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Coping with a Challenging Stock Assessment Situation: The Kamishak Bay Sac-Roe Herring Fishery

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Abstract

Aerial biomass estimates and commercial-catch and total-run age compositions were the principal components of an integrative age-structured model used to forecast spawning biomass of Pacific herring *Clupea pallasi* returning to Kamishak Bay, Alaska. Poor weather in Kamishak Bay created gaps in aerial survey coverage, and when surveys could be flown, the ability of surveyors to observe herring schools was often limited by poor water clarity. Resultant aerial biomass estimates were influenced by survey effort and conditions. Although we used standardized procedures to quantify the surface area of observed herring schools and convert them to biomass estimates, these standards could not compensate for poor survey conditions or extended gaps in survey coverage. Aerial survey difficulties highlighted the importance of maximizing the quality and influence of other data sources in the integrative model. Total-run age-composition data, derived from fishery-independent samples, were instrumental in tracking cohorts and evaluating the strength of recruiting year classes. Historical and current data indicate that age structure was not static throughout the Kamishak Bay run. In most years the age structure of herring returning to the spawning grounds shifted from older to younger fish around early May. This created the potential for a temporal sampling bias that was mitigated by collecting age data from both early- and late-spawning components of the run and weighting the data according to the relative biomasses associated with these temporally distinct spawning aggregations. Uncertainty about current abundance is increasing and warrants a conservative harvest strategy.

Introduction

Mathematical models that integrate multiple information sources to assess fish stocks have been used for many years (Deriso et al. 1985, Megrey 1989, Hilborn and Walters 1992). Integrative models, although representing a marked improvement over assessments using a single information source such as fishery catch-per-unit-effort (CPUE), are still limited by the quality of their input data and the model's ability to relate estimated parameters to some aspect of stock dynamics. Problems that compromise the quality of individual parameter estimates limit the model's ability to accurately represent natural phenomena. While this recognition is intuitive, approaches to mitigate the problems are not. Our paper uses the 1998 forecast of the sac-roe fishery for Pacific herring *Clupea pallasi* in Kamishak Bay as a case study to illustrate some practical assessment challenges and strategies to mitigate them. Although the integrative model used to assess Kamishak herring is briefly described, our discussion focuses on the assessment and management processes: adjusting sampling strategies to maximize data quality, and considering sensitivity analyses and auxiliary information when forecasting.

Study Area

Kamishak Bay is located at about 59°10'N latitude, 153°50'W longitude, along the western shore of lower Cook Inlet in southcentral Alaska. Located 150 km from Homer, Kamishak Bay is characterized by extensive rocky reefs that create navigational hazards to mariners but provide abundant spawning habitat for herring. Kamishak Bay is vulnerable to weather fronts emanating from several directions; high winds and strong currents resulting from tidal fluctuations in excess of 8 meters frequently produce rough seas in the area. These conditions stir up sediments along the beaches and shallow bays that, combined with glacial silt from several freshwater drainages, create persistent turbidity in the marine environment. This turbidity hinders the ability of aerial surveyors to observe and quantify herring schools in the 12 index areas composing the Kamishak Bay District (Fig. 1).

Methods

Fishery and Assessment History

Pacific herring were first commercially harvested in lower Cook Inlet in 1914; however, not until 1973 did spotter pilots and pioneering fishermen first locate and exploit herring in Kamishak Bay (Schroeder 1989). Frequent storms, treacherous reefs, and the relatively remote location were responsible for the Kamishak Bay fishery's delayed development. These same characteristics created challenges for assessing and managing the fishery. The fishery developed rapidly from 220 t harvested by just a few

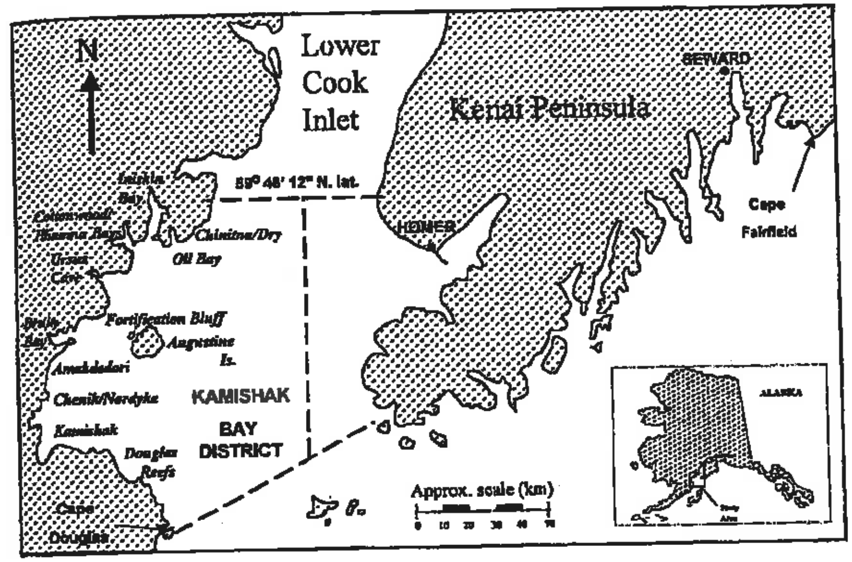

Figure 1. Lower Cook Inlet Alaska and the Kamishak Bay District. Names of index areas are italicized; they indicate where aerial surveys of herring schools occur.

permit holders in 1973 to nearly 4,400 t landed by 66 permit holders in 1976. To abate further expansion of effort, a ceiling of 73 permits was established when limited entry was imposed on the Kamishak Bay sac-roe herring fishery in 1977.

The Alaska Department of Fish and Game (ADFG) began collecting herring scales to estimate catch-age composition in 1973 and aerial surveys to estimate spawning biomass were initiated in 1978 (Fig. 2). The aerial estimate of total spawning biomass in a year was used to set the harvest guideline for the succeeding year. However, harvests rapidly declined from 4,393 t in 1976 to 376 t in 1979, and the fishery was closed from 1980 through 1984 to allow stock rebuilding. Limited age, weight, length, and sex data were collected, and aerial surveys were conducted to monitor stock status during the closed period. The fishery reopened in 1985 with a revised assessment program and more conservative harvest strategies. Catch-age analysis was used to develop age-specific estimates of natural mortality and recruitment. These data were integrated with aerial estimates of spawning biomass to track stock status and forecast the following year's return (Yuen et al. 1990). A stepwise harvest strategy implemented by the Alaska Board of Fisheries in 1993 set maximum exploitation rates ≤10% of the spawning biomass if that biomass was projected to be

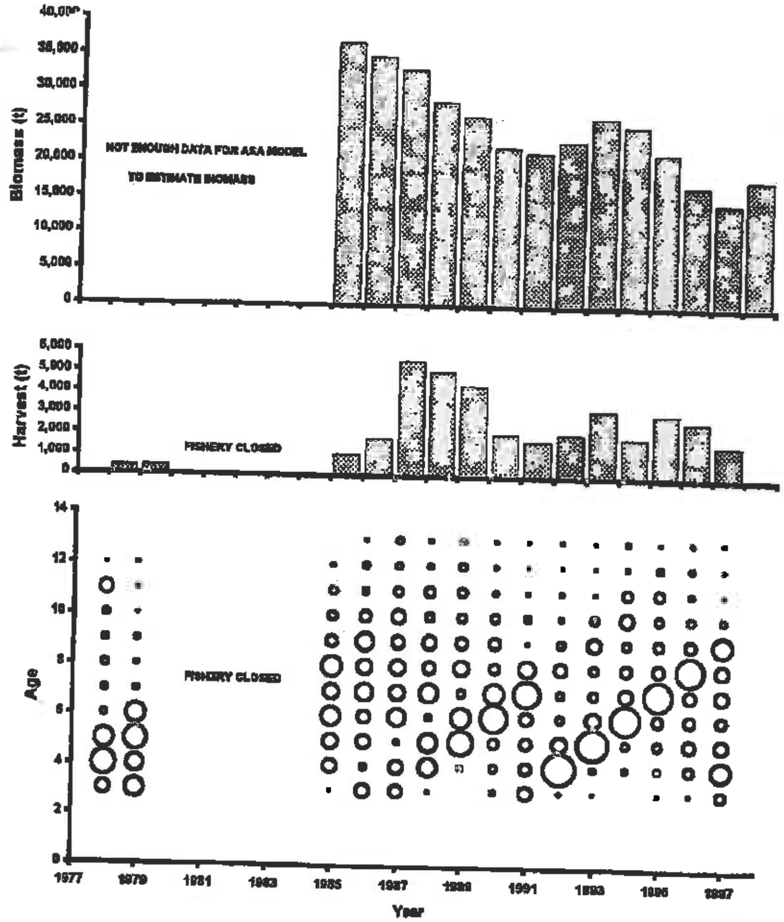

Figure 2. Kamishak Bay sac-roe herring fishery history: biomass trend, commercial harvest trend, and commercial catch age composition by year. Circle size represents the proportion that cohort contributed to the overall age composition in a given year.

7,257-18,144 t, ≤15% for biomasses of 18,144-27,216 t, or ≤20% for biomasses over 27,216 t. No harvest is allowed from a spawning biomass that is projected to be < 7,257 t (ADFG 1996, 5 AAC 27.465.e [Alaska Administrative Code]). Twenty percent is a relatively conservative maximum exploitation rate for herring (Zheng et al. 1993, Schweigert 1993, Funk and Rowell 1995). Reduced exploitation rates facilitate increased roe production since more old fish survive to be harvested in subsequent fisheries (Funk 1991). Conservative harvest rates are also prudent when stock abundance is low and/or uncertain; our stepwise harvest strategy guards against overexploitation of low biomasses.

Beginning in 1990, observer subjectivity in aerial surveys was reduced by more rigidly quantifying the biomass estimation process and documenting survey effort and conditions. In this process, the surface area of a herring school observed from a fixed distance above the water surface was converted to a biomass estimate based on a correlation developed for herring in Bristol Bay (Lebida and Whitmore 1985). Conversion ratios were stratified by water depth. Aerial observations in Bristol Bay were periodically calibrated when a commercial seine vessel captured an estimated school of herring and the catch was pumped aboard a tender vessel to determine the actual biomass. The 95% confidence interval (CI) around Bristol Bay biomass estimates based on these conversion ratios has ranged from ±14% to ±37% (L. Brannian, ADFG, Anchorage, unpublished data). Adoption of these quantitative procedures helped Kamishak Bay managers standardize aerial surveys and estimates of observed herring schools, but could not compensate for the poor visibility and large temporal gaps that hamper survey coverage in Kamishak Bay. As a result, estimates of total annual spawning biomass from aerial surveys were frequently compromised. To reduce the dependence on annual aerial surveys, Yuen et al. (1994) developed an age-structured assessment (ASA) model for Kamishak Bay.

ASA Model

The ASA model was developed in the Microsoft Excel spreadsheet using the Solver function (Microsoft 1993). The 2-dimensional format of the spreadsheet facilitates a more intuitive understanding of the model's mechanics. This feature has been very useful when explaining the model's basis to fishery managers and the Alaska Board of Fisheries, two very important links in the management chain in Alaska.

Herring are first accounted for in our model at age 3 when they begin to recruit to sexual maturity and are vulnerable to our sampling program. Herring older than age 12 do not compose a significant component of the stock and are pooled as age 13+. The ASA model integrates three heterogeneous sources of stock information: commercial catch age composition, total run age composition (i.e., total spawning biomass), and aerial survey estimates of spawning biomass. Although some fishery and stock information is available since 1978, we believed the data and collection procedures prior to 1985 were too inconsistent for inclusion in the ASA model. Thus, we truncated the model's source information in 1985, the year the fishery reopened and ADFG began consistently collecting stock information. The model estimates values for age-specific maturity, age-specific fishery selectivity, and initial cohort abundance. Differences between predicted and observed values for the three input information sources are minimized using a nonlinear optimization function (Excel Solver). Further details on model mechanics are provided in Otis and Bechtol (1997).

Because we did not believe sufficient data were available for the model to estimate survival (*S*), we fixed *S* for all years at 0.67, a relatively conservative rate that falls within the range of survival estimates reported in the literature (Funk and Sandone 1990).

Although the model updated estimates of historical abundance from 1985 to present, our primary goal was to generate a 1-year-ahead forecast of the herring spawning biomass. A forecast allows area managers to set harvest guidelines for the following year's commercial sac-roe fishery and allows the industry to plan accordingly. Unless in-season assessment data dramatically conflict with the pre-season forecast, the fishery is managed based on the pre-season forecast.

Forecast Procedure

Model inputs for the 1998 forecast included commercial harvests, catch age compositions, total run age compositions, weights-at-age, and aerial survey biomass estimates from 1985 to 1997. Final parameter estimates for initial cohort abundance and age-specific maturity and fishery selectivity from the 1997 forecast were used as starting values for the 1998 forecast. Several scenarios were constructed whereby data inputs were slightly modified. For instance, the 1997 aerial survey data were of low value due to weather-induced gaps in survey coverage and a decision had to be made whether to ultimately include those data in the model. Trials were run with and without the 1997 aerial survey data to evaluate their effect on results. Once all viable data input scenarios had been identified, they were run through the model several times while incrementally increasing the weighting factor attributed to each model component. The resulting sum of squares (SSQ) values and historical biomass trends were then plotted relative to these incremental changes to evaluate their respective effects on select model results. This sensitivity analysis identified weighting scenarios yielding unstable or unrealistic model results. The primary goal of data weighting is to allow the model to explore options to incorporate the different data sets, such that the deviation between predicted and observed values is minimized among all available data. Finally, in a process that involved some qualitative decisions based on all available auxiliary information, a single model run was selected to represent the current stock status and provide a 1-year-ahead forecast.

Results

Model Inputs

Since 1987, the commercial fishery has typically occurred over a very brief period in late April. The 1997 fishery similarly consisted of short openings on April 29 and 30 and May 1. ADFG staff collected catch samples from as many fishing vessels as possible while the catch was pumped aboard tenders. Age, weight, length, and sex information were later compiled in our Homer laboratory. Each sampled vessel's contribution to the total catch was determined from harvest tickets, and the data were weighted accordingly to estimate the age composition for the total catch.

Collecting age composition data to accurately represent the total run was more problematic. Fishing vessels on the grounds prior to the commercial opening collected early season data. Because ADFG will not announce fishery openings until adequate samples are collected to estimate the age composition of the biomass on the grounds, the fleet had a vested interest in collecting those data. ADFG's ability to collect age samples diminished when the fishery closed and the fleet departed the grounds around 2 May. Successive waves of herring continued to enter the spawning grounds until early June. Historical data collected in Kamishak Bay indicated the age structure shifted from older to younger fish around the first week of May (Yuen 1994). Samples collected from two temporally distinct spawning aggregations in 1997 revealed a similar shift in age structure (Fig. 3), and chi-square analysis indicated the shift was significant at $\alpha = 0.005$ ($\chi^2 = 1711$; 10 d.f.). The mean weight of early returning fish ($\bar{x}$ = 202.8 g, SD = 65.6; n = 2,883) also differed significantly from late-returning fish ($\bar{x}$ = 122.4 g, SD = 38.2; n = 2,203; two-tailed, two-sample t-test, $p < 0.0001$). Differences in mean weights between components of the run did not just result from their significantly different age structures; herring mean weights-at-age were also consistently greater for early returning fish (Fig. 3). These results revealed the potential for a temporal sampling bias when estimating the total run age composition, herring mean weight-at-age, and overall mean weight.

Although we have not yet evaluated the impact a temporal sampling bias would have on the model's estimate of stock level, we chose to guard against potential impacts by selecting a transition date to represent the shift between early and late returning components of the run. We then weighted the age samples by the respective aerial-survey biomasses estimated before and after the transition date. Based upon historical observations of age shift occurrence (Yuen 1994), we selected 8 May as the transition date for 1997. By this criterion, early run fish composed 41% and late-run fish 59% of the season's total biomass. We used the same ratio to weight our overall mean weight and mean weight-at-age data prior to their inclusion in the model.

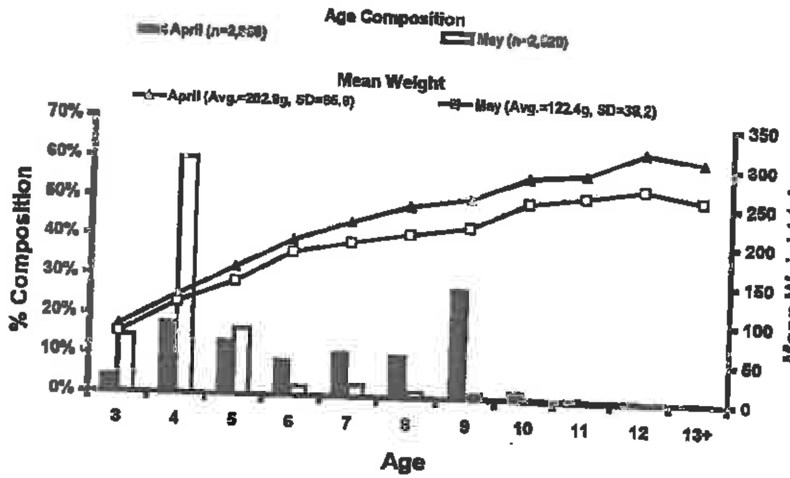

Figure 3. Age compositions and mean weights-at-age of two temporally distinct spawning aggregations of herring sampled in Kamishak Bay, Alaska, 1997.

Since the aerial survey program was restructured in 1990, only 1990 and 1992 were judged to have adequate survey coverage and conditions during peak biomass periods to yield realistic total spawning biomass estimates. An example of what we considered to be unrealistic aerial survey results occurred in 1991, a year characterized by good early season survey coverage, but poor survey conditions. The peak counts of herring biomass in 1991 amounted to less than 3,000 t. This contrasts with the roughly 23,000 t estimated during 1990 and 1992. Ancillary stock abundance information (e.g., fleet hydroacoustic observations and achievement of the harvest quota after only 1 hour of fishing) also indicated that the 1991 aerial survey biomass estimate grossly under-represented the actual abundance of spawning herring.

Evaluation of the 1990 survey year illustrates how important "good timing" is, along with adequate survey effort and conditions, in order to estimate total spawning biomass in Kamishak Bay (Figs. 4a and 4b). The observed biomass increased rapidly from 22 to 25 April in 1990. As evidenced by miles of spawn observed from the air, significant spawning also occurred throughout that period. Evidence of spawn in Kamishak Bay disappeared concurrent with the abrupt departure of the spawning biomass between 25-27 April 1990. This suggests the first spawning wave of herring had a brief period of residency and immediately left the area after spawning. About 4,500 t of spawning herring would not have been detected if flyable weather and good water visibility had not coincided during that brief 4-day period in early April 1990. Similarly, another 4,500 t would

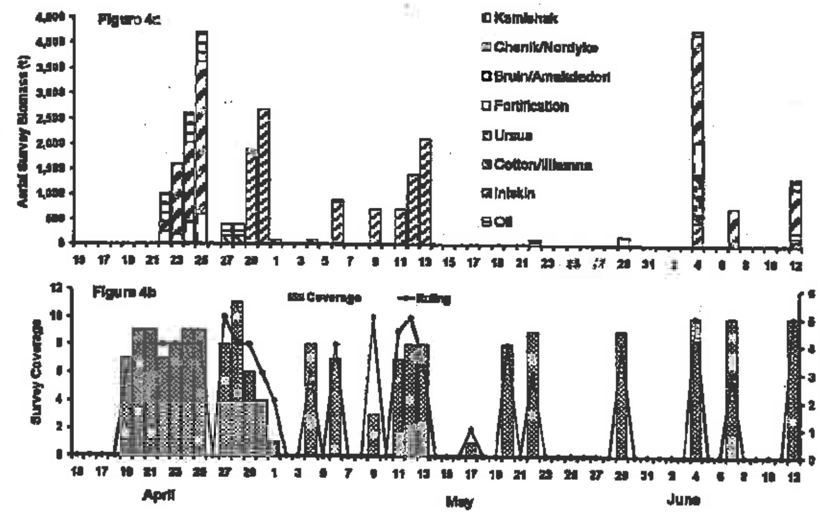

Figure 4. (a) Herring biomass estimates by index area from aerial surveys flown in Kamishak Bay, Alaska, 1990; and (b) Aerial survey coverage and survey condition ratings for aerial surveys flown in Kamishak Bay, Alaska, 1990. Survey coverage indicates the number of index areas flown on a given day; rating refers to the survey conditions: 0 = no survey, 5 = excellent.

have been unaccounted for had the 4 June survey not been successful. The combined biomass from these two events, which easily could have been missed, composed nearly 40% of the total observed spawning biomass for 1990.

Weather-induced gaps in survey coverage hampered our ability to estimate total spawning biomass in 1997. Because of the effect that poor survey coverage can clearly have on biomass estimates, we decided not to include the 1997 aerial surveys in the model. Instead, we again used only the survey years in which comprehensive coverage and adequate conditions facilitated realistic total spawning biomass estimates.

Sensitivity Analysis and Forecast

Aerial survey weights >0.01 stabilized the forecast biomass (Fig. 5a). Thus, we selected an aerial survey weight ≥0.01 that was strong enough to draw the historical biomass trend through the 1990 and 1992 aerial survey data points. We determined that an aerial survey weight around 0.1 was sufficient to achieve this result without compromising the fit to the age composition data (Fig. 5b).

Similar techniques were used to filter out unstable weightings for catch and total-run age composition data. The catch and total-run age composition

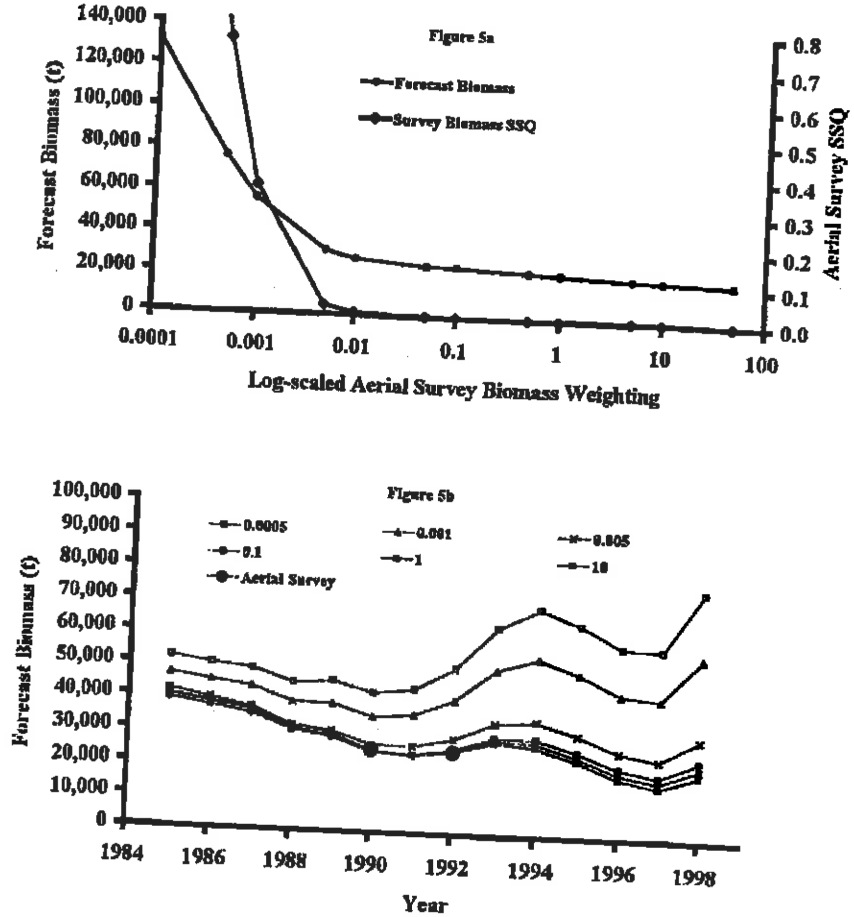

Figure 5. *(a) ASA forecast biomass and aerial survey sum of squares (SSQ) trends relative to increases in the log-scaled aerial survey weighting; and (b) Historical biomass trend relative to increases in the log-scaled aerial survey weighting.*

sums of squares conflicted in their reactions to increases in weighting (Fig. 6). Catch and total-run weightings in the range of 0.5-1.0 provided relatively stable results without pushing the forecasted biomass into what we perceived to be unrealistic ranges. The forecasted biomasses from these alternative weightings ranged from 14,250 to 32,830 t. This wide forecast range suggested there was some uncertainty, and perhaps even data conflicts, associated with the various model inputs. Given these uncertainties, a relatively conservative forecast was the only prudent alternative. We selected a final weighting schedule that yielded a forecast of 17,870 t and a harvest guideline of 1,787 t.

Other auxiliary information was also instrumental in the final qualitative decision to select a conservative forecast and harvest strategy. Our 1997 field samples indicated strong recruitment from the 1993 and 1994 cohorts; these year classes combined are projected to make up over 55% of the 1998 return. However, these two cohorts are just beginning to appear in our field samples and their absolute abundance is still highly uncertain. In addition, the regulatory Kamishak Bay Herring Management Plan contains a provision to limit exploitation on herring age 5 and younger. This provision necessitates a conservative harvest strategy for 1998 because recruit classes are projected to compose the majority of our 1998 return. Forecast uncertainty is also increasing because of the years elapsed since the last quality aerial survey biomass estimate in 1992.

Discussion

Aerial surveys generally provide the most direct means for assessing herring spawner abundance. However, poor weather in Kamishak Bay creates gaps in the aerial survey time series and high water turbidity frequently limits the ability of surveyors to observe herring schools when surveys can be flown. Resultant aerial-survey biomass estimates are sometimes unrealistically low and highly influenced by a given year's survey effort (i.e., spatial and temporal coverage) and conditions. Our efforts to mitigate these effects by standardizing survey effort across years have been largely unsuccessful. Attempts to standardize aerial biomass estimates for survey effort by documenting the number of survey hours flown and index areas surveyed does not account for temporal effects and variable survey conditions. Surveys that are missed, incomplete, or of poor quality during periods of peak abundance compromise the estimate of total spawning biomass more than surveys missed between spawning waves. It is difficult to build this effect into a model (e.g., by fitting a run-timing curve to aerial survey estimates) when the run is divided into waves of returning herring whose spawning peaks exhibit inter-annual temporal variability (H. Yuen, ADFG, Homer, unpublished manuscript). It is doubtful that a long-term average run-timing curve will accurately represent the actual run timing within a given year. Developing a baseline of run-timing curves relative to varying physical (e.g., tide series, water temperature: Wespestad

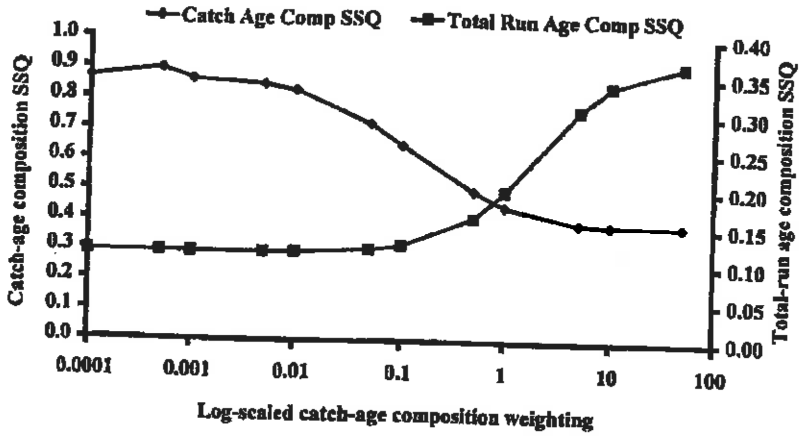

Figure 6. Catch- and total-run age composition sum of squares relative to increases in the log-scaled catch-age composition weighting.

1991) and biological (e.g., age composition, fat content, and mean weight-at-age of returning fish: Ware and Tanasichuk 1989, Rajasilta 1992) relationships may allow us to incorporate these parameters in future models.

Many herring are unaccounted for by our aerial survey assessments, even during good survey years. For instance, in 1990 the miles of observed spawn peaked on 21 April, prior to any herring schools being observed from the air, despite good survey effort and conditions. Nøttestad et al. (1996) found that Norwegian spring-spawning herring schools immigrating to the spawning grounds swam much deeper than spawning, feeding, or emigrating schools. This behavioral trait may make immigrating schools less susceptible to aerial assessment and partially explain why no herring schools were observed in 1990 until spawning began in earnest.

More tangible evidence of unsurveyed herring biomasses was consistently documented during the years 1992-1996. In each of these 5 years, virtually no herring were observed from the air by management staff prior to the date of the first commercial landings. An average of 2,050 t of unassessed herring was caught in these initial openings, and over 3,200 t of unassessed herring were caught in 1993. These data, along with anecdotal hydroacoustic observations by fishermen, have led us to be very critical of our aerial survey results, particularly when poor weather inhibits visibility or creates lengthy gaps in survey coverage.

By using ancillary stock-abundance information and sensitivity analyses to identify weak data sets, we can mitigate their impact on forecasts by down-weighting them or excluding them from the model. While this treatment of weak data is intuitively appealing, it can create side effects. Although the ASA model does not require an abundance-scaling index for every year, moderate amounts of auxiliary information are required to stabilize stock estimates generated by catch age analysis (Deriso et al. 1985). The greater the period between the last abundance-index (i.e., good survey year) and the current forecast, the more uncertain the forecast becomes.

We have tried to enhance the quality of other model inputs to compensate for uncertainties caused by our lack of consistent auxiliary information. Our expectation is that the effects of not having a recent abundance index could be mitigated if we had a continuous time series of data to annually represent the age composition of the total run. Collection of these data has only been possible during 8 of the past 13 years. Lacking a continuous time series of total run age composition data, the model cannot effectively scale upcoming recruit classes to strong cohorts it has tracked for several years. Recognizing the importance of this limitation to the model, ADFG has now begun to re-emphasize late-season sampling with the addition of an annually chartered test-fishing vessel. As this continuous time series grows and incorporates more years in which upcoming recruit classes overlap with strong older age classes, the model's ability to compensate for infrequent aerial survey estimates should be enhanced. The model's ability to scale upcoming recruits to older year classes will be particularly improved if a good aerial assessment occurs at least once during the life span of strong year classes. Maintaining continuous time series for both catch and total run age compositions also should improve our estimates of age-specific maturity and fishery selectivity and allow the model to estimate survival. These improvements may reduce the forecast uncertainty resulting from our lack of a consistent abundance index.

Although maintaining a continuous time series of catch and total run age compositions should improve the model's performance, a reliable abundance-scaling index remains its most integral component. Given the inconsistency with which aerial surveys have been able to provide this index we are considering other methods. Compact airborne spectrographic imaging (CASI) equipment has been used successfully to digitally remote-sense and quantify forage fish schools in Canada (Borstad et al. 1992, Nakashima and Borstad 1997) and Alaska (Funk et al. 1995). CASI works by discriminating between the spectral signatures of fish schools and their natural background; the surface areas of observed herring schools are then calculated from the digital images captured by CASI. Unfortunately, the turbid waters and inhospitable flying conditions characteristic of Kamishak Bay would likely inhibit CASI's ability to improve upon our current aerial survey program (Pers. comm., Gary Borstad, G.A. Borstad Assoc. Ltd., B.C. V8L 3S1, February 1998.).

Miles-of-milt indices have been used to scale spawner-abundance in Prince William Sound herring assessments (Funk 1994). We have consistently documented miles of milt observed during aerial surveys in Kamishak Bay since 1990. However, the same conditions that limit our aerial assessment of herring schools in Kamishak Bay also reduce our ability to observe and quantify evidence of spawn. Consequently, there is a high level of uncertainty regarding the completeness of our miles-of-milt data that has made us reluctant to use them in our model. In the future, we may investigate the utility of including miles-of-milt indices from years with good survey coverage and conditions. Developing technology, such as high resolution images from low orbit satellites (Pers. comm., Ron Brooks, remote sensing consultant, Fairbanks, AK, March 1998.), may facilitate locating and quantifying spawning events (i.e., miles of milt) more consistently in the future.

Egg deposition surveys have been used in Alaska (Funk 1994) and elsewhere in the Pacific Northwest (Schweigert and Stocker 1988, Burton 1991) to calculate estimates of total spawning biomass. In 1991, ADFG conducted foot surveys of the intertidal reefs and shoreline around Chenik Lagoon in Kamishak Bay to determine the feasibility of estimating egg deposition (Yuen 1993). These data allowed a rough calculation (i.e., 95% CI was ±100% of the estimate) of spawning biomass for the small area surveyed; however, several factors limit the feasibility of pursuing spawn deposition surveys in Kamishak Bay. Most of them involve the fact that the timing and distribution of spawning is protracted and would require costly, labor-intensive surveys to obtain a viable sample. Akenhead et al. (1993) investigated the feasibility of using CASI to quantify exposed egg biomass at low tide. Remotely sensing herring eggs is a relatively expensive and uncertain process that we decided not to pursue given the unique characteristics of Kamishak Bay (e.g., poor flying conditions, relatively sparse and widely distributed spawn, high potential for subtidal spawning to be missed; pers. comm., Gary Borstad, G.A. Borstad and Associates, Ltd. B.C., V8L 3S1, February 1998.).

Another consideration that reduces the feasibility of spawn deposition surveys in Kamishak Bay involves establishing the extent of subtidal spawning. To estimate spawning biomass from egg deposition with any accuracy, one must estimate the total number of eggs deposited. Annual scuba surveys would be required to estimate the contribution subtidal spawning makes to total egg deposition. Along with their expense, high energy beaches, swift tidal currents, sea lions and kelp forests make scuba diving in Kamishak Bay an undesirable assessment method. These practical and budgetary limitations restrained our interest in pursuing egg deposition surveys during an era when weather permitted the periodic success of aerial surveys. Now that 5 years have passed since our last "good survey" year, we are reconsidering alternative methods to obtain consistent abundance indices to stabilize our age-structured herring assessment model. Despite the challenges associated with securing accurate and consistent input data, we believe our use of an integrative model has resulted in improved management of the Kamishak Bay sac-roe herring fishery.

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