The Prince William Sound Herring Recruitment Failure of 1989: Oil Spill or Natural Causes?

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In 1989, herring spawned in Prince William Sound 2-4 weeks after the T/V *Exxon Valdez* ran aground. The resultant oil spill contaminated some herring spawning beaches and may have affected food chains used by larval herring. The Alaska Department of Fish and Game (ADF&G) has routinely collected a variety of assessment information on the Prince William Sound herring stock since the early 1970's. We sought to use this information to determine whether the abundance of the 1989 year class of herring was different than might have been expected from historical data.

Information about the abundance of a year class of herring is first obtained when herring begin to return to spawn in their third year of life; therefore, 1992 was the first opportunity to assess the effect of the oil spill on the abundance of the 1989 year class. Stock assessment data routinely collected by ADF&G include age compositions of the catch and spawning populations, aerial survey estimates of biomass, miles of milt observed from aerial surveys, and spawn deposition survey estimates of biomass.

We used an age-structured assessment (ASA) model to synthesize all of the available stock assessment information into a single time series of historical abundance. In this paper the ASA model of Funk and Sandone (1990) was updated to include additional sources of auxiliary information, additional gear types, and natural mortality estimation; we also extended the time series of data to include information through the spring of 1992. Our goal was to produce a historical abundance time series that "smooths" or averages the often-conflicting stock assessment information. We then sought to examine how the strength of the 1989 year class compared with that predicted from the spawner-recruit model developed from the historical abundances and environmental conditions during early life history.

In a similar herring population in Sitka Sound, sea surface temperature anomalies explained at least 40% of the variability in recruitment patterns (Zebdi 1991). Because herring year class strength in Prince William Sound is correlated with the year class strength of other herring stocks around the Gulf of Alaska coast, we also sought to compare the relative strength of the 1989 year class in Prince William Sound with that in Sitka Sound.

Our approach uses an ASA model which incorporates auxiliary information, similar to that used by Deriso et al. (1985). The ASA model estimates initial cohort abundances which best fit observed age composition and abundance information, after accounting for removals at each age and year. Deviations of model estimates from observations are ascribed to measurement error in the observations.

While our primary goal was to use the model to estimate the historical abundance time series, the model also estimates natural mortality, maturity, and gear selectivities for purse seine, gillnet, pound, and food and bait fisheries, and a coefficient which relates miles of milt observed in aerial surveys to spawning biomass.

The ASA model begins tracking herring cohorts at age 3, the first year that a measurable proportion usually return to spawn. The survival model accounts for natural mortality and harvest processes with a difference equation which describes the number of fish in a cohort at each age and year. The survival model removes the catch at each age resulting from the spring purse seine and gillnet and pound fisheries, and the fall food and bait fishery. The number of fish in a cohort includes both mature and immature herring measured at a time after annulus formation but before the spawning run or spring roe fisheries. The biomass of herring spawning at each age and year was estimated in the ASA model from the survival model's estimated number of fish at age, weight at age sampling, and the proportion mature at each age. The model estimated the proportions mature at each age and the proportion mature at each was assumed not to change from 1973 to 1992.

The harvest of herring by age for purse seine sac roe, gillnet sac roe, pound, and food and bait fisheries was tabulated for the 1973 to 1992 period from ADF&G catch records. Observed numbers of fish in the catch for each gear were also converted to age composition (percent by age) for each gear, for comparison to age compositions estimated from ASA model. Gear selectivity was defined to include both the effects of immature fish not being present on the fishing grounds (partial recruitment or maturity), and active selection or avoidance of certain fish sizes by the gear or fishermen's behavior. A logistic selectivity function was used for gears which were thought to have asymptotic selectivities (purse seine, pound, and food and bait); a gamma-type function was used for gillnet gear where selectivity might decrease at the older ages.

The volume of milt deposited by male herring each year was assumed to be proportional to the mature biomass. Since 1972, ADF&G aerial herring surveys have routinely recorded the miles of shoreline adjacent to milt discolorations visible in the water. A goodness of fit measure for miles of milt was developed by assuming that this linear measurement was directly proportional to the mature biomass. Spawn deposition surveys were conducted in 1984, and 1988-92. These surveys estimate biomass by back-calculation from the numbers of eggs deposited, using additional sampling to estimate fecundity and sex ratio. A goodness of fit measure for the ASA model was developed from the differences between ASA estimates of mature numbers at age and the spawn deposition survey estimates of numbers at age.

In addition to the time series of the catch by age, a relatively long time series of age compositions of the spawning population are available. Since 1984, age samples have been collected from spawning herring. Sampling effort was lower for years prior to 1984, and spawning age compositions were reconstructed primarily from purse seine catch samples from each area. Sample sizes were judged to be too small in 1973, 1974-78, and 1980-81 to reliably construct estimates of spawning age composition. A goodness of fit measure was developed from these age compositions as the difference between the ASA model's estimated age compositions and those observed during ADF&G sampling.

A total sum of squares was computed by adding each of the component goodness of fit measures where each component was assigned an ad hoc weight. The ad hoc weights reflected our attempt to weight data equitably, but also incorporate some prior knowledge of our confidence in each component. The model estimates a total of 37 parameters: 23 initial cohort sizes, 10 gear selectivity function parameters, 2 maturity function parameters, 1 aerial milt survey biomass coefficient, and 1 survival rate parameter. The combined weighted sum of squares was minimized using nonlinear least squares techniques to estimate values for the 37 parameters.

Biomass estimates from the ASA model were relatively low (20,000-40,000 metric tons) during the 1970's and increased to higher levels (50,000-110,000 metric tons) in the 1980's. Recent trends in abundance, indicated by the age composition and aerial milt survey data, are different than the abundance trend from the spawn deposition survey. While the strong 1984 year class began dominating the age compositions in 1987, the spawn deposition survey biomass did not increase until 1990. The cause for this discrepancy is unknown, but it may indicate that spawn survey measurement error is much greater than anticipated.

While the design goal for spawn deposition surveys was a precision such that 95% confidence intervals would be ±25% of the true biomass value, the absolute deviations of spawn deposition survey biomass estimates from the ASA biomass estimates averaged 48%. The ASA model reflected these inconsistencies by essentially scaling the biomass to a "smooth" of recent spawn deposition survey biomass estimates, while manipulating year class strengths to track trends in age composition data more closely. The estimated survival rate of 65% (equivalent to an instantaneous natural mortality rate of 0.43) was very similar to the midpoint of the range used by Funk and Sandone (1990). The ASA model estimated that, on average, one mile of milt from aerial surveys corresponded to be 821.2 metric tons of spawning herring.

Year class strength in Prince William Sound is characterized by occasional years of very strong recruitment. Beginning with the 1976 year class, these strong year classes have occurred every four years. The 1989 year class is among the smallest observed since the beginning of the data series in the early 1970's and resulted from one of the largest egg depositions. First quarter sea surface temperatures in 1989 were also relatively low and low sea surface temperatures tend to be associated with weak year classes.

However, corresponding data from Sitka Sound indicate that the 1989 year class there was not as weak. Because the 1989 year class has appeared in assessment samples only for a single year, the precision of the estimate of its abundance is not high.

Precision is further reduced because only a portion (approximately 25%) of a year class is recruited at age 3, and the proportion recruited varies somewhat from year to year. The precision of the abundance estimate of the 1989 year class will continue to improve with additional years of sampling. However, most of the improvement in the precision of the abundance estimate for the 1989 year class will be realized by 1995.

References

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