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[Contact IPHC]

Biological Research

General

Halibut, Climate and Fisheries Oceanography

by

Steven R. Hare

Background

In 1997, the International Pacific Halibut Commission (IPHC or Commission) initiated new research on halibut fisheries oceanography. The intent of this research is to better understand the influence of climate variability on Pacific halibut biology, particularly growth and recruitment. Beyond better understanding the factors that influence halibut population dynamics, the ultimate goal of the project is to integrate the fisheries oceanography research more closely with the stock assessment, hoping to expand it beyond a single–species, environment-free model. During this year, several lines of research were extended and initiated. These are summarized below.

Empirical Indicators of Climate Variability And Ecosystem Response Since 1965

In the early 1990s, a wide array of evidence began accumulating that a major climate event had transpired in the mid-1970s with widespread consequences for the biota of the Northeast Pacific Ocean and Bering Sea. The event was eventually termed a “regime shift” and several studies have been published recently documenting the climatic (Miller et al. 1994) and ecosystem (Hare and Francis 1995, Francis et al. 1998, McGowan et al. 1998) changes that took place. Recognition of the 1976-77 regime shift has opened the question of whether that event was unique or merely the latest in a sequence of regime shifts in the historical record. Based on analyses of temperature, atmospheric pressure, tree ring and salmon catch records, several researchers have hypothesized that climate shifts in the Northeast Pacific also occurred in the early 1920s and mid 1940s (Kondo 1988, Mantua et al. 1997, Zhang et al. 1997, Minobe 1997, Ingraham et al. 1998). Mantua et al. (1997) coined the term “Pacific Decadal Oscillation” (PDO) to describe this interdecadal climate variability. They described the PDO as a long-lived El Niño-Southern Oscillation (ENSO) like pattern of Pacific climate variability. As seen with ENSO, extremes in the PDO pattern are marked by widespread variations in Pacific Basin and North American climate. Two main characteristics distinguish the PDO from ENSO. First, typical PDO “events” have shown remarkable persistence relative to those attributed to ENSO events - in this century, major PDO regimes have persisted for 20 to 30 years. Second, the climatic fingerprints of the PDO are most visible in the North Pacific/North American sector, while secondary signatures exist in the tropics - the opposite is true for ENSO.

The question we address in this study is whether there is empirical evidence for a North Pacific climate regime shift since 1976-77. A number of recent studies have suggested that a shift occurred in the winter of 1988-89 (Polovina et al. 1994, Sugimoto and Tadokoro 1998, Watanabe and Nitta 1999, Overland et al. 1999, Beamish et al. 1999, Brodeur et al. 1999, Welch et al. (in press)), while others have suggested that we are still in the post-1977 regime (McGowan et al. 1998, Ingraham et al. 1998). Further, the winter PDO index shifted from positive to negative in

1989. However, the summer and annual PDO indices remained generally positive up until 1997. There does not appear to be wide support for another critical time period, at least not in the 1990 to 1997 period. Therefore, our focus is on 1988-89 as a potential regime shift year. Beamish et al. (1999) addressed a similar question using four Northern Hemisphere climate indices to form a single "regime index". Their results were equivocal as to whether a regime shift transpired in the late 1980s. Our approach in this study is comparable to that of Ebbesmeyer et al. (1991), where we assemble a diverse array of physical and biological datasets and use objective methods to determine statistical significance of a regime change in 1988-89.

We find evidence for two major regime shifts in the large marine ecosystems of the North Pacific/Bering Sea between 1965 and 1997. Applying the objective approach of Ebbesmeyer et al. (1991) to our data matrix also finds evidence for statistically significant regime shifts in 1977 and 1989. A late-1970's regime shift explains the greatest fraction of the total variance in our climate and ecosystem data matrix. Independent analyses of climate-only and ecosystem-only data matrices point to pervasive 1977 changes in both Pacific climate and marine ecology. A 1989 regime shift also explains a significant portion of the total variance in our combined climate-ecological data matrix. It is notable that an analysis of climate data by itself does not offer strong support for a 1989 climate regime shift, while an analysis of ecological data does. It is also important to note that the 1989 change was clearly not a simple reversal of climate and ecosystem conditions established by the 1977 regime shift.

This paper was presented at the 8th Annual Meeting of PICES (North Pacific Marine Science Organization) as an invited talk for the Science Board Symposium "The nature and impacts of regime shifts." The paper is currently in review and will be published in a special edition of the journal Progress in Oceanography. A preprint of the manuscript is available at the following URL: http://www.iphc.washington.edu/Staff/hare/html/papers/ei/abst_ei.html.

Climate-based Short-term Halibut Recruitment Predictions

Introduction

Previous research has shown that recruitment in halibut has undergone decadal-scale variability over the past several decades (Clark et al. 1998). The trend in recruitment is highly correlated with an index of the Pacific Decadal Oscillation (Hare 1998), as are those for a number of other groundfish and salmonid stocks (Hollowed et al. 1998, Hare and Mantua, in review). To the extent that halibut recruitment is related to trends in climate – presumably acting most strongly upon fish in their first year of life - and that the proper climate indices are identified, it is possible to provide short-term recruitment predictions. There is also value in establishing a historical record of forecasts for later evaluation.

Methods

It is generally assumed that recruitment is modified by the size of the spawning biomass and for halibut a Ricker stock-recruitment (S-R) relationship is often used. The Ricker relationship is well suited to the incorporation of climate data in modeling the recruitment process. For this forecasting exercise, I first fit a series of Ricker models, both with and without climate modification.

Model fits are compared using the Bayes' Information Criterion (BIC), a performance measure that balances statistical fit with model parsimony. The model with the lowest BIC provides the best fit to the historical data. I included the r^2 value as well because this allows a comparison of the added explanatory power of each model over a "null hypothesis" model of constant productivity. For each model, forecasts are then made using the parameters from the historical fits.

I fit a total of nine S-R models although five of these are simply variants on the first four (Table 1). The first model is a density-independent (DI, or constant productivity) Ricker model in which recruitment is modeled as proportional to biomass. The second model is the traditional density-dependent Ricker (DDR) model with two terms: α which is a productivity parameter and β which determines how strongly recruitment is affected by density dependence. All other models also include α and β terms. The third model is a DDR model with a PDO covariate term added. The fourth model is a regime shift DDR model which allows for two β terms, one for the period before the 1976-77 regime shift and one for the period afterwards. The five other models are also regime shift models. Model five has two α terms and one β term while model six has two α and two β terms. The three other models allow for a 1947 regime shift as well – as suggested by Mantua et al. (1997). Models 7, 8 and 9 have three β (one α), three α (one β) and three α and three β terms, respectively.

All model fitting is done in the traditional manner, i.e., performing a linear regression of ln(R/SSB) where R is recruitment and SSB is spawning stock biomass. The PDO model is fit as a multiple linear regression using annual PDO values. The left-most panels in Figure 1 show the model fits to plots of ln(R/SSB) vs. SSB. Model comparison statistics are given in Table 1. For each of the regime shift models there are multiple regression lines – one for each regime fit. The PDO has a continuum of regression lines, each with the same slope but varying intercept with PDO value. The center panels in Figure 1 show the resultant model fits through the data plotted as stock vs. recruitment. Again, there will be multiple trajectories equal to the number of fitted regimes. A comparison of predicted and "actual" recruitment for each model for brood years 1935-1990 is illustrated in the right hand panels of Figure 1. As each of the models is biomass based, recruitment forecasts for the next eight years are also included in these plots. In the case of the regime shift models, the forecasts all assume recruitment continues in the post-1977 mode, i.e., they are based on the Ricker parameter values estimated from the 1977-1990 data.

Results

On the basis of the BIC, the 55 years of halibut spawner-recruit data are best explained by a model with three α terms and a single β term. The second best fit was the two-regime model with one α and two β terms. Models with multiple α terms imply that there are changes in the productivity of the stock in the absence of intraspecific competition, whereas multiple β terms suggest changes in carrying capacity. Given the near equality of the fits among the regime shift models there does not appear to be sufficient data to distinguish the appropriateness of one model form or the other. All of the regime shift models outperformed the non-regime-shift models. Adding a density-dependent term explained 25% more of the productivity variance than the density-independent model; the PDO model explained an additional 16% of the variance.

The considerably better fit of the regime shift models over the PDO model is interesting but perhaps understandable in light of the recent findings of Hare and Mantua (in review). The PDO is a measure of interdecadal variability in north Pacific sea surface temperature but still contains a relatively large interannual signal (noise). This is generally true of most climate indices and particularly true of atmospheric phenomena. Conversely, it appears that many biological populations integrate their environment giving a much cleaner regime-like appearance to measures such as recruitment and growth. The use of static within-regime α and β values constitutes an extreme filtering of environmental-driven variability.

Under the assumption that halibut recruitment remains in the post-1977 production regime, eight of the nine models forecast recruitment levels of 4-6 million eight year olds over the next eight years (Fig. 2a). The one exception is the density-independent model which forecasts record recruitment because of the record biomass levels the produced the incoming year classes. The density-dependent models forecast lower levels of recruitment than the average for the post-1977 period for the same reason since with these models recruitment is negatively impacted by large spawning biomass. The PDO model suggests more variable recruitment than the regime shift models because the PDO index has been in a relatively variable state since 1989, compared to the 50 previous years. In the same study cited above, Hare and Mantua (in review) found evidence for a North Pacific regime shift in 1989. Whether halibut recruitment will show a response to the 1989 shift will be known for certain only some years down the road. However, the first recruitment (at age 8) estimates from the stock assessment model show substantially fewer recruits for the 1989, 1990 and 1991 year classes (Clark and Parma, this volume). If one assumes a return to productivity parameters of the pre-1977 period, an alternative set of forecasts can be made (Fig. 2b). Forecasts made using the assumption of a 1989 regime shift (to poorer productivity parameters) are even more pessimistic than those from the no-1989 regime shift models. All six of the regime shift models forecast recruitment of around 1-2 million eight year old fish over the next eight years. Forecasts for the DI, DD and PDO Ricker models are unaffected by regime shift assumptions.

Discussion and Conclusions

The ability of the halibut population to continue sustaining the high catch levels of the past few years is critically dependent on the strength of incoming year classes. To the extent that the Ricker stock-recruit models capture the dynamics of the recruitment process, they are surprisingly consistent in their forecasts. The single biggest factor (aside from whether density dependence plays a role) affecting the forecasts is the question of whether halibut recruitment will continue to show a negative response to the 1989 climate event. As part of another study, I assembled recruitment time series for the major groundfish populations of the Bering Sea, Gulf of Alaska and U.S. West Coast. I then compared median recruitment for the five year classes prior to 1989 with median recruitment for the five year classes beginning with 1989 (Fig. 3). Of the 26 groundfish stocks for which there are five recruitment estimates for each period (halibut is therefore not included), 17 showed a decrease in recruitment and nine showed an increase. The decreases however tended to be more severe than the increases. The recruitment decreases were less severe for the Gulf stocks compared to the West Coast and Bering Sea stocks. It remains an open question, however, how large a role conditions in the Bering Sea play in halibut recruitment.

As suggested above, the other key factor to consider in modeling the recruitment process is the role of density dependence. It would, of course, be preferable from a management perspective that density dependence be moderate or non-existent. It is much easier to defend maintaining a large, healthy biomass than one harvested aggressively in the expectation of boosting recruitment. Nevertheless, the stock recruitment data for halibut suggest that recruitment is strongly density dependent - whether one believes in productivity regimes or not. The level of density-dependent recruitment is shown by the slope of the regression lines in the left hand panels of Figure 1. All models, except for the DI model, have negative slopes indicating density dependence. The regime shift models with multiple β terms suggest that the degree of density dependence varies by regime but is always a factor.

To summarize, the forecasts from this stock-recruitment modeling exercise suggest that recruitment over the next several years will be considerably weaker than the observed levels of the previous decade. At best, recruitment for the Area 2 and Area 3 stocks is forecast to be in the neighborhood of 4-6 million fish. At worst, i.e., if the halibut population has shifted to a low productivity regime, recruitment is forecast to be around 2 million fish. This would be equal to, or below, the lowest levels ever observed. Due to the continued small size-at-age of the recruiting eight year old fish, it will be several years before we are confident in our estimates of year class strength. The NMFS conducts triennial trawl surveys of groundfish populations in the Gulf of Alaska and this source of independent estimation of incoming recruitment will be added to the stock assessment in the next year. Preliminary analysis of the 1999 trawl survey results suggests a more optimistic picture than is painted by this analysis or the halibut stock assessment. The trawl data, however, are highly variable and it will be three years until the next survey will support or refute this early indication of stronger recruitment.

Understanding the relationship between stock and recruitment has been called “the most difficult problem in biological assessment of fisheries” (Hilborn and Walters 1992). Until we have more completely understood that relationship any forecast will be fraught with uncertainty. There is growing belief however that we have captured at least some of the essence of halibut recruitment dynamics, namely the existence of decadal scale productivity regimes. If we have indeed entered a low productivity regime we must anticipate that the recent low levels of recruitment are likely to persist well into the next decade. Among the many challenges facing the IPHC is the development of an optimal harvest rate under this form of uncertainty.

Other Projects Initiated

Two multi-year fisheries oceanography projects were initiated in 1999. Both completed the data collection phase and analyses and publication of results is anticipated by the 2001 Annual Meeting. Included below are abstracts outlining the nature and intent of the projects. The first project is in cooperation with Tom Kline of the Prince William Sound Science Center. The second project is in cooperation with Paul Spencer of NOAA and Terry Quinn of the University of Alaska.

Spatial and ontogenetic variability in the trophic status of Pacific halibut (Hippoglossus stenolepis) based on natural stable isotope abundance (short title: Pacific halibut trophic status)

Abstract

This project will assess spatial and ontogenetic variability in the trophic status of Pacific halibut (*Hippoglossus stenolepis*) using natural stable isotope abundance of carbon and nitrogen which is hypothesized to vary over the distribution of the species in the Northeast Pacific. Natural

stable isotope abundance is a useful research tool for fish ecology because of the predictable relationships of isotope signatures among food web constituents and isotopic gradients existing in the study area. Increase in trophic level is hypothesized to explain the large decrease in growth rate exhibited by halibut since the 1976-1977 regime shift that also affected many species in the region. Ontogenetic shifts in isotope signature are expected to indicate a shift to feeding offshore as adults. This will provide a linkage to the regime shift because changes in zooplankton abundance have been noted offshore near the continental shelf break. Showing a relationship to this carbon source through isotope matching will provide the first line of evidence for a mechanism explaining changing halibut growth patterns. There will be a synergy between this project and other fish ecology projects using natural stable isotope abundance in the N. E. Pacific region.

Pacific halibut and Bering Sea flatfish growth dynamics: environmental and density-dependent factors

Abstract

Large increases in abundance of commercially important fish stocks have occurred in the eastern Bering Sea (EBS) during the 1980s and 1990s, and it is notable that the EBS yellowfin sole fishery is the largest flatfish fishery in the United States. An understanding of ecosystem dynamics and the causal mechanisms for recent stock increases will aid the task of maintaining productive fisheries into the future. Previous studies focusing on the relation between recruitment and environmental time series have yielded mixed results. Given the importance of growth to developmental processes (e.g., feeding and swimming ability) and current recruitment theories, it is sensible to examine growth directly. The purpose of the proposed study is to examine otolith growth increments of several flatfish species from a variety of locations (Pacific halibut in the Gulf of Alaska and EBS, yellowfin sole, rock sole, flathead sole, and Alaska plaice in the EBS), and compare otolith growth to patterns of environmental variation and recruitment variability. The inclusion of several flatfish species from a range of locations allows consideration of spatial variability in growth, and how the effect of broad-scale environmental factors on flatfish may vary across regions. Randomization testing, linear statistical models, and time-series analysis will be used to indicate which factors are most important in explaining growth during early life history. The end-products of these analyses are (1) a model of growth during the early life history among species related to biological and environmental factors and (2) a spawner-recruit model that is generalized to account for early growth patterns, environmental effects, and relationships among species (Quinn and Deriso 1999). These models can then be used as one component of the scientific basis for an ecosystem approach for groundfish stock assessment and management in the North Pacific.

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Table 1. **Stock recruitment models, parameter estimates and model fit statistics for Pacific halibut year classes 1935-1990.**

Model	Equation	Parameter estimates	BIC/r^2
DI	$R_{t+8} = SSB_t e^{\alpha+\varepsilon_t}$ t = 1935-1990	α = -3.690	69.8/0.00
DD	$R_{t+8} = SSB_t e^{\alpha-\beta SSB_t+\varepsilon_t}$ t = 1935-1990	α = -3.044 β = 0.0034	65.7/0.25
PDO	$R_{t+8} = SSB_t e^{\alpha-\beta SSB_t+\gamma PDO_t+\varepsilon_t}$ t = 1935-1990	α = -2.958 β = 0.0039 γ = 0.171	62.9/0.41
2 β, 1 α	$R_{t+8} = SSB_t e^{\alpha-\beta_i SSB_t+\varepsilon_t}$ i=1; t = 1935-1976 i=2; t = 1977-1990	α = -2.090 β_1 = 0.0099 β_2 = 0.0058	47.9/0.66
2 α, 1 β	$R_{t+8} = SSB_t e^{\alpha_i-\beta SSB_t+\varepsilon_t}$ i=1; t = 1935-1976 i=2; t = 1977-1990	α_1 = -2.525 β = 0.0073 α_2 = -1.697	50.8/0.62
2 α, 2 β	$R_{t+8} = SSB_t e^{\alpha_i-\beta_i SSB_t+\varepsilon_t}$ i=1; t = 1935-1976 i=2; t = 1977-1990	α_1 = -2.119 β_1 = 0.0097 α_2 = -2.047 $\beta 2$ = 0.0059	51.9/0.66
3 β, 1 α	$R_{t+8} = SSB_t e^{\alpha-\beta_i SSB_t+\varepsilon_t}$ i=1; t = 1935-1946 i=2; t = 1947-1976 i=3; t = 1977-1990	α = -2.262 β_1 = 0.0076 β_2 = 0.0092 β_3 = 0.0052	48.4/0.70
3 α, 1 β	$R_{t+8} = SSB_t e^{\alpha_i-\beta SSB_t+\varepsilon_t}$ i=1; t = 1935-1946 i=2; t = 1947-1976 i=3; t = 1977-1990	α_1 = -2.408 β = 0.0064 α_2 = -2.765 α_3 = -1.920	46.7/0.72
3 α, 3 β	$R_{t+8} = SSB_t e^{\alpha_i-\beta_i SSB_t+\varepsilon_t}$ i=1; t = 1935-1946 i=2; t = 1947-1976 i=3; t = 1977-1990	α_1 = -1.294 β_1 = 0.0144 α_2 = -2.762 β_2 = 0.0064 α_3 = -2.047 β_3 = 0.0059	51.7/0.75

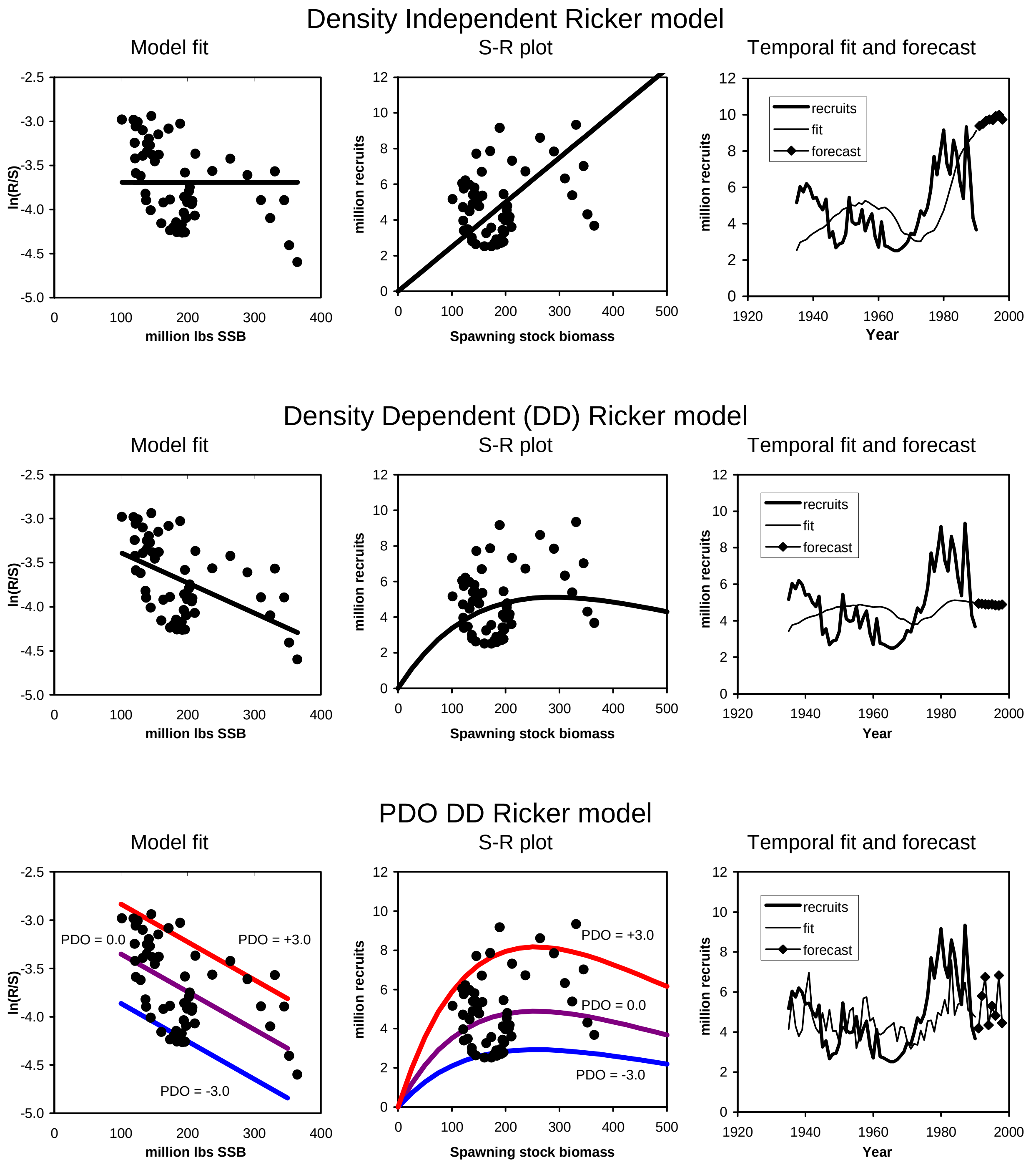
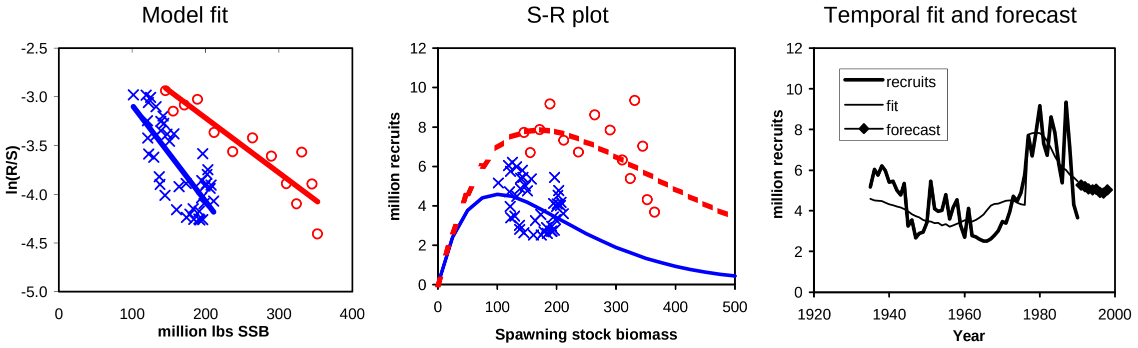
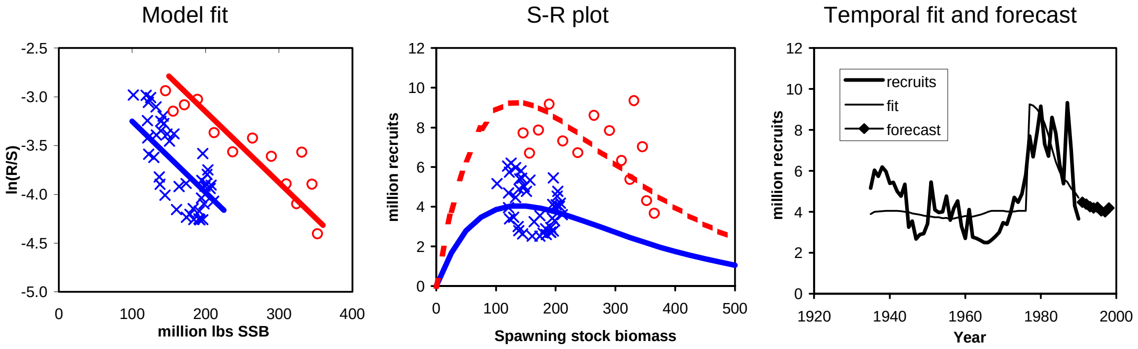


Figure 1. **Pacific halibut stock recruitment model fits to brood years 1935-1990 and forecasts of recruitment of eight year old fish. Left side plots show actual model fits, center plots show resultant stock recruitment relationships, right side plots show model fits to recruitment over time along with forecasts. See text for details on models.**

2 Beta Regime Shift DD Ricker model



2 Alpha Regime Shift DD Ricker model



2 Alpha and 2 Beta Regime Shift DD Ricker model

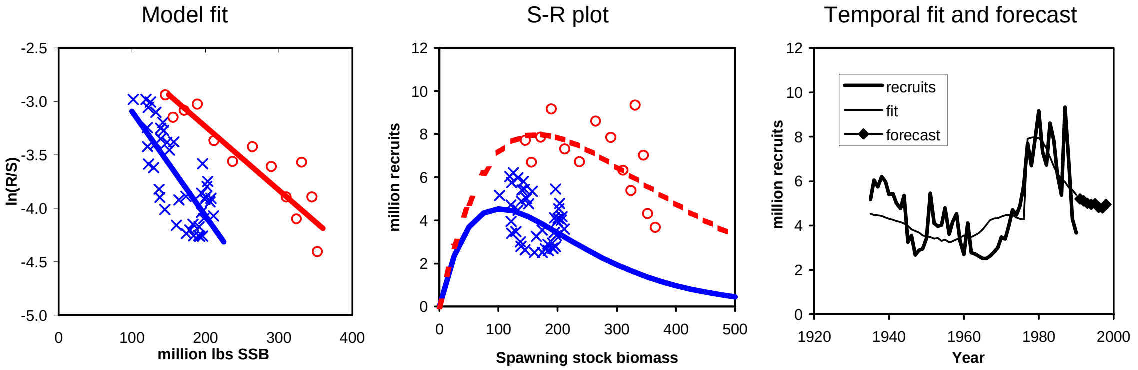
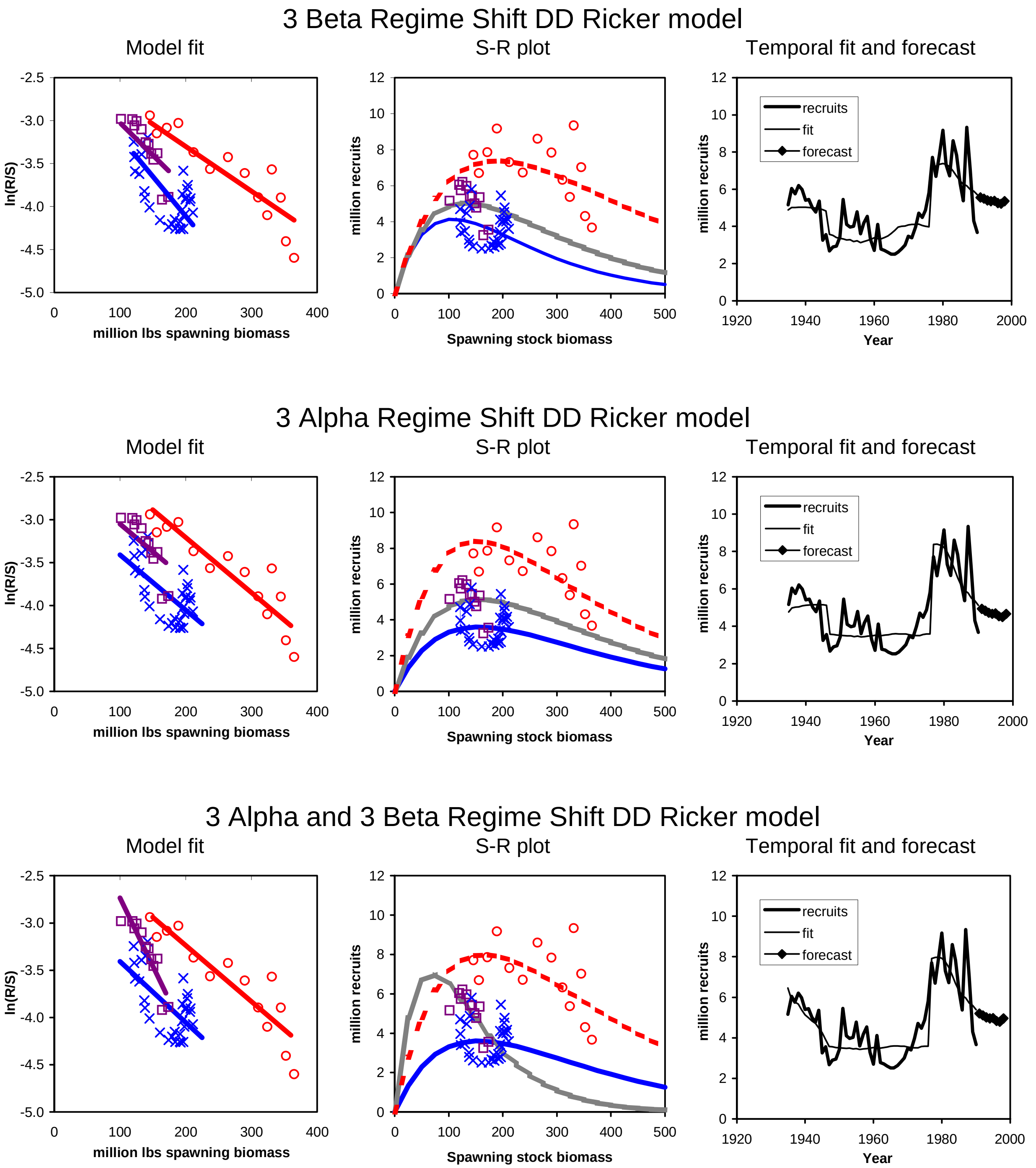


Figure 1. (cont.)



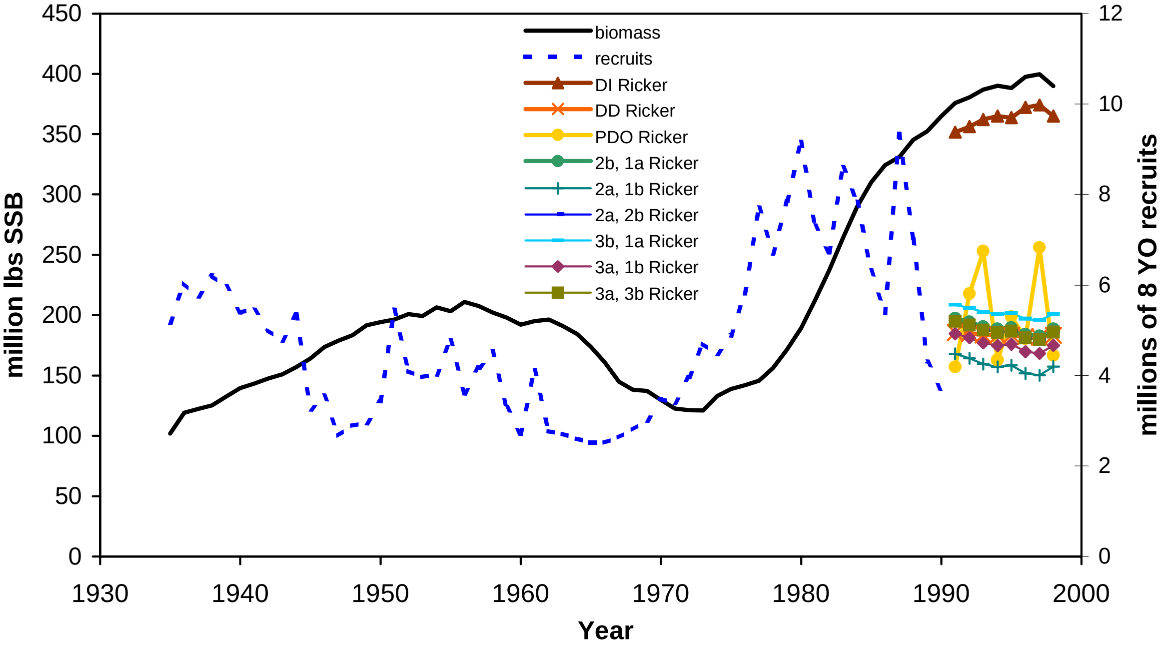
3 Beta Regime Shift DD Ricker model

3 Alpha Regime Shift DD Ricker model

3 Alpha and 3 Beta Regime Shift DD Ricker model

Figure 1. (cont.)

a) Recruitment forecasts - 1977 regime shift



b) Recruitment forecasts - 1989 regime shift

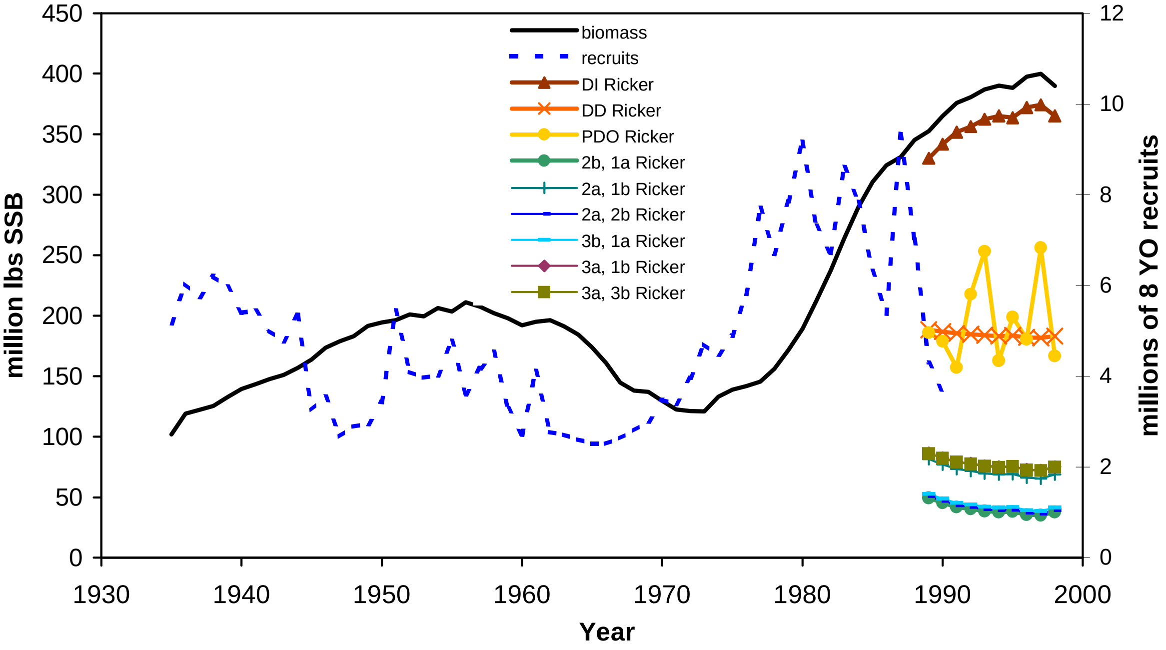


Figure 2. **Spawning stock biomass (SSB) and eight year old (YO) recruits for Pacific halibut for brood years 1935-1990. Recruitment forecasts are shown for nine stock recruitment models under the assumption of a) a 1977 regime shift and b) a 1977 and 1989 regime shift. In the caption, a and b refer to a and b of the models, respectively.**

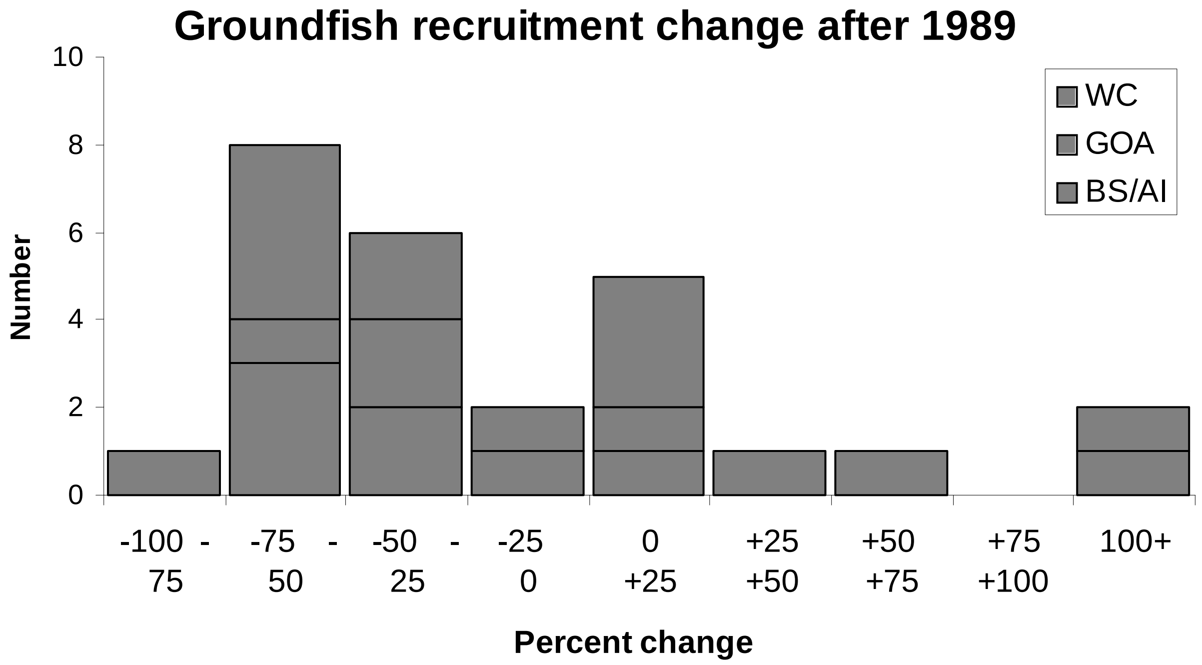


Figure 3. Change in median recruitment for 10 Bering Sea/Aleutian Island (BS/AI), 6 Gulf of Alaska (GOA) and 10 U.S. West Coast (WC) groundfish species. Percent change is computed from the median recruitment of the five years prior to 1989 and the five years beginning with 1989.

1999 Chalky Halibut Study

by

Stephen M. Kaimmer

Introduction

The IPHC is in the third calendar year of chalky fish studies. During 1999 the IPHC conducted a study suggested by industry on the effects of stunning and/or bleeding on the development of the chalky condition. A core team of industry members commented on project design and helped track evidence of chalky halibut during the 1999-fishing season. Team members include Brad Faulkner (Alaska Custom Seafood, Inc., Homer, AK), Blake Tipton (S&M Products, BC Canada), Shari Gross (HANA, Seattle, WA), and Andrew Scalzi, Gregg Best, and Rodney Pierce (IPHC Commissioners). Chalky halibut was expected to be most evident in the late summer or early fall, and the field experiments were timed to coincide with these periods of chalky occurrence.

Methods

Pilot study, tag type, and tag placement

An initial pilot study during a grid fishing charter determined a tag type and developed the methodology for tag attachment and body temperature measurement. During the pilot study, approximately 100 fish were tagged with both t-bar tags and metal strap tags, and marked with a length of surveyor's tape tied around the mouth, through the opercular flap. Tags were attached to maximize holding power while minimizing any high profiles that might result in tags being torn off during handling. Once sold, all marked fish were tallied as to whether either of the tags had been lost. Strap tags were attached to the dorsal side of the white-side pectoral fin, onto the thickest region close to the base of the fin as possible. The t-bar tags were attached into the knobby area underneath the white-side pectoral fin. This location protected the tag from abrasive removal during later handling. Difficulties in attaching the t-bar tags and in maintaining the tag applicators during the pilot study resulted in choosing the strap tag for the main study. Digital thermometers were used to determine core body temperatures on live fish immediately after capture and on dressed fish prior to their being put into the ice hold. After sale of the fish, fish were checked for chalkiness by direct observation of a cut in the dorsal region, observation of fish while being filleted or steaked, or through claims from final buyers.

Fishing time and locations

Vessel charters for the main study operated in both Area 2B and Area 3A. The IPHC awarded two vessel charters following a bid procedure, one to the *F/V Angela Lynn* in Area 3A, and one to the *F/V StarWars II* in Area 2B. Expected catches for each charter were between 30,000 and 50,000 pounds. Prior sale arrangements with New West Fisheries and S&M Products facilitated checking for chalkiness after landing, the former to buy Area 3A fish in Homer and the latter to buy the Area 2B fish. Area 3A fish were shipped to Bellingham, WA, for processing, while the Area 2B fish were shipped to Ladner, B.C. Trips were designed to recreate fishing conditions experienced by commercial fishers. Set and soak times were left to the discretion of the chartered vessels.

Shipboard handling

Each experiment was conducted as a randomized block design. Halibut were tagged with a metal strap tag when they were captured. This allowed individual fish to be tracked through shipboard handling and shore processing. After capture and tagging, fish were randomly assigned one of four treatments; stunning, bleeding, stunning and bleeding, and no treatment. A 12-fish sample of core body temperatures was taken when fish were caught to determine a typical capture temperature for all fish in a set, and time of capture was recorded for all fish tagged. Note was also taken of any fish which appeared extremely active at capture. About 1/4 to 1/3 of fish caught and tagged were set aside for up to three hours prior to dressing. Time, fish length, sex, maturity, and core body temperature were recorded for each fish after dressing and prior to being put into the ice hold.

Core Body Temperatures

Core body temperatures were taken using provided digital stem thermometers (Hanna HI9063, Hanna Instruments, Italy). After making a small cut through the skin, the thermometer probe was inserted about ½-1 inch into the flesh. Temperatures were read and recorded to the nearest 0.1 degree Centigrade.

Shore handling

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

Results

Fishing success

The *StarWars II* completed two trips in the Hecate Strait region of Area 2B. We fished from 24 through 29 August on the first trip and from 31 August through 1 September 1999 on the second. On 30 August, 34,907 pounds were delivered in Port Edward, BC from the first trip. These fish were trucked to Ladner, BC and processed on 1 September. On 3 September 17,053 pounds were delivered from the second trip in Port Hardy, B. These fish were processed in Ladner on 7 September.

The *Angela Lynn* completed one trip, fishing from 6 September through 13 September, mostly in the Semidi Island region of Area 3B. Although we had expected to fish in Area 3A, few chalky fish had been seen in this area prior to the start of the charter. The *Angela Lynn* delivered 41,656 pounds of fish to Homer, AK on 13 September. Fish were processed in Bellingham on September 16 and 17.

Chalkiness

On 1 September, the first load of fish from Area 2B was processed at Ladner, BC. Generally, we filleted 25% of the 10-20's, 50% of the 20-40 and 40-60's, and 0% of the 60+. All other fish were sent out whole. All of the 60+ fish were cut prior to shipping to determine chalkiness (1 fish was chalky).

- We filleted 264 fish and sent out whole 573 fish.
- 43 (16%) of the filleted fish were chalky.
- 33 (13%) of the filleted fish had lost the strap tag.
- 1 fish from the group sent out whole was claimed chalky by a buyer

On 5 September, some fish from the second Area 2B trip were sent out whole from Ladner. On 7 September the remaining fish from the second Area 2B trip were processed. At this time, the remaining 10-20's were shipped out whole.

- We filleted 200 fish, steaked 17 fish, and sent out about 350 fish whole
- 22 (11%) of the filleted fish and 3 (18%) of the steaked fish were chalky.
- 27 (14%) of the filleted/steaked fish had lost the strap tag.
- Buyers claimed 3 fish from the group sent out whole as chalky.

On 16 and 17 September, all fish from the Area 3A trip were headed and washed, and all number 2 fish were set aside into totes. The remaining fish were cut just below the dorsal fin to determine chalkiness. Chalky fish were set into a tote and remaining fish were sorted by market size. All of the number 2 fish, as well as all of the chalky fish, were then filleted.

- We graded 1312 fish.
- 8.7% (114 fish) were chalky and 82 fish were determined to be number 2.
- 6% (5 fish) of the number twos were later determined to be chalky, 1 entirely and 4 partially.
- Of the 114 fish initially determined as chalky, filleting revealed that 1 fish was not chalky, 95 fish were fully chalky, and 18 fish were partially chalky.
- 5% (69 fish) had lost the strap tag.

Later filleting of the chalky fish was especially interesting, revealing only one non-chalky fish in the chalky set-asides.

Data processing and final report

Data will be analyzed as soon as possible, with a final report planned to be presented before or at the IPHC Annual Meeting to be held in early January 2000. Currently, data are being entered and verified into the IPHC database.

Stable Isotope Analysis of Pacific Halibut Otoliths

by

Yongwen Gao, Robert J. Trumble, and Steven Hare

Introduction

The International Pacific Halibut Commission (IPHC) and the Pacific Biological Station, Fisheries and Ocean Canada have begun to analyze stable isotopes of Pacific halibut (*Hippoglossus stenolepis*) otoliths to determine changes in the ocean bottom environment of the Northeast Pacific, using the 60+ year IPHC collection of Pacific halibut otoliths. The IPHC has begun an initiative to evaluate the environmental impacts on Pacific halibut stocks, and effects on Pacific halibut fishery management. This initiative began after the IPHC staff documented inter-decadal variability in growth, recruitment, and production of the Pacific halibut stocks (Clark 1996), and the effect the changes had on the estimates of abundance and harvest rates (Sullivan and Parma 1997) used to manage Pacific halibut. Variation over time of Pacific halibut growth rates, abundance, and productivity (Clark et al. 1999) has major implications for future harvest and management of the halibut resource. Evidence mounts that long term (20-30 years) environmental conditions may have effects on fish productivity comparable to or greater than fishing activities. The IPHC staff and other fishery scientists have long studied the role of fishing. The staff has now begun to incorporate environmental science with halibut biology to evaluate inter-relationships.

The cornerstone of the initiative is a fishery-oceanography project that will analyze available physical and biological data that may relate to changes in halibut production and biology (IPHC 1997). Research to date shows decadal scale regime shifts in oceanographic and meteorological conditions that relate to fish production (Francis and Hare 1994; Hare and Francis 1995; Mantua et al. 1997). The long time series of halibut catch, age, and growth data provides a unique opportunity to test regime shift hypotheses for Pacific halibut with our data, to help understand observed fluctuations in halibut production and biology (Clark et al. 1999).

The IPHC collaborated with the Pacific Biological Station, Nanaimo BC to initiate analysis of stable isotope ratios of oxygen and carbon ($\delta^{18}O$ and $\delta^{13}C$) in Pacific halibut otoliths. Preliminary analysis of our data suggests that regime changes in the eastern North Pacific Ocean show up as signals on the otoliths of Pacific halibut. The combination of the extraordinary IPHC otolith collection and a powerful technique to detect environmental signals from the otoliths provides an opportunity to describe the ocean-bottom environment back to approximately 1930.

Pacific halibut undergo a complex pattern of migration related to life history stages (Trumble et al. 1993). Spawning occurs during winter on the upper continental slope along the coasts of northern British Columbia and Alaska, primarily on specific spawning grounds. Eggs and larvae drift north and west with ocean currents for approximately six months, and gradually rise to the surface waters during a transport of several hundred miles. On-shore components of the surface currents carry the larvae to nearshore areas where they metamorphose during spring. Over the course of several years, the young halibut move offshore and undertake a migration to the east and south that counters the larval drift. The counter migration ends at about the time of sexual maturity, and halibut spend summers feeding on the continental shelf. Tagging data (Trumble et al. 1990) show that summer to summer movements of mature halibut are typically less than 100 km, indicating that little migration of adults occurs summer to summer. During autumn, halibut migrate to the winter spawning grounds, and return to the feeding grounds in the spring. Halibut otoliths have the potential to record annual and seasonal environmental signals from different life stages (Quinn et al. 1983).

Use of Stable Isotopes in Environmental Research

The use of $\delta^{18}O$ in biogenic carbonates is well established as a proxy for reconstruction of temperatures in ocean settings. This is based on the theoretical proposition of Urey (1947) and numerous empirical calibrations of the temperature dependent fractionation of the $^{18}O/^{16}O$ ratio between the mineral carbonate and the water from which it forms. This temperature-dependent fractionation is well characterized for inorganically formed carbonate (both aragonite and calcite) and has been empirically refined and calibrated for a variety of taxa (Epstein et al. 1953; Friedman and O'Neil, 1977; Grossman and Ku, 1986; Zahn and Mix, 1991 and many others). In general, a "vital effect" or biologically induced disequilibrium fractionation is not the rule, such that $\delta^{18}O$ measures can be reliably used as proxies of temperature for regions not affected by large changes in ocean water salinity.

The first attempt for stable isotopic analysis in fish otoliths was by Devereux (1967), whose data suggest that the habitat of fishes can be deduced from $\delta^{18}O$ of their otoliths. Otoliths are mm-sized, laminated calcium carbonate structures located in the inner ears of teleost fishes. The laminae grow continuously through the life of the fish, and faithfully record the environmental and climatic changes the fish experienced. All otoliths comprise pure aragonite ($CaCO_3$), and their total organic matter ranges from 0.2 to 10 % (Degens et al., 1969). As a result, the $\delta^{18}O$ of otolith aragonite can be used as a measure of growth temperature; with increasing temperature, $\delta^{18}O$ decreases (cf. Kalish 1991). The estimate of 1 ‰ $\delta^{18}O$ variation corresponds to about 5°C in the temperature of seawater at constant salinity (Gao 1997). In contrast to oxygen isotopes, carbon in otolith carbonate is deposited in isotopic disequilibrium with the ambient seawater, with significant and variable metabolic sources (Mulcahy et al. 1979; Kalish 1991). Therefore, changes in $\delta^{13}C$ of otoliths can record changes in maturity of the fish or dietary shifts, whereby higher trophic-level foods result in higher $\delta^{13}C$ values (Fry 1988; Schwarcz et al. 1998).

Recent advances in otolith microsampling (at annual and intra-annual/seasonal scales) coupled with mass spectrometric techniques capable of analysis of microgram quantities of carbonate have resulted in a powerful new tool in studies of environmental biology. Even though the theory, objectives and research challenges have not changed significantly since the late 1940s, the early studies in fish otoliths (e.g., Devereux 1967; Mulcahy et al. 1979) remain as cornerstones in the field. Subsequent studies of otoliths have further extended our horizons and provided insights into the ecology many fish species (e.g., Radtke et al. 1987; Nelson et al. 1989; Kalish 1991; Iacumin et al. 1992; Patterson et al. 1993; Gauldie et al. 1994; Radtke et al. 1996; Thorrold et al. 1997; Schwarcz et al. 1998).

These studies demonstrate that stable isotope approaches can be applied to discriminate among stocks and migration patterns because they reflect the isotopic differences among different water masses and habitat areas. Nelson et al. (1989) compared the $\delta^{18}O$ values of common smelt

(*Retropinna retropinna*) otoliths with that of water sources, and concluded there is a potential to use stable isotopes, both $\delta^{18}O$ and $\delta^{13}C$, to distinguish smelt by their habitat waters and thus to examine their migration behavior. Gao (1997) analyzed the first year $\delta^{18}O$ values of cod (*Gadus morhua*) otoliths from the northeast Scotian Shelf, and was able to define two types of cod, Type 1 (local) and Type 2 (migratory), and the possible recruitment for the stock studied. Recent biological investigations even proposed that the change of migration patterns and routes might account for the population declines of salmonids in the North Pacific (Welch et al. 1998) to response to the global warming events. All these results support the use of stable isotope measurements as a very useful tool in migration and population dynamics studies. The key premise is that there are distinct isotopic signals that are characteristic of different regions of the Pacific shelf or of different stocks.

Even though the potential of using otolith $\delta^{18}O$ in environmental studies has been extensively documented in laboratory experiments (e.g., Kalish 1991; Radtke et al. 1996; Thorrold et al. 1997), studies examining archived otoliths have rarely been reported. In particular, there have been no attempts using isotopic tracers to address the impact on long term climate-related ecosystem changes in North Pacific fisheries. Under different ocean regimes (e.g., 1948-77; 1978-88; 1989-present), examination of isotopic variations ($\delta^{18}O$, $\delta^{13}C$ and $\delta^{15}N$) coupled with ocean conditions (T, S, winds and currents) can provide integrated information on stock assessment (Sullivan et al. 1999), food competition, and survival of halibut in response to the ecosystem changes. Such studies have yet to be undertaken. Therefore, research proposed here, utilizing 60+ years of archived halibut otoliths, is both timely and significant and will provide for a better understanding of the decadal-scale climate regime shifts and their influences on halibut stocks in the North Pacific.

Results

Two methods for microsampling otoliths (micro-milling and Dremel) have been tested and differences were found to be within tolerance of analytical errors (Gao 1999). Our test work on inter-laboratory analysis (McMaster University and University of British Columbia) shows, using NBS-19 standard, that the precision of the analysis for the same otolith annual growth zones is consistent, better than 0.06 and 0.07 ‰, respectively. Therefore, seasonal zones in halibut otoliths make it possible to extract the annual and seasonal isotopic records and to trace the long-term marine environmental changes that link to temperature, salinity, and chemical component of the ambient seawater. Only a few studies have adopted computer-driven microsampling techniques in otoliths (e.g., Patterson et al. 1993; Gao 1997; Schwarcz et al. 1998), and documented their isotopic results in annual and seasonal bases.

As an example of the utility of annual scale examination, we extracted records from the summer portion on annuli to document a multi-year record of the life history of halibut. We selected 10 archived otoliths each from IPHC Regulatory Areas 2B and 3A (Fig. 1) from halibut captured in 1980 and 1993. All halibut were females aged 13 yr. The annual $\delta^{18}O$ variations averaged over the 10 selected otoliths from Area 3A show two stages: a lower $\delta^{18}O$ stage and a higher $\delta^{18}O$ stage (Fig. 2). Differences in the $\delta^{18}O$ are consistent with the movements offshore from the juvenile to adult stages (Skud 1977). Furthermore, this isotopic variation pattern is independent of the capture location of an individual halibut.

The transition from the lower isotopic values of the juvenile Pacific halibut to higher values in the adult stage did not occur in the same pattern in different time periods (Fig. 2). Otoliths from the 1980 captures showed the transition of $\delta^{18}O$ from age 3 to age 4; after age 5, the $\delta^{18}O$ values remained stable. Transition for the 1993 captures occurred from age 3 to ages 7 or 8; stable values did not occur until around age 9.

We analyzed five otoliths from halibut tagged and released from 1985 to 1992 in the eastern Aleutian Islands (IPHC Area 4A) and four otoliths from halibut tagged from 1994 to 1997 and recovered near Kodiak Island (Area 3A). The ages of recovered halibut ranged from 9 to 13 years. For the fish tagged and recaptured in the same areas, the $\delta^{18}O$ values for the first year (i.e., samples from the first annulus) grouped differently for the 3A and 4A samples (Fig. 3). Similarly, the $\delta^{18}O$ of adult ages (i.e., the outermost annuli) grouped differently for the two areas, and different from the age-one samples. We selected the oldest three ages available from the otoliths when examining the $\delta^{18}O$ of adult halibut to minimize influence from the transition period. The typically colder water of the Bering Sea-Aleutian region is consistent with the higher $\delta^{18}O$ values of the Aleutian samples compared with the lower $\delta^{18}O$ values from the warmer central Gulf of Alaska.

These examples strongly suggest that environmental changes can be deduced from the isotopic signals in Pacific halibut otoliths, and that the oceanic conditions between the Bering Sea and the Gulf of Alaska near Kodiak Island during the early 1990s are different. These examples also support a sampling strategy using the stable isotopes from older ages of the otolith to minimize the age-specific effect of transition from juvenile to adult stages.

Previous studies from salmon and halibut production (Beamish and Bouillon 1993; Hare and Francis 1995; Clark et al. 1999) conclude that regime shifts of ocean environments occur at decadal scales. The 1977 regime shift appeared especially strong. Preliminary analysis indicates that another regime shift might have occurred around 1989 or 1990 (Beamish et al. 1999). We selected 7 otoliths of 13-yr old halibut in 1980 and 7 otoliths of 13-yr old halibut from Areas 2B and 3A in 1993, and compared $\delta^{18}O$ values from ages 7 to 12 for the two periods. Our test data demonstrate a 0.2 ‰ increase in $\delta^{18}O$ values for Area 2B from 1977-79 to 1990-1992, or about a 1°C temperature decrease, and a 0.4 ‰ increase in $\delta^{18}O$ values for Area 3A from 1977-1979 to 1990-1992, or about a 2°C temperature decrease (Fig. 4).

In Area 2B, $\delta^{13}C$ values occur in the same range from 1977-79 and from 1990-92, although an increasing trend occurs across the 1977 and 1990 periods (Fig 5). The 1977-79 $\delta^{13}C$ values for 3A are about 0.7 ‰ higher than for the 1990-92 period, and an increasing trend across the 1977 and 1990 periods is similar to that of Area 2B. In both areas, however, $\delta^{13}C$ values apparently drop during the presumably stable 1977-1989 period.

Ocean temperature analyses comparing the 1977-79 to 1990-92 time periods show generally similar trends for SST and OBT (Fig. 6), with cooling in the Bering Sea and warming off British Columbia. Sea surface temperatures generally cooled 0.5 to 1.5°C in the Bering Sea and along the Aleutian chain. Little temperature difference occurred across the mid-Gulf, and SSTs were 0.5 to 1.0°C warmer off the coast of British Columbia and to the south. Ocean bottom temperatures cooled as much as 2.0°C in the central Bering Sea, but averaged about 1.0°C warmer around the entire Gulf of Alaska from the Aleutian chain to southern British Columbia.

Conclusion

The 1977 regime shift has been well documented (Beamish 1993; Francis and Hare 1994; Hare and Francis 1995; Mantua et al. 1997, and others). Many demersal and pelagic fish species, marine mammals, and seabirds experienced dramatic changes in abundance and biological parameters (see review by Francis et al. 1998). The first three years of the 1977 regime shift were characterized by $\delta^{18}O$ values in summer zones of age-9 and older Pacific halibut otoliths of 1.8–1.9 ‰ in Area 3A (Fig. 4) and of 1.9-2.0 ‰ in Area 2B. During the years 1990-1992, the $\delta^{18}O$ values increased to around 2.2-2-3 ‰ in Areas 3A and 2B. For $\delta^{18}O$, this variation corresponds to a decrease in near-bottom seawater temperature of about 2°C (cf. Gao 1997).

Our temperature analysis of changes between 1977-79 and 1990-92 show that both the surface and bottom waters of the Bering Sea cooled between the two periods, while the surface and bottom waters warmed along British Columbia and bottom waters warmed in the Gulf of Alaska. At the ocean's surface the cooling trend centered in the Bering Sea extends to the Aleutian chain and the westernmost part of the Gulf. These same regions show a warming in bottom waters between the late 1970s and early 1990s.

Shifts in $\delta^{13}C$ values indicate different metabolic processes in the areas and times examined. Growth rates of Pacific halibut differed between the two periods in 3A but not in 2B, but age at maturity was similar in both areas and both periods (Clark et al. 1999). Therefore, the changes in $\delta^{13}C$ values are more likely related to diet than to maturity. The $\delta^{13}C$ values in age-9 and older halibut in Area 3A for the 1977-1979 period, -0.25 to –0.60 ‰, decreased to about –1.1 ‰ in 1990-1992 (Fig. 6), suggesting a decrease in trophic level (Schwarcz et al. 1998). In contrast, the $\delta^{13}C$ values for 2B overlapped for the two periods, from –0.5 to –1.0 ‰ in the early period, and from –0.9 to –1.0 ‰ in the later period.

These examples suggest that environmental changes can be deduced from the isotopic signals in Pacific halibut otoliths, and that the isotopic signals reflect known differences in oceanic conditions between the Bering Sea and the Gulf of Alaska near Kodiak Island during the early 1990s. These examples also support a sampling strategy using the stable isotopes from older ages of the otolith to minimize the age-specific effect of the transition from juvenile to adult stages. However, the identified trends in ocean temperatures at the 1977 and possible 1989 regime shifts do not match the trends indicated by $\delta^{18}O$. There are several possible explanations for the difference in temperature signals indicated by the $\delta^{18}O$ and ocean temperatures. We used a small number of fish from localized areas to characterize broad scale changes in the Gulf of Alaska. Ideally, one would examine adults captured at several locations around the Gulf to detect a spatial structure to changes in $\delta^{18}O$. A water mass may have moved through the Gulf of Alaska and the waters offshore of British Columbia that affected $\delta^{18}O$ in a manner larger than and opposite the observed temperature changes. The possible role of salinity cannot be fully discounted and needs to be further investigated. Ocean surface salinity in nearshore areas changes in response to precipitation and freshwater runoff, and increased precipitation over much of Alaska and the Gulf of Alaska was another impact of the 1976-77 climate regime shift (Overland et al. 1999). Determination of near ocean bottom salinity changes are currently underway.

The results provide conceptual support for using the 60+ year collection of Pacific halibut otoliths by the International Pacific Halibut Commission as a new data set for characterizing the marine environment of the north Pacific Ocean during the 1930-2000 period, although the link between $\delta^{18}O$, temperature, and water masses require further exploration.

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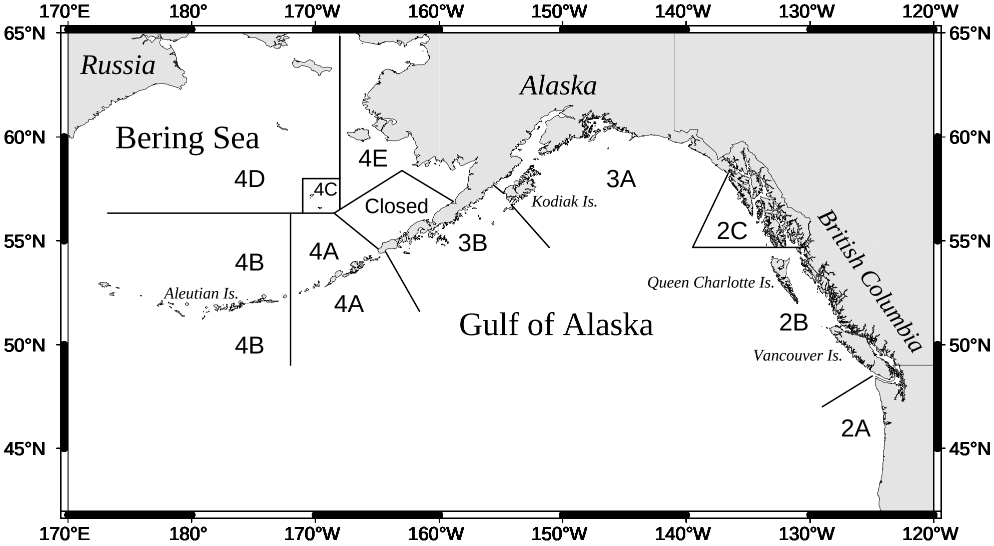


Figure 1. The Gulf of Alaska and Bering Sea, with IPHC regulatory areas.

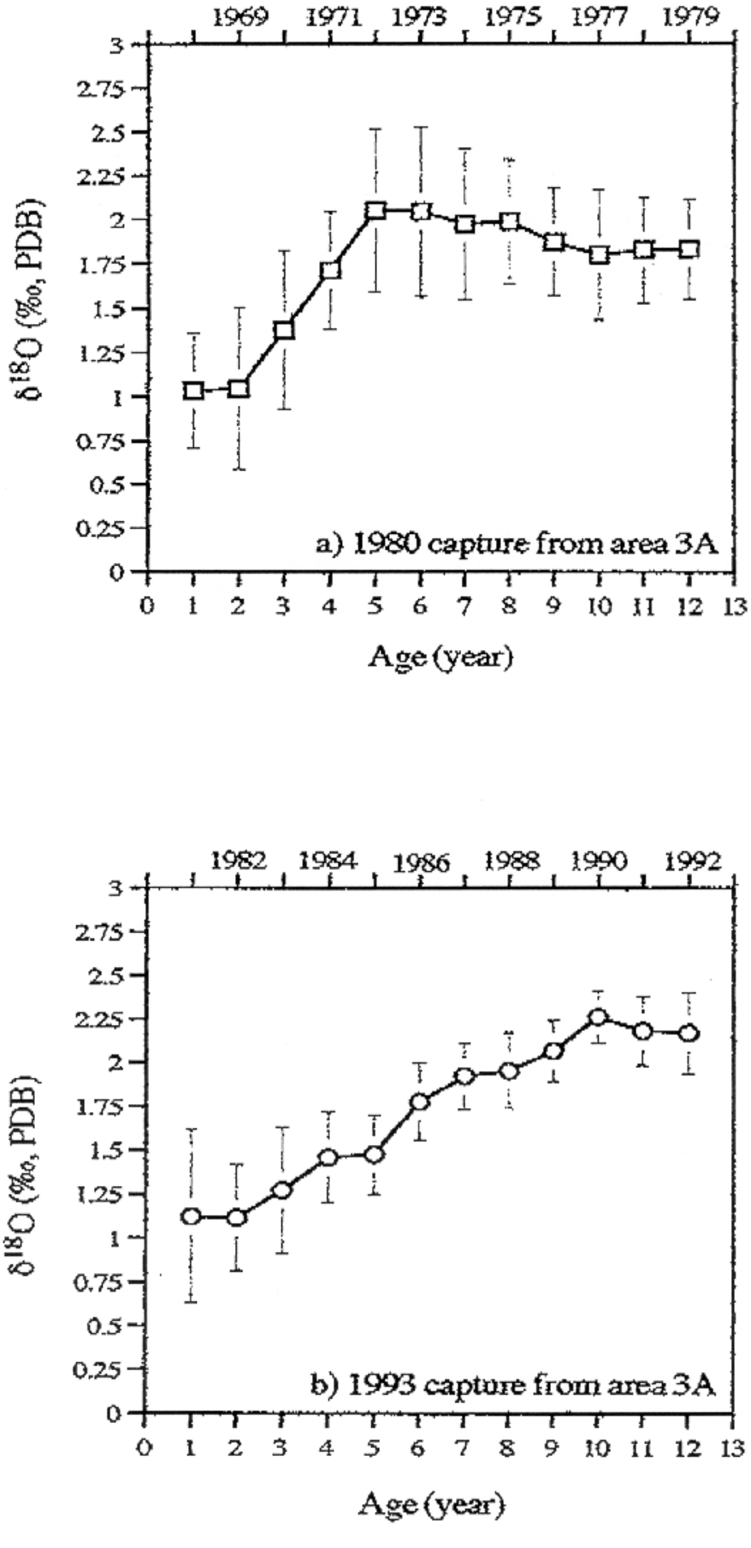


Figure 2. Changes in average annual $\delta^{18}O$ from otoliths over the lifetime of 10 Pacific halibut from the Gulf of Alaska.

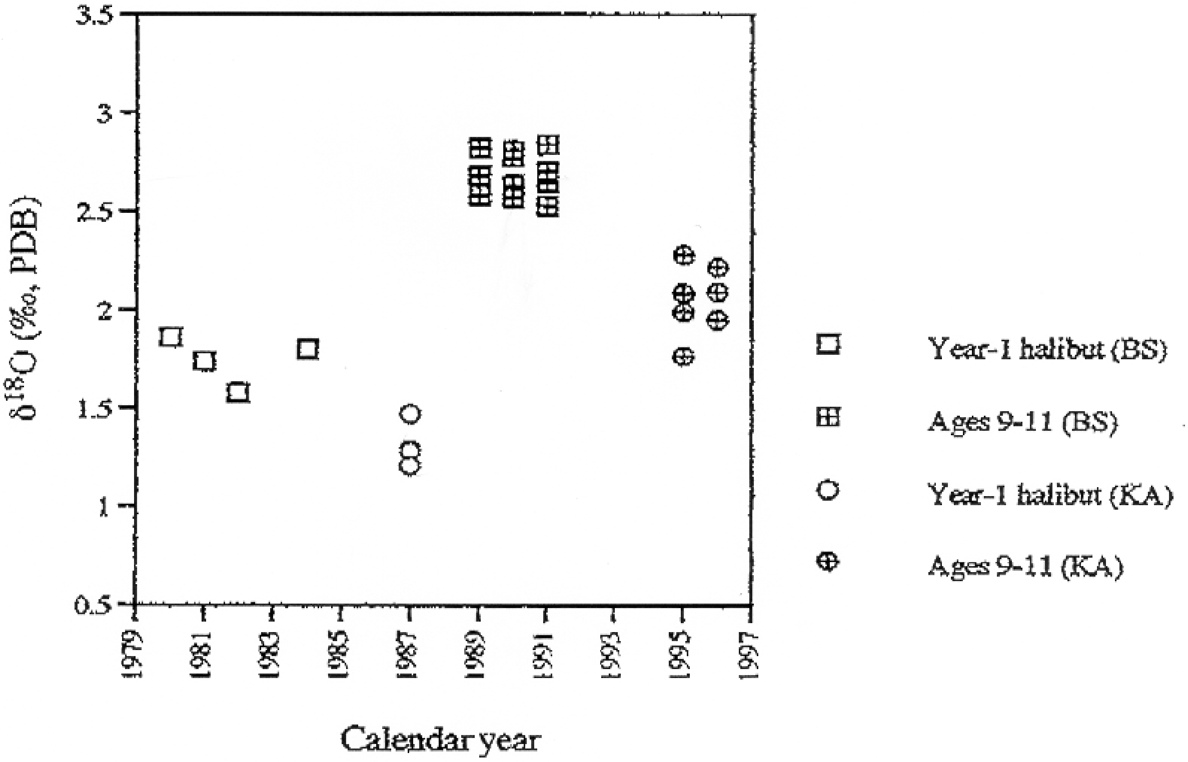


Figure 3. $\delta^{18}O$ patterns from otoliths of Pacific halibut from the Bering Sea (5 otoliths) and the Gulf of Alaska (4 otoliths).

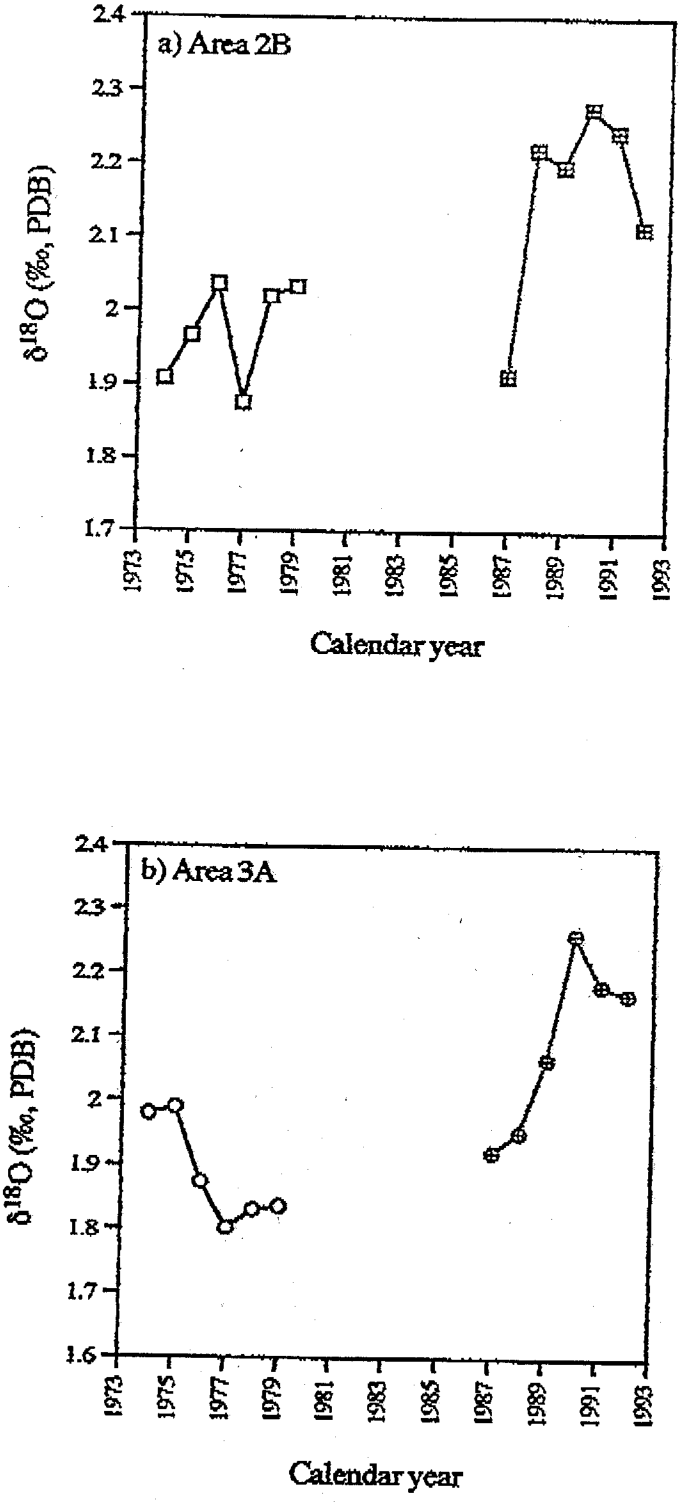
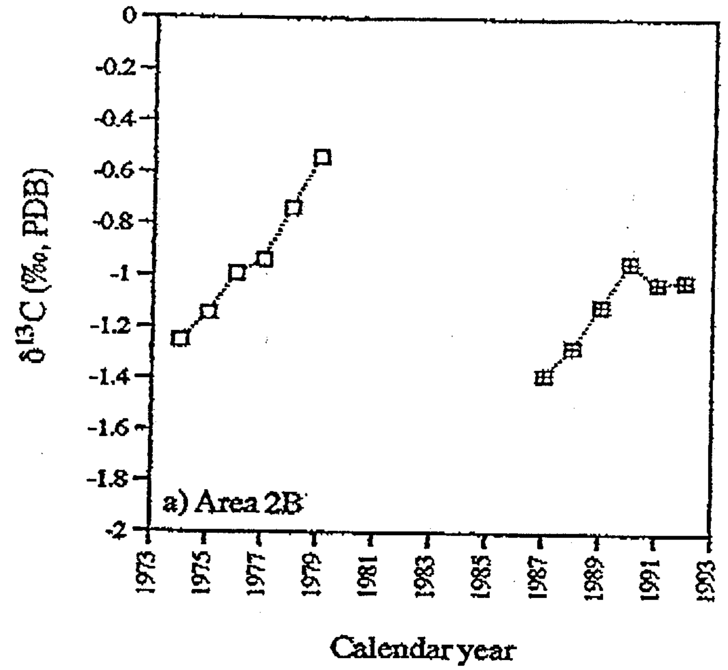


Figure 4. **The average $\delta^{18}O$ signals (*n*=7) of female halibut for the last six years of the age series (cf. Figs. 2 and 3) from areas 2B (a) and 3A (b). The time is over the 1977 and 1990 calendar year.**



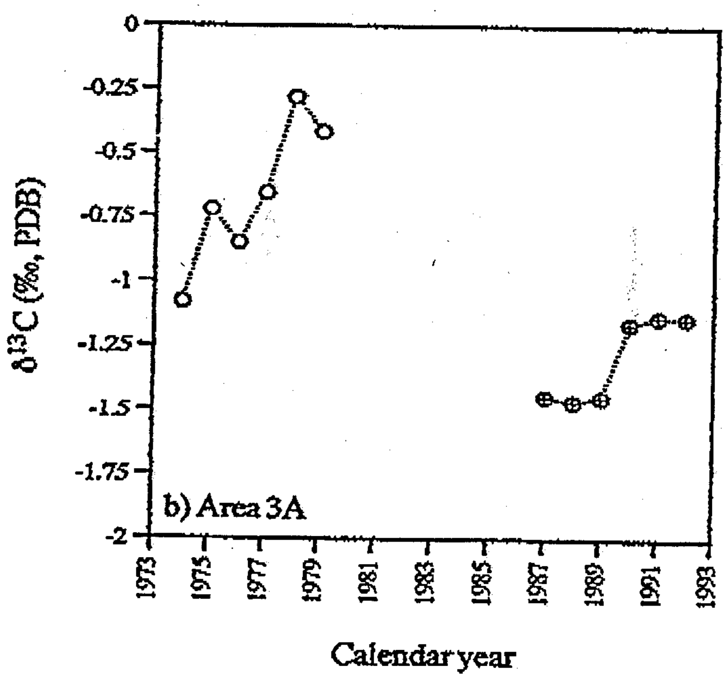


Figure 5. The average δ^{13}C signals (*n*=7) of female halibut for the last six years over 1977 and 1990 from areas 2B (a) and 3A (b).

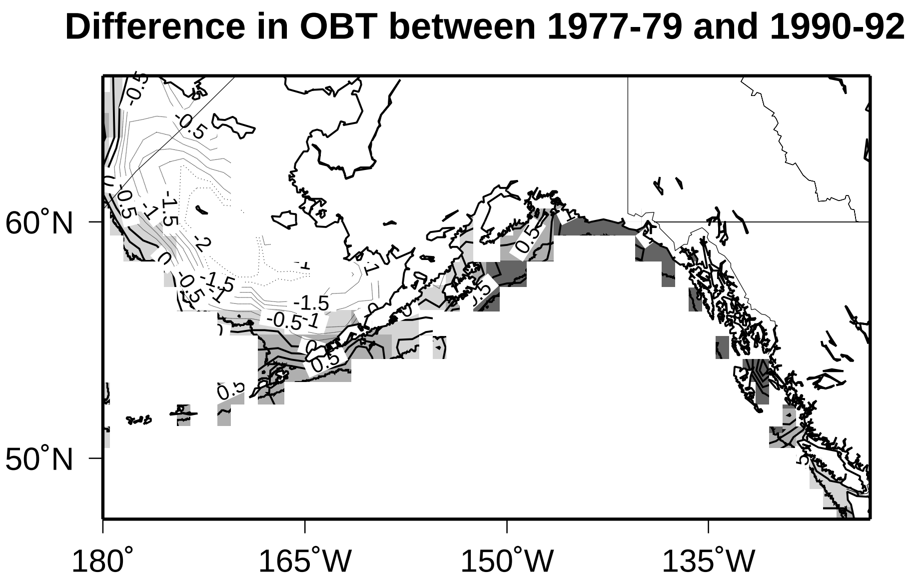


fig. a

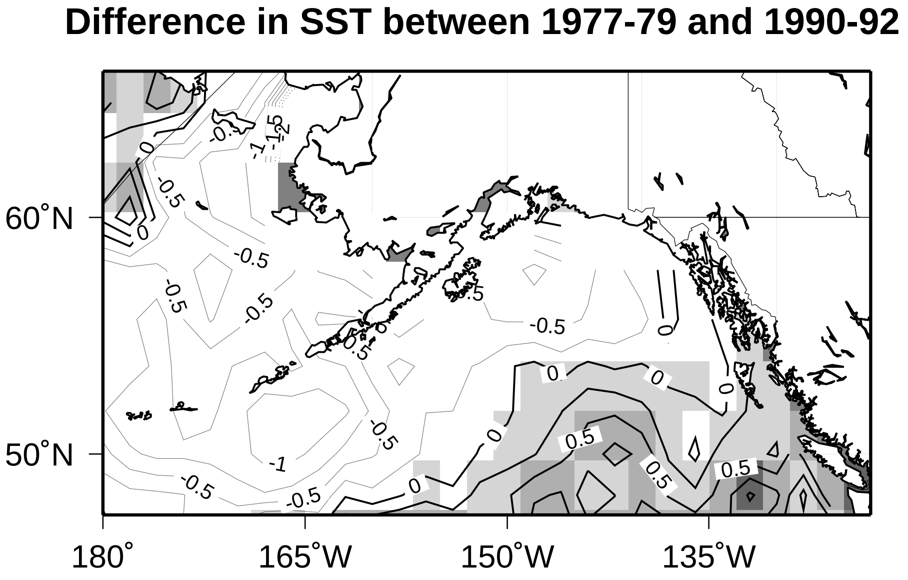


fig. b

Figure 6. **The difference in average summer (months May – Sep.) ocean bottom temperature (a) and sea surface temperature (b) in the Northeast Pacific and Bering Sea between the period 1977-79 and 1990-92. Positive values indicate that the recent period was warmer.**

Comparison of Break-and-Burn and Break-and-Bake Aging Techniques on Halibut Otoliths

by

Todd Barto

Introduction

The ages of Pacific halibut (*Hippoglossus stenolepis*) are determined by examining the growth zones on their otoliths. Each year, alternating opaque (summer) and translucent (winter or hyaline) rings are deposited on the otolith. A year's growth is called an annulus and consists of both an opaque and translucent zone. Since halibut spawn in the winter, the hyaline zones are counted to provide the age of the fish in years.

"Break and burn" is a standard otolith-aging technique (Chilton and Beamish 1982), used to assist the age reader in difficult age determinations. The process involves breaking the otolith in half through the nucleus along the dorso-ventral axis and burning the broken surface over an alcohol lamp. The flame chars the concentrated organic matter in the hyaline zone, increasing the contrast with the opaque summer growth zone. Problems with this technique include the following: burning the otolith too long, producing ash and some indistinguishable annuli; the alcohol flame leaving a dark margin along the proximal edge, possibly masking one or more hyaline zones; and insufficient or uneven burning, causing inconsistent annulus enhancement.

Scott Meyer of Alaska Department of Fish & Game (Sport Fish Division, 3298 Douglas Place, Homer, AK 99603, unpublished data) presented a break-and-bake method at the Committee of Age Reading Experts (CARE) seminar in Seattle, WA in April, 1998,. The "break and bake" technique differs by baking the otolith half in an oven rather than burning it over an alcohol lamp. The hypothesis is that the baking method could alleviate some of the problems associated with the burning method (*e.g.,* dark margins and inconsistency). Meyer compared the two methods using otoliths from black rockfish (*Sebastes melanops*) and yelloweye rockfish (*Sebastes ruberrimus*). He found no significant difference in mean ages between the two methods but that the variance was significantly lower in yelloweye rockfish using the baking method.

This study follows Meyer's experiments, using otoliths from Pacific halibut to compare the two methods.

Methods

The International Pacific Halibut Commission (IPHC) primarily uses surface reading for age determination (Quinn, et. al., 1983). All otoliths are surface-read first. A break and burn reading is performed if any or all of the following criteria are met: glycerin has not cleared the otolith completely and annular patterns are obscured; the otolith has steep edges and outer rings are not visible from the surface; the otolith has an odd ring pattern; or for any other reason, the reader is not confident of the surface age. The otoliths used in this study were otoliths that met the break and burn criteria. The goal was to obtain 30-40 otoliths each from three main regions of Alaskan waters- Southeast (IPHC Reg. Area 2C), the Gulf of Alaska (3A), and the Aleutian Islands (4A). The otoliths were collected during the 1998 IPHC setline survey. The Southeast otoliths were taken from the F/V *Ocean Viking* set. The Gulf otoliths were taken from F/Vs *Defiant* and *Taasinge*. The Aleutian Islands otoliths were taken from the first two trips of F/V *Angela Lynn*.

Each otolith was broken in half through the nucleus along the dorso-ventral axis (the narrowest axis). One half underwent the break-and-burn method while the other half underwent the break-and-bake method. Treatment methods for sequential otoliths alternated between the anterior and posterior halves (IPHC readers usually burn the posterior half only). Each otolith half was read by two age readers. Age Reader 1 prepared all otoliths.

Otoliths were placed on a stainless steel tray with 50 cells and baked in a toaster oven (General Electric Cat. No. B1 T660, 120 V, 1500 w, USA). A pilot study was performed to determine a baking time and temperature appropriate for halibut otoliths. Tests were performed on previously discarded otoliths at three temperatures (300°, 400° and 500° F) for five, 10 and 15 minute baking times. Lower temperatures (300° F) took longer to bake and had fewer distinctive annuli overall. At 500°, the otoliths did not develop optimum contrast in less than 10 minutes. Otoliths left in the oven for more than 15 min had no better clarity up to 25 min. No time test went beyond 25 min and there was no determined time at which an otolith was rendered unreadable. Based on these results, otoliths for the comparison study were baked at 500° F for 10-15 minutes.

Paired age readings were compared by method and region. A comparison was made using a paired *t*-test of mean ages (H_0: $\mu[\text{Burn}] - \mu[\text{Bake}] = 0$) at a 95% confidence level.

Results

Ages were compared by individual region and by all three regions combined. Both Southeast Alaska and Gulf of Alaska regions yielded no evidence ($P = 0.94$ and $P = 0.31$, respectively) to suggest a significant difference of ages between break-and-burn and break-and-bake methods. However, there was a significant difference ($p = 0.015$) between the two methods in the ages from the Aleutian Islands set. Nevertheless, when all regions were combined, there again was no evidence ($P = 0.074$) to suggest significant difference between methods.

Discussion

The baking method did produce a uniform roast of the otoliths. The baking method was expected to alleviate the marginal masking produced by the burning method. However, it is possible that the masking is not hiding annuli. The baking method did not produce older ages as one might suspect. The average mean ages were close (Table 1). Overall, the bake method produced slightly younger ages (18.86 yr) than the burn method (19.03 yr). The marginal masking associated with burning did not seem to affect the ages very much. If it did have any effect, it might be that the age reader assumed there were additional annuli in the masked region and adjusted the assigned age accordingly. This could be cause for concern if the average burn age is significantly higher than the bake age.

As for the low P-value in the Aleutian Island region, no real conclusion can be made. The mean difference frequency appears to have less variation than the Southeast and Gulf regions (Figure 1a-c). However, the average mean difference of the Aleutian Island region is 0.34 whereas Southeast and the Gulf average mean differences are –0.01 and 0.20, respectively. In addition, the age readers for IPHC generally agree that Southeast otoliths tend to be more difficult to read than those from the Aleutian Island region. Thus, this set of Aleutian Island otoliths may not fit the norm if more comparisons were to be made from the same region.

Figure 2 shows a near 1:1 relationship between ages obtained from the break-and-burn and break-and-bake methods.

The baking method is more efficient when baking large numbers at one time. The baking time of 10-15 minutes is about the same required to burn 10-15 otoliths. So, there is only a benefit when burning ten otoliths or more at one time. The baking method did produce visual consistency. There were no overly burnt or ashy effects produced by the baking and the margins were generally more distinct.

Overall, the break-and-bake method holds promise to be a suitable alternative method for the break-and-burn method, which is currently the standard among CARE readers. Although this study suggests there is little difference between the two methods, there is still some uncertainty. Another test with perhaps a larger and broader sample may demonstrate more convincingly whether there is any significant difference between the two methods. It might also be of some interest to determine which of the two methods provides ages that are more accurate. This type of study would have to include an age-validation method such as Oxytetracycline (OTC) injection.

Acknowledgements

Age Reader 2 was Joan Forsberg. Study methods and statistical advice given by Bob Trumble and Bill Clark.

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Table 1a. **Assigned ages from Southeast Alaska otoliths for comparison between break-and-burn and break-and-bake methods.**

Oto #	Survey #	Break and Burn				Break and Bake				Mean Difference
		Reader 1	Reader 2	Mean	St Dev	Reader 1	Reader 2	Mean	St Dev	
1	7	17	17	17.0	0.00	18	17	17.5	0.71	-0.50
2	8	22	20	21.0	1.41	22	18	20.0	2.83	1.00
3	35	17	16	16.5	0.71	16	15	15.5	0.71	1.00
4	42	15	12	13.5	2.12	13	13	13.0	0.00	0.50
5	43	12	11	11.5	0.71	13	11	12.0	1.41	-0.50
6	48	17	15	16.0	1.41	19	14	16.5	3.54	-0.50
7	67	14	13	13.5	0.71	15	13	14.0	1.41	-0.50
8	79	30	29	29.5	0.71	30	30	30.0	0.00	-0.50
9	111	15	15	15.0	0.00	15	14	14.5	0.71	0.50
10	121	29	27	28.0	1.41	26	28	27.0	1.41	1.00
11	130	14	14	14.0	0.00	15	13	14.0	1.41	0.00
12	158	15	11	13.0	2.83	13	12	12.5	0.71	0.50
13	168	13	12	12.5	0.71	15	12	13.5	2.12	-1.00
14	182	18	17	17.5	0.71	18	14	16.0	2.83	1.50
15	199	21	20	20.5	0.71	21	19	20.0	1.41	0.50
16	229	21	21	21.0	0.00	21	20	20.5	0.71	0.50
17	241	24	25	24.5	0.71	27	28	27.5	0.71	-3.00
18	244	29	29	29.0	0.00	29	30	29.5	0.71	-0.50
19	246	14	14	14.0	0.00	14	13	13.5	0.71	0.50
20	248	16	13	14.5	2.12	17	16	16.5	0.71	-2.00
21	251	17	16	16.5	0.71	17	14	15.5	2.12	1.00
22	254	20	17	18.5	2.12	20	19	19.5	0.71	-1.00
23	263	18	16	17.0	1.41	16	18	17.0	1.41	0.00
24	272	20	21	20.5	0.71	23	21	22.0	1.41	-1.50
25	300	16	16	16.0	0.00	17	16	16.5	0.71	-0.50
26	314	18	18	18.0	0.00	18	17	17.5	0.71	0.50
27	337	23	20	21.5	2.12	23	23	23.0	0.00	-1.50
28	340	16	16	16.0	0.00	17	16	16.5	0.71	-0.50
29	345	16	15	15.5	0.71	15	14	14.5	0.71	1.00
30	346	14	11	12.5	2.12	11	11	11.0	0.00	1.50
31	356	17	16	16.5	0.71	17	17	17.0	0.00	-0.50
32	371	18	17	17.5	0.71	17	15	16.0	1.41	1.50
33	391	21	19	20.0	1.41	20	18	19.0	1.41	1.00
34	417	14	10	12.0	2.83	14	12	13.0	1.41	-1.00
35	424	40	39	39.5	0.71	40	39	39.5	0.71	0.00
36	427	15	16	15.5	0.71	15	14	14.5	0.71	1.00
37	428	15	12	13.5	2.12	15	13	14.0	1.41	-0.50
38	440	21	20	20.5	0.71	20	20	20.0	0.00	0.50
	Averages	18.74	17.53	18.13	0.97	18.74	17.55	18.14	1.06	-0.01

Table 1b. **Assigned ages from Gulf of Alaska otoliths for comparison between break-and-burn and break-and-bake methods.**

Oto #	Survey #	Break and Burn				Break and Bake				Mean Difference
		Reader 1	Reader 2	Mean	St Dev	Reader 1	Reader 2	Mean	St Dev	
1	27	23	19	21.0	2.83	23	23	23.0	0.00	-2.0
2	37	22	20	21.0	1.41	23	19	21.0	2.83	0.0
3	38	23	18	20.5	3.54	21	18	19.5	2.12	1.0
4	43	19	18	18.5	0.71	18	17	17.5	0.71	1.0
5	54	25	24	24.5	0.71	23	23	23.0	0.00	1.5
6	55	22	21	21.5	0.71	22	21	21.5	0.71	0.0
7	56	19	18	18.5	0.71	19	19	19.0	0.00	-0.5
8	66	17	16	16.5	0.71	18	16	17.0	1.41	-0.5
9	69	20	24	22.0	2.83	20	20	20.0	0.00	2.0
10	80	21	21	21.0	0.00	21	17	19.0	2.83	2.0
11	86	21	19	20.0	1.41	18	19	18.5	0.71	1.5
12	88	20	20	20.0	0.00	19	20	19.5	0.71	0.5
13	116	25	24	24.5	0.71	24	21	22.5	2.12	2.0
14	117	25	24	24.5	0.71	22	22	22.0	0.00	2.5
15	118	23	24	23.5	0.71	25	21	23.0	2.83	0.5
16	119	20	21	20.5	0.71	23	19	21.0	2.83	-0.5
17	133	17	13	15.0	2.83	17	14	15.5	2.12	-0.5
18	137	22	21	21.5	0.71	22	24	23.0	1.41	-1.5
19	140	17	16	16.5	0.71	18	16	17.0	1.41	-0.5
20	152	18	16	17.0	1.41	16	17	16.5	0.71	0.5
21	174	21	20	20.5	0.71	20	20	20.0	0.00	0.5
22	189	21	18	19.5	2.12	21	21	21.0	0.00	-1.5
23	199	19	20	19.5	0.71	17	17	17.0	0.00	2.5
24	202	20	21	20.5	0.71	21	21	21.0	0.00	-0.5
25	203	17	16	16.5	0.71	18	17	17.5	0.71	-1.0
26	221	19	17	18.0	1.41	18	17	17.5	0.71	0.5
27	237	20	19	19.5	0.71	19	18	18.5	0.71	1.0
28	239	24	24	24.0	0.00	25	24	24.5	0.71	-0.5
29	254	22	20	21.0	1.41	21	18	19.5	2.12	1.5
30	255	20	16	18.0	2.83	19	19	19.0	0.00	-1.0
31	257	24	20	22.0	2.83	22	20	21.0	1.41	1.0
32	253	17	15	16.0	1.41	20	18	19.0	1.41	-3.0
33	272	18	17	17.5	0.71	18	16	17.0	1.41	0.5
34	273	18	17	17.5	0.71	18	17	17.5	0.71	0.0
35	282	15	14	14.5	0.71	15	14	14.5	0.71	0.0
36	294	15	15	15.0	0.00	15	15	15.0	0.00	0.0
37	299	20	20	20.0	0.00	21	18	19.5	2.12	0.5
38	301	19	18	18.5	0.71	22	19	20.5	2.12	-2.0
39	309	18	18	18.0	0.00	18	17	17.5	0.71	0.5
40	313	22	20	21.0	1.41	21	21	21.0	0.00	0.0
41	315	17	14	15.5	2.12	14	13	13.5	0.71	2.0
42	326	28	28	28.0	0.00	28	27	27.5	0.71	0.5
43	348	12	15	13.5	2.12	15	15	15.0	0.00	-1.5
44	365	13	15	14.0	1.41	15	14	14.5	0.71	-0.5
45	371	13	12	12.5	0.71	13	12	12.5	0.71	0.0
46	393	18	17	17.5	0.71	18	17	17.5	0.71	0.0
Averages		19.76	18.76	19.26	1.11	19.65	18.50	19.08	0.97	0.18

Table 1c. **Assigned ages from Aleutian Islands otoliths for comparison between break-and-burn and break-and-bake methods.**

to #	Survey #	Break and Burn				Break and Bake				Mean Difference
		Reader 1	Reader 2	Mean	St Dev	Reader 1	Reader 2	Mean	St Dev	
1	26	19	18	18.5	0.71	19	18	18.5	0.71	0.00
2	37	18	17	17.5	0.71	17	16	16.5	0.71	1.00
3	38	21	16	18.5	3.54	20	15	17.5	3.54	1.00
4	47	22	21	21.5	0.71	22	22	22.0	0.00	-0.50
5	50	19	17	18.0	1.41	19	18	18.5	0.71	-0.50
6	57	20	20	20.0	0.00	20	20	20.0	0.00	0.00
7	59	19	18	18.5	0.71	19	19	19.0	0.00	-0.50
8	74	31	28	29.5	2.12	29	26	27.5	2.12	2.00
9	75	21	22	21.5	0.71	20	21	20.5	0.71	1.00
10	81	22	22	22.0	0.00	24	22	23.0	1.41	-1.00
11	85	23	22	22.5	0.71	22	22	22.0	0.00	0.50
12	140	20	20	20.0	0.00	19	18	18.5	0.71	1.50
13	144	16	16	16.0	0.00	19	14	16.5	3.54	-0.50
14	165	20	20	20.0	0.00	19	18	18.5	0.71	1.50
15	169	20	18	19.0	1.41	19	18	18.5	0.71	0.50
16	173	20	20	20.0	0.00	21	20	20.5	0.71	-0.50
17	178	21	21	21.0	0.00	21	20	20.5	0.71	0.50
18	181	20	20	20.0	0.00	20	20	20.0	0.00	0.00
19	189	18	18	18.0	0.00	19	18	18.5	0.71	-0.50
20	194	20	17	18.5	2.12	19	19	19.0	0.00	-0.50
21	197	19	18	18.5	0.71	19	19	19.0	0.00	-0.50
22	199	13	14	13.5	0.71	13	11	12.0	1.41	1.50
23	201	20	20	20.0	0.00	19	20	19.5	0.71	0.50
24	202	19	19	19.0	0.00	18	18	18.0	0.00	1.00
25	204	20	20	20.0	0.00	20	20	20.0	0.00	0.00
26	221	24	24	24.0	0.00	24	23	23.5	0.71	0.50
27	230	23	23	23.0	0.00	21	20	20.5	0.71	2.50
28	231	20	20	20.0	0.00	18	20	19.0	1.41	1.00
29	257	19	18	18.5	0.71	19	18	18.5	0.71	0.00
30	259	13	12	12.5	0.71	13	10	11.5	2.12	1.00
31	263	19	19	19.0	0.00	19	19	19.0	0.00	0.00
32	267	20	21	20.5	0.71	22	21	21.5	0.71	-1.00
33	268	19	19	19.0	0.00	19	20	19.5	0.71	-0.50
34	278	18	19	18.5	0.71	18	18	18.0	0.00	0.50
35	280	18	17	17.5	0.71	17	18	17.5	0.71	0.00
36	290	25	24	24.5	0.71	25	24	24.5	0.71	0.00
37	294	20	20	20.0	0.00	19	20	19.5	0.71	0.50
38	297	19	18	18.5	0.71	19	16	17.5	2.12	1.00
Averages		19.95	19.37	19.66	0.56	19.71	18.92	19.32	0.82	0.34

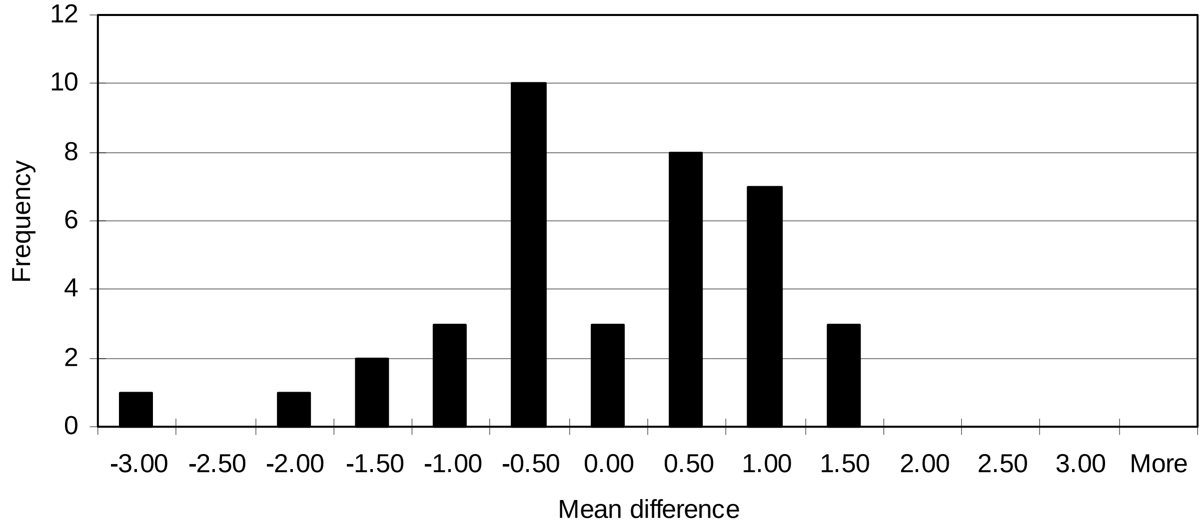

Figure 1a. **Frequency of mean difference between break-and-burn and break-and-bake aging methods for Southeast Alaska otoliths.**

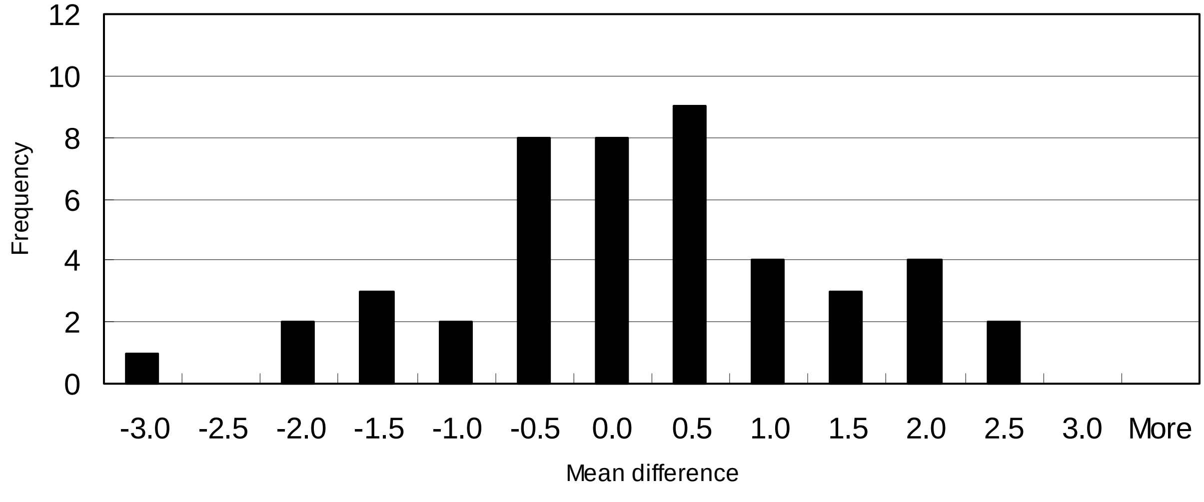

Figure 1b. **Frequency of mean difference between break-and-burn and break-and-bake aging methods for Gulf of Alaska otoliths.**

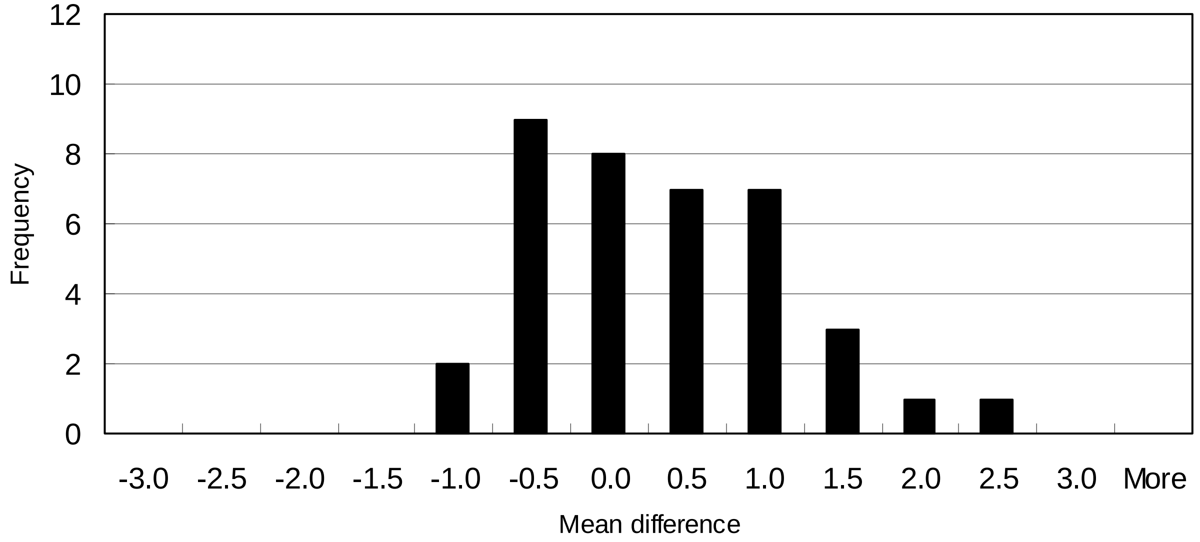

Figure 1c. Frequency of mean difference between break-and-burn and break-and-bake aging methods for Aleutian Island otoliths.

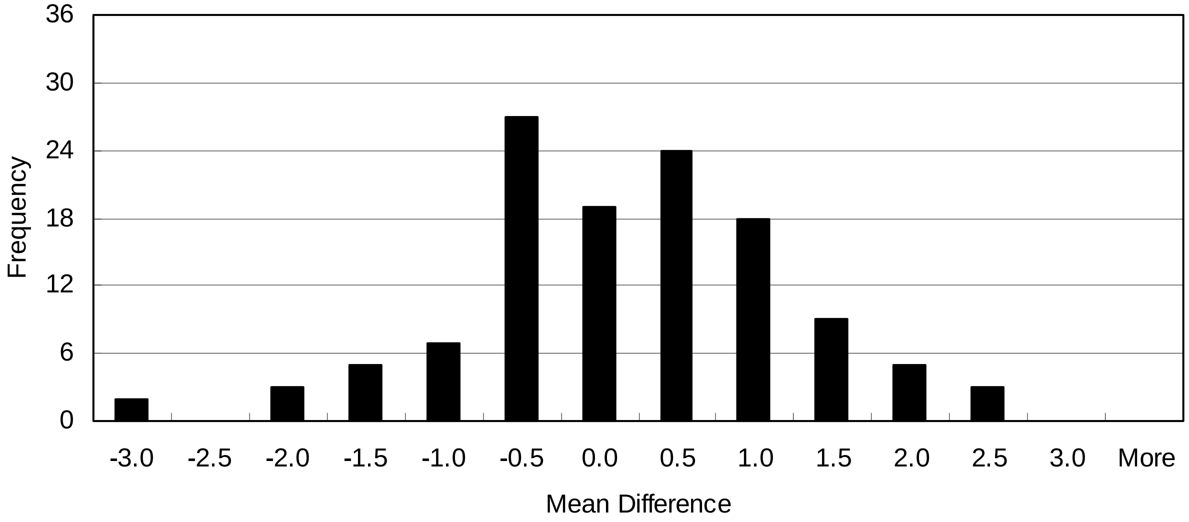

Figure 1d. Frequency of mean difference between break-and-burn and break-and-bake aging methods for otoliths from all areas combined.

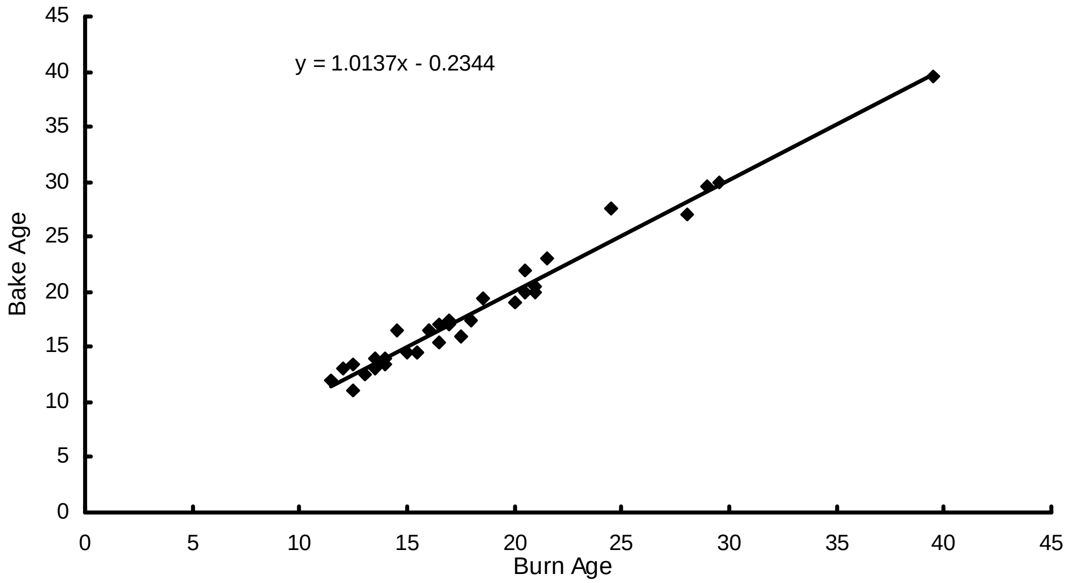

Figure 2a. **Comparison of mean ages of halibut otoliths from Southeast Alaska prepared using the break-and burn and break-and-bake methods.**

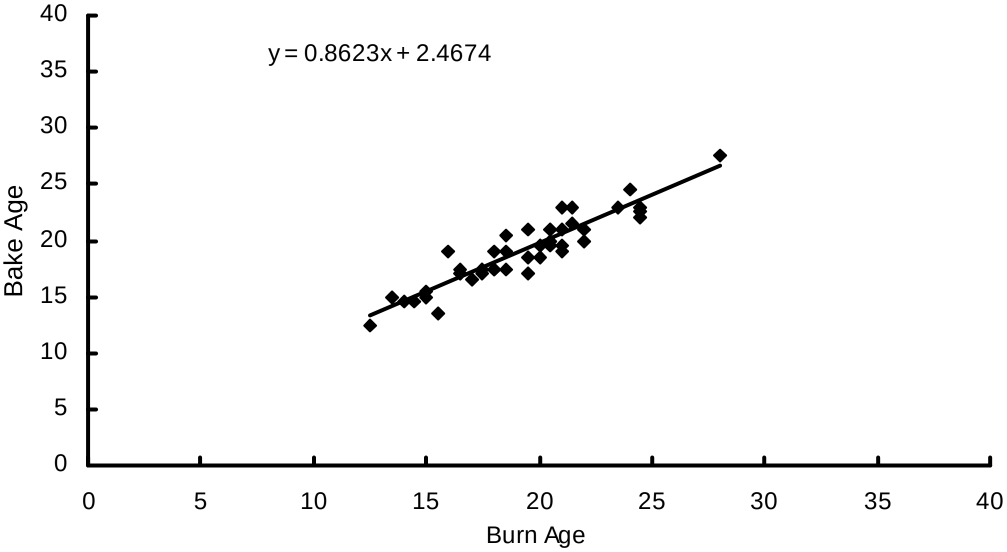

Figure 2b. **Comparison of mean ages of halibut otoliths from the Gulf of Alaska prepared using the break-and burn and break-and-bake methods.**

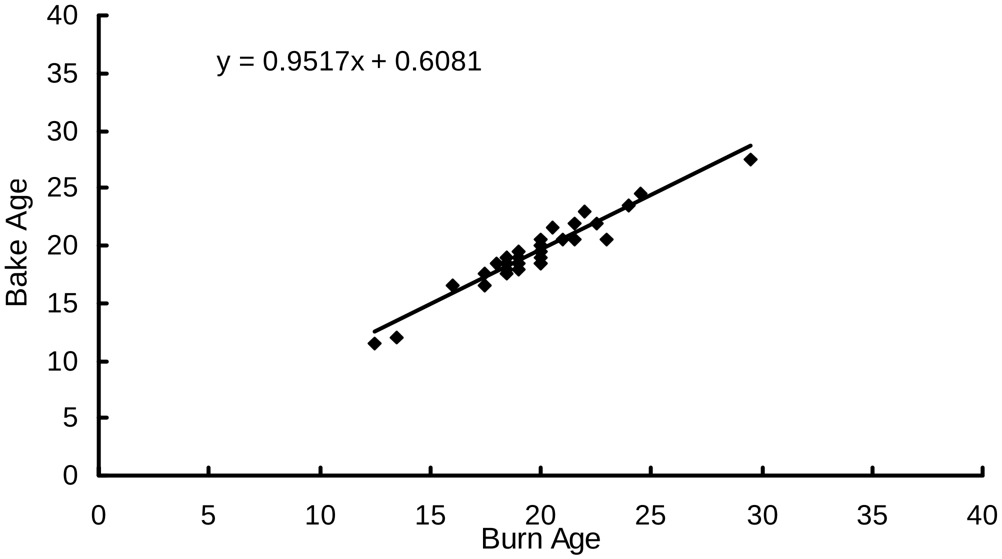

Figure 2c. Comparison of mean ages of halibut otoliths from the Aleutian Islands prepared using the break-and burn and break-and-bake methods.

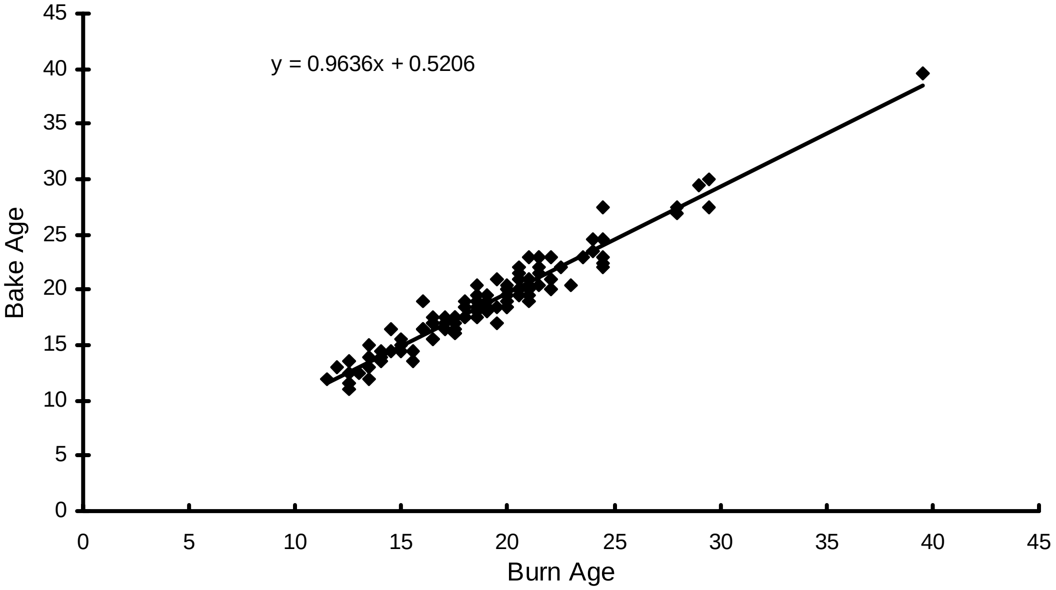

Figure 2d. Comparison of mean ages of halibut otoliths combined from Southeast, Gulf and Aleutian Islands prepared using the break-and burn and break-and-bake methods.

Halibut Otolith Exchanges Between the IPHC and Alaska Department of Fish and Game, 1991-1998

by

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Introduction

The International Pacific Halibut Commission (IPHC) is the primary agency responsible for the management of Pacific halibut *(Hippoglossus stenolepis)* fisheries in the north Pacific. The IPHC has historically gathered data from commercial, and infrequently from recreational, fisheries. As recreational effort and harvest have increased in Alaska, the IPHC has increasingly looked to the Alaska Department of Fish and Game (ADF&G) to provide information from the recreational fishery. The ADF&G has collected and summarized harvest statistics for the recreational halibut fishery in southcentral Alaska since the mid-1980s.

Estimation of age composition of the recreational halibut harvest was an objective of an ADF&G port sampling program in IPHC Area 3A during the period 1991-1998. Although the IPHC has not incorporated estimates of age composition from the recreational fishery into their stock assessment model, the two agencies exchanged otoliths nearly every year during this period. The purpose of the exchanges was to provide for consistency between agencies in assigned ages in case sport harvest age composition estimates were included in the model in the future. Estimation of age composition was dropped as an ADF&G objective in 1999, although otoliths were still collected.

The ADF&G employs one halibut age reader each year, but used four different agers during the period 1991-1998. New agers were trained using a combination of an in-house halibut aging manual, hands-on instruction, and reference sets containing from 73 to 115 otoliths that had been aged by both ADF&G and IPHC staff. New and experienced agers were required to read otoliths from at least one reference set with “acceptable results” before assigning any ages. “Acceptable results” was subjectively defined to mean at least 50% perfect agreement in assigned ages. Preferably, there should be no more than +/- 2 years difference and differences should be distributed symmetrically. In addition, there should be no significant trend in differences (residuals) as a function of age.

Collection and Aging Methods

Otoliths were collected throughout the summer fishing season (May-September) and stored dry. They were prepared for reading by soaking in a mixture of glycerin and distilled water for at least four weeks. In some years, thymol was added as an antiseptic. ADF&G aged between 2,000 and 3,000 otoliths annually and samples of 92-118 otoliths were exchanged with the IPHC nearly every year. The exchange sets were typically arbitrary selections of otoliths from either a single port or several ports, and included otoliths collected throughout the season. The 1991 exchange involved otoliths collected and read by ADF&G in 1990. These otoliths also formed the reference set for the 1991 ADF&G ager, so this exchange allowed “calibration” of ages for both years. There was no exchange in 1993, but the ADF&G ager read the 1992 exchange set in 1993 to facilitate a comparison.

Information provided to ADF&G and IPHC agers included only the sample identification number, port and date of collection. Most years the otoliths were surface-read only by ADF&G before being sent to the IPHC. The IPHC ager surface-read all otoliths, then broke and burned otoliths that were difficult to read. ADF&G readers did not break and burn halibut otoliths before 1995. Between 1995 and 1997, otoliths assigned a surface age of 15 or higher were broken and burned to determine final age. All difficult to read otoliths were aged using the break-and-burn method in 1998.

Graphic analysis of results included frequency distributions of the differences in assigned ages and plots of residuals (ADF&G age minus IPHC age) as a function of IPHC age. Age compositions of the exchange sets were compared graphically and with chi-square contingency tests to evaluate the practical and statistical significance of the deviations.

Findings

Distributions of differences indicated general consistency between agencies (Fig. 1a). The degree of perfect agreement ranged from 46-78% (Table 1). Across all years, 87-97% of ages were within +/- 1 year, and 97-100% of ages were within +/- 2 years. The average difference in assigned ages ranged from -0.22 years in 1994 to 0.31 years in 1995. The maximum difference for any otolith was -8 years (in 1994), the result of a comparison between a surface age by ADF&G and a break-and-burn age by IPHC.

The least symmetrical distribution of differences was obtained in 1995. Although the ADF&G ager tended to assign higher ages, the difference likely had little effect on the estimate of age composition. Age composition estimates of the exchange set were similar practically and statistically ($\chi^2 = 3.79$, df = 8, P = 0.88). The maximum difference in the proportion of any age class was 8% for 7-yr-olds (Fig. 2).

Residual plots suggested that in some years ADF&G agers had a very slight tendency to underestimate the ages of older fish (Fig. 1b). This was likely due to the more consistent use of the break-and-burn method by the IPHC ager. Surface readings are compared to break-and-burn ages in the 1991-1994 plots.

Conclusions

The annual exchange of halibut otoliths was beneficial in maintaining consistency in assigned ages between agencies. Estimates of age composition were robust to differences in assigned ages as long as a relatively high percentage of agreement was maintained and differences in assigned ages were roughly symmetrical.

Acknowledgements

Age readers included Paul Cyr, Bill Romberg, Mike Parish, and Philip Cowan of ADF&G and Calvin Blood and Joan Forsberg of the IPHC.

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Table 1. **Frequency distributions of differences in assigned ages from Pacific halibut otoliths exchanges between the International Pacific Halibut Commission (IPHC) and the Alaska Department of Fish and Game (ADF&G). Differences represent the ADF&G age minus the IPHC age.**

	Frequencies by Year								
Difference (years)	1990	1991	1992	1993	1994	1995	1996	1997	1998
-8	0	0	0	0	1	0	0	0	0
-7	0	0	0	0	0	0	0	0	0
-6	0	0	0	0	0	0	0	0	0
-5	0	0	0	1	0	0	0	0	0
-4	0	0	0	0	1	0	0	0	0
-3	0	0	0	0	1	0	2	0	1
-2	9	4	7	2	4	0	1	6	2
-1	22	20	25	7	22	6	13	12	13
0	46	65	62	66	47	82	79	62	80
1	20	13	12	18	14	19	20	9	7
2	3	1	6	5	5	7	2	3	0
3	0	0	1	1	0	3	1	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
Sample size:	100	103	113	100	95	117	118	92	103
% Agreement:	46	63	55	66	49	70	67	67	78
Mean Difference (yr):	-0.14	-0.13	-0.11	0.15	-0.22	0.31	0.05	-0.10	-0.13

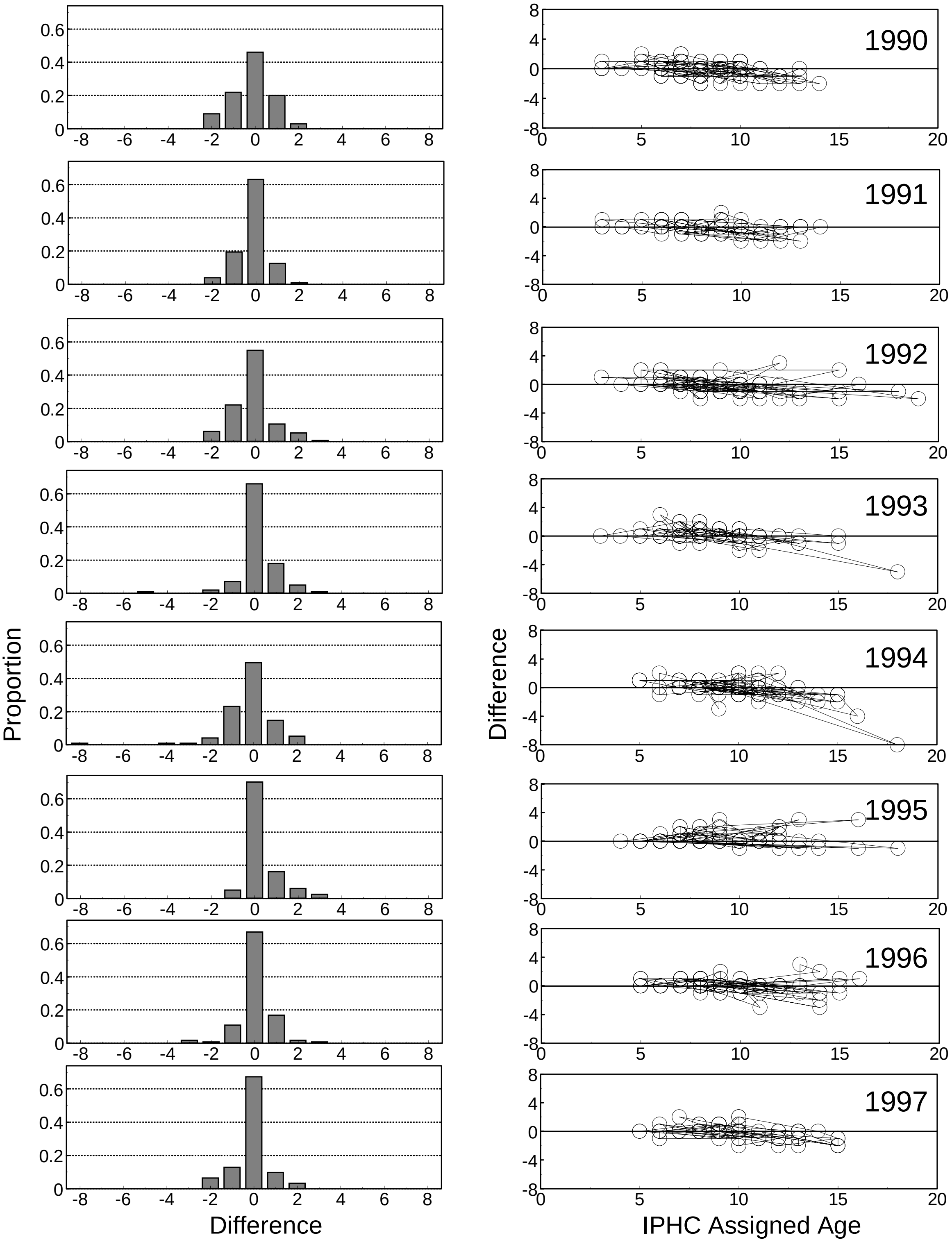

Figure 1a Figure 1b

Figure 1. **Graphical comparisons of halibut otolith ages assigned by the IPHC and ADF&G, 1991-1998. Differences are defined as ADF&G age minus IPHC age.**

Figure 2. Comparison of age composition of the 1995 halibut otolith exchange set using ages assigned by the ADF&G and IPHC.