NPAFC
Doc. 1486
Rev.____

Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Biophysical Parameters: 2012 Returns and 2013 Forecast

by

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Submitted to the

NORTH PACIFIC ANADROMOUS FISH COMMISSION

by

the United States of America

September 2013

THIS PAPER MAY BE CITED IN THE FOLLOWING MANNER:

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 Biophysical Parameters: 2012 Returns and 2013 Forecast. NPAFC Doc. 1486, 23 pp. (Available at http://www.npafc.org).

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Abstract

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. 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), adjusted for highly-correlated biophysical parameters, has been used to forecast adult pink salmon harvest (*O. gorbuscha*) in SEAK. The 2012 forecast of 18.8 M fish was 12% lower than the actual harvest of 21.3 M fish. Eight of nine forecasts produced over the period 2004-2012 have been within 17% of the actual harvest, with an average forecast deviation of 7%. The forecast for 2006 was the exception; while the simple CPUE model indicated a downturn in harvest, the prediction substantially overestimated the harvest. These results show that the CPUE information has great utility for forecasting year class strength of SEAK pink salmon, but additional information may be needed to avoid forecast “misses.” For the 2013 forecast, model selection included a review of ecosystem indicator variables and considered additional biophysical parameters to improve the simple single-parameter juvenile CPUE forecast model. The “best” forecast model for 2013 included two parameters, the Icy Strait Temperature Index (ISTI) and juvenile CPUE. The 2013 forecast of 53.8 M fish from this model, using juvenile salmon data collected in 2012, had an 80% bootstrap confidence interval of 48-60 M fish.

Introduction

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

Pink salmon are a good species to test the utility of indexes of juvenile salmon abundance in marine habitats for forecasting because of their short, two-year life cycle. Sibling recruit models are not available for this species because no leading indicator information exists (i.e., only one age class occurs in the fishery). Spawner/recruit models have also performed poorly for predicting pink salmon returns, due to high uncertainty in estimating spawner abundance and high variability in marine survival (Heard 1991; Haeseker et al. 2005). The exponential smoothing model that the Alaska Department of Fish and Game (ADFG) employs using the time series of annual harvests has provided more accurate forecasts of SEAK pink salmon than spawner/recruit analyses (Plotnick and Eggers 2004; Eggers 2006). Wertheimer et al. (2006) documented a highly significant relationship between annual peak juvenile pink salmon catch-per-unit-effort (CPUE) from the SECM research in June or July and the SEAK harvest. These CPUE data used as a direct indicator of run strength have been supplemented with associated biophysical data in some years (Wertheimer et al. 2011, 2012), or used as auxiliary data to improve the ADFG exponential smoothing model (Heinl 2012; Piston and Heinl 2013). Recently, efforts have been made to incorporate climate change scenarios into stock assessment models (Hollowed et al. 2011) and to examine relationships of ecosystem metrics to salmon production (Miller et al. 2013; Orsi et al. 2012b, 2013b). The SECM project has developed a 16-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 2012 SEAK pink salmon harvest and on the development of a prediction model for the 2013 forecast.

Methods

Study Area

This paper focuses on forecasting the fishery harvest of adult pink salmon in SEAK, using information on juvenile salmon and their associated biophysical (biological and physical) parameters from the prior year (Table 1). Pink salmon spawning aggregates originate from over 2,000 streams throughout the SEAK region (Baker et al. 1996), and are comprised of 98% wild stocks. Data on juvenile pink salmon abundance, size, and growth, and associated biophysical parameters have been collected by the SECM project annually since 1997;

detailed descriptions of the sampling locations and data collections have been reported in annual NPAFC documents (e.g., Orsi et al. 2011, 2012a, 2013a). The SECM data used in the forecasting models are from eight stations along two transects across Icy Strait in the northern region of SEAK, sampled monthly from May to August 1997-2012 (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 (2012), 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 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 (CPUE) and phenology in northern SEAK were evaluated. The CPUE data was adjusted using calibration factors to account for differences in fishing power among vessels (Wertheimer et al. 2010; Orsi et al. 2013). One index parameter was the average Ln(CPUE+1) for catches in either June or July, whichever month had the highest average catches in a given year, y (Peak CPUE, Table 1). This parameter has been identified to have the highest correlation with harvest and to provide the best performance among potential CPUE metrics for forecasting harvest (Wertheimer et al. 2006, 2011, 2012). The second parameter was the average Ln(CPUE+1) for August in northern SEAK (August CPUE, 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 third parameter was the actual month in which Peak CPUE was observed each year, also chosen to represent migratory timing or seasonality. Parameter values for the peak month in each year were assigned as: June = 1, July = 2, and August = 3. The fourth parameter was the percentage of juvenile pink salmon represented in the total annual catch of all five species of juvenile salmon.

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

Zooplankton metrics

Three 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 NORPAC net 243-µm settled volume (ml), an index of upper 20-m water column small zooplankton biomass (June/July Average Zooplankton 20-m); 2) 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 3) 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

Seven 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 3-m water temperature (°C) adjusted to a standard date of May 23 (May 3-m Water Temperature); 2) May upper 20-m integrated average water temperature (°C) adjusted to a standard date of May 23 (May 20-m Integrated Water Temperature); 3) June upper 20-m integrated average water temperature (°C, June 20-m Integrated Water Temperature); 4) the annual Icy Strait Temperature Index (°C; ISTI, see below); 5) June average mixed-layer depth (MLD, June Mixed-layer Depth); 6) July 3-m salinity (PSU, July 3-m Salinity); and 7) freshwater outflow from the Mendenhall River near Juneau from March through May (cfs; MR Spring Flow, see below). The ISTI was calculated as the summer grand average of the 20-m integrated water column temperature, using the monthly averages of ≥ 160 temperatures taken at 1-m increments for May, June, July and August each year. The MR spring flow was calculated as the sum of the monthly average flows for March, April, and May (data source: US Geological Survey).

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 an index of environmental conditions 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). 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 outmigration, year y-1. Conditions measured by the MEI in the equatorial Pacific reach Alaska approximately one year later; thus MEI values reflect conditions experienced by adult salmon harvested in year y+1.

Forecast Model Development

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

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

where γ is the coefficient for biophysical parameter X. Backward/forward stepwise regression with an alpha value of $P < 0.05$ was used to determine whether a biophysical parameter was entered into the model.

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 ($\mathrm{AIC_c}$) 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 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 1997-2011 were used to construct the regression models with SEAK harvest as the dependent variable, and the appropriate averages of the simulated catches for 2012 were used to forecast 2013 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 15 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; see also: http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/g-forecast.cfm, Orsi 2013c), and their relative ranks in 2012 were considered for selecting the best regression model to forecast the 2013 harvest.

Results

2012 Forecast Efficacy

In 2012, the SECM forecast of 18.8 M pink salmon was 12% lower than the actual 2012 harvest of 21.3 M fish (Table 2). Including the 2012 results, eight of the nine SECM forecasts since 2004 have been within 17% of the actual harvest (average 7%) and within the associated 80% confidence intervals (Figure 2). Only in 2006 has the harvest been substantially different from the forecast; in that year, the actual harvest was well outside the 80% confidence interval of the forecast (Figure 2).

2013 Forecast

Bivariate correlations were computed between SEAK pink salmon harvests for 2004-2012 using 20 potential prediction variables (Table 1). Three of these variables were significantly ($P \leq 0.05$) correlated with SEAK pink salmon harvest; two of the three were measures of juvenile pink salmon abundance or timing. Consistent with prior years' analyses, Peak CPUE was the parameter most highly correlated with harvest ($r = 0.93$, $P < 0.001$). Seasonality was negatively correlated with harvest ($r = -0.78$, $P = 0.001$), 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 ($r = 0.64$, $P = 0.013$). None of the other biophysical parameters evaluated were significantly ($P > 0.05$) correlated with harvest.

In the stepwise regression analysis, a two-parameter model including Peak CPUE and ISTI explained 91% of the variability in the harvest data (Adjusted R^2), compared to 85% for the simple linear regression with Peak CPUE (Table 3). The AIC_c was lower for the two-parameter model, indicating that this model is not over-parameterized. The 2013 forecasts using 2012 juvenile Peak CPUE were 47.8 M for the simple Peak CPUE model and 53.8 M for the two-parameter model.

The jackknife analysis indicated that forecast accuracy of the Peak CPUE forecast model for the SEAK harvest was improved by including the ISTI as an auxiliary parameter. Including these data decreased the average absolute percent deviation of the jackknife forecasts from the actual harvests for the years 1998-2012 from 24% to 20%. This improved performance of the two-parameter model was due to its better fit for the 2006 harvest, the year in which the actual forecast by the simple Peak CPUE model was poor (Table 4). By including this auxiliary parameter, the deviation of the jackknife forecast from the 2006 harvest decreased from 176% to 117%. If 2006 is excluded from the jackknife analysis, the one-parameter model actually has a slightly lower absolute average deviation (12%) relative to the two-parameter model (14%), while the median absolute deviation is higher for the one-parameter model (13%) than the two-parameter model (10%). Over the jack-knife time series, the one-parameter model provided better estimates in 8 of the 15 years (Table 4).

The 80% bootstrap CIs for the one- and two-parameter models for the 2013 forecast were compared with the 80% PIs from the regression equations (Figure 3). The regression PIs declined as the number of parameters in the model increased, from an interval width of 21 M fish for the simple Peak CPUE model to an interval width of 17 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 CIs were narrower for the simple CPUE model (10 M fish) than for the two-parameter model (12 M fish; Figure 3).

Table 5 lists annual values and ranks of the four parameters in the 16-yr SECM time series that were significantly correlated with SEAK harvest (Peak CPUE, Seasonality, and NPI), as well as the significant auxiliary variable in the two-parameter regression model (ISTI). In 2012, Peak CPUE was in the second quartile of ranks, and was the fifth highest for the time series. Seasonality was a “2” (July peak), which is the mid-value possible. The NPI was in the second quartile of ranks, the sixth highest value for the time series. The ISTI was in the bottom quartile of ranks for 2012, the third coldest year for the time series.

Discussion

2012 Returns and Forecast Efficacy

The 2012 harvest of 21 M pink salmon in SEAK was below both the recent 10-year average harvest of 39.6 M and the long-term average since statehood of 30.0 M (Eggers et al. 2013). The SECM forecast model for 2012 predicted a harvest of 18.8 M pink salmon in SEAK, which was 12% lower than the actual harvest. This level of accuracy is consistent with past model performance; forecasts for eight of the past nine years have been within 17% of the actual harvest. The single exception over the SECM forecast history was the over-estimation of the 2006 return of pink salmon. The pink salmon harvest in 2006 was very poor, and was not accurately forecast by the simple juvenile pink salmon CPUE relationship (Figure 2). However, the CPUE model did indicate a decline relative to recent years, which was not apparent in the ADFG forecast that relied only on trends in annual harvests (Table 6). Drought conditions and high stream temperatures in the late summer and fall of 2004 may have contributed to the poor year-class strength of pink salmon out-migrating in 2005 and returning in 2006. Juvenile pink salmon CPUE should, however, account for low recruitment of pink salmon from streams to the coastal marine environment following these conditions. 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 2006 suggests that such a “downstream” mortality event occurred after the SECM 2005 sampling period. In fact, 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, the harvest hindcast for 2000 was more accurate (Table 4), a year when SECM process studies documented predation impact on juvenile salmon abundance in inside waters of SEAK (Sturdevant et al. 2009).

Information on environmental conditions that affect juvenile pink salmon as they migrate through SEAK waters and enter 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 these data are collected. As in 2012, incorporating biophysical data in the forecast models improved forecasts relative to the simple Peak CPUE model in 2007, 2008, and 2010, but not in 2009 or 2011 (Table 6). Thus, while it is reasonable that including other biophysical data could improve forecast efficacy of the CPUE model, the results to date have been mixed.

For the 2012 SECM forecast, we selected the two-parameter, Peak CPUE + ISTI model as the “best” forecast because it had higher adjusted R^2 and lower AIC_c values (Wertheimer et al. 2012). In 2011, May water temperatures were cooler than average, which resulted in a higher predicted harvest for 2012 for the two-parameter model relative to that predicted by Peak CPUE alone. For our final model selection, other ecosystem indicators we considered were Seasonality and Percentage of Juvenile Pinks as well as the NPI (Wertheimer et al. 2012). Because the indications from these other ecosystem indicators were mixed, we selected the two-parameter model as the “best” forecast based on the statistical analyses. In retrospect, our selection of this model for the 2012 forecast was appropriate, as our current analysis of model efficacy puts this forecast within 12% of the actual harvest compared to 17% of the actual harvest from the one-parameter model (Table 6).

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 by 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 Peak CPUE 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 2012 was 17 M (Heinl 2012), with a -20% deviation from the actual harvest, whereas the unmodified exponential smoothing model provided a forecast of 23 M, with an 8% deviation from the actual harvest (Table 2).

Thus, the incorporation of the juvenile data did not improve the ADFG forecast in 2012. However, the modified trend analysis forecasts have improved on the original trend model in four of six years since implementation (Table 6). Also, the average absolute deviation (and range) for the modified model from 2007-2012 has been substantially better than the model adjusted with the juvenile data, 13% (range, 4-20%) versus 31% (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 Peak 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 Peak CPUE as the main predictive parameter. The two approaches have performed similarly for 2007-2012 (Table 6).

2013 Forecast

We selected the two-parameter model including Peak CPUE + ISTI as the “best” model for the 2013 SECM forecast based on model fit and the AIC_c. This model predicts a harvest of 54 million, with an 80% bootstrap confidence interval of 48-60 million. The jackknife analysis showed lower average and median deviations for predictions for the two-parameter model (Table 4); however, we did note that the one-parameter model provided better hindcasts for 8 of the 15 years evaluated, compared with 7 for the two-parameter model. We used the bootstrap confidence interval for the forecast because the bootstrap procedure accounts for measurement error in the CPUE.

In previous years (e.g., Wertheimer et al. 2011), May 20-m Temperature has been identified as the environmental parameter significantly improving the one-parameter Peak CPUE model. Colder May temperatures have been associated with higher harvests than predicted by CPUE alone. For the 2013 harvest forecast, the ISTI improved the Peak CPUE 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. If ISTI had been used instead of May 20-m Temperature to predict the 2012 harvest, the forecast would have been 20.9 million, or within 2% of the actual harvest (Table 4).

We again considered the other ecosystem indicators listed in Table 6 in our final model selection for the 2013 forecast. In 2012, besides Peak CPUE and ISTI, these included Seasonality and the NPI. Seasonality peaked in July, characteristic of “average” run strength. The NPI was in the second quartile of ranks, above average for the time period but not indicative of an unusually strong return. The ISTI was in the lower quartile of ranks for the time series, which has a positive effect on the forecast (Table 3). Because the indications from the other ecosystem indicators were average to somewhat above average, we selected the two-parameter model as the best based on the statistical analyses and the effect of the ISTI on the forecast.

The 2013 SECM forecast of 54 M pink salmon represents an excellent potential harvest of pink salmon in SEAK. This would be the fifth highest harvest during the SECM time series (since 1998), and in the upper 20% of harvests since 1960 (Piston and Heinl 2013). The ADFG forecast for 2013, using the exponential smoothing model modified with SECM Peak CPUE data, was also 54 M (Piston and Heinl 2013).

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 16 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. 2012. 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.

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.

Eggers, D., C. Tide, and A. M. Carroll (eds.). 2013. Run forecasts and harvest projections for the 2013 Alaska salmon fisheries with a review of the 2012 season. Alaska Dept. Fish Game Spec. Publ. 13-03, 116 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.

Heinl, S. 2012. Forecast area Southeast Alaska, species pink salmon. Pp. 48-51. *In*: D. M. Eggers and A. M. Carroll (eds.), Run forecasts and harvests projections for 2012 Alaska salmon fisheries and a review of the 2011 season. Alaska Department Fish and Game Special Publication 12-01. http://www.adfg.alaska.gov/FedAidPDFs/SP12-01.pdf

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 managmenet 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.

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. A., E. A. Fergusson, M. V. Sturdevant, W. R. Heard, and E. V. Farley, Jr. 2012a. Annual Survey of juvenile salmon, ecologically-related species, and environmental factors in the marine waters of Southeastern Alaska, May–August 2011. NPAFC Doc. 1428, Rev. 1. 102 pp. (Available at http://www.npafc.org).

Orsi, J., E. A. Fergusson, and M. V. Sturdevant. 2012b. 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: 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. 2013c. Using Ecosystem Indicators from the Southeast Alaska Coastal Monitoring Project to Forecast Pink Salmon Harvest in Southeast Alaska. AFSC Quarterly June/July/Aug 2013 http://www.afsc.noaa.gov/quarterly/amj2013/divrptsABL1.htm

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. Available: http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/documents/Peterson_etal_2012.pdf

Piston, A., and S. Heinl. 2013. Forecast area Southeast Alaska, species pink salmon. Pp. 50-53. *In*: D. Eggers, C. Tide, and A. M. Carroll (eds.), Run forecasts and harvests projections for 2013 Alaska salmon fisheries and a review of the 2012 season. Alaska Department Fish and Game Special Publication 13-03. http:// www.adfg.alaska.gov/FedAidPDFs/sp11-03.pdf

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.

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., M. F. Sigler, and J. A. Orsi. 2009. Sablefish predation on juvenile salmon in the coastal marine waters of Southeast Alaska in 1999. Transactions of the American Fisheries Society 138:675–691.

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 xx 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. xx pages, 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 (Rappoteur) (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. 2012. 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 1997-2011 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		
Peak CPUE	**0.93**	**<0.001**
August CPUE	-0.34	0.211
Seasonality	**-0.78**	**0.001**
Percentage of Juvenile Pinks	0.46	0.083
Juvenile pink salmon growth and condition		
Pink Salmon Size July 24	0.26	0.356
Condition Index	-0.03	0.923
Energy Content	0.17	0.539
Zooplankton standing crop		
June/July Average Zooplankton 20-m	0.23	0.421
June/July Average Zooplankton Total Water Column	0.17	0.539
June Preferred Prey	0.10	0.973
Local-scale physical conditions		
May 3-m Water Temperature	0.13	0.645
May 20-m Integrated Water Temperature	0.06	0.823
June 20-m Integrated Water Temperature	-0.09	0.743
Icy Strait Temperature Index (ISTI)	-0.05	0.849
June Mixed-layer Depth	-0.03	0.909
July 3-m Salinity	0.32	0.258
MR Spring Flow (March-May)	-0.07	0.801
Basin-scale physical conditions		
Pacific Decadal Oscillation (PDO, y-1)	0.31	0.258
Northern Pacific Index (NPI, y**)**	**0.65**	**0.009**
ENSO Multivariate Index (MEI, y-1)	0.42	0.115

Table 2.—Southeast Coastal Monitoring (SECM) and Alaska Department of Fish and Game (ADFG) forecasts for 2012 pink salmon harvest in Southeast Alaska (SEAK). The ADFG forecasts are from Heinl (2012). NA = not applicable.

	Pink salmon (M of fish)	**Deviation from actual harvest**
SECM forecast	18.8	-12%
ADFG forecast (w/ Peak CPUE data)	17.0	-20%
ADFG forecast (w/o Peak CPUE data)	23.0	8%
Actual harvest	21.3	NA

Table 3.—Regression models relating juvenile pink salmon catch-per-unit-effort (CPUE) in year *y* to adult harvest in Southeast Alaska (SEAK) in year *y* +1, for *y* = 1997-2011. 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	**Harvest area**	**Adjusted R^2**	**AIC_C**	**Regression *P* -value**	**2013 Prediction (M)**
Ln(PeakCPUE)	SEAK	85%	99.3	<0.001	47.8
Ln(PeakCPUE) + ISTI	SEAK	91%	94.6	<0.001	53.8

Table 4.—Results of hind-cast jackknife analysis for one-parameter (juvenile pink salmon CPUE) and two-parameter (CPUE + ISTI) regression models for efficacy of Southeast Alaska (SEAK) adult pink salmon harvest predictions.

		CPUE Model		**CPUE + ISTI**	
Year	**SEAK Harvest (millions)**	**Predicted Harvest**	**% Abs. Deviation**	**Predicted Harvest**	**% Abs. Deviation**
1998	42.5	36.7	13.6%	34.3	19.3%
1999	77.8	96.4	23.9%	96.6	24.2%
2000	20.3	23.5	16.3%	25.9	27.9%
2001	67.0	55.6	17.0%	59.2	11.6%
2002	45.3	43.1	4.8%	41.6	8.2%
2003	52.5	41.1	21.7%	48.2	8.2%
2004	45.3	46.7	3.1%	41.5	8.3%
2005	59.1	59.6	0.7%	57.2	3.3%
2006	11.6	32.0	175.7%	25.2	116.7%
2007	44.8	38.2	14.7%	42.2	5.8%
2008	15.9	16.3	2.7%	14.1	11.5%
2009	38.0	37.2	2.0%	51.5	35.6%
2010	24.0	31.6	35.1%	27.5	14.3%
2011	58.9	56.2	3.9%	53.5	9.1%
2012	21.3	17.7	17.1%	20.9	2.1%
Average			23.5%		20.4%
Median			14.7%		11.5%
Average	(exclude 2006)		12.2%		13.6%
Median	(exclude 2006)		13.3%		10.3%

Table 5.—Annual measures and rankings (in parentheses) 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 Peak CPUE with SEAK pink salmon harvest. TBD: to be determined, table compiled prior to completion of 2013 harvest.

Adult year	**Juvenile year**	**SEAK harvest (M)**	**Peak CPUE (ln+1)**	**Seasonality (peak month)**	**NPI Index**	**Icy Strait Temperature Index (°C)**
1998	1997	42.5 (9)	2.5 (11)	July (2)	15.6 (12)	9.5 (7)
1999	1998	77.8 (1)	5.6 (1)	June (1)	18.1 (1)	9.6 (6)
2000	1999	20.2 (13)	1.6 (14)	July (2)	15.8 (9)	9.0 (11)
2001	2000	67.0 (2)	3.7 (3)	July (2)	17.0 (3)	9.0 (10)
2002	2001	45.3 (6)	2.9 (7)	July (2)	16.8 (5)	9.4 (8)
2003	2002	52.5 (5)	2.8 (8)	July (2)	15.6 (13)	8.6 (15)
2004	2003	45.3 (7)	3.1 (6)	July (2)	16.1 (7)	9.8 (2)
2005	2004	59.1 (3)	3.9 (2)	June (1)	15.1 (15)	9.7 (3)
2006	2005	11.6 (15)	2.0 (13)	August (3)	15.5 (14)	10.3 (1)
2007	2006	44.8 (8)	2.6 (9)	June (1)	17.0 (4)	8.9 (13)
2008	2007	15.9 (14)	1.2 (16)	August (3)	15.7 (10)	9.3 (9)
2009	2008	38.0 (10)	2.5 (10)	August (3)	16.1 (8)	8.3 (16)
2010	2009	23.4 (11)	2.1 (12)	August (3)	15.1 (16)	9.6 (5)
2011	2010	59.0 (4)	3.7 (4)	June (1)	17.6 (2)	9.6 (4)
2012	2011	21.3 (12)	1.3 (15)	August (3)	15.7 (11)	8.9 (12)
2013	2012	TBD	3.2 (5)	July (2)	16.7 (6)	8.7 (14)

Table 6.—Southeast Alaska (SEAK) pink salmon harvest (in millions of fish, M) and associated forecasts from Southeast Coastal Monitoring (SECM) juvenile CPUE 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 and the multi-parameter CPUE models (if simple model was not used for forecast) are shown. Similarly for ADFG, both the exponential smoothing model with (2007-2012) and without the addition of the SECM juvenile CPUE data are shown (Steve Heinl, ADFG, personal communication).

		SECM CPUE Models		**ADFG Exp. Smoothing Models**	
Year	**SEAK harvest (M)**	**CPUE 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%)

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

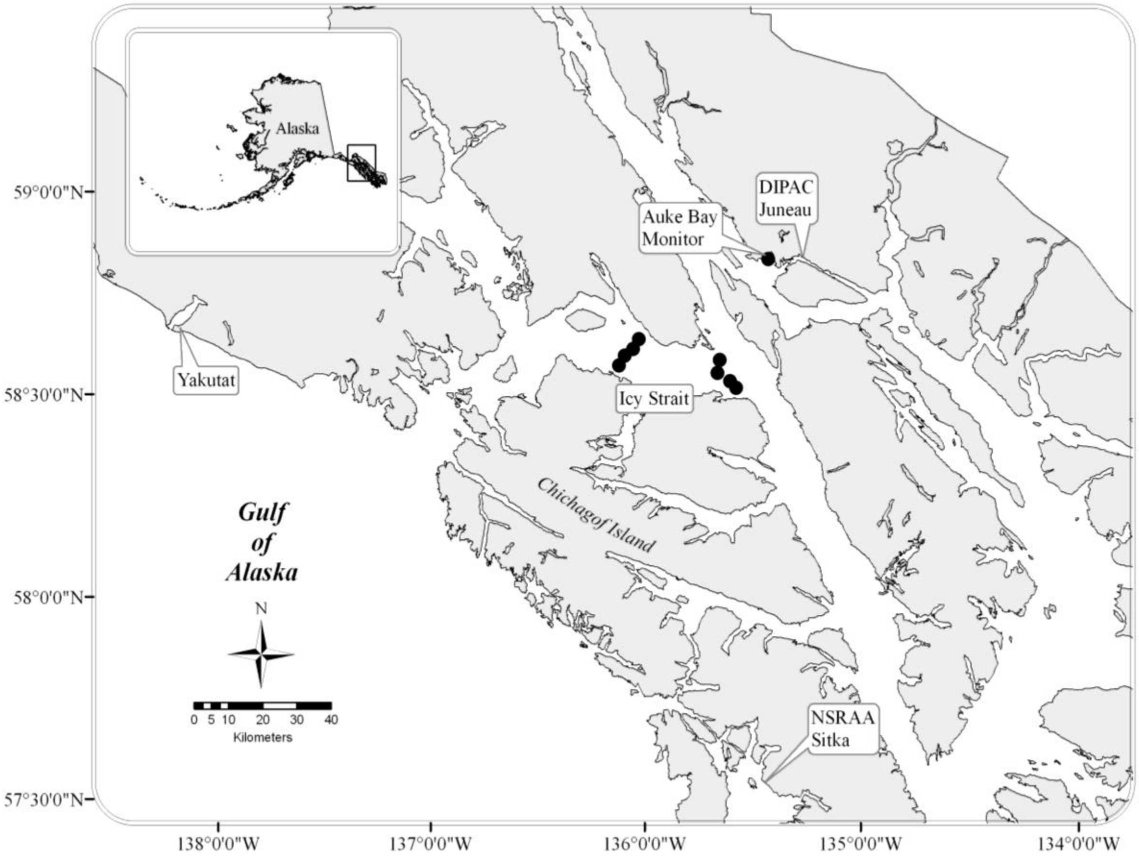

Figure 1.—Stations sampled for juvenile pink salmon and associated biophysical parameters along the Icy Strait transects in the northern region of Southeast Alaska for the development of pink salmon harvest forecast models. Stations were sampled monthly from May to August, 1997–2012. Oceanography was conducted in all months and surface trawling for juvenile salmon occurred only from June to August.

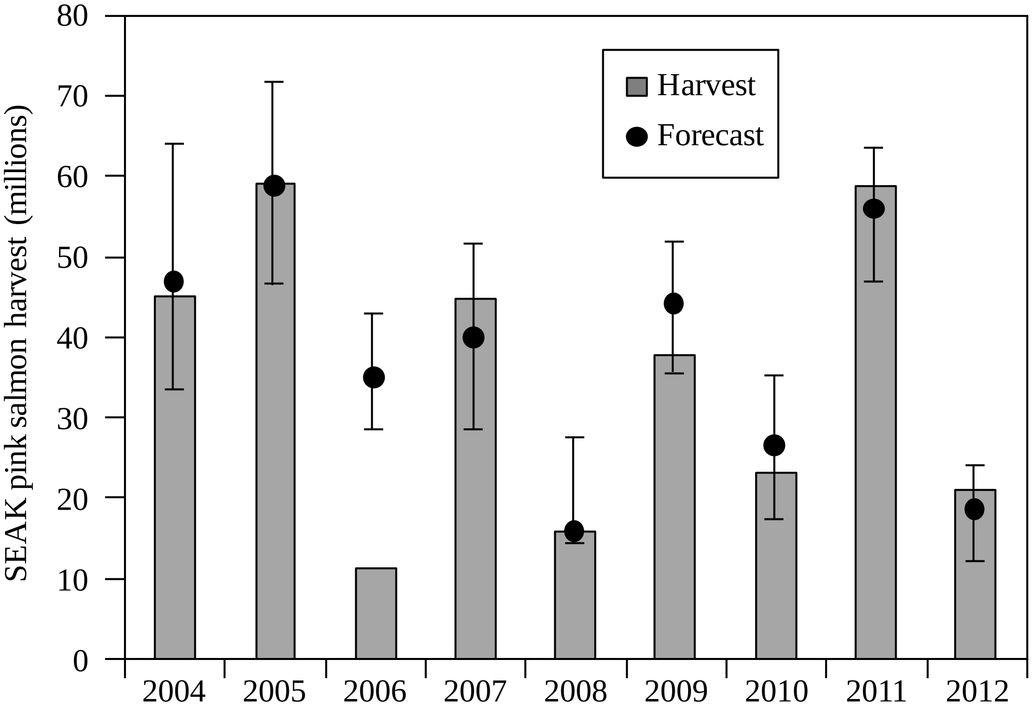

Figure 2.—Southeast Coastal Monitoring (SECM) pink salmon harvest forecasts for Southeast Alaska (SEAK; symbols), associated 80% confidence intervals (lines), and actual SEAK pink salmon harvests (colored bars), 2004-2012.

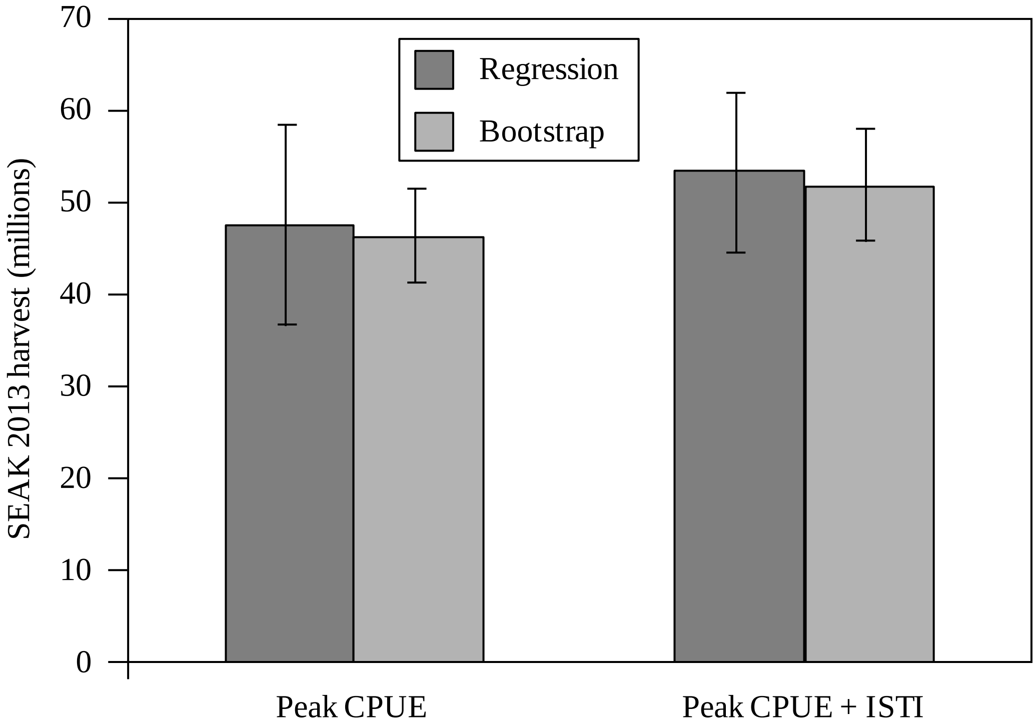

Figure 3.—Harvest predictions from parametric regression (dark bars) and bootstrap (light bars) analyses with 80% confidence intervals (lines) for Southeast Alaska (SEAK) pink salmon in 2013 using two models incorporating juvenile peak (catch-per-unit-effort) CPUE data in 2012. See text for descriptions of model parameters.