Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Biophysical Parameters: 2015 Returns and 2016 Forecast

by

Alex C. Wertheimer, Joseph A. Orsi, Emily A. Fergusson, and Andrew Gray

Auke Bay Laboratories, Alaska Fisheries Science Center,
NOAA Fisheries, United States Department of Commerce,
Ted Stevens Marine Research Institute,
17109 Point Lena Loop Road,
Juneau, AK 99801 USA

Submitted to the

NORTH PACIFIC ANADROMOUS FISH COMMISSION

by

United States of America

September 2016

THIS PAPER MAY BE CITED IN THE FOLLOWING MANNER:
Wertheimer, A. C., J. A. Orsi, and E. A. Fergusson. 2016. Forecasting pink salmon harvest in southeast Alaska from juvenile salmon abundance and associated biophysical parameters: 2015 returns and 2016 forecast. NPAFC Doc. xxxx. 25 pp. Auke Bay Lab., Alaska Fisheries Science Center, NOAA, NMFS. (Available at http://www.npafc.org).

Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Biophysical Parameters: 2015 Returns and 2016 Forecast

Keywords: forecast models, pink salmon harvest, ecosystem indicators, juvenile salmon, Southeast Alaska

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 SECM forecast was for an excellent odd-year harvest of 54.5 M fish. However, the actual 2015 SEAK harvest was 35.1 million fish, the lowest odd-year harvest since 1997. Thus the 2015 SECM forecast was 56% over the actual harvest. Nine of 12 forecasts over 2004-2015 have been within 20% of the actual harvest, with an average forecast deviation of 9%. Most (66%) of the harvest was in northern SEAK, consistent with strong returns in more northerly regions of the Gulf of Alaska, e.g., Prince William Sound and Kodiak. For the 2016 forecast, model selection included a review of ecosystem indicator variables and consideration of additional biophysical parameters to improve the simple single-parameter juvenile CPUE forecast model. Two measures of CPUE were examined for forecast efficacy: $CPUE_{cal}$, the time series of CPUE calibrated for changes in sampling vessels; and $CPUE_{ttd}$, catch per distance trawled. An alternative model using the regression of harvest and the average ranks of select ecosystem indicators, was also considered. The “best” forecast model for 2016 included two parameters, the ecosystem rank index and a measure of May water temperatures in Icy Strait. The 2016 forecast from this model, using juvenile salmon data collected in 2015, was 30.4 M with an 80% regression model prediction interval of 16-45 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. 2013a, Orsi and Fergusson 2014, 2015). 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 (e.g., Wertheimer et al. 2013, 2014, 2015), or used as auxiliary data to improve the ADFG exponential smoothing model (Piston and Heinl 2014, 2015, 2016). 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. 2012, 2013b, 2016). The SECM project has developed a 19-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 2015 SEAK pink salmon harvest and on the development of a prediction model for the 2016 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 (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 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. 2013a; Orsi and Fergusson 2014, 2015). 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 1997-2015 (Figure 1).

Data Descriptions and Sources

Parameters considered for forecasting models included pink salmon harvest as the dependent (response) variable and 20 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).

Juvenile pink salmon metrics

Four 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 ($CPUE_{cal}$, 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 Wertheimer et al. (2014), 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 is evaluated as an alternative to the current need to calibrate $CPUE_{cal}$ for changes in vessel fishing power. The third 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 four parameter was the actual month in which Peak CPUE was observed each year, 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.

Four 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 1997-2014 (Condition Index); 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); and 4) the percent of the body weight of juvenile pink salmon represented by stomach contents for a sample of 10 salmon captured in July.

Predator Indexes

Of all the potential juvenile pink salmon predator species identified and examined onboard during the annual SECM surveys, adult coho salmon have been the most consistent predator species encountered (Orsi et al. 2000; Sturdevant et al. 2013a). Adult coho salmon are returning from the GOA to SEAK concurrent with the outmigration of juvenile pink salmon from SEAK to the GOA, and could have an effect on survival variation "downstream" of the SECM juvenile CPUE assessment. A time series of SEAK coho salmon total returns (Leon Shaul, Alaska Department of Fish and Game, personal communication) was used as a measure of the degree of potential predation. A second predator index was defined as the numbers of returning adult coho salmon in year y divided by the $CPUE_{ttd}$ in year y. This predator index reflected the ratio of adult coho salmon to juvenile pink salmon each year; and the potential likelihood of predation occurring irrespective of other factors such as timing and distributions of either species and the availability of alternative prey resources.

Zooplankton metrics

One measures of zooplankton standing crop was evaluated as indicators of secondary production that could influence pink salmon harvest (Table 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).

Local and basin-scale physical metrics

Five 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: 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);

and 5) July 3-m salinity (PSU, July 3-m Salinity). 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. Four 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 down welling oceanographic conditions (Trenberth and Hurrell 1994); higher values indicate a relaxation of down welling along the Alaska coast adjacent to the eastern GOA and a widening of the Alaska Coastal Current. The third basin-scale index is the North Pacific Gyre Oscillation (NPGO), a measure of sea level height thought to influence the strength of the North Pacific gyre. The fourth 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.

Ecosystem Ranks Index

Beginning in 2014, an ecosystem indicators rank index (ERI) was developed using a suite of six ecosystem metrics and their average rank scores each year (Wertheimer et al. 2015; Orsi et al. 2016) . These six ecosystem metrics were the parameters in Table 1 that were significantly correlated with SEAK pink salmon harvest over the SECM time series: 1) $CPUE_{cal}$, 2) $CPUE_{ttd}$, 3) peak migration month, 4) proportion of pinks in hauls, 5) adult coho predation index, and 6) the North Pacific Index. For each of these variables, an average rank score was assigned for each ocean year, and ranked from “best” (lowest rank score) to “worst” (highest rank score). These ranks were then averaged (without weighting) for the six parameters. The annual rank score was then correlated with the pink salmon harvest (Table 1). The ERI includes three parameters using measures of CPUE ($CPUE_{cal}$; $CPUE_{ttd}$; Coho Abundance/$CPUE_{ttd}$), and so is not independent of the previous models based on CPUEcal or $CPUE_{ttd}$. The ERI was used as an alternative to CPUE for developing forecast models for 2016.

Forecast Model Development

We applied a four-step process 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 or the EIR, with physical conditions, zooplankton measures, adult coho abundance, and pink salmon growth indexes considered as additional parameters (Table 1). The coho predation index of coho adult abundance divided by juvenile pink salmon CPUE was not considered in the CPUE models because of the confounding and high correction (r = 0.89) of the predation index with juvenile CPUE. Similarly, the variables combined in the EIR index were not considered as additional parameters for the ERI model. The potential model was

$$\text{Harvest} = \alpha + \beta(Y) + \gamma_1 X_1 + \ldots + \gamma_n X_n + \varepsilon,$$

Where Y is either Ln(CPUE+1) or ERI, and 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 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 19 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 2013b), and their relative ranks in 2014 were considered for selecting the best regression model to forecast the 2015 harvest.

If the selected model uses a CPUE parameter as the primary predictive variable, a fifth step has been 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 (Wertheimer et al. 2011). This approach was not possible for the ERI model.

Results

2015 Forecast Efficacy

In 2015, the SECM forecast of 54.5 M pink salmon was 55% higher than the actual 2015 harvest of 35.1 M fish (Table 2). Harvest in 2015 was outside the 80% confidence intervals for the forecast (Figure 2).

2016 Forecast

Correlations with Harvest

Bivariate correlations were computed between SEAK pink salmon harvests for 2004-2015 using 21 potential prediction variables (Table 1). Six of these variables were significantly ($P \leq 0.05$) correlated with SEAK pink salmon harvest; five of the six were or included measures of juvenile pink salmon abundance or timing. Three measures of pink salmon abundance were significantly and positively associated with harvest: $CPUE_{cal}$, $CPUE_{ttd}$, and the percentage of pinks in the catches of juvenile salmon ($r = 0.78$, $r = 0.74$, and $r = 0.55$, respectively). The predation index of adult coho salmon abundance/ $CPUE_{cal}$ was highly and negatively correlated with harvest ($r = -0.80$). This may be indicative of a strong predator effect, but the significant negative correlation may also be driven by the inverse of $CPUE_{cal}$ in the denominator of the index. Seasonality was negatively correlated with harvest ($r = -0.55$), 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 ($r = 0.62$), indicating that relaxed downwelling and expansion of the ACC is associated with higher harvests. The ERI, which is a composite of these six variables, had the highest correlation with harvest, $r = -0.83$.

CPUE Forecast Models

We used the stepwise regression approach with two measures of juvenile abundance, the standard $CPUE_{cal}$, the alternative $CPUE_{ttd}$, and the ERI 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 70% of the variability in the harvest data (Adjusted R^2), compared to 59% 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 2016 forecasts using 2015 juvenile Peak CPUE were 34.6 M for the simple $CPUE_{cal}$ model and 24.2 M for the two-parameter model.

The $CPUE_{ttd}$ models had slightly poorer 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 66% of the variability in the harvest data (Adjusted R^2), compared to 53% for the simple linear regression with $CPUE_{ttd}$ (Table 3). The AIC_c was also lower for the two-parameter model for $CPUE_{ttd}$ than the corresponding one-parameter model, but was higher than the two-parameter $CPUE_{cal}$ model (151.4 vs 149.4). The 2016 point forecasts using 2015 juvenile $CPUE_{ttd}$ were lower than for $CPUE_{cal}$, 30.4 M for the simple $CPUE_{ttd}$ model and 20.1 M for the two-parameter $CPUE_{ttd}$ model.

The ERI model had the best fits to the harvest data for both the one-parameter and two-parameter models (Table 1). The one-parameter model explained 68% of the variability in the harvest data, and the two-parameter model with ERI and May 20-m temperatures explained 78%. The AIC_c was lowest for the two-parameter ERI model in comparison to the ERI one-parameter model and the CPUE models (Table 1). The 2016 point forecasts was 37.1 M for the one-parameter ERI model, and 30.3 million for the two-parameter ERI model.

The jackknife analysis comparing the one-parameter models for each of the three predictor variables showed that both average and median absolute deviations of hindcast harvests to actual harvests were substantially higher for the $CPUE_{ttd}$ model than for either the $CPUE_{cal}$ models or ERI model (Table 4). For this reason, the $CPUE_{ttd}$ model was dropped from consideration for the 2016 forecast, and further evaluation was focused on the $CPUE_{cal}$ and ERI parameters.

For the one-parameter models, the average absolute deviation for the jackknife analyses was lower for the ERI model (26%) than for the $CPUE_{cal}$ model (28%), and the median absolute deviations were identical at 15% (Table 4). However, for the two-parameter models, the $CPUE_{cal}$ was lower than the ERI for both average (22% vs 26%) and median (13% vs 23%) absolute deviations.

Table 5 and 6 list annual values and ranks of the six parameters in the 19-yr SECM time series that were significantly correlated with SEAK harvest ($CPUE_{cal}$, $CPUE_{ttd}$, Seasonality, % pink salmon juveniles, coho predation index, and NPI), as well as the significant auxiliary variables in the two-parameter regression models (ISTI and 20-m May temperatures). Four of these parameters have a positive association with harvest, while the predation index, seasonality, and the temperature parameters have a negative association with harvest. In 2015, $CPUE_{cal}$, $CPUE_{ttd}$, and % Pinks were below average for the time series (Table 5) and in the third, fourth, and third quartile of ranks respectively (Table 6). Seasonality was a “1” (June peak), which is the “best” value possible. The predation index was above average, and in the second quartile of ranks. The NPI was below average, and also in the third quartile of ranks. The temperature indexes were both above average; ISTI was in the first quartile of ranks, due to the second highest temperatures in the time series (Table 5), and 20-m May temperature was in the second quartile of ranks (Table 6).

Discussion

2015 Forecast Efficacy

The 2015 harvest of 35.1 M pink salmon in SEAK was the lowest odd- year harvest in SEAK since 1997.The 2015 harvest was much poorer than the two prior odd-year harvests in SEAK: 59 M in 2011 and the historic high of 95 M in 2013.

The SECM forecast was for an excellent odd-year return of 54.5 M fish, 56% above the actual harvest. The 2015 forecast was the third time the forecast has substantially deviated from actual harvest over the 12 years (2004-2015) that predictions have been made from SECM juvenile pink salmon data. Nine of 12 forecasts over this time period have been within 20% of the actual harvest, with an average forecast deviation of 9%. The ability of

association of the CPUE index to predict harvest one year later in 75% of the years suggests that marine survival after the early marine recruitment and survival for SEAK pink salmon tends to be relatively stable. 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 poor performance of the CPUE model in forecasting the very poor 2006 harvest, the record 2013 harvest, and the poorer than expected 2015 harvest suggest that "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*).
Ocean conditions in the Gulf of Alaska for the 2015 return were again characterized by anomalously warm water temperatures. In 2014, when the pink salmon juveniles entered the Gulf of Alaska, an area of warm water labeled the "warm blob" (Bond et al. 2015) formed in the North Pacific, and was augmented by an onset of El Niño conditions. These conditions may have affected salmon food resources or predator complexes.

The pattern of pink salmon returns in SEAK and elsewhere along the eastern Pacific Rim indicate that the warm ocean conditions differentially affected pink salmon production across broad geographic scales. Pink salmon returns to southern SEAK were lower than expected in 2015, following the record parent-year return in 2013 (Piston and Heinl 2016). Similarly, pink salmon returns in British Columbia were weak, with the Fraser River return less than half the forecast for 2015 (Relyea 2015). In Northern SEAK, harvests and escapements were actually above average, and to the north and west along the Gulf of Alaska coastline, pink salmon returns were very strong. Harvests of pink salmon were the highest ever recorded in Prince William Sound, and the third highest for Kodiak (Brenner and Munro 2016).

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 six of the nine years it has been used (Table 7), with an average deviation of 22% versus 24%. In 2015, incorporating the ISTI parameter into the forecast model moved the forecast in the right direction, but only by a small amount, decreasing forecast error by 2%. One problem with seeking a "silver-bullet" of environmental data for improving forecasts is that the signal for physical conditions that may affect survival in the GOA "downstream" from the inside waters of SEAK, e.g. NPI or temperature during the pink salmon's winter or following spring at sea, have not occurred or are not available in time for preseason forecasting in November or December preceding the harvest year.

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; Table 7). 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 2015 was 46 M for the unmodified and 58 M for the modified exponential smoothing models (Piston and Heinl 2015). These forecasts were 31% and 66% above the actual harvest, respectively (Table 2). Thus, the incorporation of the juvenile data did not improve the ADFG forecast in 2015. The modified trend analysis forecasts have improved on the original trend model in five of nine years since implementation (Table 7). The average absolute deviation (and range) for the modified model from 2007-2015 has been substantially better than the unadjusted model, 25% (range, 4-66%) versus 33% (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 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 as the main predictive parameter. Although the two modeling approaches are fundamentally different, they have performed similarly for 2007-2015 (Table 7).

2016 Forecast

For the 2016 forecast, we examined the use of two alternatives to the forecast model based on the $CPUE_{cal}$ parameter. These alternative models were based on either the $CPUE_{ttd}$ parameter or the average of select ecosystem indicators annual ranks (EIR model). The $CPUE_{ttd}$ measure of juvenile pink salmon catch has the advantage of not depending on past vessel calibration studies to adjust for differences in fishing power among sampling vessels. The EIR model integrates a number of ecosystem indicators to provide a quantitative prediction of subsequent harvest.

The ERI model had better statistical fit to the harvest data than the $CPUE_{cal}$ model, but the two parameter $CPUE_{cal}$ model performed better in the jackknife analyses than the two-parameter ERI model. To choose between these models, we considered the prediction outcomes in relation to other ecosystem indicators. The two- parameter ERI model forecast is 30.3 M pink salmon, compared to 24.2 million for the $CPUE_{cal}$ (Table 3). The seasonality index indicates a stronger than average run in 2016. The NPI, although below average, indicates a run on the order of 36 M based on a simple regression of harvest with NPI. The warm water temperatures in the spring and summer of 2016 are associated with poorer returns, but these effects have been incorporated in the two-parameter models. In addition, the size of juvenile pink salmon in the 2016 sampling is the largest on record for the SECM time series (Orsi and Ferguson 2016), which indicates exceptional growth and possibly enhanced survival potential. In consideration of these factors, we chose the two-parameter ERI model to forecast harvest in 2016.

The forecast of 30.3 M pink salmon from the ERI+May20Temp model has an 80% prediction confidence interval of 16-45 M. The prediction interval accounts for process error in the regression. The composite nature of the ERI parameter proscribed defining bootstrap confidence intervals incorporating measurement error, as we have previously done for the $CPUE_{cal}$ models (e.g., Wertheimer et al. 2015).

The two-parameter $CPUE_{cal}$ model and the EIR model were very similar in model fit and predicted harvests. They had virtually identical R^2 and AIC_c statistics (Table 3), and the EIR prediction of 58 M was within 10% of the $CPUE_{cal}$ forecast. The jackknife analysis showed lower average and median deviations for the $CPUE_{cal}$ model (Table 4), but the hindcasts from the EIR model were closer to the actual harvest in 10 of the 17 years. Based on the lower average and median deviations, and for consistency with past forecasts, we selected the two-parameter $CPUE_{cal}$ model as the "best" forecast model for 2015. However, given the similarity in model statistics and the hindcast performance of the EIR model, we will continue to track its performance as an alternative forecast tool.

Acknowledgments

We thank the vessel captains and crews and the many biologists, students, contractors, and volunteers who have contributed to SECM sampling for the past 19 years. The Northern Fund of the Pacific Salmon Commission and the Alaska Sustainable Salmon Fund have provided essential funding to continue this sampling. The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Oceanic and Atmospheric Administration, the U.S. Department of Commerce.

Literature Cited

ADFG. 2013. Recent years harvest statistics. Alaska Department Fish and Game Commercial Fisheries Division. http://www.cf.adfg.state.ak.us/cf_home.htm

Baker, T. T., A.C. Wertheimer, R. D. Burkett, R. Dunlap, D. M. Eggers, E. I. Fritts, A. J. Gharrett, R. A. Holmes, and R. L. Wilmot. 1996. Status of Pacific salmon and steelhead escapements in southeastern Alaska. Fisheries 21(10):6-19.

Beamish, R. J., and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Progress in Oceanography 49:423-437.

Bond, N. A. M. F. Cronin, H. Freeland, and N. Mantua. 2015. Causes and impacts of the 2014 warm anomaly in the NE Pacific. Geophys. Res. Letter 42, 3414–3420.

Eggers, D. 2006. Run forecasts and harvest projections for 2006 Alaska salmon fisheries and review of the 2005 season. Alaska Dept. Fish Game Spec. Publ. 06-07, 83 p.

Fergusson, E. A., M. V. Sturdevant, and J. A. Orsi. 2013. Trophic relationships among juvenile salmon during a 16-year time series of climate variability in Southeast Alaska. NPAFC Tech. Rep. 9. (Available at http://www.npafc.org)

Haeseker, S. L., R. M. Peterman, Z. Su, and C. C. Wood. 2005. Retrospective evaluation of preseason forecasting models for pink salmon. North American Journal of Fisheries Management 25:897-918.

Heard, W. R. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*). Pp. 119-230 In: C. Groot and L. Margolis (editors). Pacific Salmon Life Histories. Vancouver, B.C., Canada, UBC Press.

Hollowed, A. B., M. Barange, S.-i. Ito, S. Kim, H. Loeng, and M. A. Peck. 2011. Effects of climate change on fisheries: forecasting impacts, assessing ecosystem responses, and evaluating management strategies. ICES Journal Marine Science: Journal du Conseil 68: 984-985,

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Journal of Climatology 8:241-253.

Miller, J. A., D. Teel, A. Baptista, and C. Morgan. 2013. Disentangling bottom-up and top-down effects on survival during early ocean residence in a population of Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Science 70(4): 617-629.

Mortensen, D. G., A. C. Wertheimer, S. G. Taylor, and J. H. Landingham. 2000. The relation between early marine growth of pink salmon, *Oncorhynchus gorbuscha*, and marine water temperature, secondary production, and survival to adulthood. Fishery Bulletin 98:319-335.

Moss, J. H., D. A. Beauchamp, A. D. Cross, K. W. Myers, E. V. Farley, J. M. Murphy, and J. H. Helle. 2005. Evidence for size-selective mortality after the first summer of ocean growth by pink salmon. Transactions of the American Fisheries Society 134:1313-1322.

Munro, A. R. and C. Tide (eds.). 2014. Run forecasts and harvests projections for 2014 Alaska salmon fisheries and a review of the 2013 season. Alaska Department Fish and Game Special Publication 14-10. 115 pp.

NCDC. 2007. Multivariate ENSO index. NOAA Climate Data Center. www.cdc.noaa.gov/people/klaus.wolter/MEI/mei.html

Orsi, J. A., D. M. Clausen, A. C. Wertheimer, D. L. Courtney, and J. E. Pohl. 2006. Diel epipelagic distribution of juvenile salmon, rockfish, and sablefish and ecological interactions with associated species in offshore habitats of the Northeast Pacific Ocean (NPAFC Doc. 956) Auke Bay Lab., Alaska Fish. Sci. Cen., Nat. Mar. Fish. Serv., NOAA, 11305 Glacier Highway, Juneau, AK 99801-8626, USA, 26 p.

Orsi J. A., E. A. Fergusson, M. V. Sturdevant, W. R. Heard, and E. Farley, Jr. 2011. Annual Survey of juvenile salmon, ecologically-related species, and environmental factors in the marine waters of Southeastern Alaska, May–August 2010. NPAFC Doc. 1342, 87 pp. (Available at http://www.npafc.org).

Orsi, J., E. A. Fergusson, and M. V. Sturdevant. 2012. Recent harvest trends of pink and chum salmon in Southeast Alaska: Can marine ecosystem indicators be used as predictive tools for management? NPAFC Tech. Rep. 8:130-134. (Available at: http://www.npafc.org/new/pub_technical8.html)

Orsi, J. A., E. A. Fergusson, M. V. Sturdevant, W. R. Heard, and E. V. Farley, Jr. 2013a. Annual survey of juvenile salmon, ecologically-related species, and biophysical factors in the marine waters of southeastern Alaska, May–August 2012. (NPAFC Doc. 1485). Auke Bay Lab., Alaska Fish. Sci. Cent., Natl. Mar. Fish., NOAA, NMFS, 17109 Point Lena Loop Road, Juneau, 99801, USA. 92 pp. (Available at http://www.npafc.org).

Orsi, J. A., M. V. Sturdevant, E. A. Fergusson, & 4 co-authors. 2013b. Connecting the "dots" among coastal ocean metrics and Pacific salmon production in Southeast Alaska, 1997-2012. NPAFC Tech. Rep. 9. (Available at http://www.npafc.org)

Orsi, J. A., and E. A. Fergusson. 2014. Annual survey of juvenile salmon, ecologically-related species, and biophysical factors in the marine waters of southeastern Alaska, May–August 2013. (NPAFC Doc. 1554). Auke Bay Lab., Alaska Fish. Sci. Cent., Natl. Mar. Fish., NOAA, NMFS, 17109 Point Lena Loop Road, Juneau, 99801, USA. 86 pp. (Available at http://www.npafc.org).

Orsi, J. A. and E. A. Fergusson. 2015. Annual survey of juvenile salmon, ecologically related species, and biophysical factors in the marine waters of southeastern Alaska, May–August 2014. NPAFC Doc. 1617. 64 pp. National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center, Auke Bay Laboratories, Ted Stevens Marine Research Institute (Available at http://www.npafc.org).

Orsi, J.A., E.A. Fergusson, A.C. Wertheimer, E.V. Farley, and P.R. Mundy. 2016. Forecasting pink salmon production in Southeast Alaska using ecosystem indicators in times of climate change N. Pac. Anadr. Fish Comm. Bull. 6: xx-xx.

Parker, R. R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, central British Columbia. Journal Fisheries Research Board Canada 25:757-794.

Peterson, W. T., C. A. Morgan, J. O. Peterson, J. L. Fisher, B. J. Burke, and K. Fresh. 2012. Ocean ecosystem indicators of salmon marine survival in the northern California Current. 89 pgs. http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/documents/Peterson_etal_2012.pdf

Piston, A., and S. Heinl. 2014. Forecast area Southeast Alaska, species pink salmon. Pp. 50-54. In: A. R. Munro and C. Tide (eds.), Run forecasts and harvests projections for 2014 Alaska salmon fisheries and a review of the 2013 season. Alaska Department Fish and Game Special Publication 14-10.

Piston, A., and S. Heinl. 2015. Forecast area Southeast Alaska, species pink salmon. Pp. 50-53. In: A. R. Munro (ed.), Run forecasts and harvests projections for 2015 Alaska salmon fisheries and a review of the 2012 season. Alaska Department Fish and Game Special Publication 15-04.

Piston, A., and S. Heinl. 2016. Forecast area Southeast Alaska, species pink salmon. Pp. 50-54. In: R. E. Brenner and A. R. Munro (eds.), Run forecasts and harvests projections for 2016 Alaska salmon fisheries and a review of the 2015 season. Alaska Department Fish and Game Special Publication 16-07.

Plotnick, M., and D. M. Eggers. 2004. Run forecasts and harvest projections for 2004 Alaska salmon fisheries and review of the 2003 season. Alaska Dept. Fish Game Regional Inf. Rept. 5J04-01.

Relyea, K. 2015. Fraser River pink salmon run a poor haul for US fishermen. Bellingham Herald, Bellingham, WA. http://www.bellinghamherald.com/news/local/article34975239.html

Shono, H. 2000. Efficiency of the finite correction of Akaike's information criteria. Fisheries Science 66:608-610.

Sturdevant, M.V., E.A. Fergusson, J.A. Orsi, and A.C. Wertheimer. 2004. Diel feeding and gastric evacuation of juvenile pink and chum salmon in Icy Strait, Southeastern Alaska, May-September 2001. NPAFC Tech. Rep. 5. (Available at http://www.npafc.org).

Sturdevant, M. V., R. Brenner, E. Fergusson, J. Orsi, and B. Heard. 2013a. Does predation by returning adult pink salmon regulate pink salmon or herring abundance? NPAFC Tech. Rep. 9. (Available at http://www.npafc.org).

Sturdevant, M., E. Fergusson, and J. Orsi. 2013b Long-term zooplankton trends in Icy Strait, Southeast Alaska. Pages 111-115 in S. Zador, editor. Ecosystem Considerations 2013, Stock Assessment and Fishery Evaluation Report. North Pacific Fishery Management Council, 605 W. 4th Ave. Suite 306, Anchorage, AK 99501. Available at http://access.afsc.noaa.gov/reem/ecoweb/.

Trenberth, K. E., and J. W. Hurrell. 1994. Decadal atmosphere-ocean variations in the Pacific Climate Dynamics, Berlin 9(6):303-319.

Wertheimer A. C., J. A. Orsi, M. V. Sturdevant, and E. A. Fergusson. 2006. Forecasting pink salmon harvest in Southeast Alaska from juvenile salmon abundance and associated environmental parameters. Pp. 65-72 In: H. Geiger (Rapporteur) (ed.), Proceedings of the 22nd Northeast Pacific Pink and Chum Workshop. Pacific Salmon Commission, Vancouver, British Columbia.

Wertheimer, A. C., and F. P. Thrower. 2007. Mortality rates of chum salmon during their initial marine residency. American Fisheries Society Symposium Series 57:233-247.

Wertheimer, A. C., J. A. Orsi, M. V. Sturdevant, and E. A. Fergusson. 2008. Forecasting pink salmon abundance in Southeast Alaska from juvenile salmon abundance and associated environmental parameters. Final Report, Pacific Salmon Commission Northern Fund, 41 p.

Wertheimer, A. C., J. A. Orsi, E. A. Fergusson, and M. V. Sturdevant. 2010. Calibration of Juvenile Salmon Catches using Paired Comparisons between Two Research Vessels Fishing Nordic 264 Surface Trawls in Southeast Alaska, July 2009. (NPAFC Doc. 1277). Auke Bay Laboratories, Alaska Fish. Sci. Cen., Nat. Mar. Fish. Serv., NOAA, 17109 Point Lena Loop Road, Juneau, 99801, USA, 19 pp. (Available at http://www.npafc.org).

Wertheimer, A. C., J. A. Orsi, E. A. Fergusson, and M. V. Sturdevant. 2011. Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Environmental Parameters: 2010 Returns and 2011 Forecast. (NPAFC Doc. 1343) Auke Bay Laboratories, Alaska Fish. Sci. Cen., Nat. Mar. Fish. Serv., NOAA, 17109 Point Lena Loop Road, Juneau, 99801, USA, 20 pp. (Available at http://www.npafc.org).

Wertheimer, A. C., J. A. Orsi, E. A. Fergusson, and M. V. Sturdevant. 2013. Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Environmental Parameters: 2012 Returns and 2013 Forecast. (NPAFC Doc. 1486) Auke Bay Laboratories, Alaska Fish. Sci. Cen., Nat. Mar. Fish. Serv., NOAA, 17109 Point Lena Loop Road, Juneau, 99801, USA, 24 pp. (Available http://www.npafc.org).

Wertheimer, A. C., J. A. Orsi, E. A. Fergusson, and M. V. Sturdevant. 2014. Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Environmental Parameters: 2013 Returns and 2014 Forecast. (NPAFC Doc. 1555) Auke Bay Laboratories, Alaska Fish. Sci. Cen., Nat. Mar. Fish. Serv., NOAA, 17109 Point Lena Loop Road, Juneau, 99801, USA, 24 pp. (Available http://www.npafc.org).

Wertheimer, A. C., J. A. Orsi, and E. A. Fergusson. 2015. Forecasting pink salmon harvest in southeast Alaska from juvenile salmon abundance and associated biophysical parameters: 2014 returns and 2015 forecast. NPAFC Doc. 1618. 26pp. Auke Bay Lab., Alaska Fisheries Science Center, NOAA, NMFS. (Available at http://www.npafc.org).

Wertheimer, A. C., J. A. Orsi, E. A. Fergusson, and M. V. Sturdevant. 2015. Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Environmental Parameters: 2011 Returns and 2012 Forecast. (NPAFC Doc. 1414, Rev. 1) Auke Bay Laboratories, Alaska Fish. Sci. Cen., Nat. Mar. Fish. Serv., NOAA, 17109 Point Lena Loop Road, Juneau, 99801, USA, 20 pp. (Available http://www.npafc.org).

Willette, T. M., R. T. Cooney, V. Patrick, D. M. Mason, G. L. Thomas, and D. Scheel. 2001. Ecological processes influencing mortality of juvenile pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound, Alaska. Fisheries Oceanography 10(1):14-41.

Table 1.—Correlation coefficients for juvenile pink salmon biophysical parameters and ecosystem metrics in year *y* for 1997-2014 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		
$CPUE_{cal}$	**0.78**	**<0.001**
$CPUE_{ttd}$	**0.74**	**<0.001**
Seasonality	**-0.55**	**0.019**
Percentage of Juvenile Pinks	**0.55**	**0.010**
Juvenile pink salmon growth and condition		
Pink Salmon Size July 24	0.05	0.847
Condition Index	-0.05	0.856
Energy Content	-0.01	0.958
Percent Stomach Contents	-0.08	0.745
Predator Indexes		
Adult Coho Abundance	-0.27	0.273
Adult Coho Abundance/$CPUE_{cal}$	**-0.80**	**<0.001**
Zooplankton standing crop		
June/July Average Zooplankton Total Water Column	0.12	0.624
Local-scale physical conditions	-	
May 20-m Integrated Water Temperature	0.01	0.978
June 20-m Integrated Water Temperature	-0.24	0.343
Icy Strait Temperature Index (ISTI)	-0.18	0.488
June Mixed-layer Depth	-0.03	0.906
July 3-m Salinity	0.00	0.995
Basin-scale physical conditions		
Pacific Decadal Oscillation (PDO, y-1)	0.01	0.983
Northern Pacific Index (NPI, y**)**	**0.62**	**0.007**
ENSO Multivariate Index (MEI, Nov (*y-1)*-March (*y*))	0.25	0.326
North Pacific Gyre Oscillations	0.30	0.234
Ecosystem Indicators Rank Index (ERI)	**-0.83**	**<0.001**

Table 2.—Southeast Coastal Monitoring (SECM) and Alaska Department of Fish and Game (ADFG) forecasts for 2015 pink salmon harvest in Southeast Alaska (SEAK). The ADFG forecasts are from Piston and Heinl (2015). NA = not applicable.

	Pink salmon (M of fish)	**Deviation from actual harvest**
SECM forecast	54.5	57%
ADFG forecast (w/ $CPUE_{cal}$ data)	46.0	66%
ADFG forecast (w/o $CPUE_{ttd}$ data)	58.0	31%
Actual harvest	35.0	NA

Table 3.—Regression models relating juvenile pink salmon catch-per-unit-effort ($CPUE_{cal}$ and $CPUE_{ttd}$) and the Ecosystem Ranks Index in year *y* to adult harvest in Southeast Alaska (SEAK) in year *y* +1, for *y* = 1997-2014. 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**	**2016 Prediction (M)**
Ln($CPUE_{cal}$)	59%	153.2	<0.001	34.6
Ln($CPUE_{cal}$) + ISTI	70%	149.4	<0.001	24.2
Ln($CPUE_{ttd}$)	53%	155.6	<0.001	30.4
Ln($CPUE_{ttd}$) + May20Temp	66%	151.4	<0.001	20.1
Ecosystem Ranks	68%	148.9	<0.001	37.1
Ecosystem Ranks+May20Temp	78%	143.8	<0.001	30.3

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($CPUE_{cal}$)	28.5	15.2
Ln($CPUE_{ttdl}$)	36.0	24.2
Ecosystem Ranks	26.0	15.2
Ln($CPUE_{cal}$) + ISTI	21.8	13.0
Ecosystem Ranks+ May20Temp	26.0	22.7

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 2016 harvest.

Juvenile year y	**Harvest year y+1 (M)**	**Ln ($CPUE_{cal}$)**	**Ln ($CPUE_{ttd}$)**	**Seasonality**	**% Pinks**	**Coho Predation Index**	**NPI Index**	**ISTI**	**May 20m temp**
1997	42.5	2.5	2.22	July	0.17	1.54	15.6	9.5	7.3
1998	77.8	5.6	5.32	June	0.42	0.80	18.1	9.6	7.8
1999	20.2	1.6	1.39	July	0.10	3.92	15.8	9.0	6.5
2000	67.0	3.7	3.34	July	0.25	0.95	17.0	9.0	6.6
2001	45.3	2.9	2.64	July	0.28	2.01	16.8	9.4	7.1
2002	52.5	2.8	2.48	July	0.26	2.48	15.6	8.6	6.4
2003	45.3	3.1	2.74	July	0.22	1.76	16.1	9.8	7.4
2004	59.1	3.9	3.39	June	0.31	1.42	15.1	9.7	7.6
2005	11.6	2.0	1.72	Aug	0.26	3.28	15.5	10.3	8.3
2006	44.8	2.6	2.27	June	0.26	1.91	17.0	8.9	6.7
2007	15.9	1.2	0.97	Aug	0.15	3.70	15.7	9.3	7.0
2008	38.0	2.5	2.18	Aug	0.29	2.13	16.1	8.3	6.1
2009	23.4	2.1	2.68	Aug	0.27	1.72	15.1	9.6	7.3
2010	59.0	3.7	5.01	June	0.61	0.94	17.6	9.6	8.3
2011	21.3	1.3	1.64	Aug	0.25	4.07	15.7	8.9	6.7
2012	94.7	3.2	4.26	July	0.48	1.12	16.7	8.7	6.7
2013	37.2	1.9	2.67	July	0.12	2.85	16.0	9.2	6.5
2014	35.0	3.4	4.47	July	0.57	1.99	15.8	9.4	7.7
2015	TBD	2.2	1.84	June	0.19	2.57	15.7	9.8	7.6
Average	**43.9**	**2.7**	**2.80**	**July**	**0.29**	**2.17**	**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 2016 harvest.

Juvenile year y	**Harvest y+1**	**$CPUE_{cal}$**	**$CPUE_{ttd}$**	**Seasonality**	**% Pinks**	**Coho Predation Index**	**NPI Index**	**ISTI**	**May 20m temp**
1997	10	11	13	2	16	14	15	8	8
1998	2	1	1	1	4	19	1	5	3
1999	16	17	18	2	19	2	10	13	16
2000	3	3	6	2	12	17	3	13	15
2001	7	8	10	2	7	9	5	9	10
2002	6	9	11	2	9	7	15	18	18
2003	7	7	7	2	14	12	7	2	7
2004	4	2	5	1	5	15	18	4	5
2005	18	15	16	3	9	4	17	1	1
2006	9	10	12	1	9	11	3	15	12
2007	17	19	19	3	17	3	12	11	11
2008	11	11	14	3	6	8	7	19	19
2009	14	14	8	3	8	13	18	5	8
2010	5	3	2	1	1	18	2	5	1
2011	15	18	17	3	12	1	12	15	12
2012	1	6	4	2	3	16	6	17	12
2013	12	16	9	2	18	5	9	12	16
2014	13	5	3	2	2	10	10	9	4
2015	TBD	13	15	1	15	6	12	2	5

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 (2007-2015) and without the addition of the SECM juvenile $CPUE_{cal}$ data are shown.

		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%)
2014	37	30	(20%)	30	(20%)	22	(41%)	22	(41%)
2015	35	56	(59%)	54	(57%)	46	(31%)	58	(66%)

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

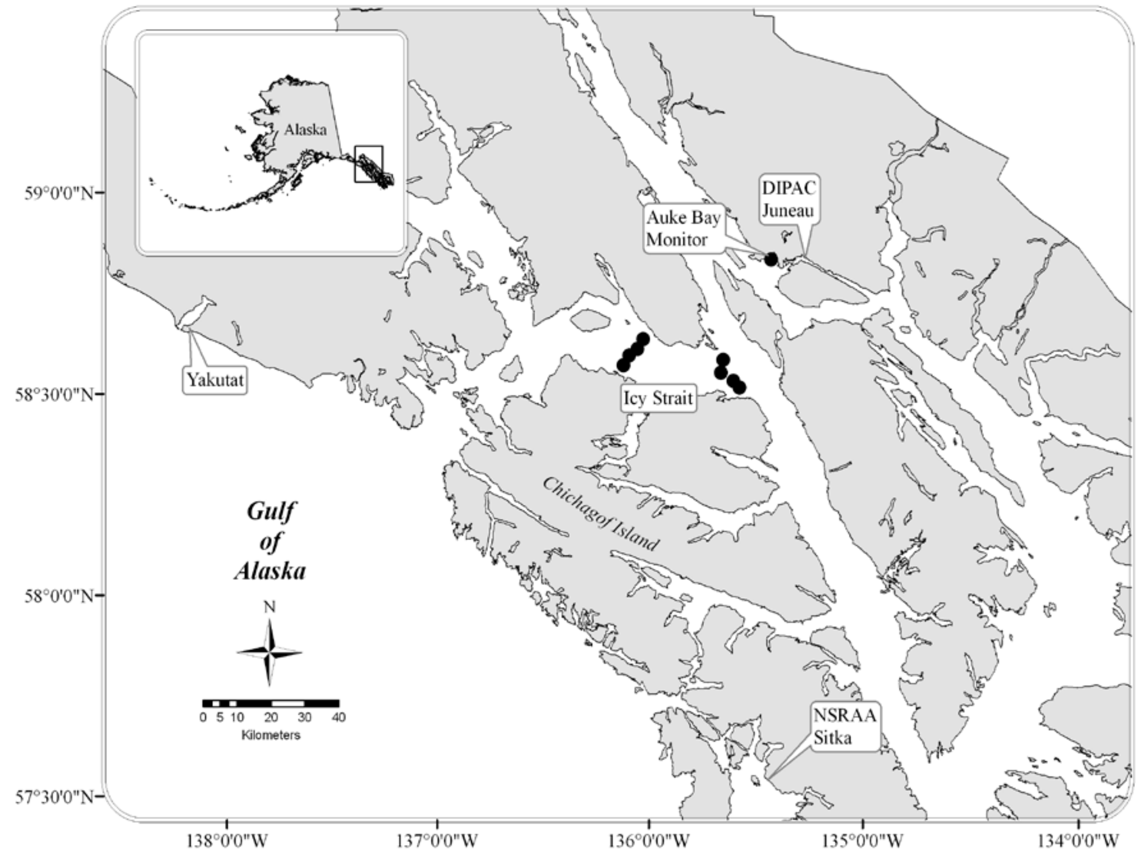

Figure 1.—Stations sampled for juvenile pink salmon and associated biophysical parameters along the Icy Strait transects in the northern region of Southeast Alaska for the development of pink salmon harvest forecast models. Stations were sampled monthly from May to August, 1997–2015. Oceanography was conducted in all months and surface trawling for juvenile salmon occurred from June to August.

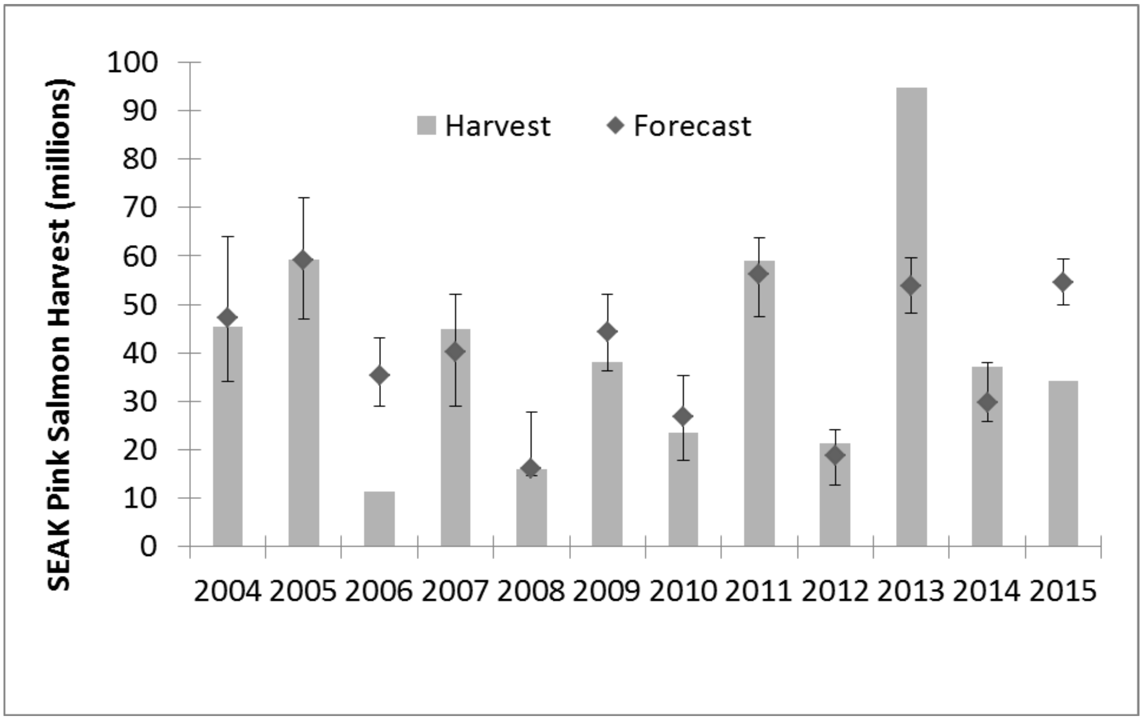

Figure 2.—Southeast Coastal Monitoring (SECM) project pink salmon harvest forecasts for Southeast Alaska (SEAK; symbols), associated 80% confidence intervals (lines), and actual SEAK pink salmon harvests (grey bars), 2004-2015.