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# Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Biophysical Parameters: 2014 Returns and 2015 Forecast

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# Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Biophysical Parameters: 2014 Returns and 2015 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 ($\mathrm{CPUE_{cal}}$), adjusted for highly-correlated biophysical parameters, has been used to forecast adult pink salmon harvest (*O. gorbuscha*) in SEAK. The 2014 SEAK harvest was 37.2 million fish, the largest even-year harvest since 2004. The SECM forecast was for a relatively strong even-year return of 29.9 M fish, which turned out to be 20% lower than actual. Nine of 11 forecasts over 2004-2014 have been within 20% of the actual harvest, with an average forecast deviation of 9%. The 2014 harvest is indicative of continued recovery of the even-year run since the very poor return in 2006. However, most (89%) of the harvest was in southern SEAK, and some areas in northern SEAK had very poor escapements. For the 2015 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: $\mathrm{CPUE_{cal}}$, the time series of CPUE calibrated for changes in sampling vessels; and $\mathrm{CPUE_{ttd}}$, 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 2015 included two parameters, the Icy Strait Temperature Index (ISTI) and juvenile $\mathrm{CPUE_{cal}}$. The 2015 forecast of 54.5 M fish from this model, using juvenile salmon data collected in 2014, had an 80% bootstrap confidence interval of 48-58 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. 2012a, 2013a, Orsi and Fergusson 2014). 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. 2012, 2013, 2014), or used as auxiliary data to improve the ADFG exponential smoothing model (Piston and Heinl 2013, 2014, 2015). 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 an 18-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 2014 SEAK pink salmon harvest and on the development of a prediction model for the 2015 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 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. 2012a, 2013a; Orsi and Fergusson 2014). 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 1997-2014 (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 Yakutat 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

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 $\mathrm{CPUE}_{\mathrm{cal}}$ 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* ($\mathrm{CPUE}_{\mathrm{ttd}}$, Table 1). This parameter is evaluated as an alternative to the current need to calibrate $\mathrm{CPUE}_{\mathrm{cal}}$ 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, 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).

## 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. 2012). 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 CPUEcal 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

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).

## 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 (MR Spring Flow). 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 local-scale 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.

### CPUE 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, 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 model because of the confounding and high correction (r = 0.89) of the predation index with juvenile CPUE. The potential model was

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

where $\gamma$ 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 $\text{CPUE}_{\text{cal}}$ and $\text{CPUE}_{\text{ttd}}$ 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 1997-2013 were used to construct the regression models with SEAK harvest as the dependent variable, and the appropriate averages of the simulated juvenile catches for 2014 were used to forecast the 2015 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 18 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.

### Ecosystem Indicator Regression Model

In 2014, an ecosystem indicators rank(EIR) model, was developed using a suite of six ecosystem metrics and their average rank scores each year. 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) CPUEcal, 2) CPUEttd, 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). The annual rank score represented the strength of the combined variable correlations to the actual pink salmon harvest. A regression model was developed with SEAK pink salmon harvest as the dependent variable and the average rank score as the predictor variable. Annual estimates from the EIR model were then compared to the actual harvest over the time series. The EIR model included three parameters using measures of CPUE abundance ($\text{CPUE}_{\text{cal}}$; $\text{CPUE}_{\text{ttd}}$; Coho Abundance/CPUEttd), and so is not independent of the previous models based on $\text{CPUE}_{\text{cal}}$ or $\text{CPUE}_{\text{ttd}}$. Model efficacy at predicting pink salmon harvest from 1998-2014 was evaluated using jackknife analysis, and compared to the CPUE models. The EIR model was then used to produce an alternative forecast for 2015.

## Results

### 2014 Forecast Efficacy

In 2014, the SECM forecast of 29.9 M pink salmon was 20% lower than the actual 2014 harvest of 37.2 M fish (Table 2). Harvest in 2014 was within the 80% confidence intervals for the forecast (Figure 2).

### 2015 Forecast

Correlations with Harvest

Bivariate correlations were computed between SEAK pink salmon harvests for 2004-2014 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: $\text{CPUE}_{\text{cal}}$, $\text{CPUE}_{\text{ttd}}$, and the percentage of pinks in the catches of juvenile salmon ($r = 0.81$, $r = 0.85$, and $r = 0.67$, respectively). The predation index of adult coho salmon abundance/ $\text{CPUE}_{\text{cal}}$ was highly and negatively correlated with harvest (r = -0.81). This may be indicative of a strong predator effect, but the negative correlation may also be driven by the inverse of $\text{CPUE}_{\text{cal}}$ in the denominator of the index. 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.

CPUE Forecast Models

We used the stepwise regression approach with two measures of juvenile abundance, the standard $\text{CPUE}_{\text{cal}}$ and the alternative $\text{CPUE}_{\text{ttd}}$, 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 $\text{CPUE}_{\text{cal}}$, a two-parameter model including ISTI explained 74% of the variability in the harvest data (Adjusted $R^2$), compared to 63% for the simple linear regression with $\text{CPUE}_{\text{cal}}$ (Table 3). The $\text{AIC}_{\text{c}}$ was lower for the two-parameter model, indicating that this model is not over-parameterized. The 2015 forecasts using 2014 juvenile Peak CPUE were 55.5 M for the simple $\text{CPUE}_{\text{cal}}$ model and 54.5 M for the two-parameter model.

The $\text{CPUE}_{\text{ttd}}$ models had slightly better fits to the harvest data for both one-parameter and two-parameter models than did the $\text{CPUE}_{\text{cal}}$ models. The two-parameter model including May 20-m temperatures explained 81% of the variability in the harvest data (Adjusted $R^2$), compared to 69% for the simple linear regression with $\mathrm{CPUE}_{\mathrm{ttd}}$ (Table 3). The $\mathrm{AIC}_{\mathrm{c}}$ was also lower for the two-parameter model for $\mathrm{CPUE}_{\mathrm{ttd}}$. The 2015 point forecasts using 2014 juvenile $\mathrm{CPUE}_{\mathrm{ttd}}$ were higher than for $\mathrm{CPUE}_{\mathrm{cal}}$, 74.0 M for the simple $\mathrm{CPUE}_{\mathrm{ttd}}$ model and 71.5 M for the two-parameter $\mathrm{CPUE}_{\mathrm{ttd}}$ model.

The EIR model was similar to the two-parameter $\mathrm{CPUE}_{\mathrm{cal}}$ model for both fit and $\mathrm{AIC}_{\mathrm{c}}$ (Table 1). It also explained 74% of the variability in the harvest data. The 2015 point forecast for this model was 57.9 M, with 80% regression prediction interval of 42-74 M.

The jackknife analysis showed that both average and median absolute deviations of hindcast harvests to actual harvests were lower for the $\mathrm{CPUE}_{\mathrm{cal}}$ than the corresponding $\mathrm{CPUE}_{\mathrm{ttd}}$ 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 EIR model was intermediate between the $\mathrm{CPUE}_{\mathrm{cal}}$ models and the $\mathrm{CPUE}_{\mathrm{ttd}}$ models in average and median absolute deviations. The lowest average absolute deviation was 20.0% for the two-parameter $\mathrm{CPUE}_{\mathrm{cal}}$ model, and the lowest absolute median deviation was 11.3% for the one-parameter $\mathrm{CPUE}_{\mathrm{cal}}$ model. Over the jack-knife time series, the two-parameter model $\mathrm{CPUE}_{\mathrm{cal}}$ model provided better estimates in 11 of the 17 years compared to the one-parameter $\mathrm{CPUE}_{\mathrm{cal}}$ model, in 11 of the 17 years compared to the two-parameter $\mathrm{CPUE}_{\mathrm{ttd}}$ model, and in 7 of 17 years compared to the EIR model.

The 80% bootstrap CIs for the one- and two-parameter $\mathrm{CPUE}_{\mathrm{cal}}$ models for the 2015 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 $\mathrm{CPUE}_{\mathrm{cal}}$ 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 10 M for both the one- and two-parameter models (Figure 3).

Table 5 and 6 list annual values and ranks of the six parameters in the 18-yr SECM time series that were significantly correlated with SEAK harvest ($\mathrm{CPUE}_{\mathrm{cal}}$, $\mathrm{CPUE}_{\mathrm{ttd}}$, 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). Five of the correlated parameters have a positive association with harvest, while the predation index and the temperature parameters have a negative association with harvest. In 2014, $\mathrm{CPUE}_{\mathrm{cal}}$, $\mathrm{CPUE}_{\mathrm{ttd}}$, and % Pinks were above average for the time series (Table 5) and in the second, first, and first quartile of ranks respectively (Table 6). Seasonality was a “2” (July peak), which is the mid-value possible. The predation index was below average, and in the third 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 second quartile of ranks, and 20-m May temperature was in the first quartile of ranks, due to the second highest May temperatures in the time series (Table 6.).

## Discussion

### 2014 Forecast Efficacy

The 2014 harvest of 37.2 M pink salmon in SEAK was the best even year harvest in SEAK since 2004. The SECM forecast was for a relatively strong even-year return of 29.9 M fish. Although the forecast was 20% lower than the actual harvest, it was indicative of continued recovery of the even-year returns since the very poor 2006 return. The 2014 forecast also continues the trend of generally good forecasts using the SECM juvenile pink salmon data. Nine of 11 forecasts over 2004-2014 have been within 20% of the actual harvest, with an average forecast deviation of 9%. 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. 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 and the record 2013 harvest suggests 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*), 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..

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 $\mathrm{CPUE}_{\mathrm{cal}}$ model in five of the eight years it has been used (Table 7), with an average deviation of 18% versus 20%. In 2014, incorporating the ISTI parameter into the forecast model made virtually no difference in the predicted harvest. 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 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). As a result, since 2006, the ADFG forecast has used the SECM $\mathrm{CPUE}_{\mathrm{cal}}$ 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 2014 was 22 M for both the unmodified and modified exponential smoothing models (Piston and Heinl 2014). This forecast was 41% below the actual harvest (Table 2). Thus, the incorporation of the juvenile data did not improve the ADFG forecast in 2014. However, the modified trend analysis forecasts have improved on the original trend model in five of eight years since implementation (Table 7). Also, the average absolute deviation (and range) for the modified model from 2007-2014 has been substantially better than the unadjusted model, 20% (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 $\mathrm{CPUE}_{\mathrm{cal}}$ 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 $\mathrm{CPUE}_{\mathrm{cal}}$ as the main predictive parameter. Although the two modeling approaches are fundamentally different, they have performed similarly for 2007-2014 (Table 7).

## 2015 Forecast

For the 2015 forecast, we examined the use of two alternatives to the forecast model based on the $\mathrm{CPUE}_{\mathrm{cal}}$ parameter. These alternative models were based on either the $\mathrm{CPUE}_{\mathrm{ttd}}$ parameter or the average of select ecosystem indicators annual ranks (EIR model). The $\mathrm{CPUE}_{\mathrm{ttd}}$ 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.

Although the $\mathrm{CPUE}_{\mathrm{ttd}}$ was slightly better correlated with SEAK harvest than the $\mathrm{CPUE}_{\mathrm{cal}}$ parameter (Table 1), and provided better regression model fits to the harvest data (Table 3), the $\mathrm{CPUE}_{\mathrm{cal}}$ model was selected as a better predictor for three reasons. First, the jackknife analysis across all years indicated that $\mathrm{CPUE}_{\mathrm{ttd}}$ did not predict harvest as well as $\mathrm{CPUE}_{\mathrm{cal}}$ (Table 4). Second, the higher 2015 forecasts of the $\mathrm{CPUE}_{\mathrm{ttd}}$ models were also not consistent with the rankings of the ecosystem indicators in Table 7. The two-parameter $\mathrm{CPUE}_{\mathrm{ttd}}$ forecast of 72 M harvest is very high, but the ecosystem indicators in Table 7 are mixed, with the CPUE parameters indicating above average harvest and the seasonality, NPI, and temperature parameters indicating average or below average harvest. Third, the "best" $\mathrm{CPUE}_{\mathrm{ttd}}$ two-parameter model predicted a 2014 harvest of 51M (Wertheimer et al. 2014), well above the actual harvest of 37 M. This result, along with the high forecast for 2015, may indicate a tendency for the $\mathrm{CPUE}_{\mathrm{ttd}}$ to be biased high.

For the $\mathrm{CPUE}_{\mathrm{cal}}$ models, the two-parameter model including Peak $\mathrm{CPUE}_{\mathrm{cal}}$ + ISTI was selected as the "best" model for the 2015 SECM forecast based on model fit and the $\mathrm{AIC}_{\mathrm{c}}$. This model predicts a harvest of 54.5 million, with an 80% bootstrap confidence interval of

48-58 million. The jackknife analysis showed lower average deviations for predictions for the two-parameter model, but slightly lower median deviations for the one-parameter model (Table 4). The two-parameter model, however, provided better hindcasts for 11 of the 17 past years. The bootstrap confidence interval for the forecast was used because the bootstrap procedure accounts for measurement error in the $\mathrm{CPUE}_{\mathrm{cal}}$.

In previous years (e.g., Wertheimer et al. 2011, 2013, 2014), temperature indexes, either ISTI or May 20m temperatures, have been identified as the environmental parameter significantly improving the one-parameter $\mathrm{CPUE}_{\mathrm{cal}}$ model. Colder temperatures have been associated with higher harvests than predicted by CPUE alone. For the 2015 harvest forecast, the ISTI again improved the $\mathrm{CPUE}_{\mathrm{cal}}$ 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 2014 caused a small decrease in the forecast of the two-parameter model relative to the one-parameter model, 54.5 M versus 55.5 M. Consistent with last year's analysis (Wertheimer et al. 2014), May 20m temperatures entered the $\mathrm{CPUE}_{\mathrm{ttd}}$ model rather than ISTI, and because May 20m temperatures were warmer than average, also decreased the forecast from the two-parameter $\mathrm{CPUE}_{\mathrm{ttd}}$ model relative to the single-parameter model (Table 3).

The two-parameter $\mathrm{CPUE}_{\mathrm{cal}}$ model and the EIR model were very similar in model fit and predicted harvests. They had virtually identical $R^2$ and $\mathrm{AIC}_c$ statistics (Table 3), and the EIR prediction of 58 M was within 10% of the $\mathrm{CPUE}_{\mathrm{cal}}$ forecast. The jackknife analysis showed lower average and median deviations for the $\mathrm{CPUE}_{\mathrm{cal}}$ 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 $\mathrm{CPUE}_{\mathrm{cal}}$ 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.

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Table 1.—Correlation coefficients for juvenile pink salmon biophysical parameters and ecosystem metrics in year *y* for 1997-2013 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$_{cal}$** | **0.81** | **<0.001** |
| **CPUE$_{ttd}$** | **0.84** | **<0.001** |
| AugustCPUE | -0.08 | 0.751 |
| **Seasonality** | **-0.62** | **0.008** |
| **Percentage of Juvenile Pinks** | **0.61** | **0.010** |
| Juvenile pink salmon growth and condition | | |
| Pink Salmon Size July 24 | 0.12 | 0.510 |
| Condition Index | 0.12 | 0.643 |
| Energy Content | -0.01 | 0.967 |
| Predator Indexes | | |
| Adult Coho Abundance | -0.28 | 0.326 |
| **Adult Coho Abundance/CPUE$_{cal}$** | **-0.81** | **<0.001** |
| Zooplankton standing crop | | |
| June/July Average Zooplankton Total Water Column | 0.10 | 0.704 |
| June Preferred Prey | -0.21 | 0.423 |
| Local-scale physical conditions | | |
| May 20-m Integrated Water Temperature | 0.05 | 0.843 |
| June 20-m Integrated Water Temperature | -0.24 | 0.364 |
| Icy Strait Temperature Index (ISTI) | -0.17 | 0.515 |
| June Mixed-layer Depth | 0.07 | 0.800 |
| July 3-m Salinity | 0.00 | 0.998 |
| MR Spring Flow (March-May) | -0.14 | 0.589 |
| PC1 for local physical conditions | -0.17 | 0.530 |
| Basin-scale physical conditions | | |
| Pacific Decadal Oscillation (PDO, y-1) | 0.02 | 0.950 |
| **Northern Pacific Index (NPI**, y**)** | **0.61** | **0.009** |
| ENSO Multivariate Index (MEI, Nov (*y-1*)-March (*y*)) | 0.30 | 0.246 |

Table 2.—Southeast Coastal Monitoring (SECM) and Alaska Department of Fish and Game (ADFG) forecasts for 2014 pink salmon harvest in Southeast Alaska (SEAK). The ADFG forecasts are from Piston and Heinl (2014). NA = not applicable.

| | **Pink salmon (M of fish)** | **Deviation from actual harvest** |
|---|---|---|
| SECM forecast | 29.9 | -20% |
| ADFG forecast (w/ CPUE$_{cal}$ data) | 22.0 | -41% |
| ADFG forecast (w/o CPUE$_{ttd}$ data) | 22.0 | -41% |
| Actual harvest | 37.2 | 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* = 1997-2013. $R^2$ = 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($CPUE_{cal}$) | 63% | 143.0 | <0.001 | 55.5 |
| Ln($CPUE_{cal}$) + ISTI | 74% | 137.8 | <0.001 | 54.5 |
| Ln($CPUE_{ttd}$) | 69% | 141.1 | <0.001 | 74.0 |
| Ln($CPUE_{ttd}$) + May20Temp | 81% | 134.4 | <0.001 | 71.5 |
| Ecosystem Ranks | 74% | 137.5 | <0.001 | 57.9 |

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($CPUE_{cal}$) | 28.0 | 11.3 |
| Ln($CPUE_{cal}$) + ISTI | 20.0 | 11.9 |
| Ln($CPUE_{ttd}$) | 30.2 | 16.5 |
| Ln($CPUE_{ttd}$) + May20Temp | 26.8 | 29.1 |
| Ecosystem Ranks | 24.4 | 14.4 |

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 2015 harvest.

| **Juvenile Year Y+1** | **Harvest Year Y (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 | 2.79 | 16.0 | 9.2 | 6.5 |
| 2014 | TBD | 3.4 | 4.47 | July | 0.57 | 2.08 | 15.8 | 9.4 | 7.7 |
| **Average** | **44.5** | **2.8** | **2.86** | **July** | **0.30** | **2.15** | **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 2015 harvest.

| **Juvenile Year Y** | **Harvest Y+1** | **$\text{CPUE}_{\text{cal}}$** | **$\text{CPUE}_{\text{ttd}}$** | **Seasonality** | **% Pinks** | **Coho Predation Index** | **NPI Index** | **ISTI** | **May 20m Temp** |
|---|---|---|---|---|---|---|---|---|---|
| 1997 | 10 | 12 | 13 | 2 | 15 | 6 | 14 | 7 | 7 |
| 1998 | 2 | 1 | 1 | 1 | 4 | 1 | 1 | 6 | 3 |
| 1999 | 15 | 16 | 17 | 2 | 18 | 17 | 10 | 13 | 16 |
| 2000 | 3 | 3 | 6 | 2 | 12 | 3 | 3 | 12 | 14 |
| 2001 | 7 | 8 | 10 | 2 | 7 | 10 | 5 | 8 | 9 |
| 2002 | 6 | 9 | 11 | 2 | 11 | 13 | 15 | 17 | 17 |
| 2003 | 8 | 7 | 7 | 2 | 14 | 8 | 7 | 2 | 6 |
| 2004 | 4 | 2 | 5 | 1 | 5 | 5 | 17 | 3 | 5 |
| 2005 | 17 | 14 | 15 | 3 | 9 | 15 | 16 | 1 | 2 |
| 2006 | 9 | 10 | 12 | 1 | 10 | 9 | 4 | 14 | 12 |
| 2007 | 16 | 18 | 18 | 3 | 16 | 16 | 12 | 10 | 10 |
| 2008 | 11 | 11 | 14 | 3 | 6 | 12 | 8 | 18 | 18 |
| 2009 | 13 | 13 | 8 | 3 | 8 | 7 | 18 | 5 | 8 |
| 2010 | 5 | 4 | 2 | 1 | 1 | 2 | 2 | 4 | 1 |
| 2011 | 14 | 17 | 16 | 3 | 13 | 18 | 13 | 14 | 11 |
| 2012 | 1 | 6 | 4 | 2 | 3 | 4 | 6 | 16 | 13 |
| 2013 | 12 | 15 | 9 | 2 | 17 | 14 | 9 | 11 | 15 |
| 2014 | TBD | 5 | 3 | 2 | 2 | 11 | 10 | 8 | 4 |

Table 7.—Southeast Alaska (SEAK) pink salmon harvest (in millions of fish, M) and associated forecasts from Southeast Coastal Monitoring (SECM) juvenile $\text{CPUE}_{cal}$ models and Alaska Department Fish and Game (ADFG) exponential smoothing models. Accuracy of the forecast is shown in parentheses. For SECM, both the simple $\text{CPUE}_{cal}$ and the multi-parameter $\text{CPUE}_{cal}$ models are shown. Similarly for ADFG, both the exponential smoothing model with (2007-2014) and without the addition of the SECM juvenile $\text{CPUE}_{cal}$ data are shown.

| | | **SECM** $\text{CPUE}_{cal}$ **Models** | | **ADFG Exp. Smoothing Models** | |
|---|---|---|---|---|---|
| **Year** | **SEAK harvest (M)** | $\text{CPUE}_{cal}$ **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%) |

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

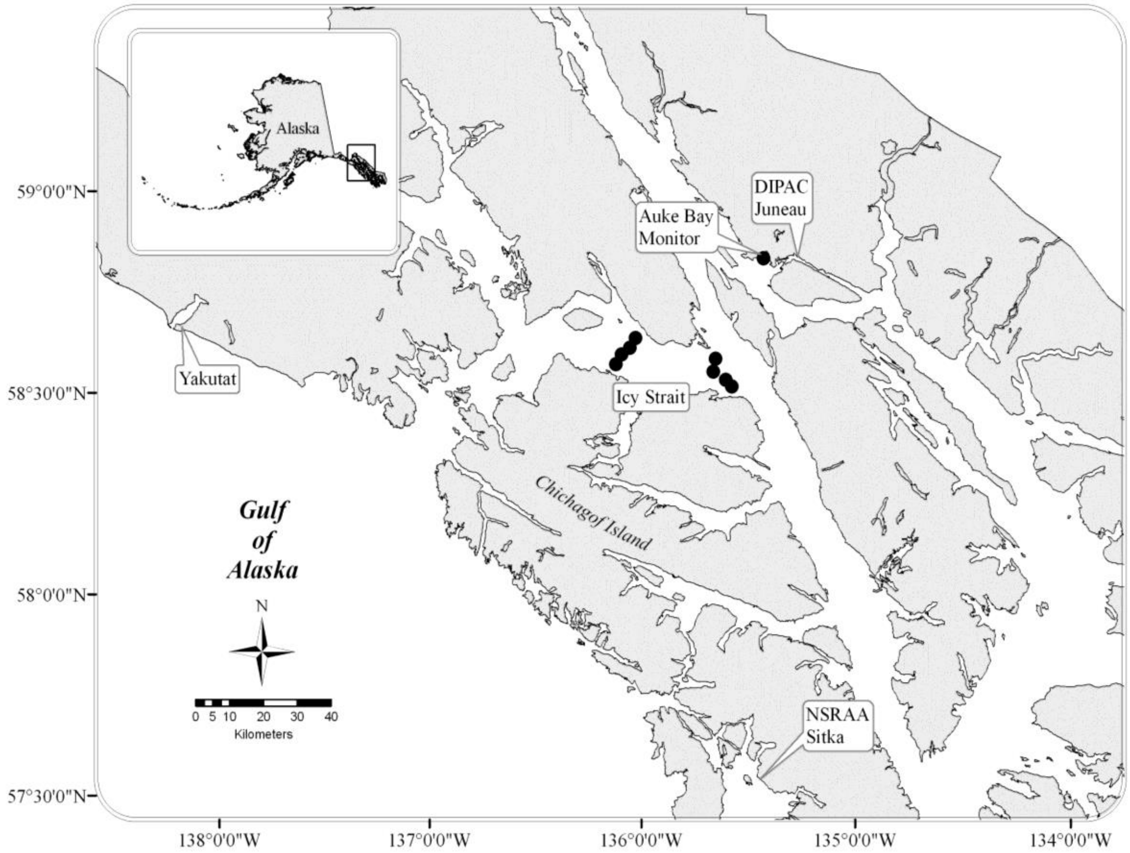

Figure 1.—Stations sampled for juvenile pink salmon and associated biophysical parameters along the Icy Strait transects in the northern region of Southeast Alaska for the development of pink salmon harvest forecast models. Stations were sampled monthly from May to August, 1997–2014. Oceanography was conducted in all months and surface trawling for juvenile salmon occurred from June to August.

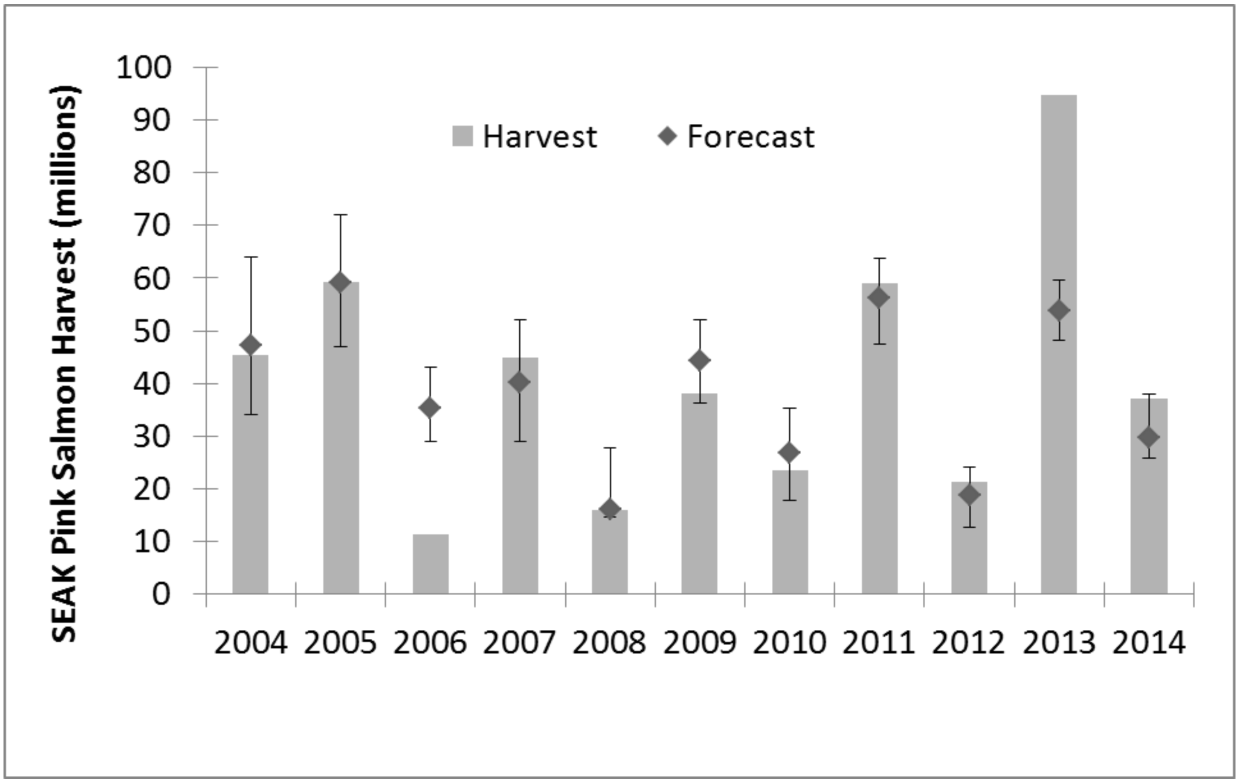

Figure 2.—Southeast Coastal Monitoring (SECM) project pink salmon harvest forecasts for Southeast Alaska (SEAK; symbols), associated 80% confidence intervals (lines), and actual SEAK pink salmon harvests (grey bars), 2004-2013.

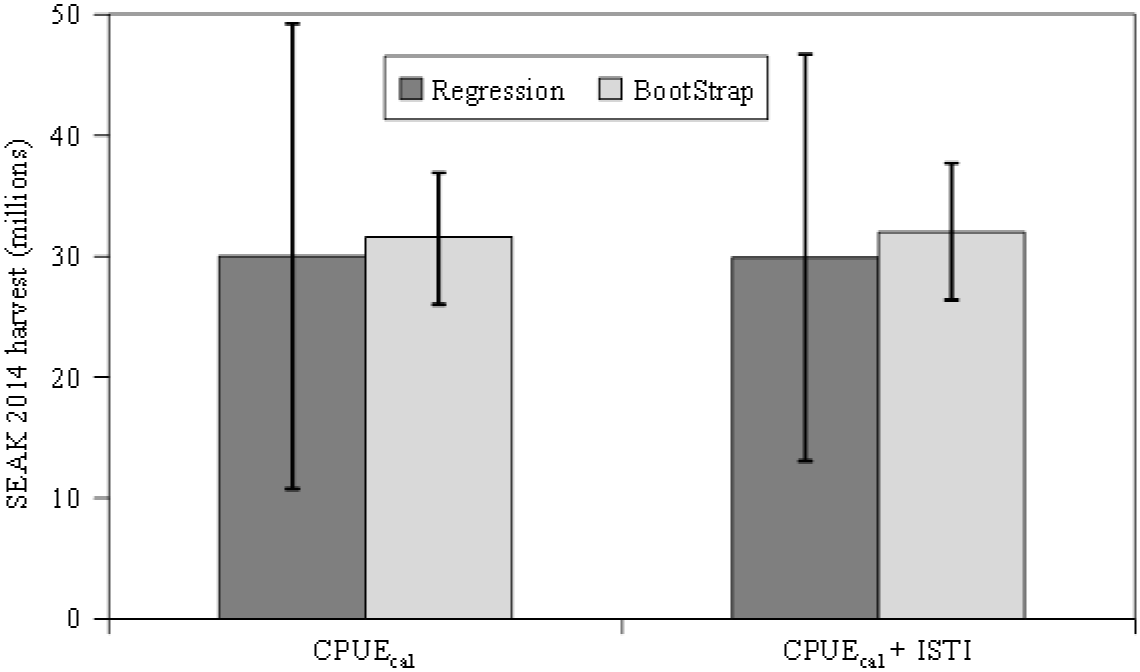

Figure 3.—Harvest predictions from parametric regression (dark bars) and bootstrap (light bars) analyses with 80% confidence intervals (lines) for Southeast Alaska (SEAK) pink salmon in 2015 using two models incorporating juvenile peak (catch-per-unit-effort) CPUE$_{cal}$ data in 2014. See text for descriptions of model parameters.