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Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Biophysical Parameters: 2013 Returns and 2014 Forecast

by

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Abstract

The Southeast Alaska Coastal Monitoring (SECM) project has been sampling juvenile salmon (*Oncorhynchus* spp.) and associated biophysical parameters in the northern region of Southeast Alaska (SEAK) annually since 1997 to better understand effects of environmental change on salmon production. A pragmatic application of the annual sampling effort is to forecast the abundance of adult salmon returns in subsequent years. Since 2004, peak juvenile pink salmon catch-per-unit-effort ($CPUE_{cal}$), adjusted for highly-correlated biophysical parameters, has been used to forecast adult pink salmon harvest (*O. gorbuscha*) in SEAK. The 2013 SEAK pink salmon harvest was an all-time record 94.7 million fish, the largest harvest since catch records were recorded dating back to 1900. The SECM forecast was for a strong harvest of 53.8 M fish, but the forecast was 43% lower than the actual record harvest. Eight of ten forecasts over the 2004-2013 period have been within 17% of the actual harvest, with an average forecast deviation of 7%. The forecast for 2013 joins the forecast of 2006 as exceptions to this degree of accuracy. In both of these years, the $CPUE_{cal}$ model did correctly indicate the direction of the harvest trends (lower in 2006, higher in 2013), but underestimated the degree of these trends. These results show that the $CPUE_{cal}$ information has great utility for forecasting year class strength of SEAK pink salmon, but additional information may be needed to avoid forecast "misses." For the 2014 forecast, model selection included a review of ecosystem indicator variables and considered additional biophysical parameters to improve the simple single-parameter juvenile $CPUE_{cal}$ forecast model. We also examined the use of a different CPUE parameter using catch per distance trawled, $CPUE_{ttd}$. The "best" forecast model for 2014 included two parameters, the Icy Strait Temperature Index (ISTI) and juvenile $CPUE_{cal}$. The 2014 forecast of 29.9 M fish from this model, using juvenile salmon data collected in 2013, had an 80% bootstrap confidence interval of 26-38 M fish.

Introduction

The Southeast Alaska Coastal Monitoring (SECM) project has been sampling juvenile salmon (*Oncorhynchus* spp.) and associated biophysical parameters in northern Southeast Alaska (SEAK) annually since 1997 to better understand effects of environmental change on salmon production (e.g., Orsi et al. 2011, 2012a, 2013a). A pragmatic application of the information provided by this effort is to forecast the abundance of adult salmon returns in subsequent years. Mortality of juvenile pink (*O. gorbuscha*) and chum (*O. keta*) salmon is high and variable during their initial marine residency, and is thought to be a major determinant of year-class strength (Parker 1968; Mortensen et al. 2000; Willette et al. 2001; Wertheimer and Thrower 2007). Sampling juveniles after this period of high initial mortality may therefore provide information that can be used with associated environmental data to more accurately forecast subsequent adult year-class strength.

Because of their short, two-year life cycle, pink salmon are a good species to test the utility of indexes of juvenile salmon abundance in marine habitats for forecasting. Also, sibling recruit models are not available for this species because no leading indicator information exists (i.e., only one age class occurs in the fishery). Spawner/recruit models have also performed poorly for predicting pink salmon returns, due to high uncertainty in estimating spawner abundance and high variability in marine survival (Heard 1991; Haeseker et al. 2005). The exponential smoothing model that the Alaska Department of Fish and Game (ADFG) employs using the time series of annual harvests has provided more accurate forecasts of SEAK pink salmon than spawner/recruit analyses (Plotnick and Eggers 2004; Eggers 2006). Wertheimer et al. (2006) documented a highly significant relationship between annual peak juvenile pink salmon catch-per-unit-effort (CPUE) from the SECM research in June or July and the SEAK harvest. These CPUE data used as a direct indicator of run strength have been supplemented with associated biophysical data in some years (Wertheimer et al. 2011, 2012, 2013), or used as auxiliary data to improve the ADFG exponential smoothing model (Piston and Heinl 2013, 2014). Recently, efforts have been made to incorporate climate change scenarios into stock assessment models (Hollowed et al. 2011) and to examine relationships of ecosystem metrics to salmon production (Miller et al. 2013; Orsi et al. 2012b, 2013b). The SECM project has developed a 17-yr time series of ecosystem metrics for such applications (Fergusson et al. 2013; Orsi et al. 2012b, 2013b; Sturdevant et al. 2013 a, b). This paper reports on the efficacy of using the SECM time series data for forecasting the 2013 SEAK pink salmon harvest and on the development of a prediction model for the 2014 forecast.

Methods

Study Area

This paper uses prior year information on juvenile salmon and their associated biophysical (biological and physical) parameters to forecast adult pink salmon harvest in (Table 1). Pink salmon spawning aggregates originate from over 2,000 streams throughout the SEAK region (Baker et al. 1996), and are comprised of 97% wild stocks (Piston and Heinl 2013, 2014). Data on juvenile pink salmon abundance, size, and growth, and associated biophysical parameters have been collected by the SECM project annually since 1997; detailed descriptions of the sampling locations and data collections have been reported in annual NPAFC documents (e.g., Orsi et al. 2011, 2012a, 2013a). The SECM data used in the forecasting models are from eight stations along two transects across Icy Strait in the northern region of SEAK, sampled monthly from May to August 1997-2013 (Figure 1).

Data Descriptions and Sources

Parameters considered for forecasting models included pink salmon harvest as the dependent (response) variable and 21 potentially-predictive biophysical variables collected by SECM or accessed from indexes of broad-scale environmental conditions that influence temperature and productivity in the Gulf of Alaska (GOA). The harvest data were collected and reported by the ADFG (2013), and included the total harvest for SEAK except for a small number of fish taken in the Yakatat area (Figure 1). One caveat for using harvest as the dependent variable in juvenile salmon CPUE forecast models is that juvenile salmon CPUE should be an index of total run (harvest plus escapements to the spawning streams) rather than harvest alone. In contrast to harvest data, the escapement index of pink salmon in SEAK is not a precise measure of actual escapement. Wertheimer et al. (2008) examined the use of scaled escapement index data with harvest data to develop an index of total run; however, this total run index did not improve the fit of the CPUE forecast model, because it was highly correlated with harvest (r = 0.99). In addition, a forecast of total run must assume an average exploitation rate (percent of fish harvested in relation to the total return) to predict harvest, i.e., the equivalent of assuming that harvest directly represents total run strength. For these reasons, the use of accurate and precise harvest data as a proxy for total run is preferred for developing the forecast models.

Biophysical parameters examined for forecasting pink salmon harvest represent a subset of the monthly SECM metrics and others with potential influence on pink salmon harvest (Table 1).

<u>Juvenile pink salmon metrics</u>

Five indexes of juvenile pink salmon abundance or phenology in northern SEAK were evaluated. One index parameter was the average Ln(CPUE+1) for catches in either June or July, whichever month had the highest average in a given year, y, where effort was a standard trawl haul (CPUEcal, Table 1). The $CPUE_{cal}$ data was adjusted using calibration factors to account for differences in fishing power among vessels (Wertheimer et al. 2010; Orsi et al. 2013). This parameter has been previously identified to have the highest correlation with harvest and to provide the best performance for forecasting harvest (Wertheimer et al. 2006, 2012, 2013). The second parameter, evaluated for the first time in this report, was the average (Ln(catch+1)/trawl track distance) for catches in either June or July, whichever month had the highest average in a given year, y ($CPUE_{ttd}$, Table 1). This parameter was evaluated as an alternative to the current need to calibrate $CPUE_{cal}$ for changes in vessel fishing power. The third parameter was the average Ln(CPUE+1) for August in northern SEAK (AugustCPUE, Table 1). This parameter was included as a possible indicator of delayed migratory timing through northern SEAK that could be associated with low year-class strength (Wertheimer et al. 2008). The fourth parameter was the percentage of juvenile pink salmon represented in the total annual catch of all five species of juvenile salmon, a proxy for the relative abundance and distribution of pink salmon each year. The fifth parameter was the actual month in which Peak CPUE was observed each year, also chosen to represent migratory timing or phenology (seasonality). Parameter values for the peak month in each year were assigned as: June = 1, July = 2, and August = 3.

Three measures of growth and condition of juvenile pink salmon were considered as indicators of biological variation that could influence pink salmon harvest (Table 1). These included: 1) a weighted average length (mm, fork length) adjusted to a standard date (Pink Salmon Size July 24); 2) the average annual residuals derived from the regression relationship of all paired Ln(weights) and Ln(lengths) for pink salmon collected during SECM sampling from 1997-2012 (Condition Index); and 3) the average energy content (calories/gram wet weight, determined by bomb calorimetry) of subsamples of juvenile pink salmon captured in July of each year (Energy Content).

Zooplankton metrics

Two measures of zooplankton standing crop were evaluated as indicators of secondary production (or prey fields) that could influence pink salmon harvest (Table 1). These were: 1) average June and July 333-µm bongo net standing crop (displacement volume divided by water volume filtered, ml/m^3), an index of integrated mesozooplankton to 200-m depth (June/July Zooplankton Total Water Column); and 2) average density ($number/m^3$) of preferred prey available in June, an index computed from total density of six zooplankton taxa typically utilized by planktivorous juvenile salmon in summer (Sturdevant et al. 2004) and present in integrated 333-µm bongo net samples (June Preferred Prey). In previous reports, we also considered average June and July NORPAC net 243-µm settled volume (ml), an index of upper 20-m water column small zooplankton biomass (June/July Average Zooplankton 20-m). We decided to drop this parameter because of its lack of correlation with adult harvest or juvenile size and condition, and because important prey items of juvenile pink salmon were not effectively sampled with this gear.

Local and basin-scale physical metrics

Six physical measures were chosen to represent local conditions in the northern region of SEAK that could be linked to the growth and survival of juvenile salmon, including: 1) May upper 20-m integrated average water temperature (°C) adjusted to a standard date of May 23 (May 20-m Integrated Water Temperature); 2) June upper 20-m integrated average water temperature (°C, June 20-m Integrated Water Temperature); 3) the annual Icy Strait Temperature Index (°C; ISTI, see below); 4) June average mixed-layer depth (MLD, June Mixed-layer Depth); 5) July 3-m salinity (PSU, July 3-m Salinity); and 6) freshwater outflow from the Mendenhall River near Juneau from March through May (cfs; MR Spring Flow, see below). The ISTI was calculated as the summer grand average of the 20-m integrated water column temperature, using the monthly averages of ≥ 160 temperatures taken at 1-m increments for May, June, July and August each year. The MR spring flow was calculated as the sum of the monthly average flows for March, April, and May (data source: US

Geological Survey). Also evaluated were the first principle component scores for the six physical measures (PC1, Table 1).

Three indexes of annual basin-scale physical conditions that affect the entire GOA and North Pacific Ocean were also evaluated for their influence on pink salmon harvest (Table 1). One was the November to March average for the Pacific Decadal Oscillation (PDO) during the winter prior to juvenile pink salmon seaward migration, year y-1. The PDO is the first principle component of water temperatures from a broad array of sites in the North Pacific that has been linked to year-class strength of juvenile salmon in their first year at sea (Mantua et al. 1997). The second basin-scale index was the June-July-August average of the North Pacific Index (NPI) in year y; NPI is a measure of atmospheric air pressure in the GOA thought to affect upwelling and downwelling oceanographic conditions (Trenberth and Hurrell 1994); higher values indicate a relaxation of downwelling along the Alaska coast adjacent to the eastern GOA and a widening of the Alaska Coastal Current. The third basin-scale index was the average for the November to March Multivariate El Niño Southern Oscillation (ENSO) Index (MEI; NCDC 2007) prior to juvenile pink salmon seaward migration in year y. Conditions measured by the MEI in the equatorial Pacific reach Alaska the following summer; thus MEI values reflect conditions experienced by juvenile salmon in year y.

Forecast Model Development

We applied the five-step process described by Wertheimer et al. (2011) to identify the "best" forecast model for predicting pink salmon harvest in SEAK. The first step was to develop a regression model of annual harvest and juvenile salmon CPUE, with physical conditions, zooplankton measures, and pink salmon growth indexes considered as additional parameters (Table 1). The potential model was

$$\text{Harvest} = \alpha + \beta(\text{Ln}(\text{CPUE}+1)) + \gamma_1 X_1 + ... + \gamma_n X_n + \varepsilon,$$

where γ is the coefficient for biophysical parameter *X*. Backward/forward stepwise regression with an alpha value of $P < 0.05$ was used to determine whether a biophysical parameter was entered into the model. In separate runs, we used $CPUE_{cal}$ and $CPUE_{ttd}$ for the CPUE variable.

The second step was to calculate the Akiake Information Criterion (AIC) for each significant step of the stepwise regression, to prevent over-parameterization of the model. The AIC was corrected (AIC_c) for small sample sizes (Shono 2000).

The third step was a jackknife approach to evaluate "hindcast" forecast accuracy over the entire SECM time series. This procedure generated forecast model parameters by excluding a year of juvenile data, then used the excluded year to "forecast" harvest for the associated harvest year; this process was repeated so that each year in the time series was excluded sequentially and used to generate a forecast. The average and median relative forecast error was then calculated for each model.

The fourth step in developing the model was to compare bootstrap confidence intervals (CIs) for the regression prediction intervals (PIs) of the forecasts to examine the effect of process error and measurement error on the forecasts. For the bootstrap approach, monthly juvenile pink salmon catches for each year were randomly re-sampled n_{my} times, where *n* is the number of hauls in month *m* in year *y*, and then the re-sampled catches for each month and year were averaged. Average simulated catches of juvenile pink salmon for the years 1997-2012 were used to construct the regression models with SEAK harvest as the dependent variable, and the appropriate averages of the simulated juvenile catches for 2013 were used to forecast the 2014 harvest. This process was repeated 1,000 times, generating 1,000 forecasts for each model. The forecasts were ordered from lowest to highest, and the lowest and highest 10% were removed to define the 80% bootstrap CIs. These results were then compared to the PIs for the regression model based on the observed annual average catches.

The fifth step for selecting the "best" forecast model was to evaluate model forecasts in the context of auxiliary run strength indicators. Parameters that had significant bivariate correlation with the SEAK harvest (Table 1) or that were significant auxiliary variables in the stepwise regression model, were ranked for each of the 16 years of SECM data, and tabulated with ranks of the SEAK harvest by year. These parameters were considered to be indicators of ecosystem conditions that could contribute to salmon survival (Peterson et al. 2012; Orsi 2013c), and their relative ranks in 2013 were considered for selecting the best regression model to forecast the 2014 harvest.

Results

2013 Forecast Efficacy

In 2013, the SECM forecast of 53.8 M pink salmon was 43% lower than the actual 2013 harvest of 94.7 M fish (Table 2). Harvest in 2013 was outside the 80% confidence intervals for the forecasts (Figure 2).

2014 Forecast

Bivariate correlations were computed between SEAK pink salmon harvests for 2004-2013 using 20 potential prediction variables (Table 1). Five of these variables were significantly ($P \leq 0.05$) correlated with SEAK pink salmon harvest; four of the five were measures of juvenile pink salmon abundance or timing. $CPUE_{cal}$ and $CPUE_{ttd}$ were the parameters most highly correlated with harvest ($r = 0.82$ and 0.85, respectively. The percentage of pinks in the catches of juvenile salmon was also significantly correlated with harvest (r = 0.67), Seasonality was negatively correlated with harvest ($r = -0.63$), indicating early (June) peak CPUE is associated with higher harvests and late (August) peak CPUE is associated with lower harvests. One basin scale variable, the NPI, was positively correlated with harvest ($r = 0.61$), indicating that relaxed downwelling and expansion of the ACC is associated with higher harvests.

We used the stepwise regression approach with two measures of juvenile abundance, the standard $CPUE_{cal}$ and the alternative $CPUE_{ttd}$, to examine the relationship between SEAK harvest of pink salmon with an index of juvenile abundance and the other biophysical parameters listed in Table 1. For $CPUE_{cal}$, a two-parameter model including ISTI explained 77% of the variability in the harvest data (Adjusted R^2), compared to 67% for the simple linear regression with $CPUE_{cal}$ (Table 3). The AIC_c was lower for the two-parameter model, indicating that this model is not over-parameterized. The 2014 forecasts using 2013 juvenile Peak CPUE were 30.0 M for the simple $CPUE_{cal}$ model and 29.9 M for the two-parameter model.

The $CPUE_{ttd}$ models had slightly better fits to the harvest data for both one-parameter and two-parameter models than did the $CPUE_{cal}$ models. The two-parameter model including May 20-m temperatures explained 84% of the variability in the harvest data (Adjusted R^2), compared to 70% for the simple linear regression with $CPUE_{ttd}$ (Table 3). The AIC_c was also lower for the two-parameter model for $CPUE_{ttd}$. The 2014 point forecasts using 2013 juvenile $CPUE_{ttd}$ were higher than for $CPUE_{cal}$, 43.3 M for the simple $CPUE_{ttd}$ model and 51.4 M for the two-parameter $CPUE_{ttd}$ model.

The jackknife analysis showed that both average and median absolute deviations were lower for the $CPUE_{cal}$ than the $CPUE_{ttd}$ models (Table 4). For both CPUE parameters, the average absolute deviation was lower for the two-parameter model, but the median absolute deviation was lower for the one-parameter models. The lowest average absolute deviation was 20.2% for the two-parameter $CPUE_{cal}$ model, and the lowest absolute median deviation was 10.5% for the one-parameter $CPUE_{cal}$ model. Over the jack-knife time series, the two-parameter model $CPUE_{cal}$ model provided better estimates in 10 of the 16 years compared to the one-parameter $CPUE_{cal}$ model, and in 12 of the 16 years compared to the two-parameter $CPUE_{ttd}$ model.

The 80% bootstrap CIs for the one- and two-parameter $CPUE_{cal}$ models for the 2014 forecast were compared with the 80% PIs from the regression equations (Figure 3). The regression PIs declined slightly as the number of parameters in the model increased, from an interval width of 38 M fish for the simple $CPUE_{cal}$ model to an interval width of 33 M fish for the two-parameter model. The decreasing interval widths reflected the improved model fit and the corresponding reduction in process error. However, the regression PIs did not incorporate measurement error because the observations of CPUE are single averages for each sampling year. The bootstrap CIs incorporated the measurement error by randomly re-sampling the catches for 1,000 iterations for each year. When measurement error was incorporated in this way, the bootstrap CIs were substantially narrower than for the regression PIs, and were approximately 11 M for both the one- and two-parameter models (Figure 3).

Table 5 and 6 list annual values and ranks of the five parameters in the 17-yr SECM time series that were significantly correlated with SEAK harvest ($CPUE_{cal}$, $CPUE_{ttd}$, Seasonality, % and NPI), as well as the significant auxiliary variables in the two-parameter regression models (ISTI and 20-m May temperatures). The correlated parameters have a positive association with harvest, while the temperature parameters have a negative effect on predicted harvest. In 2013, $CPUE_{cal}$, $CPUE_{ttd}$, % Pinks, and NPI were all below the average over the time series (Table 5) and in the fourth, second, fourth, and third quartile of ranks respectively (Table 6). Seasonality was a “2” (July peak), which is the mid-value possible. The temperature indexes were somewhat contradictory: 2013 ISTI was warmer than average and ranked in the third quartile, whereas May 20m temperatures were cooler than normal, the third coldest in the time series, and ranked in the fourth quartile.

Discussion

2013 Forecast Efficacy

The 2013 harvest of 94.7 M pink salmon in SEAK was an all-time record since 1900, when catch records were first available. The SECM forecast was for an excellent harvest of 53.8 M fish relative to historic harvests (Piston and Heinl 2014), but the forecast was still 43% lower than the actual harvest. Eight of ten forecasts produced over the period 2004-2013 have been within 17% of the actual harvest, with an average forecast deviation of 7%. The forecast for 2013 joins the forecast of 2006 as exceptions to this degree of accuracy. In both of these years, the CPUE model did correctly indicate the direction of the harvest trends (lower in 2006, higher in 2013). Interannual variation in overwinter mortality after the early marine period may also contribute to variability in year-class strength of Pacific salmon (Beamish and Mahnken 2001; Moss et al. 2005). The relatively consistent association of the CPUE index with subsequent harvest one year later suggests that marine survival after the early marine recruitment and survival for SEAK pink salmon tends to be relatively stable, while the poorer performance of the CPUE model in 2006 and 2013 suggests that such “downstream” variation can cause both large negative and positive deviations after the SECM sampling period. The Northeastern Pacific Ocean was anomalously warm in the summer of 2005, and as a result juvenile salmon may have encumbered higher energetic demands related to ocean temperature, as well as increased interactions with unusual migratory predators and competitors documented to occur at this time, such as Humboldt squid (*Dosidicus gigas*), blue sharks (*Prionace glauca*), and Pacific sardines (*Sardinops sagax*) (Orsi et al. 2006). In contrast, when SECM process studies documented predation impact on juvenile salmon abundance by immature, one-ocean sablefish (*Anoplopoma fimbria*) in inside waters of SEAK (Sturdevant et al. 2009) the harvest hindcast for 2000 was more accurate since predation was occurring during the early season sampling in Icy Strait. In 2013, pink salmon returns were at record highs for Alaska stocks from SEAK to the Alaska Peninsula (Munro and Tide 2014), suggesting that conditions in the Gulf of Alaska (GOA) were especially favorable for juveniles entering the GOA in 2012.

Information on environmental conditions affecting juvenile pink salmon migrating through SEAK waters to the GOA could potentially improve forecast accuracy for the juvenile CPUE prediction model, and could help avoid large forecast error due to variability in survival that occurs after the CPUE data are collected. Incorporating biophysical data in the forecast models since 2007 has improved forecasts relative to the simple $CPUE_{cal}$ model in five of the seven years it has been used (Table 7), with an average deviation of 17% versus 19%. However, even though incorporating ISTI data into the forecast model improved the 2013 forecast to some degree, the two-parameter prediction was still well below the actual harvest. One problem with seeking a “silver-bullet” of environmental data for improving forecasts is that the signal for physical conditions in the GOA that may affect survival, e.g. NPI or temperature during the pink salmon's winter at sea, have not occurred or are not available in time for preseason forecasting in November or December.

The ADFG forecast for pink salmon in SEAK has been based on an exponential smoothing model since 2004 (Eggers 2006). This model uses the trend from previous harvests to predict future harvest, which assumes that year-class performance responds to persistent patterns of environmental conditions. However, no mechanisms are identified or metrics used to adjust the trend analysis for shifts in freshwater or marine environmental patterns. Thus, the trend analysis predicted a large return (52 M) in 2006, whereas the actual return was very poor (12 M). As a result, since 2006, the ADFG forecast has used the SECM $CPUE_{cal}$ data to modify the exponential smoothing model forecast (e.g., Heinl 2012; Piston and Heinl 2013). The ADFG forecast for SEAK pink salmon returning in 2013 was 54 M (Piston and Heinl 2013), with a -43% deviation from the actual harvest, whereas the unmodified exponential smoothing model provided a forecast of 52 M, with a -44% deviation from the actual harvest (Table 2). Thus, the incorporation of the juvenile data slightly improved the ADFG forecast in 2013, and the modified trend analysis forecasts have improved on the original trend model in five of seven years since implementation (Table 7). Also, the average absolute deviation (and range) for the modified model from 2007-2013 has been substantially better than the model adjusted with the juvenile data, 17% (range, 4-43%) versus 34% (range, 6-81%). This overall improved performance for the ADFG model further demonstrates the utility of the juvenile pink salmon abundance index for forecasting year-class strength. In this case, the $CPUE_{cal}$ is used to modify and adjust a time-series analysis of harvest trends, a very different approach to the SECM forecast approach that uses the $CPUE_{cal}$ as the main predictive parameter. Although the two modeling approaches are fundamentally different, they have performed similarly for 2007-2013 (Table 7).

2014 Forecast

For the 2014 forecast, we examined the use of an alternative CPUE parameter, $CPUE_{ttd}$. This measure of juvenile pink salmon catch was slightly better correlated with SEAK harvest than the $CPUE_{cal}$ parameter (Table 1), and provided better regression model fits to the harvest data (Table 3). $CPUE_{ttd}$ has the advantage of direct calculation from the sampling data without requiring calibration for differences in vessel fishing power. The jackknife analysis gave a hindcast forecast for 2013 of 63 M for the one-parameter and 75 M for the two-parameter model. This latter forecast would have been considerably closer to the actual harvest than the $CPUE_{cal}$ forecast of 54 M.

Although $CPUE_{ttd}$ fit the data better and provided a better hindcast for the 2013 harvest, we decided that it was not a better predictor than $CPUE_{cal}$ for the 2014 SEAK harvest for two reasons. First, the jackknife analysis across all years indicated this parameter did not predict harvest as well as $CPUE_{cal}$ (Table 4). Second, the higher 2014 forecasts of the $CPUE_{ttd}$ models were not consistent with the rankings of the ecosystem indicators in Table 7. The ecosystem indicators were more consistent with harvests lower than average observed for the SECM time series. The $CPUE_{cal}$ models predicted harvests of around 30 million pink salmon, which is at the low end of the "strong" range, just1 M above the "average" range defined by

ADFG (Piston and Heinl 2014). In contrast, $CPUE_{ttd}$ models forecast 43-51 million, which are in the high end of the “strong” and low end of the “excellent” harvest ranges.

For the $CPUE_{cal}$ models, there was little difference in the 2014 forecasts between the one- and two-parameter models. We selected the two-parameter model including Peak $CPUE_{cal}$ + ISTI as the “best” model for the 2014 SECM forecast based on model fit and the AIC_c. This model predicts a harvest of 29.9 million, with an 80% bootstrap confidence interval of 24-36 million. The jackknife analysis showed lower average deviations for predictions for the two-parameter model, but lower median deviations for the one-parameter model (Table 4). The two-parameter model, however, provided better hindcasts for 10 of the 16 past years. We used the bootstrap confidence interval for the forecast because the bootstrap procedure accounts for measurement error in the $CPUE_{cal}$.

In previous years (e.g., Wertheimer et al. 2011, 2013), temperature indexes, either ISTI or May 20m temperatures, have been identified as the environmental parameter significantly improving the one-parameter $CPUE_{cal}$ model. Colder temperatures have been associated with higher harvests than predicted by CPUE alone. For the 2014 harvest forecast, the ISTI improved the $CPUE_{cal}$ model significantly more than the May temperatures did. Because it takes into account May-August temperatures, the ISTI provides an average seasonal signal of the environment experienced by juvenile pink salmon in SEAK waters in their first summer at sea, and it is correlated with the MEI (Fergusson et al. 2013). As with May temperatures, colder ISTI values are associated with higher harvests than predicted using CPUE alone; thus the slightly warmer than average ISTI in 2013 caused a small decrease in the forecast of the two-parameter model relative to the one-parameter model. Interestingly, May 20m temperatures entered the $CPUE_{ttd}$ model rather than ISTI, and because May 20m temperatures were actually cooler than average, resulted in a higher forecast from the two-parameter $CPUE_{ttd}$ model (Table 3). The differences in May 20m temperatures and ISTI relative to average values of these data series were consistent with climate conditions in SEAK in 2013. April and May were cooler than normal, but June-August was warmer than normal.

The 2014 SECM forecast of 30 M pink salmon would be the sixth lowest harvest during the SECM time series (since 1998), but it would be the highest harvest of even-year pink salmon returns in SEAK since 2004 (Table 5). It would also be in the upper 40% of harvests since 1960 (Piston and Heinl 2014), and indicative of a recovery of the even-year run in SEAK since the very poor return in 2006. The ADFG forecast for 2014, using the exponential smoothing model modified with SECM Peak CPUE data, was 22 M (Piston and Heinl 2014). This forecast is 27% lower than the SECM, and would continue the pattern of below average harvests of even year pink salmon realized since 2006. We await the results of the 2014 fishery to further examine the efficacy of these forecasting methods for SEAK pink salmon.

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Table 1.—Correlation coefficients for juvenile pink salmon biophysical parameters and ecosystem metrics in year *y* for 1997-2012 with adult pink salmon harvest in Southeast Alaska (SEAK) in year *y* + 1. Parameters with statistically significant correlations are in bold text; the probabilities were not adjusted for multiple comparisons.

Parameter	***r***	***P*-value**
Juvenile pink salmon abundance		
$CPUE_{cal}$	**0.82**	**<0.001**
$CPUE_{ttd}$	**0.85**	**<0.001**
AugustCPUE	-0.10	0.701
Seasonality	**-0.63**	**0.009**
Percentage of Juvenile Pinks	**0.67**	**0.004**
Juvenile pink salmon growth and condition		
Pink Salmon Size July 24	0.15	0.569
Condition Index	0.12	0.653
Energy Content	0.12	0.658
Zooplankton standing crop		
June/July Average Zooplankton Total Water Column	0.09	0.731
June Preferred Prey	0.03	0.917
Local-scale physical conditions		
May 20-m Integrated Water Temperature	0.05	0.845
June 20-m Integrated Water Temperature	-0.25	0.354
Icy Strait Temperature Index (ISTI)	-0.21	0.444
June Mixed-layer Depth	0.07	0.809
July 3-m Salinity	-0.01	0.983
MR Spring Flow (March-May)	-0.13	0.625
PC1	-0.17	0.530
Basin-scale physical conditions		
Pacific Decadal Oscillation (PDO, y-1)	0.02	0.948
Northern Pacific Index (NPI, y**)**	**0.61**	**0.012**
ENSO Multivariate Index (MEI, Nov (*y-1)*-March (*y*))	0.25	0.343

Table 2.—Southeast Coastal Monitoring (SECM) and Alaska Department of Fish and Game (ADFG) forecasts for 2013 pink salmon harvest in Southeast Alaska (SEAK). The ADFG forecasts are from Piston and Heinl (2013). NA = not applicable.

	Pink salmon (M of fish)	**Deviation from actual harvest**
SECM forecast	53.8	-43%
ADFG forecast (w/ $CPUE_{cal}$ data)	54.0	-43%
ADFG forecast (w/o $CPUE_{ttd}$ data)	52.0	-44%
Actual harvest	94.7	NA

Table 3.—Regression models relating juvenile pink salmon catch-per-unit-effort ($CPUE_{cal}$ and $CPUE_{cal}$) in year *y* to adult harvest in Southeast Alaska (SEAK) in year *y* +1, for *y* = 1997-2012. R^2 = coefficient of determination for model; AIC_c = Akiake Information Criterion (corrected); *P* = statistical significance of regression equation. Adult harvest is the total for SEAK harvest (except Yakutat).

Model	Adjusted R^2	AIC_C	Regression *P* -value	2014 Prediction (M)
Ln($CPUE_{cal}$)	67%	135.8	<0.001	30.0
Ln($CPUE_{cal}$) + ISTI	77%	131.2	<0.001	29.9
Ln($CPUE_{ttd}$)	70%	133.5	<0.001	43.3
Ln($CPUE_{ttd}$) + May20Temp	84%	125.6	<0.001	51.4

Table 4.—Results of hind-cast jackknife analysis of efficacy of harvest predictions for regression models relating juvenile salmon catch per unit effort (CPUE) in year *y* to Southeast Alaska (SEAK) harvest in year *y*+1.

Model	Average Absolute % Error	Median Absolute % Error
Ln($CPUE_{cal}$)	27.7	10.5
Ln($CPUE_{cal}$) + ISTI	20.2	11.2
Ln($CPUE_{ttd}$E)	31.3	18.0
Ln($CPUE_{ttd}$) + May20Temp	26.7	23.1

Table 5.—Annual measures for the Southeast Coastal Monitoring (SECM) time series for parameters either (a) significantly correlated with Southeast Alaska (SEAK) pink salmon harvest, or (b) significant as an auxiliary variable in multiple regression models relating juvenile pink salmon CPUE with SEAK pink salmon harvest. TBD: to be determined, table compiled prior to completion of 2014 harvest.

Harvest Year	**Juvenile Year**	**Harvest (M)**	**Ln ($CPUE_{cal}$)**	**Ln ($CPUE_{ttd}$)**	**Seasonality**	**% Pinks**	**NPI Index**	**ISTI**	**May 20m Temp**
1998	1997	42.5	2.5	2.22	July	0.17	15.6	9.5	7.3
1999	1998	77.8	5.6	5.32	June	0.42	18.1	9.6	7.8
2000	1999	20.2	1.6	1.39	July	0.10	15.8	9.0	6.5
2001	2000	67.0	3.7	3.34	July	0.25	17.0	9.0	6.6
2002	2001	45.3	2.9	2.64	July	0.28	16.8	9.4	7.1
2003	2002	52.5	2.8	2.48	July	0.26	15.6	8.6	6.4
2004	2003	45.3	3.1	2.74	July	0.22	16.1	9.8	7.4
2005	2004	59.1	3.9	3.39	June	0.31	15.1	9.7	7.6
2006	2005	11.6	2.0	1.72	Aug	0.26	15.5	10.3	8.3
2007	2006	44.8	2.6	2.27	June	0.26	17.0	8.9	6.7
2008	2007	15.9	1.2	0.97	Aug	0.15	15.7	9.3	7.0
2009	2008	38.0	2.5	2.18	Aug	0.29	16.1	8.3	6.1
2010	2009	23.4	2.1	2.68	Aug	0.27	15.1	9.6	7.3
2011	2010	59.0	3.7	5.01	June	0.61	17.6	9.6	8.3
2012	2011	21.3	1.3	1.64	Aug	0.25	15.7	8.9	6.7
2013	2012	94.7	3.2	4.26	July	0.48	16.7	8.7	6.7
2014	2013	TBD	1.9	2.67	July	0.12	16.0	9.2	6.5
Average		**44.8**	**2.7**	**2.76**		**0.28**	**16.2**	**9.3**	**7.1**

Table 6.—Annual rankings for the Southeast Coastal Monitoring (SECM) time series for parameters either (a) significantly correlated with Southeast Alaska (SEAK) pink salmon harvest, or (b) significant as an auxiliary variable in multiple regression models relating juvenile pink salmon CPUE with SEAK pink salmon harvest. TBD: to be determined, table compiled prior to completion of 2014 harvest.

Harvest Year	**Juvenile Year**	**Harvest**	**$CPUE_{cal}$**	**$CPUE_{ttd}$**	**Seasonality**	**% Pinks**	**NPI Index**	**ISTI**	**May 20m Temp**
1998	1997	10	11	12	2	14	13	7	6
1999	1998	2	1	1	1	3	1	6	3
2000	1999	14	15	16	2	17	10	12	15
2001	2000	3	3	5	2	11	3	11	13
2002	2001	7	7	9	2	6	5	8	8
2003	2002	6	8	10	2	10	14	16	16
2004	2003	8	6	6	2	13	7	2	5
2005	2004	4	2	4	1	4	16	3	4
2006	2005	16	13	14	3	8	15	1	2
2007	2006	9	9	11	1	9	4	14	11
2008	2007	15	17	17	3	15	11	9	9
2009	2008	11	10	13	3	5	8	17	17
2010	2009	12	12	7	3	7	17	5	7
2011	2010	5	4	2	1	1	2	4	1
2012	2011	13	16	15	3	12	12	1	10
2013	2012	1	5	3	2	2	6	15	12
2014	2013	TBD	14	8	2	16	9	10	14

Table 7.—Southeast Alaska (SEAK) pink salmon harvest (in millions of fish, M) and associated forecasts from Southeast Coastal Monitoring (SECM) juvenile $CPUE_{cal}$ models and Alaska Department Fish and Game (ADFG) exponential smoothing models. Accuracy of the forecast is shown in parentheses. For SECM, both the simple $CPUE_{cal}$ and the multi-parameter $CPUE_{cal}$ models are shown. Similarly for ADFG, both the exponential smoothing model with (2007-2013) and without the addition of the SECM juvenile $CPUE_{cal}$ data are shown (Steve Heinl, ADFG, personal communication).

		SECM $CPUE_{cal}$ Models		**ADFG Exp. Smoothing Models**	
Year	**SEAK harvest (M)**	$CPUE_{cal}$ **only**	**Multi-parameter CPUE**	**Trend analysis only**	**Trend analysis w/juvenile data**
2004	45	47 (4%)	NA	50 (11%)	NA
2005	59	59 (0%)	NA	49 (17%)	NA
2006	12	35 (209%)	NA	52 (333%)	NA
2007	45	38 (16%)	40 (10%)	58 (29%)	47 (4%)
2008	16	18 (13%)	16 (1%)	29 (81%)	19 (19%)
2009	38	37 (3%)	44 (17%)	52 (37%)	41 (8%)
2010	23	31 (33%)	29 (15%)	22 (6%)	19 (19%)
2011	59	55 (5%)[1]	45 (24%)[1]	46 (22%)	55 (6%)
2012	21	17 (17%)	18 (12%)	23 (8%)	17 (20%)
2013	95	48 (49%)	54 (43%)	52 (44%)	54 (43%)

[1]Single-parameter model was used for 2011 forecast (Wertheimer et al. 2011).

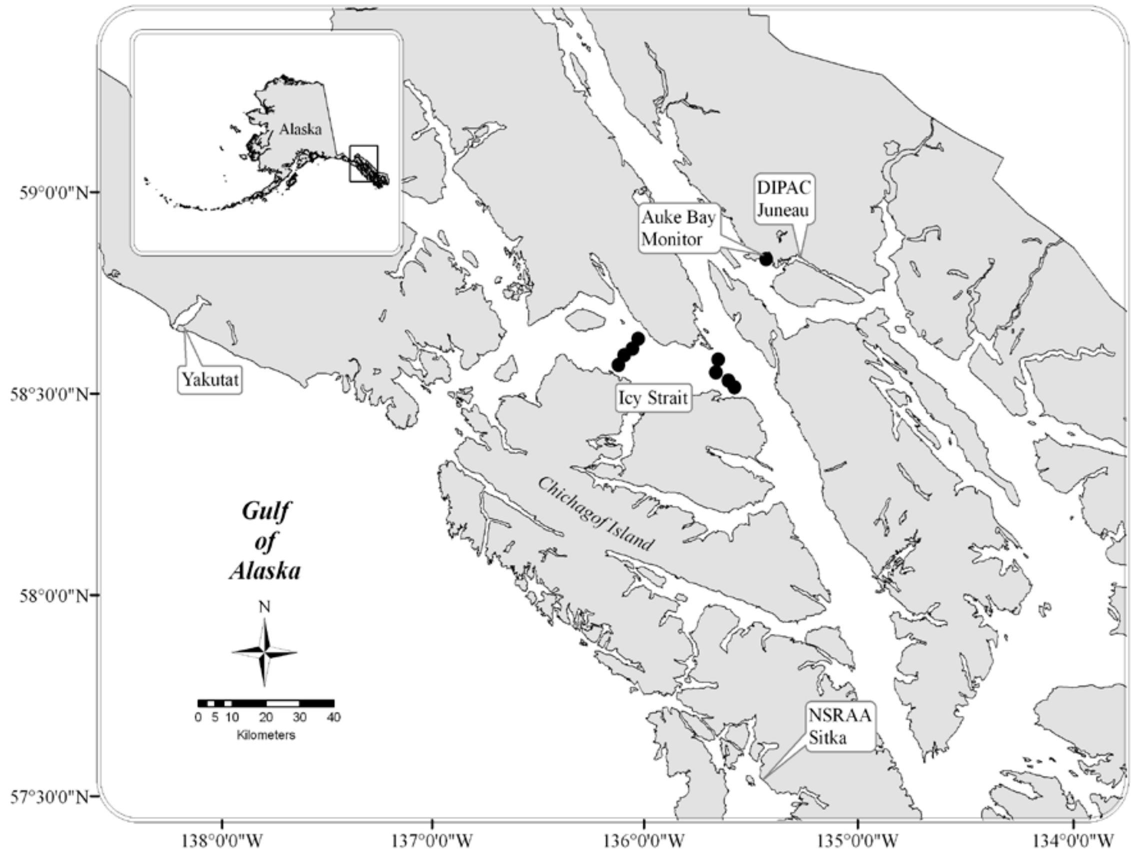

Figure 1.—Stations sampled for juvenile pink salmon and associated biophysical parameters along the Icy Strait transects in the northern region of Southeast Alaska for the development of pink salmon harvest forecast models. Stations were sampled monthly from May to August, 1997–2013. Oceanography was conducted in all months and surface trawling for juvenile salmon occurred from June to August.

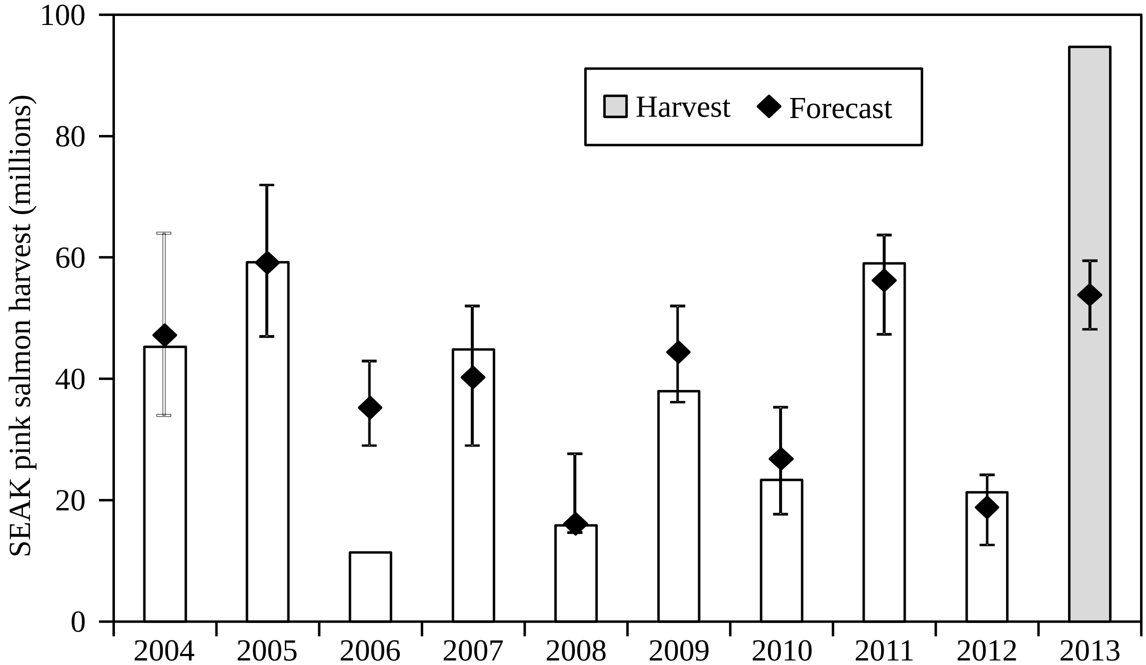

Figure 2.—Southeast Coastal Monitoring (SECM) project pink salmon harvest forecasts for Southeast Alaska (SEAK; symbols), associated 80% confidence intervals (lines), and actual SEAK pink salmon harvests (grey bars), 2004-2013.

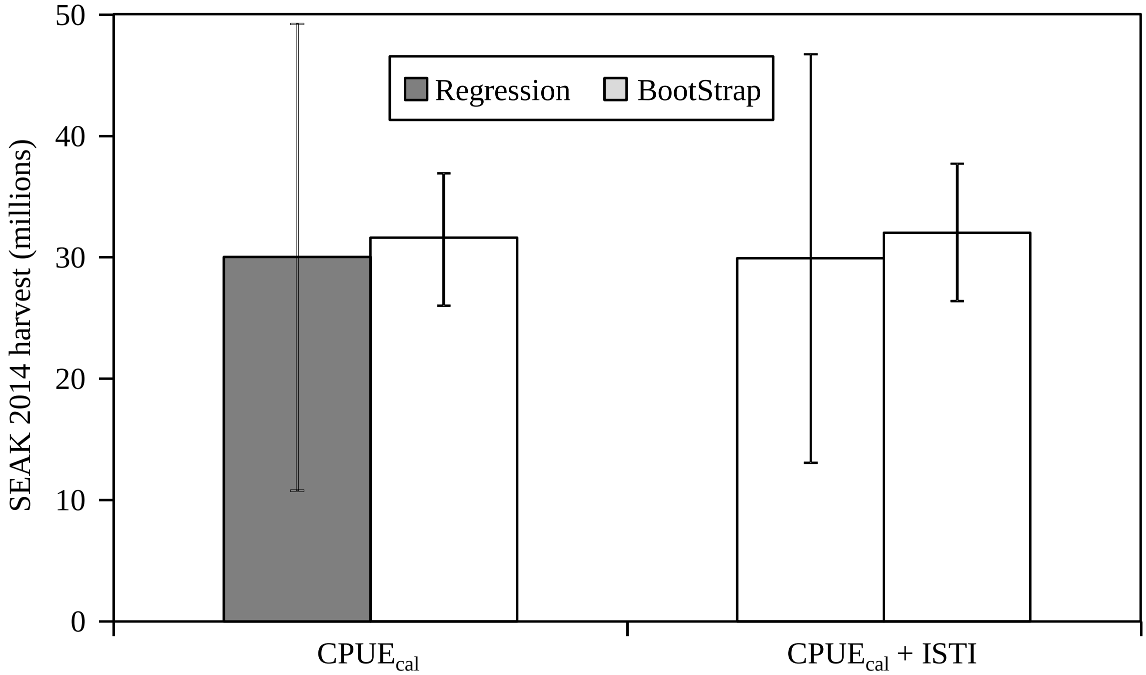

Figure 3.—Harvest predictions from parametric regression (dark bars) and bootstrap (light bars) analyses with 80% confidence intervals (lines) for Southeast Alaska (SEAK) pink salmon in 2014 using two models incorporating juvenile peak (catch-per-unit-effort) CPUE$_{cal}$ data in 2013. See text for descriptions of model parameters.