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# Identifying the Spatial Distribution of Stocks of Migrating Adult Sockeye Salmon Using Age Composition Data

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ABSTRACT: We present a model for identification of the spatial distributions of component stocks of sockeye salmon *Oncorhynchus nerka* in the Port Moller test fishery, which are migrating to Bristol Bay, Alaska, using the differential age composition of those stocks. We model the spatial distribution of each stock as a normal density with parameters of mean and standard deviation of distance along the sampling transect. The model predicts the number and age composition of sockeye salmon at different sampling stations, and compares them to the observed abundance and age composition at these sampling stations. Some level of stock separation is apparent at Port Moller, but the ability to discriminate a component stock depends on both its uniqueness of age composition and its relative magnitude. We believe these methods may provide additional information that can be integrated with other sources currently used for inseason projections of sockeye salmon runs in Bristol Bay.

## INTRODUCTION

A multitude of methods exist for stock identification, each requiring the collection of one or more types of data including morphology (Cadrin 2000), genetics (Guthrie et al. 2000), scale patterns (Suga et al. 1989) and occurrence of parasites (Urawa et al. 1998). There has been, however, little use of age composition. A literature review produced few references to models for stock identification based on age composition, and only a handful of mentions of age composition information supporting conclusions drawn from other methods. McKinnell et al. (1999) cited age composition in support of conclusions drawn from microsatellite DNA and scale patterns of Fraser River sockeye salmon *Oncorhynchus nerka*. Gable and Cox-Rogers (1993) also cited age composition as “accessory data used to refine the analysis” of stock identification of Fraser River sockeye salmon based on scale patterns. Wood et al. (1988) compared four methods of stock identification for sockeye salmon in Northern British Columbia and Southeast Alaska, including freshwater age. Researchers concluded that the use of freshwater age composition is too variable among years of return to be useful in their application. Although age composition of sockeye salmon is variable over time, stock identity information is contained in age composition data if stocks differ and age compositions are monitored over time.

One case in which age composition data has been utilized with regularity by the Alaska Department of Fish and Game (ADF&G) is that of postseason analyses to estimate the stock composition of commercial catches. Witteveen (1998) provides an example for the Ilnik River System. The researcher estimated the stock composition of the commercial fishery on the Alaska Peninsula for a postseason run reconstruction by comparing the age composition of commercial catches to those in river escapements. Both total age compositions and a single “marker” age class were modeled separately for the purpose of run reconstruction, and both methods provided similar results.

The Bristol Bay sockeye salmon fishery experiences extremely variable harvests, and has ranged from 10 million to more than 45 million fish over the past two decades (ADF&G 2000). Roughly 80% of the harvest occurs between June 27 and July 12 in remote Southwest Alaska, isolated from sources of materials

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and labor (Helton 1991). If a run is much larger than expected, processors are not able to quickly increase processing capacity and may be forced to institute catch limits or to ship unprocessed fish to distant plants with concomitant increased costs and decreased quality. Conversely, if runs are smaller than expected and there is excess capacity, the associated fixed costs may remove profitability. These conditions also present managerial challenges. Bristol Bay management biologists must decide on opening and closing the fishery for harvest periods before the actual escapements are known, based on the estimated number of inriver fish and the estimated number of incoming fish.

The Port Moller salmon test fishery provides information regarding incoming fish roughly one week before they enter the fishing districts (Helton 1991). The test fishery samples stations along a transect extending from Port Moller toward Cape Newenham (Figure 1). Stations 2, 4, 6, and 8 have been fished regularly since the Fisheries Research Institute/Alaska Salmon Program took over the test fishing program in 1987, but recent years have included additional stations (Table 1). Station 0 was fished regularly during the 1980s and thus is included in figures, but was not

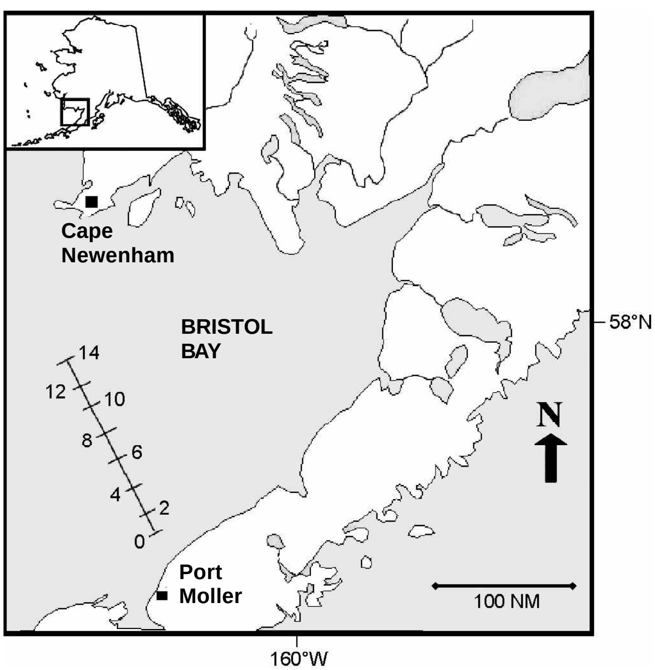


Figure 1. Port Moller salmon test fishery sampling stations (0–14) and the relative position of Bristol Bay commercial fishing districts (station 0 has not been sampled regularly since the 1980s and thus is not included in the analysis). The label **a** indicates the Nushagak District, **b** the Naknek-Kvichak District, **c** the Egegik District, and **d** the Ugashik District.

fished during the years for which the analysis is performed. Weather permitting, the test fishery samples each station daily between June 10 and July 10, and an updated forecast for the Bristol Bay run is issued each day (Helton 1991). However, the commercial fishery is composed of four major commercial fishing districts that are managed separately (Figure 1; ADF&G 2000), and each is located at the entrance of one or more major rivers. In most cases, fishermen are required to wait 48 hours before transferring between these districts, and travel time for processing and support vessels can further limit processing capacity. Although the inseason forecasts provided by the Port Moller test fishery are valuable, information regarding the proportion of the run headed for each commercial fishing district would increase their value significantly.

Sockeye salmon sampled at Port Moller are homing to Bristol Bay, but their river destination is unknown (Straty 1975). Based primarily on tagging studies completed by Straty (1975), stocks with differing ocean distributions are believed to have already converged on a common migratory path as they pass offshore from Port Moller, yet are only in the initial stages of separation for return to their home rivers. Straty (1975) reported specifically that directly offshore from Port Moller "segregation of stocks destined for rivers entering on the northwest and southeast sides of Bristol Bay is apparent," and stated that Nushagak District and Naknek-Kvichak District stocks are more abundant in the offshore waters, while Egegik District and Ugashik District stocks are more abundant closer to shore. However, tagging data was deemed insufficient to draw quantitative conclusions. If the level of stock separation offshore from Port Moller is substantial, then the observed unimodal distribution of fish across the transect (Figure 2) may actually be composed of more than one distinct distribution, and one or more sampling station may be substantially more or less representative of incoming runs to one or more commercial district.

We develop a model for using age composition data to estimate the physical distribution of each district stock along the sampling transect using catch-of-age data from each test fishery station along the transect and run-of-age data from each commercial fishing district, and use this model for the purpose of stock identification along the Port Moller sampling transect. We estimate the spatial distribution of each component stock within the total spatial distribution to determine their degree of similarity. We treat each possible physical location of each stock as a competing hypothesis, and select the most plausible of those hypotheses (Hilborn and Mangel 1997). We perform

Table 1. Age composition of the Port Moller test fishery sockeye salmon catches and estimated sockeye salmon runs to Bristol Bay's commercial fishing districts for each year that Port Moller data is available electronically, 1993 and 1996–2000. Catches are listed by age class and by sampling station; runs are listed by age class and by commercial fishing district. Blanks indicate no observations.

| | | Catch by Station | | | | | | | Run by district (thousands of fish) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Age | 2 | 4 | 6 | 8 | 10 | 12 | 14 | Nushagak | Naknek-Kvichak | Egegik | Ugashik |
| 1993 | 1.2 | 13 | 39 | 104 | 103 | | | | 1,502 | 5,370 | 887 | 1,676 |
| | 1.3 | 123 | 195 | 238 | 221 | | | | 2,644 | 3,173 | 1,662 | 821 |
| | 2.2 | 91 | 252 | 444 | 294 | | | | 153 | 5,074 | 10,182 | 1,752 |
| | 2.3 | 356 | 528 | 596 | 372 | | | | 159 | 1,866 | 3,057 | 671 |
| 1996 | 1.2 | 33 | 67 | 80 | 47 | | | | 2,714 | 795 | 335 | 191 |
| | 1.3 | 380 | 609 | 383 | 221 | | | | 4,937 | 6,661 | 3,939 | 3,167 |
| | 2.2 | 131 | 179 | 54 | 26 | | | | 62 | 1,114 | 3,113 | 597 |
| | 2.3 | 195 | 365 | 155 | 115 | | | | 322 | 2,714 | 4,721 | 1,218 |
| 1997 | 1.2 | 43 | 184 | 222 | 189 | | | | 1,844 | 1,181 | 461 | 238 |
| | 1.3 | 129 | 415 | 563 | 453 | | | | 2,321 | 795 | 1,039 | 547 |
| | 2.2 | 221 | 488 | 481 | 129 | | | | 107 | 800 | 4,490 | 900 |
| | 2.3 | 184 | 450 | 453 | 99 | | | | 108 | 491 | 2,483 | 306 |
| 1998 | 1.2 | 9 | 106 | 301 | 196 | | | | 3,077 | 2,476 | 368 | 333 |
| | 1.3 | 81 | 428 | 588 | 233 | | | | 2,404 | 2,441 | 537 | 352 |
| | 2.2 | 16 | 87 | 142 | 106 | | | | 150 | 1,180 | 880 | 241 |
| | 2.3 | 164 | 572 | 313 | 132 | | | | 87 | 564 | 3,099 | 827 |
| 1999 | 1.2 | 211 | 472 | 412 | 308 | 256 | 55 | | 4,160 | 10,178 | 3,053 | 2,710 |
| | 1.3 | 96 | 200 | 226 | 141 | 124 | 40 | | 3,424 | 2,024 | 943 | 314 |
| | 2.2 | 146 | 287 | 231 | 188 | 131 | 27 | | 532 | 4,252 | 4,127 | 673 |
| | 2.3 | 38 | 74 | 78 | 62 | 65 | 24 | | 277 | 1,267 | 977 | 195 |
| 2000 | 1.2 | 13 | 28 | 42 | 93 | 374 | 68 | 12 | 2,747 | 686 | 469 | 213 |
| | 1.3 | 21 | 59 | 112 | 300 | 1,429 | 511 | 48 | 4,126 | 3,800 | 3,102 | 1,495 |
| | 2.2 | 5 | 27 | 33 | 70 | 159 | 28 | 5 | 153 | 785 | 1,517 | 167 |
| | 2.3 | 5 | 18 | 31 | 116 | 323 | 77 | 2 | 125 | 627 | 3,031 | 265 |

postseason analyses for the sake of simplicity, with several potential inseason applications. If a consistent migration pattern were to be observed, abundance information from individual stations could be used for inseason forecasting specific to one or more individual commercial fishing district. Moreover, if the model is able to clearly distinguish between stocks postseason, it could potentially be feasible inseason.

## METHODS

### Available Data

The analysis was performed for all years for which data was available in electronic form, 1993 and 1996–2000. Data for 1994, 1995, and years prior to 1993 were not available from the Alaska Salmon Program or from ADF&G. We chose to examine the season's test fishery catches and runs of sockeye salmon in Bristol Bay as a whole, for the sake of simplicity. If a clear pattern of distribution emerges for the season as a whole, that pattern may differ slightly at a given time during the forecasting season. Certain commercial fishing districts tend to have earlier arrivals than others, and migration time likely varies between Port Moller and these districts. However, temporal patterns are relatively consistent from year to year (i.e., Egegik District is consistently earlier than Ugashik District), and could potentially be modeled if a consistent spatial pattern was established. Additionally, although both the Nushagak District and the Naknek-Kvichak District are composed of more than one major river system, we treated each commercial district as a single population for this analysis. This treatment is justified because stocks within a district are generally fished simultaneously (ADF&G 2000), so actual returns to each river system within a district are not precisely known. Moreover, the age composition of stocks within a commercial fishing district tend to more closely resemble each other than stocks in other districts (Rogers 1987).

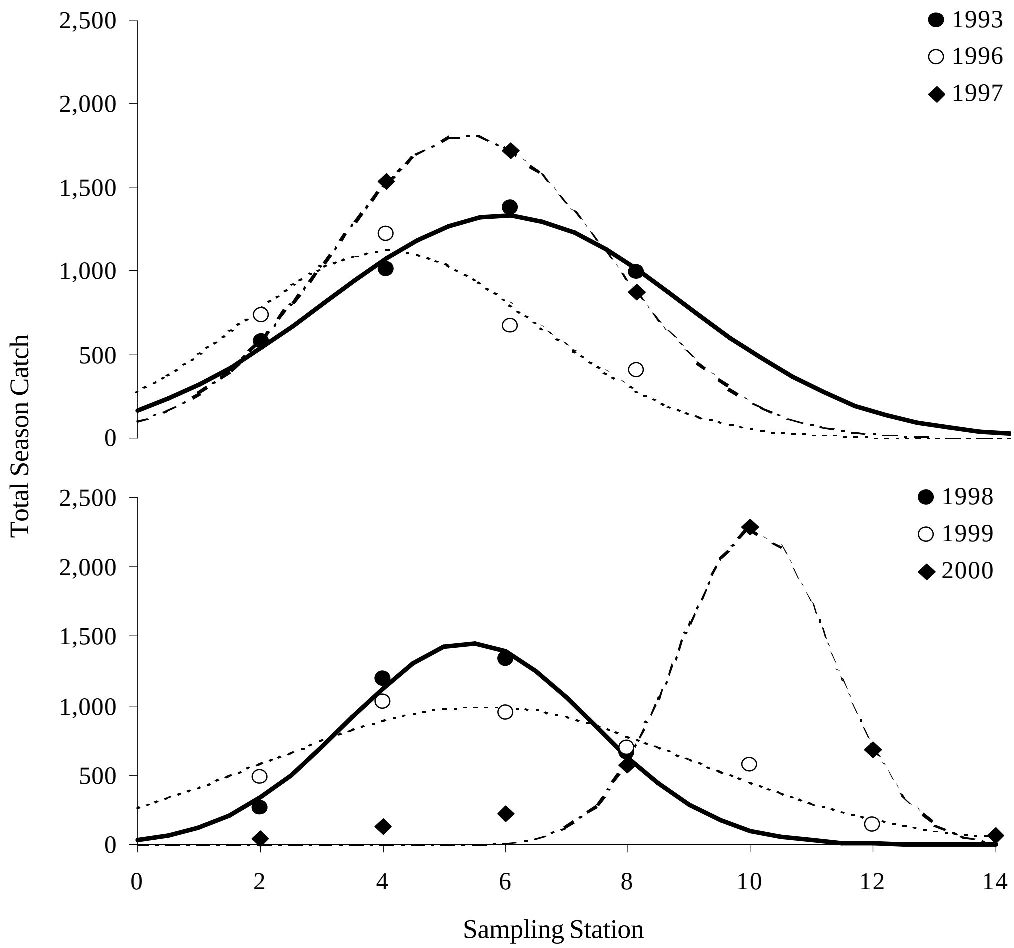


Figure 2. Total season catches at Port Moller test fishery sampling stations for each year that Port Moller data is available electronically (1993 and 1996–2000), and normal distributions fit to the data. Station 0 was not sampled during these years, but it is included for reference.

Table 1 shows the catch for each year, age class, and Port Moller sampling station, and the returns to each commercial fishing district for each year that Port Moller data is available electronically, 1993 and 1996–2000. Catch-of-age data from the test fishery is available from scale samples taken routinely from every fish caught. Estimates of run sizes were provided by ADF&G. Commercial catches are estimated by weighing fish in randomly selected samples and extrapolating over reported commercial catch poundage, for each commercial fishing period of the season, in each commercial fishing district. Escapements are estimated by visual enumeration for 10-minute periods each hour from escapement counting towers, extrapolated over the full hour, each day of the season, on each major river. Age composition data for commercial catches and escapements is collected by the routine sampling of commercial catches from each gear type and commercial fishing district, and of each escapement counting tower. Both scale samples from the Port Moller test fishery and from the commercial catches and escapements are aged by ADF&G personnel. Because the sample sizes used to determine age composition are so large (approximately 30,000 per year; F. West, Alaska Department of Fish and Game, Anchorage, personal communication), we are ignoring any errors that may occur. Table 2 summarizes the proportions by age of the Port Moller catch and of the total runs, and the age composition of test fishery catches (Figure 3) and runs to each district (Figure 4) are illustrated for further clarity.

## Notation

The following notations are used for the observed data:

$N_{say}$ = the number of fish in the run of stock *s* that is of age group *a* in year *y*. We assume no uncertainty in these numbers; and,

Table 2. Relative vulnerability-of-age of sockeye salmon captured in the Port Moller test fishery for each year that Port Moller data is available electronically, 1993 and 1996–2000.

| | Age | Proportion in Catch | Proportion in Run | Relative Vulnerability |
|---|---|---|---|---|
| 1993 | 1.2 | 0.07 | 0.23 | 0.28 |
| | 1.3 | 0.20 | 0.20 | 0.96 |
| | 2.2 | 0.27 | 0.42 | 0.65 |
| | 2.3 | 0.47 | 0.14 | 3.30 |
| 1996 | 1.2 | 0.07 | 0.11 | 0.68 |
| | 1.3 | 0.52 | 0.51 | 1.03 |
| | 2.2 | 0.13 | 0.13 | 0.96 |
| | 2.3 | 0.27 | 0.25 | 1.11 |
| 1997 | 1.2 | 0.14 | 0.21 | 0.66 |
| | 1.3 | 0.33 | 0.26 | 1.28 |
| | 2.2 | 0.28 | 0.35 | 0.81 |
| | 2.3 | 0.25 | 0.1 | 1.35 |
| 1998 | 1.2 | 0.18 | 0.33 | 0.54 |
| | 1.3 | 0.38 | 0.30 | 1.27 |
| | 2.2 | 0.10 | 0.13 | 0.78 |
| | 2.3 | 0.34 | 0.24 | 1.41 |
| 1999 | 1.2 | 0.44 | 0.51 | 0.86 |
| | 1.3 | 0.21 | 0.17 | 1.24 |
| | 2.2 | 0.26 | 0.25 | 1.06 |
| | 2.3 | 0.09 | 0.07 | 1.26 |
| 2000 | 1.2 | 0.16 | 0.18 | 0.89 |
| | 1.3 | 0.62 | 0.54 | 1.15 |
| | 2.2 | 0.08 | 0.11 | 0.73 |
| | 2.3 | 0.14 | 0.17 | 0.82 |
| Mean | 1.2 | 0.17 | 0.26 | 0.65 |
| | 1.3 | 0.38 | 0.33 | 1.15 |
| | 2.2 | 0.19 | 0.23 | 0.83 |
| | 2.3 | 0.26 | 0.18 | 1.54 |

$C_{iay}$ = the number of individuals caught at station $i$ of age group $a$ in the Port Moller test fishery in year $y$.

The following notations are used for the parameters to be estimated:

$u_{sy}$ = the average spatial location (in units of station numbering, see Figure 1) of stock $s$ in year $y$; and,

$s_{sy}$ = the standard deviation of the spatial location (in units of station numbering see Figure 1) of stock $s$ in year $y$.

The following notations are used for intermediate calculations:

$q_{siy}$ = the proportion of stock $s$ at station $i$ in year $y$;

$v_{ay}$ = the relative vulnerability of age group $a$ to the Port Moller test fishing gear in year $y$;

$p_{iay}$ = the proportion of catch at station $i$ of age $a$ in year $y$; and,

$S_{iay}$ = the sample size used in the multinomial likelihood for station $i$, age $a$, year $y$.

## Model calculations

The predicted proportion, $q_{siy}$, of each stock at each station is modeled by the normal density function (cumulative station catches resemble a normal distribution; see Figure 2),

$$q_{siy} = \frac{\exp\left[-\frac{(i-u_{sy})^2}{2s_{sy}^2}\right]}{\sum_i \exp\left[-\frac{(i-u_{sy})^2}{2s_{sy}^2}\right]}, \qquad (1)$$

where $i$ refers to a given station and includes only stations fished (2, 4, 6, 8, 10, 12, or 14).

The relative vulnerability of fish of age $a$, to the Port Moller test fishery in year $y$, $r_{ay}$, is the ratio between the age composition in the total run and the Port Moller catch, where

$$v_{ay} = \frac{\left[\frac{\sum_i C_{iay}}{\sum_i \sum_a C_{iay}}\right]}{\left[\frac{\sum_s N_{say}}{\sum_s \sum_a N_{say}}\right]}. \qquad (2)$$

The predicted proportion, $p_{iay}$, of each age group at each station is determined by calculating, for each stock, the proportion of the fish of stock $s$ traveling through that station multiplied by the observed number of fish in the run of stock $s$ that are of age group $a$ ($N_{say}$), summing across stocks, and then multiplying by the age-specific vulnerability ($v$), where

$$p_{iay} = v_{ay} \frac{\sum_s q_{siy} N_{say}}{\sum_a \sum_s q_{siy} N_{say}}. \qquad (3)$$

We used the multinomial likelihood to evaluate the relative support the data provide for possible parameter values, and thus, competing hypotheses about the spatial distribution of each stock. The actual observed sample sizes at Port Moller are reasonably large, often several hundred. As an initial step we down-weighted the sample sizes of the test fishery catches so that the sample size used in the multinomial likelihood was 100. This initial trial is to establish maximum likelihood estimates (MLEs); the appropriate sample size is calculated after obtaining those estimates. Effective catches of each age group at each station in each year is calculated as follows:

$$S_{iay} = 100\frac{C_{iay}}{\sum_i \sum_a C_{iay}}. \quad (4)$$

The likelihood, $L$, of a hypothesized $m_{sy}$ and $s_{sy}$ given the data is thus (note the factorial term is dropped for simplicity and computational convenience):

$$L(u_{sy}, s_{sy} \mid N_{say}, C_{iay}) = \prod_i \prod_a p_{iay}^{S_{iay}}. \quad (5)$$

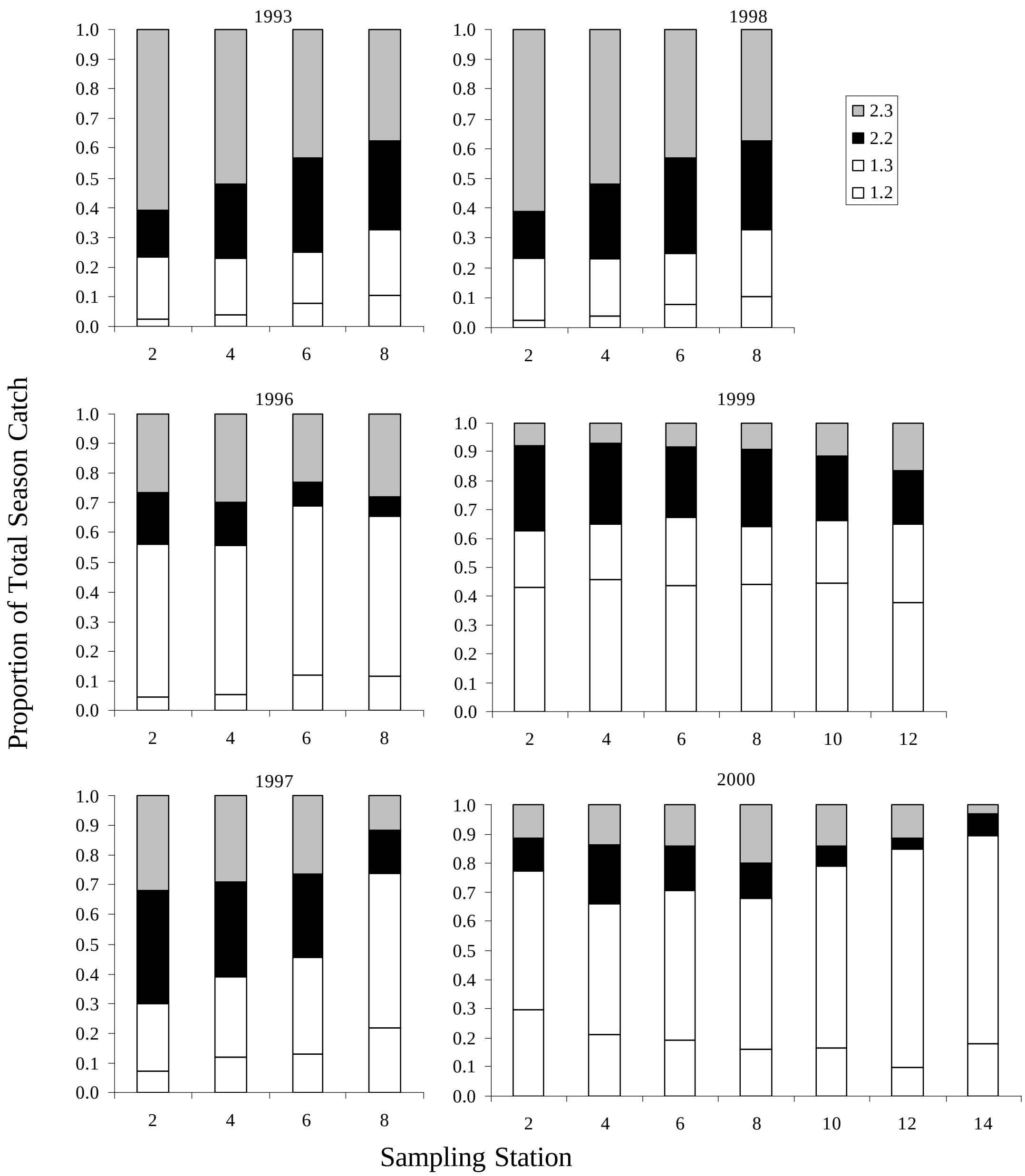


Figure 3. Age composition of Port Moller test fishery catches by sampling station for each year that Port Moller data is available electronically, 1993 and 1996–2000.

## Calculation of Bayes posterior distributions

We assumed uniform priors for the mean location parameters along the full range of locations sampled: stations 2 to 8 for the years 1993 and 1996–1998, and a slightly wider range in 1999–2000 (Table 1). We assumed uniform priors for the standard deviation parameters between 0.5 and 5.0; a standard deviation of 0.5 results in almost all of one district's fish expected at one station, and a standard deviation of 5.0 results in a nearly even distribution across stations. We used the Sampling Importance Resampling (SIR) method (Gelman et al. 1995), drawing 500,000 samples from the prior distributions as the importance function and resampling 1,000. Because the multinomial likelihood function has no variance parameter, it is accepted prac-

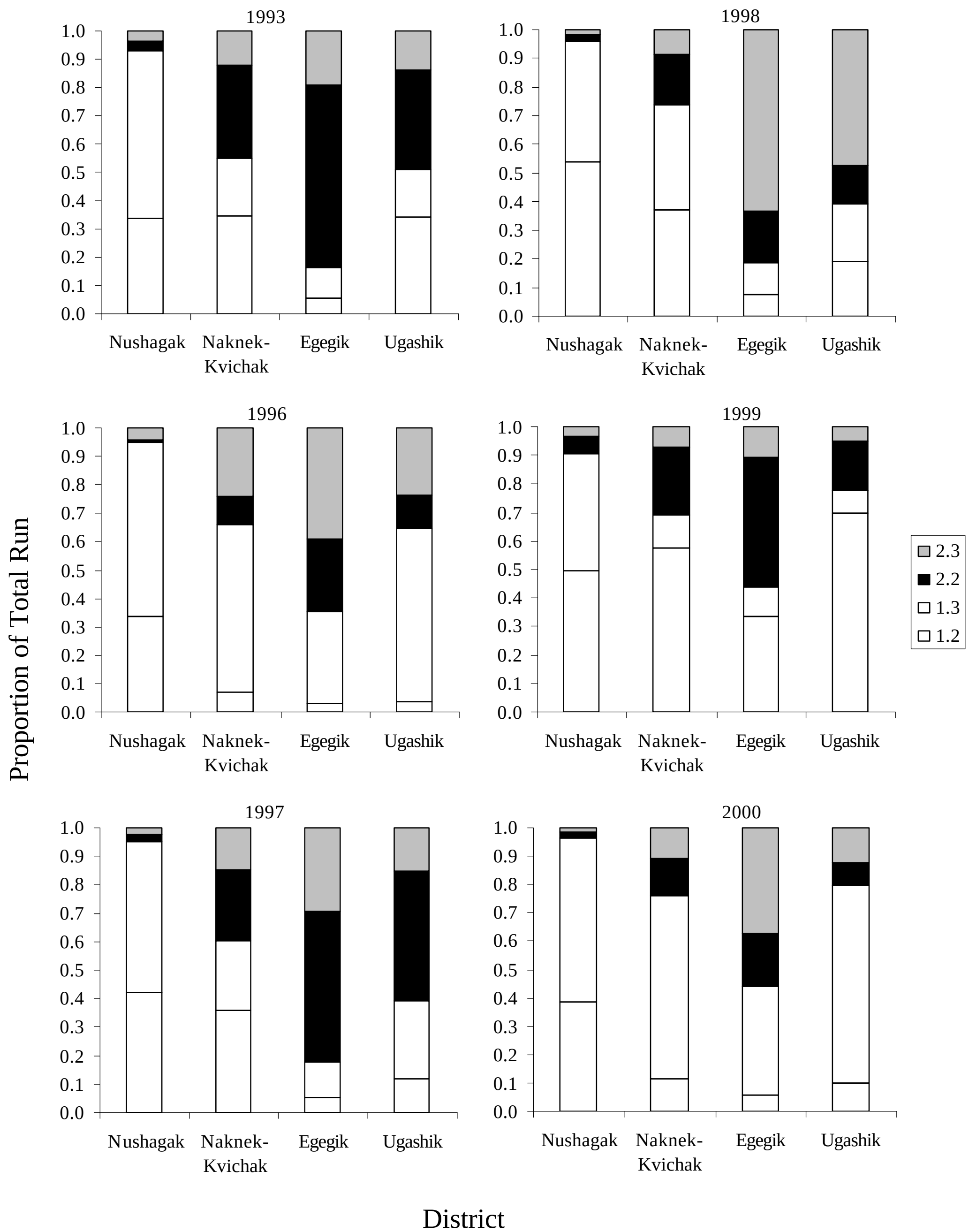


Figure 4. Age composition of returns to each commercial fishing district for each year that Port Moller data is available electronically, 1993 and 1996–2000.

tice to use 'implied' rather than observed sample sizes (McAllister and Ianelli 1997). After obtaining MLEs for all parameters (the means of the posterior distributions), we calculated the effective sample size, $n$, between all years according to the formula developed by McAllister and Ianelli (1997),

$$n = \frac{\sum_y \sum_a \sum_i \hat{p}_{iay}(1-\hat{p}_{iay})}{\sum_y \sum_a \sum_i (\hat{p}_{iay} - p_{iay})^2}, \qquad (6)$$

where $n$ is a function of the predicted and observed proportions of each age class at each station in each year. We then repeated the SIR exercise scaling to the appropriate sample size and drawing at least 1,000,000 times from the prior distributions. We report the median of each parameter; however, given the near normal distributions of most of the posteriors there was little discrepancy between the median and mode. Given these estimated parameters we calculated the proportion of the sample catches expected at each station.

## RESULTS

Results are summarized in Table 3 and illustrated in Figure 5 with a box plot of the estimated central spatial location of each stock in each year. In 1993, all stocks appear to have had similar offshore locations, although the Naknek-Kvichak District stock's central location MLE is approximately one station further offshore from those of the other stocks (6.6 vs. 5.4–5.7). The variances of the posterior distributions are large compared to the differences between them (Figure 5).

In 1996, there appears to have been slightly more separation along the sampling transect. The Naknek-Kvichak District stock and the Ugashik District stock

Table 3. Means and standard deviations (SD) of the Bayes posterior distributions for mean and standard deviations of the distributions of stocks along the Port Moller sampling transect for each year that Port Moller data is available electronically, and resulting estimates of the expected proportion of each stock's sample catch at each sampling station.

| | | Median of Posterior Distribution | | Proportion of Expected Sample Catch by Station | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | District | Mean | SD | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 |
| 1993 | Nushagak | 5.7 | 3.4 | 0.06 | 0.13 | 0.22 | 0.24 | 0.19 | 0.11 | 0.04 | 0.01 |
| | N-K[a] | 6.6 | 2.8 | 0.02 | 0.08 | 0.18 | 0.28 | 0.25 | 0.14 | 0.05 | 0.01 |
| | Egegik | 5.4 | 3.5 | 0.07 | 0.15 | 0.22 | 0.23 | 0.18 | 0.10 | 0.04 | 0.01 |
| | Ugashik | 5.6 | 2.7 | 0.03 | 0.12 | 0.25 | 0.29 | 0.20 | 0.08 | 0.02 | 0.00 |
| 1996 | Nushagak | 5.5 | 3.5 | 0.07 | 0.14 | 0.22 | 0.23 | 0.18 | 0.10 | 0.04 | 0.01 |
| | N-K[a] | 4.2 | 3.1 | 0.11 | 0.21 | 0.27 | 0.23 | 0.13 | 0.05 | 0.01 | 0.00 |
| | Egegik | 3.4 | 1.9 | 0.09 | 0.33 | 0.40 | 0.16 | 0.02 | 0.00 | 0.00 | 0.00 |
| | Ugashik | 4.4 | 2.6 | 0.08 | 0.20 | 0.31 | 0.26 | 0.12 | 0.03 | 0.00 | 0.00 |
| 1997 | Nushagak | 7.1 | 2.4 | 0.00 | 0.03 | 0.14 | 0.30 | 0.31 | 0.16 | 0.04 | 0.01 |
| | N-K[a] | 5.5 | 2.6 | 0.03 | 0.13 | 0.26 | 0.30 | 0.19 | 0.07 | 0.01 | 0.00 |
| | Egegik | 4.6 | 1.8 | 0.02 | 0.16 | 0.42 | 0.33 | 0.07 | 0.00 | 0.00 | 0.00 |
| | Ugashik | 5.2 | 2.6 | 0.04 | 0.15 | 0.28 | 0.30 | 0.17 | 0.05 | 0.01 | 0.00 |
| 1998 | Nushagak | 5.8 | 1.5 | 0.00 | 0.02 | 0.26 | 0.52 | 0.18 | 0.01 | 0.00 | 0.00 |
| | N-K[a] | 6.7 | 1.8 | 0.00 | 0.02 | 0.15 | 0.41 | 0.34 | 0.09 | 0.01 | 0.00 |
| | Egegik | 4.3 | 1.6 | 0.01 | 0.17 | 0.49 | 0.29 | 0.04 | 0.00 | 0.00 | 0.00 |
| | Ugashik | 4.8 | 2.4 | 0.05 | 0.17 | 0.31 | 0.29 | 0.14 | 0.03 | 0.00 | 0.00 |
| 1999 | Nushagak | 6.0 | 3.6 | 0.06 | 0.12 | 0.20 | 0.23 | 0.20 | 0.12 | 0.06 | 0.02 |
| | N-K[a] | 5.4 | 3.2 | 0.06 | 0.14 | 0.23 | 0.25 | 0.18 | 0.09 | 0.03 | 0.01 |
| | Egegik | 5.5 | 3.4 | 0.07 | 0.14 | 0.22 | 0.24 | 0.18 | 0.10 | 0.04 | 0.01 |
| | Ugashik | 6.2 | 2.5 | 0.01 | 0.08 | 0.22 | 0.32 | 0.25 | 0.10 | 0.02 | 0.00 |
| 2000 | Nushagak | 10.3 | 0.9 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.80 | 0.15 | 0.00 |
| | N-K[a] | 8.8 | 3.2 | 0.01 | 0.03 | 0.08 | 0.17 | 0.25 | 0.24 | 0.16 | 0.07 |
| | Egegik | 9.8 | 1.3 | 0.00 | 0.00 | 0.00 | 0.01 | 0.23 | 0.62 | 0.14 | 0.00 |
| | Ugashik | 10.0 | 2.0 | 0.00 | 0.00 | 0.01 | 0.06 | 0.24 | 0.39 | 0.24 | 0.06 |

[a] Naknek-Kvichak District

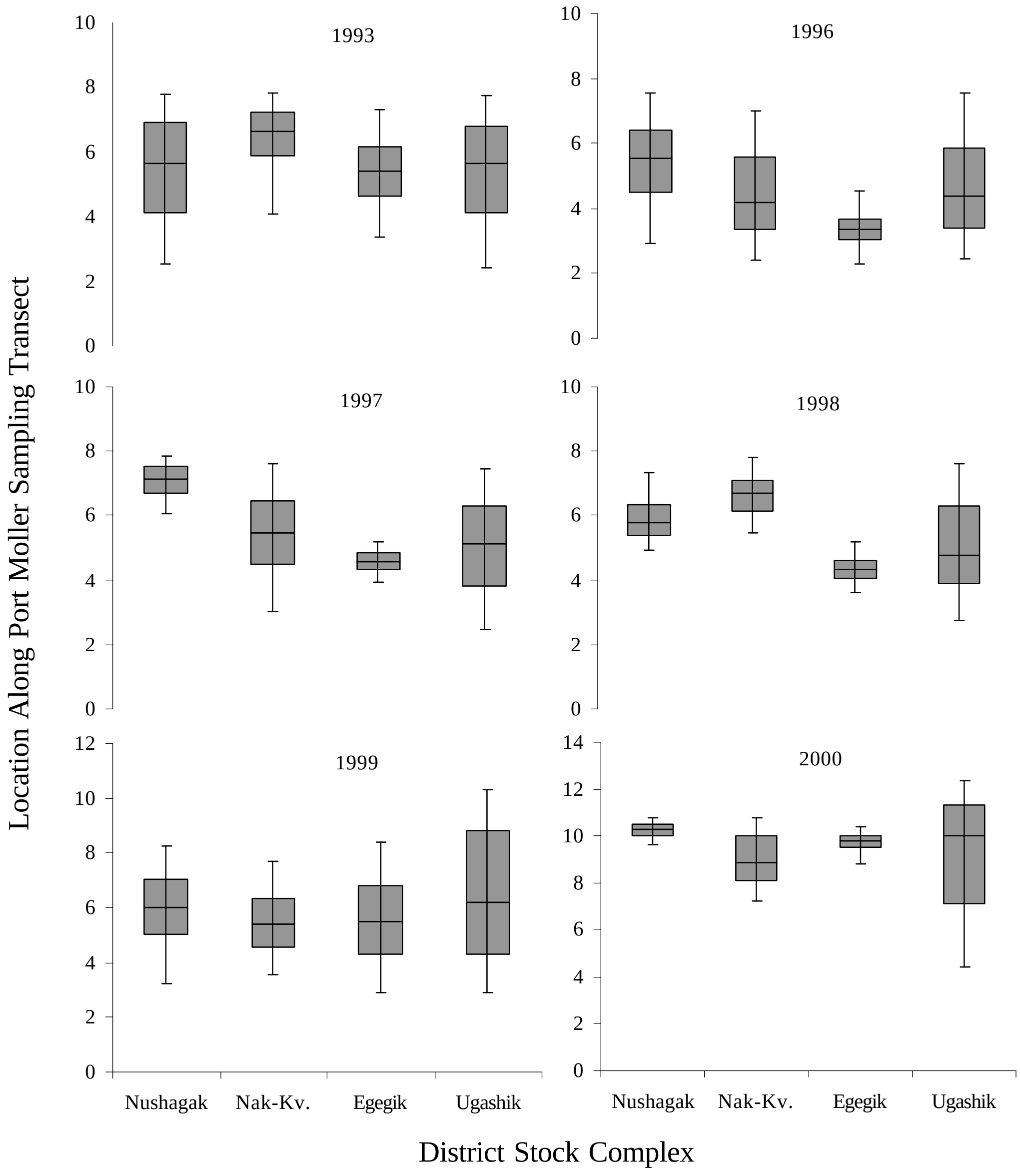


Figure 5. Bayes posterior distributions for mean location parameters for each year that Port Moller data is available electronically, 1993 and 1996–2000. Box plots indicate means (maximum likelihood estimates) and middle quartiles; error bars indicate 5th and 95th percentiles. Station 0 was not sampled during these years, but it is included for reference.

had MLEs with relatively central locations (4.2 and 4.4, respectively), while the Nushagak District stock's MLE was approximately a station offshore (5.5), and the Egegik District stock's MLE was approximately a station further inshore (3.4). In 1996, the variance of the posterior distribution for the Egegik District stock's MLE was much smaller than the others, which again were relatively large compared to the differences between them (Figure 5).

Results for 1997 show a similar pattern, although all stocks appear to have crossed the transect approximately one station further offshore. The central location of the stocks' MLEs of the Naknek-Kvichak and Ugashik Districts are 5.2 and 5.5, respectively, while the relatively offshore MLE of the Nushagak District stock is 7.1 and the relatively inshore MLE of the Egegik District stock is 4.6. In 1997, the variances of the poster distributions of the stock's mean locations for both the Nushagak and the Egegik Districts are relatively small (Figure 5).

Results for 1998 indicate relative positions along the sampling transect more closely resembling those of 1993. The Naknek-Kvichak District stock's MLE is the furthest offshore (6.7), the Egegik District stock's

MLE is the furthest inshore (4.3), and the stocks' MLEs of the Nushagak and Ugashik Districts are intermediate (5.8 and 4.8, respectively). During 1998, the variances of the posterior distributions for the stocks of the Nushagak, Naknek-Kvichak, and Ugashik Districts were all relatively small compared to the differences in their MLEs (Figure 5).

In 1999, the stocks' MLEs of the Nushagak and Ugashik Districts were further offshore (6.0 and 6.2, respectively) than the stocks' MLEs of the Egegik and Naknek-Kvichak Districts (5.5 and 5.4, respectively). In 1999, the posterior distributions of all stocks had large variances relative to the differences in their MLEs, but that of the Ugashik District stock is particularly large (Figure 5).

In 2000, the entire run traveled much further offshore than in any other year, and spatial distributions appeared to be more compact. However, as in 1999, the stocks' MLEs of the Nushagak and Ugashik Districts were further offshore (10.3 and 10.0, respectively) than the stocks' MLEs of the Egegik and Naknek-Kvichak Districts (9.8 and 8.8, respectively). The variances of the posterior distributions for the Naknek-Kvichak District, and particularly the Ugashik District stocks, were large relative to the differences in their MLEs.

Overall, stock separation appeared to be in the expected directions based on the final destination of the stocks; the stocks of the Nushagak and Naknek-Kvichak Districts tended to be located further offshore than the stocks of the Egegik and Ugashik Districts, although the spatial location of the Ugashik District's stock was the least discernable.

## DISCUSSION

The spatial distributions of each district's stocks along the Port Moller sampling transect were subject to a significant degree of annual variability (Figure 5). However, several patterns are discernable. The Nushagak District stocks tend to be located further offshore and Egegik District stocks tend to be located further inshore. These results were expected based on the geographic destinations of those stocks (Figure 1), as well as by the conclusions of Straty (1975). The central location of the Naknek-Kvichak District stock appears more variable, ranging from locations offshore of the Nushagak District stock to approximately equal to that of the Egegik District stock. The location of the Ugashik District stock was not consistently discernable, as evidenced by the large variance of the posterior distributions. An additional observed trend was that of the overall locations of the combined stocks, which appear to be shifting further offshore during the past several years (Figure 5).

Two key questions arise with our interpretation of these results: how unique is the age composition of each stock, and what is the relative magnitude of each stock? We found that the overall clarity of the posterior distributions, as quantified by their standard deviations, appear to be more dependent on the stock's relative magnitude than on their deviations from the mean age composition. Even if the age composition between stocks is identical, the model will estimate the positions of stocks based on abundance alone. In such a case, there would be no basis for differentiation between them, so the resulting posterior distributions would have identical parameters to that of the total catch, even though they may actually be spatially separated. Extremely low relative magnitudes, however, result in the obvious 'non-result' of a near uniform posterior distribution.

Although our results indicate that the migration patterns of Bristol Bay's component stocks were not consistent from year to year, we believe the exercise to be valuable for several reasons. As more data from the Port Moller test fishery become available, an identifiable pattern may emerge for sockeye salmon migrating to Bristol Bay. For example, results from these six years suggest that separation may be greater in years when ocean temperatures are warmer (Flynn and Hilborn, unpublished data). The migrating salmon may also be affected directly by temperature conditions, or possibly by current regimes (Favorite and Ingraham 1972) or salinity distribution (D. E. Rogers, University of Washington, Seattle, personal communication). Although migration routes may not be consistent, they may be consistently influenced by one or more easily quantifiable factors, identifiable from the model's results. Moreover, the model could easily be adapted to interpret data from another test fishery, where more consistent patterns may occur.

We believe that the model introduced herein provides a convenient method for interpreting the information contained in abundance-at-age data. Aside from the ease and economy of data acquisition, the involved calculations are simple and the required computer code can be written with little or no computer programming experience. Age information may be used independently, as in our example, or as an additional source of information to complement or compare to genetic or scale pattern data. We urge readers not to overlook the information contained in abundance-at-age data, which may be valuable for modeling the distribution and abundance of component stocks of migrating salmon.

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