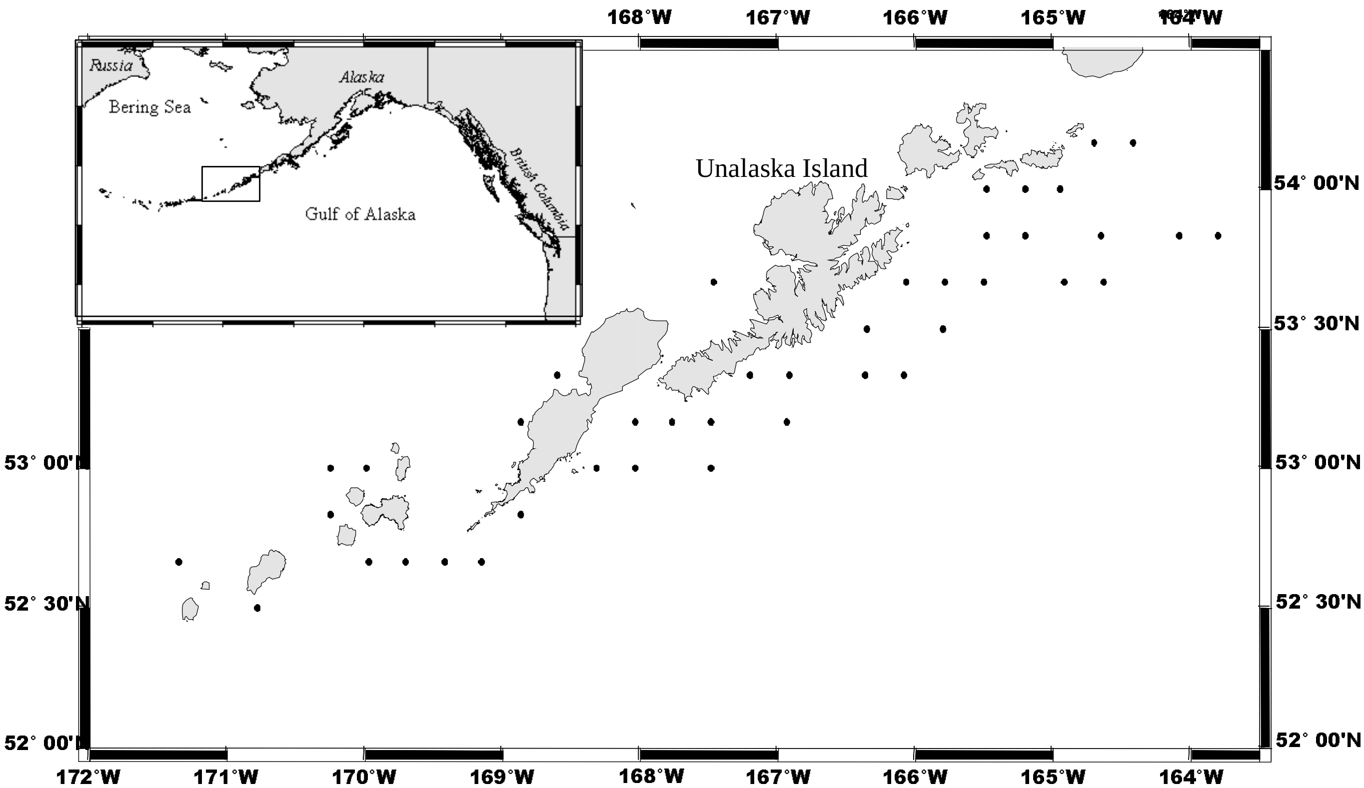

Figure 1. Study area in the Unalaska region of the Aleutian Isalnds, Alaska. Dots represent locations at which bird transects were conducted during setting of longline gear.

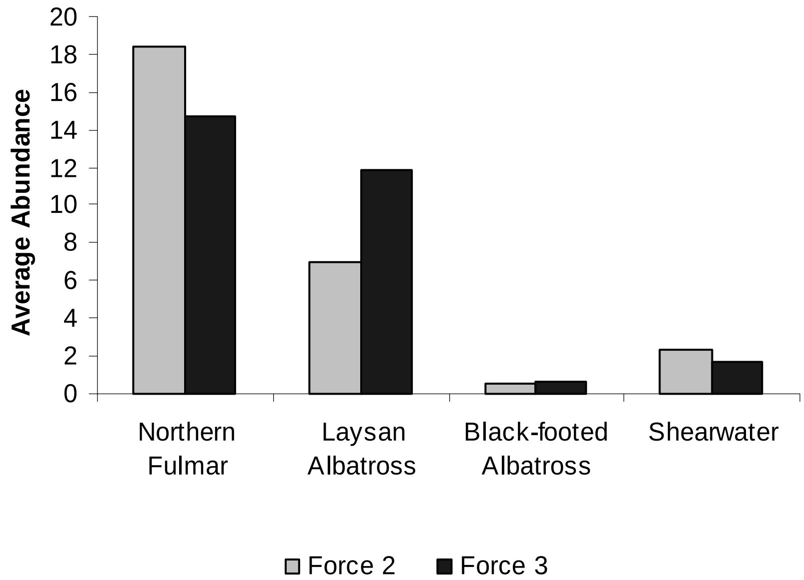

Figure 2. Average abundance of ship-following species during setting of longline gear, in force two and force three weather conditions.

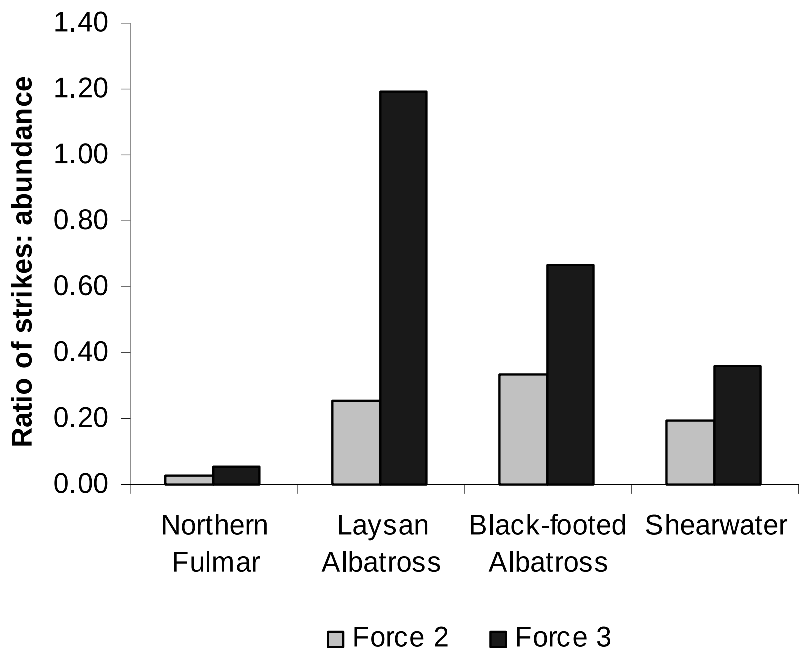

Figure 3. Behavior of ship-following seabirds during setting, characterized as the ratio of number of strikes observed to abundance, in force two and force three weather conditions.

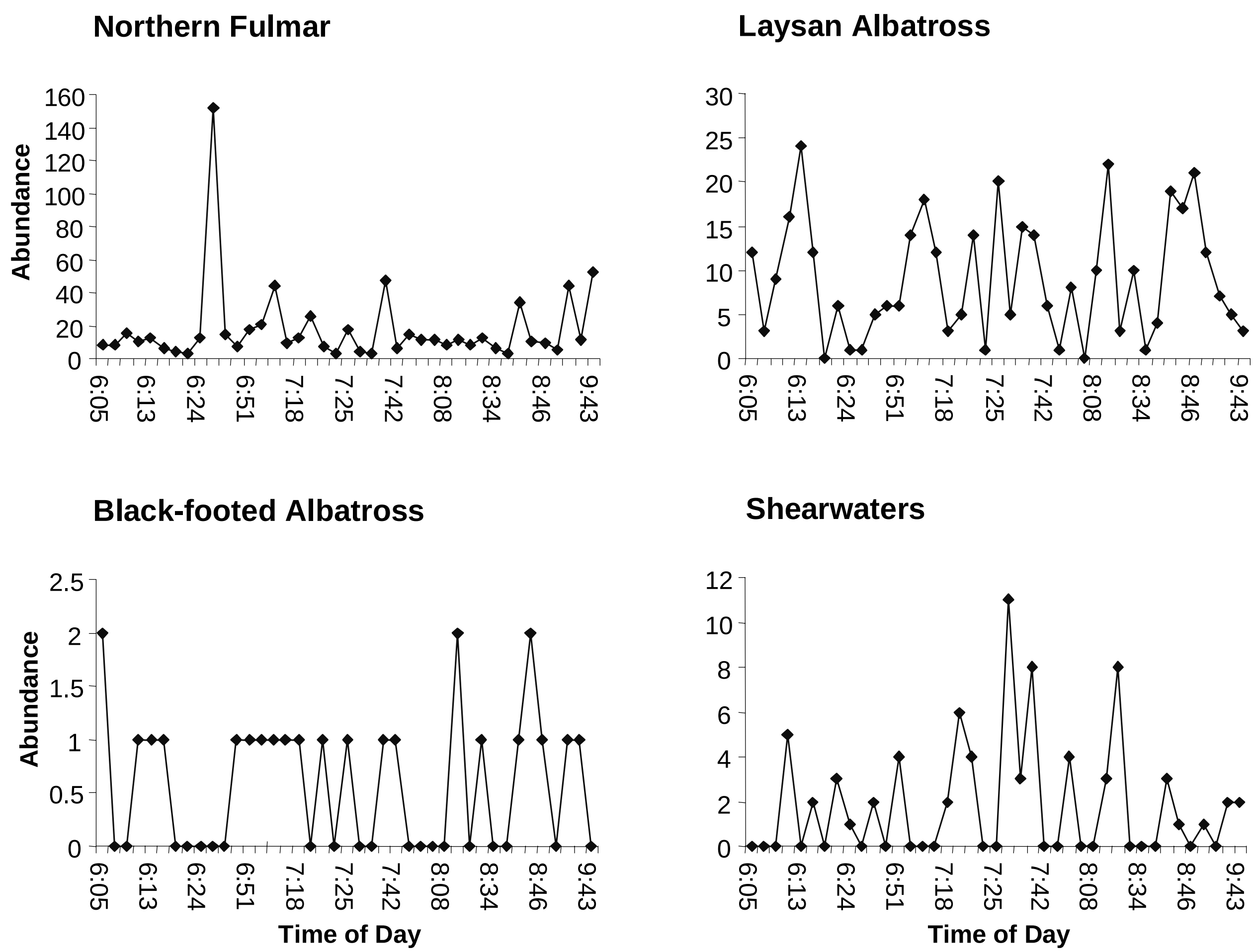

Figure 4. Variations in seabird abundance with the time of day that longline gear was set. Each dot represents an individual set.

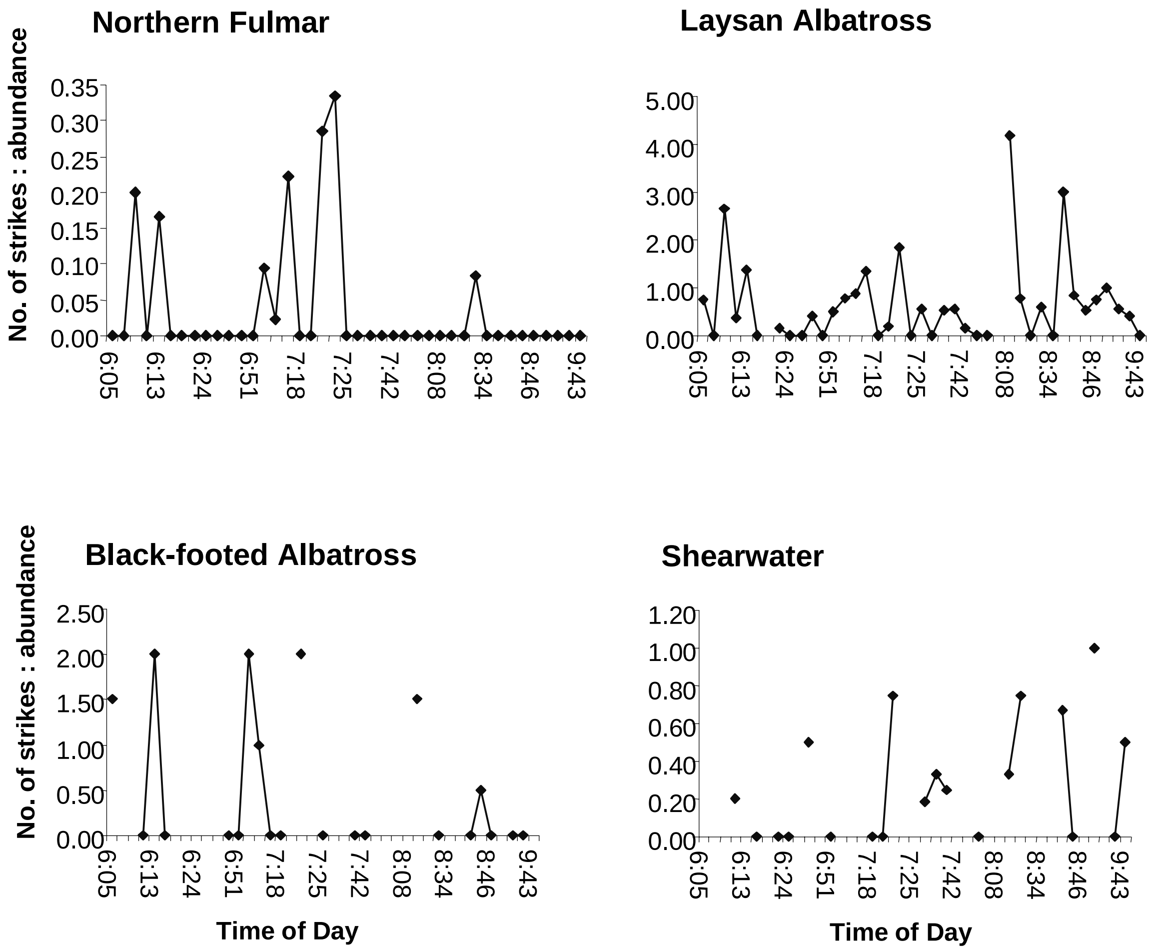

Figure 5. Variations in seabird behavior with the time of day that longline gear was set. Each dot represents an individual set.

Development of a Geographic Information System

Richard C. Leickly

Abstract

In 2001, two significant applications of the International Pacific Halibut Commission's new Geographic Information System were developed: all coastal and Bering Sea statistical areas, and all regulatory areas were given digital representation. Several other applications began development in 2001, and the development of many additional applications will begin in 2002.

Introduction

In June 2000, the International Pacific Halibut Commission (IPHC) acquired the ArcView Geographic Information System (GIS). There followed a period of training on the new software and an assessment of potential GIS projects. A Needs Assessment identified the staff activities and research projects that would benefit from a GIS.

The Needs Assessment made it clear that digital representation (i.e. thematic maps) in the GIS of the Commission's statistical and regulatory areas would affect the largest number of Commission activities. During the development of the Needs Assessment, the feasibility of the project was demonstrated by a preliminary project in which ArcView was used to create a thematic map of several of the southeast Alaska statistical areas. Following this success, the full development of the thematic maps for all of the statistical and regulatory areas was given the highest priority.

Digital representation of IPHC statistical areas

The IPHC currently recognizes 96 coastal statistical areas in the Pacific Ocean, stretching from northern Californian to eastern Russian waters; and approximately 240 Bering Sea statistical areas, covering the region beginning at the western coast of Alaska and extending to approximately 166° E longitude. The representation of these areas in the GIS relied on the IPHC's current reference definitions for the coastal and Bering Sea statistical areas.

Coastal statistical areas

The first 35 coastal statistical areas were defined in 1930. These areas were "based upon a line following the general trend of the coast, the line included in each area equal to 60 minutes of mean latitude of the area in questions. The divisions between them extend seaward and perpendicular to the line mentioned" (Thompson and Herrington 1930). Areas were defined from Coos Bay, OR (area 1) to Unimak Pass, AK (area 35).

Current IPHC staff members have limited knowledge of the origins of the other 61 areas[1]. It is possible that they are documented within some of the IPHC publications of the last forty years. An IPHC document[2] of unknown provenance contains a map showing that, by 1961, the number of coastal statistical areas had grown to 42. (It also shows that eight statistical areas had been defined for the Bering Sea side of the Alaska Peninsula the Aleutian Archipelago out to about Unimak Island. Those definitions have been supplanted.) An additional, but undated, table in the same document gives the current three-digit numbering scheme for 38 of the coastal statistical areas, and provides a new way of describing them. A base line for each area is defined as a "direction in true degrees" from a base point, which is given as a geographical coordinate. According to the table, these were derived from the "original chart of W.F.T.- C. & G. S. Chart No. 9000". W. F. Thompson's (the W.F.T. mentioned in the table) chart has been lost (T. Kong, IPHC, Seattle, WA, personal communication), but his definitions are still in use.

In the years since 1962, additional coastal areas were added to include inland waterways and bays, especially in the areas between Vancouver Island, BC and Kodiak, AK. Retired IPHC staff member G. Peltonen apparently played a large role in the creation of these additional areas (T. Kong, IPHC, Seattle, WA, personal communication). No attempt was made to define these areas in any way other than drawing them on a chart. These charts are the current reference: they now define the IPHC coastal statistical areas.

In 1999, IPHC staff member T. Kong and an intern began the task of characterizing the statistical areas in a form useful for a GIS. Using the reference charts, they considered each statistical area as a polygon and determined the geographical coordinates of the vertices (T. Kong, IPHC, Seattle, WA, personal communication). In 2001, I wrote a program in the ArcView scripting language (i.e. Avenue) that used Kong's vertex file to plot the vertices in the GIS, and to then draw line segments through them, recreating the entire set statistical area polygons. The output was stored in the ArcView shapefile format. The resulting thematic map is shown in Figure 1.

Bering Sea statistical areas

No current staff member is familiar with the origins of the Bering Sea statistical areas[3]. The current reference is a 1965 drawing of the Bering Sea upon which a grid has been superimposed[4]. The drawing shows that the grid is defined with rectangular cells 30 minutes tall and 60 minutes wide. The longitudinal edges of the grid cells are located on degrees exactly divisible by 60 minutes. The latitudinal edges of the grid cells are positioned on degrees exactly divisible by 30 minutes. An exception is the horizontal line of cells between 56° 20' N and 57° N and, which has a height of 40 minutes. The entire grid extends approximately from 166° E longitude to the easternmost extent of Bristol Bay, AK (approximately 157° W longitude), and north of the Aleutian Island chain to 61° N latitude. The horizontal axis of the grid extends from 278 to 157, representing an

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[1] Based on responses to an email communication to the Seattle IPHC staff in September, 2001.
[2] International Pacific Halibut Commission - Description of Statistical Areas", dated 22 October 1962. Author unkown. Contact Richard Leickly for more information.
[3] Based on responses to an email communication to the Seattle IPHC staff in September, 2001.
[4] Obtained from T. Kong, IPHC, Seattle, WA.

encoded longitude (e.g. 278 is 178° E; 157 is 157° W). The vertical axis extends from 520 to 603 and represents an encoded latitude (e.g. 520 is 52° 00' N; 523 is 52° 30' N).

I wrote a program in Avenue that mathematically generated the vertices and grid lines of the current reference. The output was stored in the ArcView shapefile format. The resulting thematic map is shown in Figure 2.

Digital representation of IPHC regulatory areas

The IPHC currently recognizes ten regulatory areas, comprising the same areal extent as the statistical areas described above, except for the exclusion of a closed area in the Bering Sea. The regulatory areas (and the closed area) are defined in the "Pacific Halibut Fishery Regulations" (International Pacific Halibut Commission 2001). This is the current reference. I wrote a series of ArcView scripts (one for each regulatory area) to draw the regulatory area polygons. The thematic map is shown in Figure 3. In the vicinity of the Alaskan Peninsula, the same line segments used to define the northern boundaries of the statistical areas were also used to define the southern boundaries of area 4E and of the closed area.

Other GIS applications completed in 2001

Comparison of IPHC and Alaska Department of Fish and Game statistical areas

The Alaska Department of Fish and Game (ADF&G) has defined a large number of statistical areas in Alaskan waters for the purposes of groundfish management. The IPHC keeps a database table that correlates the ADF&G statistical areas with the IPHC statistical areas. Recently, the ADF&G added some new areas and retired some others, necessitating a revision of the IPHC tables. The IPHC GIS was used to make the revision. An ArcView shapefile of the ADF&G statistical areas was downloaded from the ADF&G website[5] and loaded into the IPHC GIS. Then it was overlaid with a shapefile of the IPHC statistical areas. The correlations between the IPHC and ADF&G areas were easily discerned visually and the updates made to the table.

GIS applications currently under development

Using the GIS and geospatial statistics to estimate and display the abundance distribution of halibut

The GIS in concert with S-Plus (an advanced statistical analysis system) is being used to apply spatial statistics to the problem of estimating halibut abundance. The current estimation technique make essentially no use of the spatial distribution of the catch and survey data, treating the data from each regulatory area as a single number. In contrast, the GIS facilitates the application of the statistical technique known as kriging, which makes it possible to estimate halibut abundance at every point in an area, thus utilizing the spatial information. We will examine and test both spatial and temporal changes.

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[5] The ADF&G statistical area shapefile, Pvg_stat_2001, was prepared by Tim Haverland and posted at the website: http://maps.cf.adfg.state.ak.us/.

Distribution and intensity of hook-injured halibut

We are investigating the occurrence of halibut with facial injuries resulting from previous encounters with a hook. I recently entered these data into the GIS. Figure 4 shows the distribution of halibut with severe prior hook injury (PHI) that were caught in the IPHC 2001 setline survey. Some interesting correlations may result when PHI thematic maps are overlaid with thematic maps showing the distribution of fishing effort by the non-halibut directed fisheries.

Using the GIS to facilitate management of the setline survey

Efforts are currently underway to bring the GIS to the setline survey management team. During the development of the Needs Assessment it became obvious that the management of the setline survey is a natural application of the GIS since it allows the integration of spatial and non-spatial information. IPHC survey staff began training on the GIS via ESRI's online tutorial, and I will begin developing their applications this year.

National Marine Fisheries Service trawl survey

We are interested in the feasibility of using the IPHC GIS to analyze the National Marine Fisheries Service (NMFS) trawl survey data. I entered a sample of NMFS survey data from the 2000 trawl survey into the GIS. At each location in the Bering Sea, the total number of Pacific halibut caught was displayed using a color ramp. The project showed that the GIS would be useful in discerning trends in halibut distribution.

GIS applications from the Needs Assessment that will be developed in 2002-2003

The next 12-24 months will be busy as additional staff are trained and other applications continue or begin development. A brief list of the GIS projects is given below.

- Interfacing ArcView with S-Plus
- Miscellaneous programming applications for commercial data management
- Bycatch analysis and management
- PIT tagging project
- Distribution of collected otoliths
- Thematic map development (e.g. bathymetry, sea-bottom temperature)
- Area determinations from bathymetric maps
- Influence of commercial fishing on the setline survey
- Influence of string spacing on catchability
- Hook occupancy study
- Distribution of historical tag release and catch locations
- Geographic patterns of mercury distribution in halibut
- Geographic patterns of shark bycatch during the IPHC setline survey
- Regional variation in length-weight tables

Newly identified GIS applications that will be developed in 2002-2003

Three new projects with GIS-components have been proposed since the Needs Assessment was written.

Geographic distribution of chalky halibut

IPHC has been studying chalky halibut for several years. We are interested in combining data from the fish processors with IPHC logbook records to understand the geographical location of chalky halibut.

Use of otolith elemental composition to identify halibut stocks

IPHC is interested in analyzing the elemental composition of the otoliths of young (i.e., less than two years old) halibut to identify a "chemical signature" that can be used to differentiate halibut stocks. As part of the project we will attempt to match spawning female halibut to their natal grounds. A goal of the project is to develop a map of halibut stocks. Since the rate of incorporation of elements into the otolith is temperature-sensitive they will require information on the distribution of sea-surface temperatures.

Use of carbon-14 to validate otolith aging results

Using the IPHC otolith archive, we will sample otoliths from halibut born during the years of atmospheric nuclear bomb testing. The core of the otolith will be analyzed for carbon-14. We expect to find a relationship between the concentration of carbon-14 and the year the halibut's year of birth. With this relationship, the year of birth of an arbitrary otolith can be determined from its carbon-14 level. That age can be compared to the age measured by the counting of the otolith growth rings. Maps of sea-surface currents are required since the currents have a strong influence on the availability of carbon-14.

References

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International Pacific Halibut Commission. 2001. Pacific Halibut Fishery Regulations.

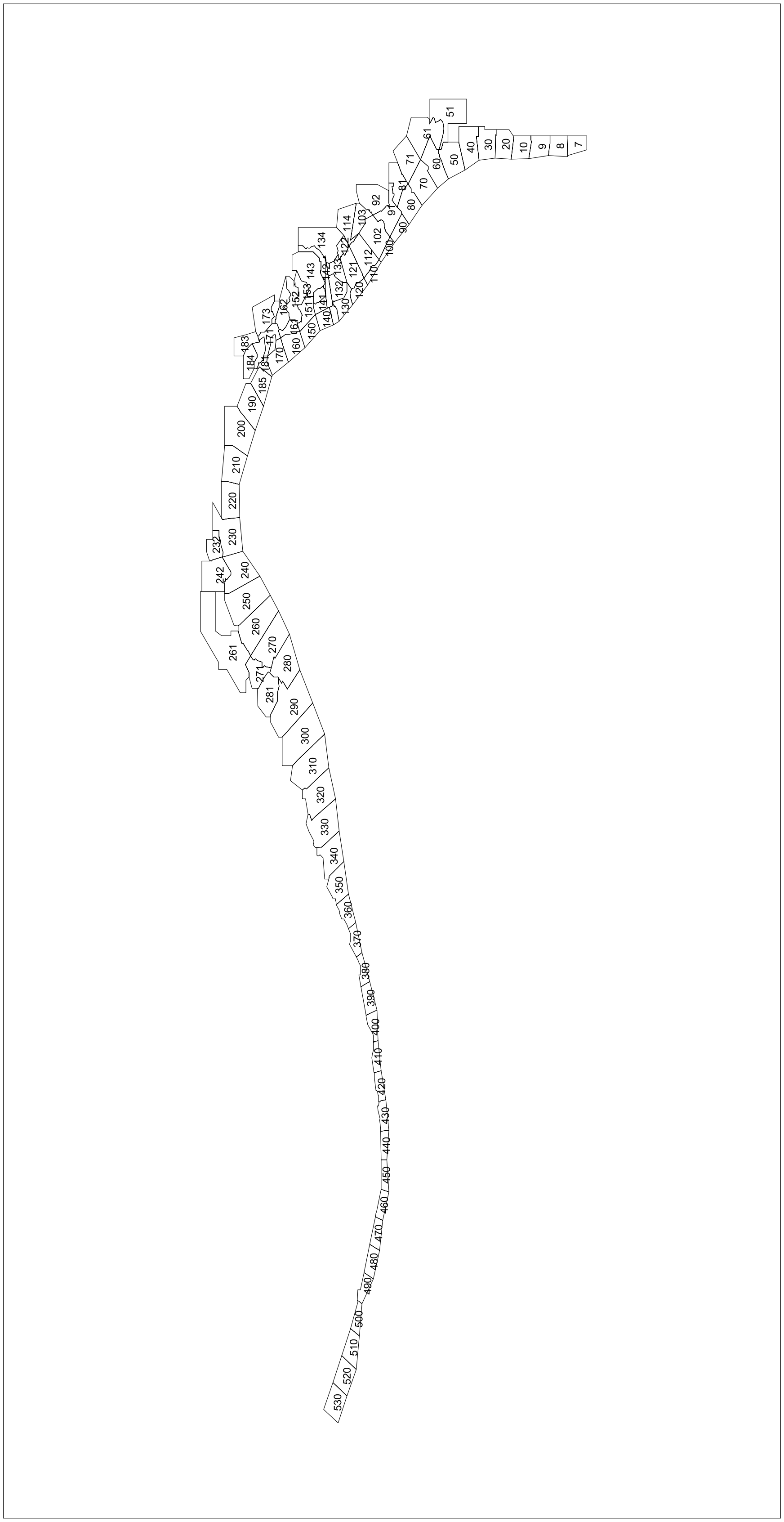

Figure 1. GIS Representation of IPHC Coastal Statistical Areas

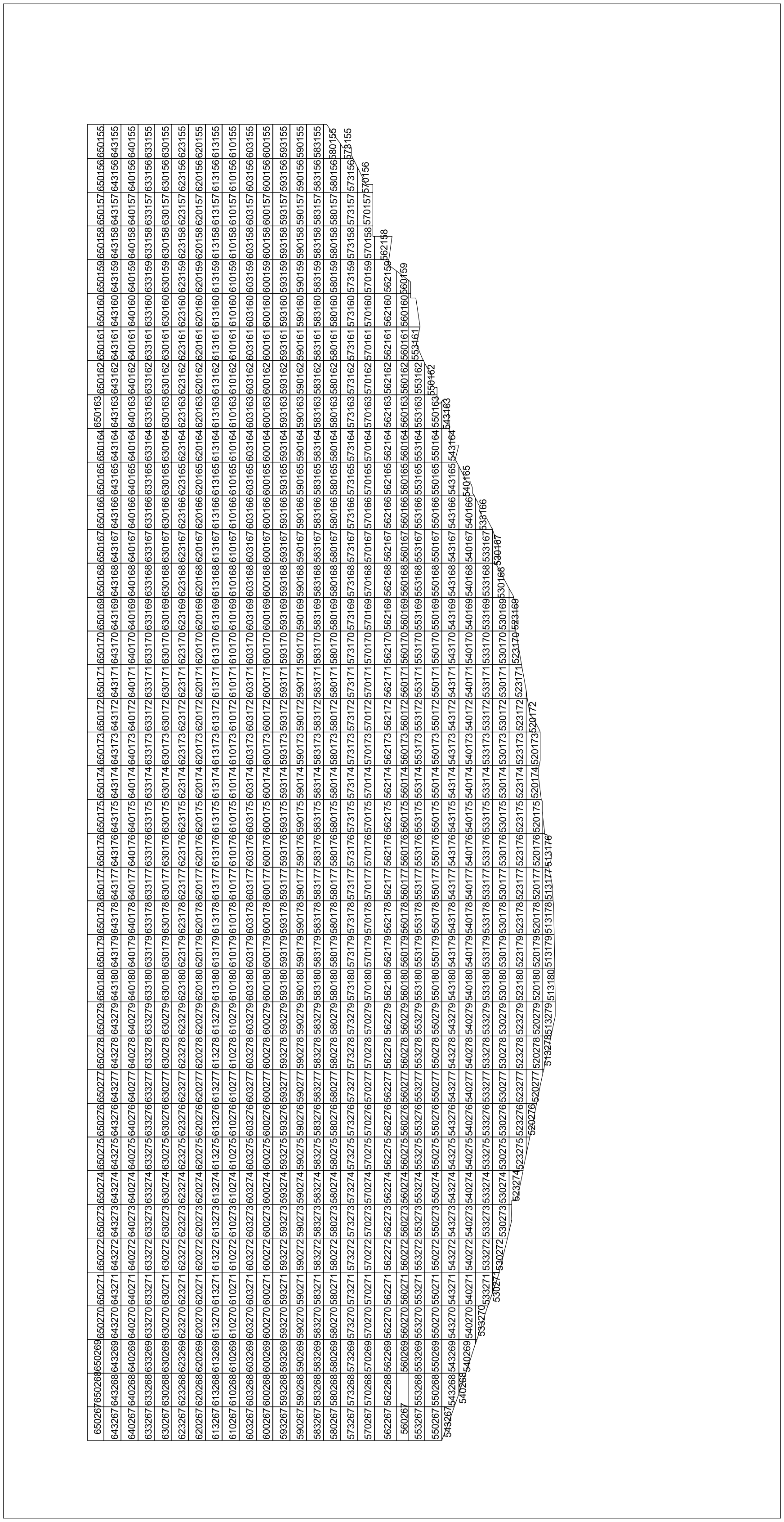

Figure 2. GIS Representation of IPHC Bering Sea Statistical Areas

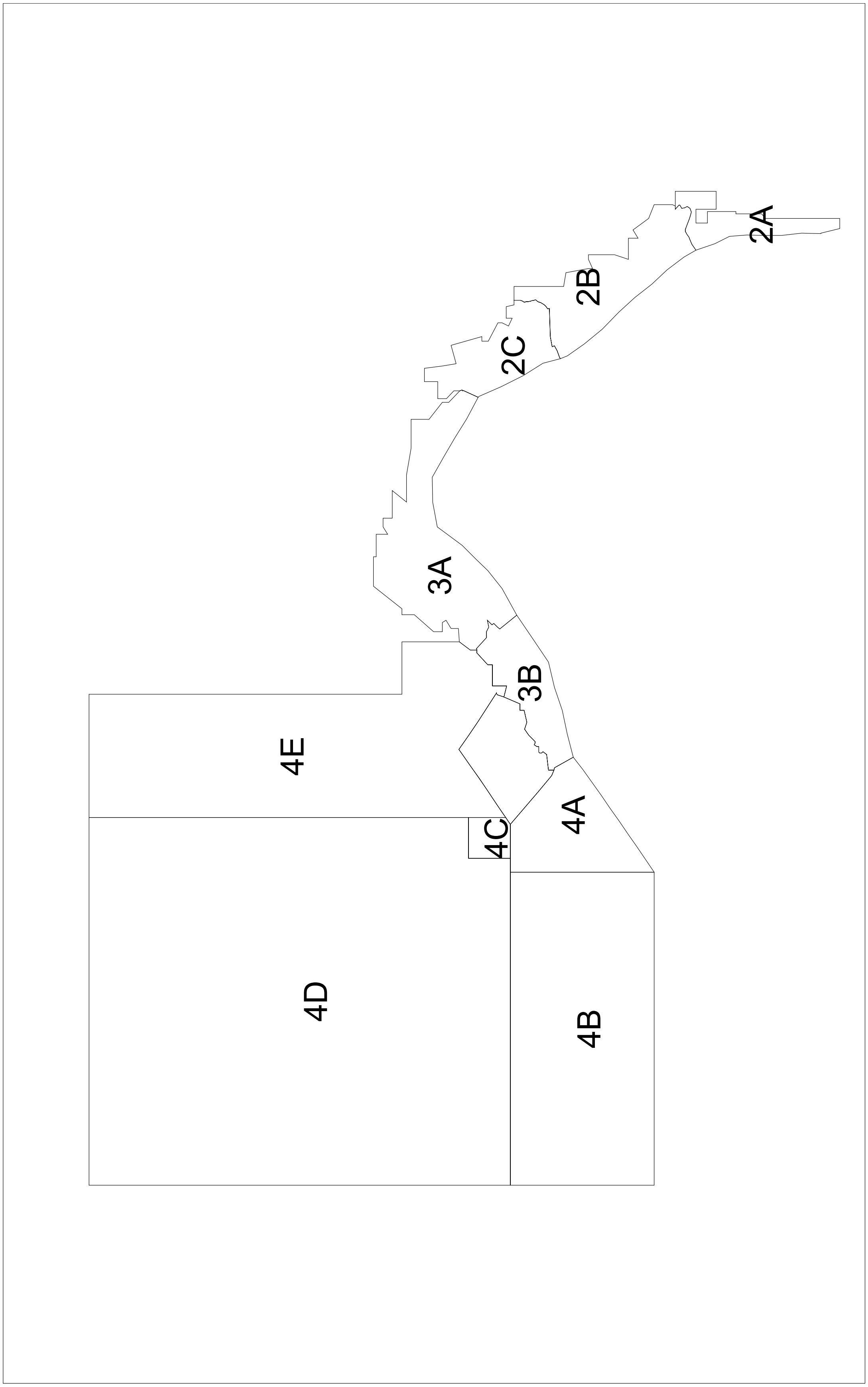

Figure 3. GIS Representation of IPHC Regulatory Areas

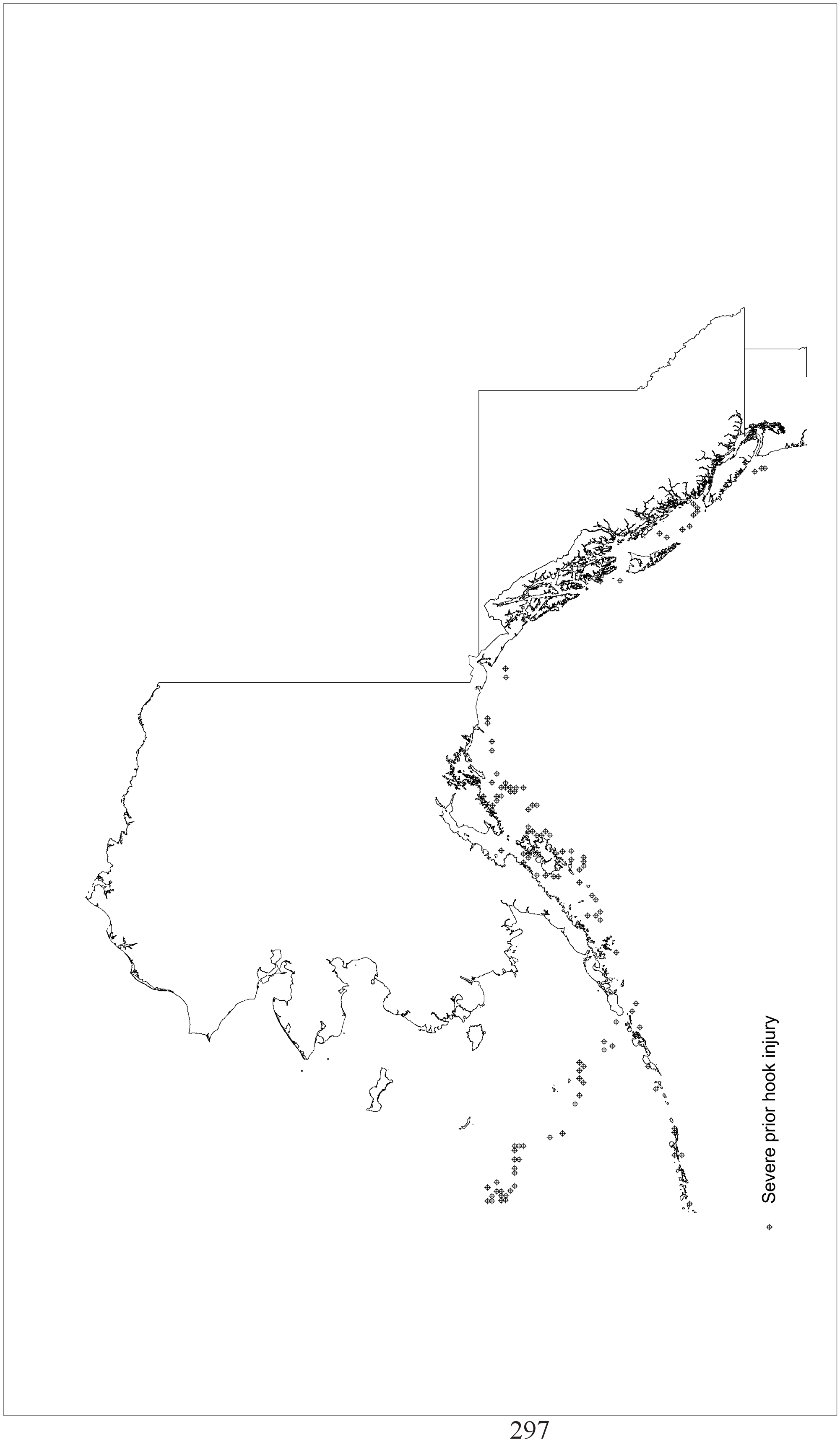

Figure 4. Occurrence of severe prior hook injury in IPHC setline survey