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Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Biophysical Parameters: 2011 Returns and 2012 Forecast

by

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Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Biophysical Parameters: 2011 Returns and 2012 Forecast

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, juvenile peak salmon catch per unit effort (CPUE) from SECM, adjusted for highly-correlated biophysical parameters, has been used to forecast harvest of adult pink salmon (*O. gorbuscha*) in SEAK. The 2011 forecast of 56.2 M fish was 5% lower than the actual harvest of 59.0 M fish. Seven of eight forecasts produced over the period 2004-2011 have been within 0-17% 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 still overestimated the harvest by 209%. 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 “misses” such as the forecast for the 2006 return. For the 2012 forecast, model selection included a review of ecosystem indicator variables and considered additional biophysical parameters to improve the simple single-parameter CPUE forecast model. A two-parameter model, including May temperature data as well as juvenile CPUE, was selected as the “best” forecast model for 2012. The 2012 forecast from this model, using juvenile salmon data collected in 2011, was for 18.8 M fish, with an 80% bootstrap confidence interval of 13-25 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). 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 provide a good test species to determine 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 appropriate for this species because no leading indicator information exists (ie, 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 have (Plotnick and Eggers 2004; Eggers 2006). In 2006, a highly significant relationship was documented between peak juvenile pink salmon catch per unit effort (CPUE) from the SECM research in June or July and the SEAK harvest (Wertheimer et al. 2006). The CPUE data used as a direct indicator of run strength have been supplemented with associated biophysical data in some years (Wertheimer et al. 2010a, 2011), or used as auxiliary data to improve the ADFG exponential smoothing model (Heinl 2011, 2012). Recently, efforts have been made to incorporate climate change scenarios into stock assessment models (Hollowed et al. 2011) and examine relationships of ecosystem metrics to salmon production (Orsi et al. 2012b). This paper reports on the efficacy of using the SECM data for forecasting the 2011 SEAK pink salmon harvest and on the development of a prediction model for the 2012 forecast.

Methods

Study Area

This paper focuses on forecasting the fishery harvest of adult pink salmon in SEAK, using information on juveniles and their associated biophysical (biological and physical) parameters from the prior year (Table 1). Pink salmon spawn throughout the SEAK region, with spawning aggregates originating from over 2,000 streams (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 collection have been reported in a series of NPAFC documents (e.g., Orsi et al., 2010, 2011, 2012a). The SECM data used in the forecasting models are from eight stations along two transects in the strait habitat of northern SEAK, sampled from 1997 to 2011 (Figure 1).

Data Descriptions and Sources

Parameters considered for forecasting models included pink salmon harvest as the response parameter and 17 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 (2011), 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 of the 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; this is equivalent to assuming that harvest is directly representative of total run. For these reasons, the use of accurate and precise harvest data as a proxy for total run is preferred for developing the forecast models.

The biophysical parameters examined for forecasting harvest are listed in Table 1 and represent a subset of the monthly measures selected for their potential influence on pink salmon harvest. Four indexes of juvenile pink salmon abundance in northern SEAK were evaluated. One 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 (Peak CPUE, Table 1). This parameter has been previously identified as having the highest correlation with harvest and providing the best performance among potential CPUE metrics for forecasting harvest (Wertheimer et al. 2006, 2010a, 2011). 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 measure was the month in which peak CPUE was observed, and was also chosen to represent migratory timing or seasonality. Parameter values were assigned for the peak month in each year: June = 1, July = 2, and August = 3. The fourth measure was the percentage of juvenile pink salmon represented in the total annual catch 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 1997-2011 (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).

Two measures of zooplankton standing crop were evaluated as indicators of secondary production that could influence pink salmon harvest (Table 1). These were:
1) average June and July NORPAC 243-µm settled volume (ml), an index of upper 20-m water column small zooplankton biomass (June/July Average Zooplankton 20-m); and 2) average June and July 333-µm bongo 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).

Five biophysical measures were chosen to represent conditions in northern SEAK that could have a biological link to the growth and survival of juvenile salmon, including: 1) May 3-m water temperature (°C, May 3-m Water Temperature) adjusted to a standard date (May 23); 2) May upper 20-m integrated average water temperature (°C, May 20-m Integrated Water Temperature) adjusted to a standard date (May 23); 3) June upper 20-m integrated average water temperature (°C, June 20-m Integrated Water Temperature); 4) June average mixed-layer depth (MLD, June Mixed-layer Depth); and 5) July 3-m salinity (PSU, July 3-m Salinity).

Three indexes of 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 annual November to March average for the Pacific Decadal Oscillation (PDO) during the winter prior to juvenile pink salmon seaward migration. 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), 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 annual sum of the monthly multivariate El Niño Southern Oscillation (ENSO) index (NCDC 2007) from the year prior to adult residence in the GOA. The ENSO index was used as an indicator of ocean conditions encountered by immature and adult pink salmon in the GOA.

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 harvest and juvenile salmon CPUE, with physical conditions, zooplankton measures, and pink salmon growth indices considered as additional parameters. The potential model was

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

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 added or retained in 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 (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 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) to the regression prediction intervals (PIs) for the forecasts to examine the effect of process error and measurement error on the forecasts. For the bootstrap approach, juvenile pink salmon catches for each month in 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 1997-2010 were used to construct the regression models with SEAK harvest as the dependent variable, and the appropriate averages of the simulated catches for 2011 were used to forecast 2012 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 that SECM data has been collected, 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. 2010), and their relative ranks in 2011 were considered for selecting the best regression model to forecast the 2012 harvest.

Results

Forecast Efficacy

In 2011, the SECM forecast of 56.2 M pink salmon was 5% lower than the actual 2011 harvest of 59.0 M fish (Table 2). Including the 2011 results, seven of the eight SECM forecasts since 2004 have been within 0-17% 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).

2012 Forecast

Bivariate correlations were computed between SEAK pink salmon harvests for 2004-2011 using 17 potential prediction variables (Table 1). Four of these parameters were significantly ($P < 0.05$) correlated with SEAK pink salmon harvest; three of the four 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 =0.92, P < 0.001). Seasonality was negatively correlated with harvest (r =-0.75, P < 0.002), indicating early (June) Peak CPUE is associated with higher harvests and late (August) Peak CPUE is associated with lower harvests. The percentage of juvenile pink salmon in the catch was positively correlated with harvest (r = -0.57, P < 0.033). One basin scale variable, the NPI, was positively correlated with harvest (r = 0.64, P = 0.013). None of the other parameters evaluated were significantly (P > 0.2) correlated with harvest.

In the stepwise regression analysis, a two-parameter model including Peak CPUE and May 20-m Integrated Water Temperature explained 89% of the variability in the harvest data (Adjusted R^2), as compared to 83% for the simple linear regression with Peak CPUE (Table 3). The AIC_c was lower for the two-parameter model (Table 3), indicating that this model is not over-parameterized. The 2012 forecasts using 2011 juvenile Peak CPUE were 17.7 M for the simple Peak CPUE model and 18.8 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 May 20-m integrated temperature as an auxiliary parameter. Including this data decreased the average absolute percent deviation of the jackknife forecasts from the actual harvests for the years 1998-2011 from 26% to 23%. 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. Also, by including this auxiliary parameter, the deviation of the jackknife forecast from the 2006 harvest decreased from 175% to 121%. If 2006 is excluded from the jackknife analysis, the one-parameter model actually has a slightly lower absolute average deviation relative to the two-parameter model, 13% compared to 15%.

The 80% bootstrap CIs for the one- and two-parameter models for the 2012 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 24 M fish for the simple Peak CPUE model to an interval width of 20 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 also narrower for the simple CPUE model (11 M fish) than for the two-parameter model (12 M fish; Figure 3).

Table 4 lists annual values and ranks of the four parameters in the SEAK time series that were significantly correlated with SEAK harvest (Peak CPUE, Seasonality, percentage of juvenile pinks, and NPI), as well as the significant auxiliary variable in the two-parameter regression model (May 20-m integrated temperature). In 2012, Peak CPUE was in the bottom quartile, and was the second lowest for the time series. Seasonality was also in the bottom quartile. In contrast, the percentage of juvenile pinks was in the top quartile, the third highest for the time series. The NPI and the May 20-m temperature were both in the third quartile for their respective time series.

Discussion

2011 Returns

The 2011 harvest of 59 M pink salmon in SEAK was excellent, ranking in the upper 20% of harvests since 1960 (Heinl 2011). The SECM forecast model for 2011 predicted a harvest of 56.2 M pink salmon in SEAK, which was only 5% lower than the actual harvest. This level of accuracy is consistent with past model performance. 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 5). 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 outmigrating 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 negative 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).

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 pink salmon 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 improved forecasts relative to the simple Peak CPUE model in 2007, 2008, and 2010, but not in 2009 (Table 5). 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 2011 SECM forecast, we selected the single parameter, simple CPUE model as the best forecast even though a two-parameter model including May ocean temperatures had higher adjusted R^2 and lower AIC_c values. Because of the negative effect of May temperature in the two-parameter model, the high May temperatures in 2010 caused a lower forecast (45 M) relative to the one-parameter CPUE model (Wertheimer et al. 2011). Average May temperatures in 2010 were similar to those that occurred in 2005 (Table 4), the year associated with the inaccurately high forecast for the 2006 adult pink salmon harvest from the single-parameter CPUE model. In 2005, high May temperatures were also followed by higher than average temperatures throughout the summer. In contrast, high temperatures in 2010 were not sustained after May (Orsi et al. 2011), and the unusual fauna observed in 2005 in the GOA adjacent to SEAK (Orsi et al. 2006) were not observed in 2010. We also considered the high rankings of the ecosystem indicators for 2010 (Table 4) to be indicative of a stronger run in 2011. In retrospect, our selection of the single parameter model for the 2011 forecast was appropriate, as this forecast was within 5% of the actual harvest while the two-parameter model predicted a forecast 24% lower than the actual harvest (Table 5).

The accurate prediction from the single parameter model appears to validate the use of calibration factors derived from paired comparisons of fishing power between agency research vessels and chartered commercial trawlers (Wertheimer et al. 2010b). Average catches per trawl of juvenile salmon were the highest observed during SECM sampling (Orsi et al. 2011). When adjusted for fishing power, the 2010 calibrated Peak CPUE was the fourth highest in the time series, and was associated in 2011with the fourth highest harvest (Table 4). If no calibration had been taken into account in the 2010 Peak CPUE, and the un-calibrated Peak CPUEs were input to the simple CPUE model, the 2011 harvest forecast would have exceeded 100 M, considerably over the 59 M actual harvest and greater than any harvest in the history of the SEAK pink salmon fishery. Thus, the calibration factors apparently worked well, even though the chartered fishing vessel used in 2010 (FV *Northwest Explorer*) was a different one than the vessel used in the calibration trials in 2009 (FV *Chellissa*). We assume these vessels had comparable fishing efficiencies due to their similar beam and operational configurations.

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, there is no mechanism in such trend analysis to detect shifts in the direction of such 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 2010, 2011). The ADFG forecast for SEAK pink salmon returning in 2011 was 55 M (Heinl 2011), which had a deviation of -6% from the actual harvest, whereas the unmodified exponential smoothing model provided a forecast of 46 M, which had a deviation of -22% from the actual harvest (Table 2). The modified trend analysis forecasts have improved on the unmodified trend model in every year since implementation except for 2010 (Table 5). The average absolute deviation (and range) for the modified model from 2007-2011 has been substantially better than the model adjusted with the juvenile data, 11% (4-19%) versus 35% (6-81%). This improved performance for the ADFG model again demonstrates the utility of the juvenile pink salmon abundance index for forecasting year-class strength. In this case, the index 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 and modifies for associated biophysical data. The two approaches have performed similarly for 2007-2011 (Table 5).

2012 Forecast

For the 2012 forecast, the two-parameter model including PeakCPUE and May 20-m integrated water temperatures was again designated as the best model based on model fit and the AIC_c (Table 3). 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 PeakCPUE alone. We again considered the other ecosystem indicators listed in Table 4 in our final model selection: seasonality, percentage of pinks, and the NPI. In 2010, these indicators were all consistent with a strong run in 2011 (Wertheimer et al. 2011). However, in 2011, the pattern of these indicators was not consistent. Seasonality was late, indicating a poorer run, but percentage of pinks was high, indicating a stronger run. The NPI was below average for the time period, but was in the third quartile for the time series, indicating a mediocre run. Because the indications from the auxiliary ecosystem indicators were mixed, we selected the two-parameter model as the best based on the statistical analyses.

The 2012 SECM forecast of 19 M pink salmon represents a weak potential harvest of pink salmon in SEAK. This would be the third lowest harvest during the SECM time series (since 1998), and in the lower 40% of harvests since 1960 (Heinl 2011).

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Table 1.—Correlation coefficients for juvenile pink salmon metrics and associated biophysical parameters in year *y* for 1997-2010 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	**0.92**	**0.001**
August CPUE	-0.38	0.184
Seasonality	**-0.75**	**0.002**
Percentage of Juvenile Pinks	**0.57**	**0.033**
Juvenile pink salmon growth and condition		
Pink Salmon Size July 24	0.25	0.391
Condition Index	-0.08	0.784
Energy Content	0.14	0.629
Zooplankton standing crop		
June/July Average Zooplankton Total Water Column	0.17	0.559
June/July Average Zooplankton 20-m	0.13	0.654
Local-scale physical conditions		
May 3-m Water Temperature	-0.52	0.859
May 20-m Integrated Water Temperature	0.08	0.787
June 20-m Integrated Water Temperature	-0.07	0.694
June Mixed-layer Depth	-0.00	0.997
July 3-m Salinity	0.32	0.258
Basin-scale physical conditions		
Pacific Decadal Oscillation (Ocean Winter)	0.25	0.380
Northern Pacific Index	**0.64**	**0.013**
El Nino Southern Oscillation (prior year annual average)	0.32	0.259

Table 2.—Southeast Coastal Monitoring (SECM) and Alaska Department of Fish and Game (ADFG) forecasts for 2011 pink salmon harvest in Southeast Alaska (SEAK). The ADFG forecasts are from Heinl (2011). NA = not applicable.

	2011 SEAK pink salmon harvest (M of fish)	**Deviation from actual harvest**
SECM forecast	56.2	-5%
ADFG forecast (w/ Peak CPUE data)	55.0	-6%
ADFG forecast (w/o Peak CPUE data)	46.0	-22%
Actual harvest	59.0	NA

Table 3.—Regression models relating juvenile catch per unit effort (CPUE) of pink salmon in year *y* to adult harvest in Southeast Alaska (SEAK) in year *y* +1, for *y* = 1997-2010. 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**	**2012Prediction (M)**
Ln(PeakCPUE)	SEAK	83%	99.3	<0.001	17.7
Ln(PeakCPUE) + May20-mTemp	SEAK	89%	95.9	<0.001	18.8

Table 4.—Annual measures and rankings (in parentheses) for the Southeast Coastal Monitoring time series for parameters either (1) significantly correlated with Southeast Alaska (SEAK) pink salmon harvest or (2) significant as an auxiliary variable in multiple regression models relating juvenile pink salmon Peak CPUE with SEAK pink salmon harvest.

Adult year	**Juvenile year**	**SEAK harvest (M)**	**Peak CPUE (ln+1)**	**Seasonality (peak month)**	**% Pink juveniles**	**NPI Index**	**May 20-m integrated temperature (^{o}C)**
1998	1997	42.5 (9)	2.5 (10)	July (2)	18% (15)	15.6 (11)	7.3 (6)
1999	1998	77.8 (1)	5.6 (1)	June (1)	69% (2)	18.1 (1)	7.8 (3)
2000	1999	20.2 (12)	1.6 (13)	July (2)	22% (13)	15.8 (8)	6.5 (13)
2001	2000	67.0 (2)	3.7 (3)	July (2)	28% (12)	17.0 (3)	6.6 (12)
2002	2001	45.3 (6)	2.9 (6)	July (2)	38% (9)	16.8 (5)	7.1 (8)
2003	2002	52.5 (5)	2.8 (7)	July (2)	48% (6)	15.6 (12)	6.4 (14)
2004	2003	45.3 (7)	3.1 (5)	July (2)	49% (5)	16.1 (6)	7.4 (5)
2005	2004	59.1 (3)	3.9 (2)	June (1)	40% (8)	15.1 (14)	7.6 (4)
2006	2005	11.6 (14)	2.0 (12)	August (3)	31% (11)	15.5 (13)	8.3 (2)
2007	2006	44.8 (8)	2.6 (8)	June (1)	43% (7)	17.0 (4)	6.7 (10)
2008	2007	15.9 (13)	1.2 (15)	August (3)	21% (14)	15.7 (9)	7.0 (9)
2009	2008	38.0 (10)	2.5 (9)	August (3)	58% (4)	16.1 (7)	6.1 (15)
2010	2009	23.4 (11)	2.1 (11)	August (3)	32% (10)	15.1 (15)	7.3 (7)
2011	2010	59.0 (4)	3.7 (4)	June (1)	85% (1)	17.6 (2)	8.3 (1)
2012	2011		1.3 (14)	August (3)	59% (3)	15.7 (10)	6.7 (10)

Table 5.—Southeast Alaska (SEAK) pink salmon harvest (in M of fish) 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 (2007-2010 only) 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%)

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

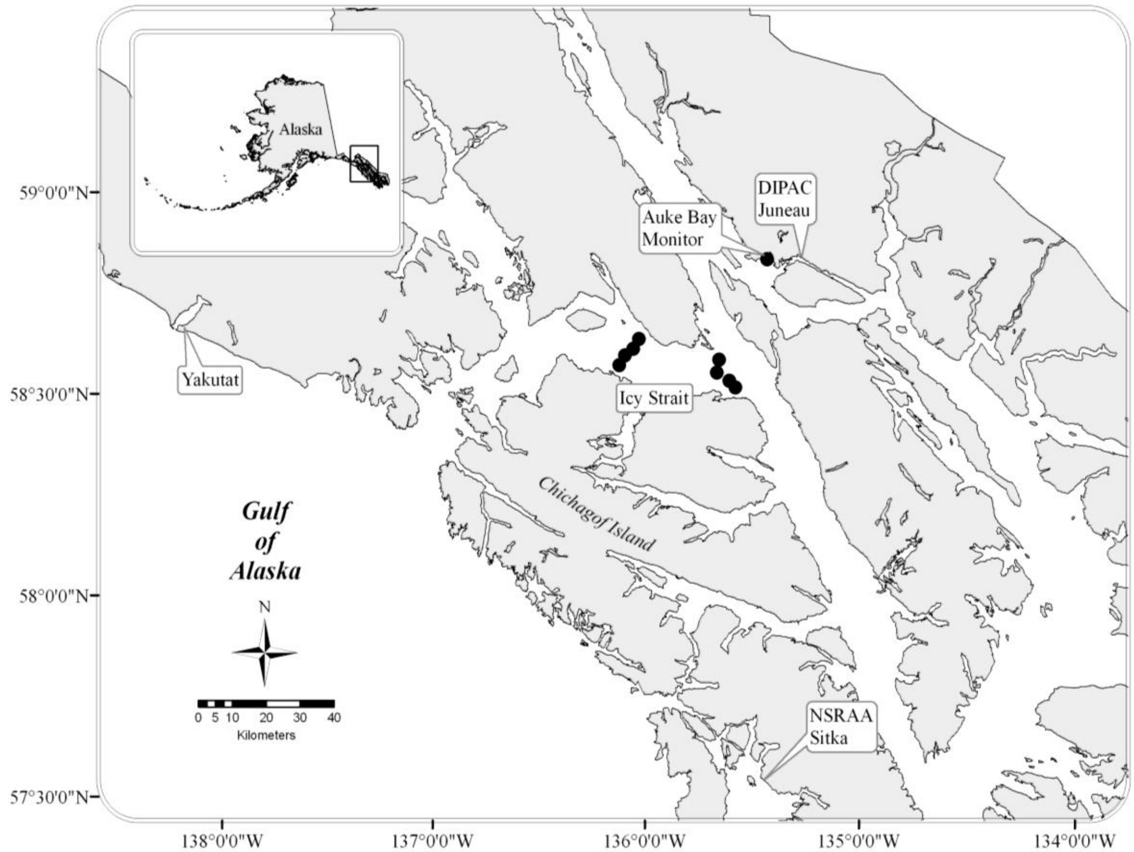

Figure 1.—Stations sampled for juvenile pink salmon and associated biophysical parameters along the Icy Strait transects in the northern region of Southeast Alaska for the development of pink salmon harvest forecast models. Stations were sampled monthly during May–August from 1997–2011. Oceanography was conducted all months, and surface trawling for juvenile salmon occurred only from June to August.

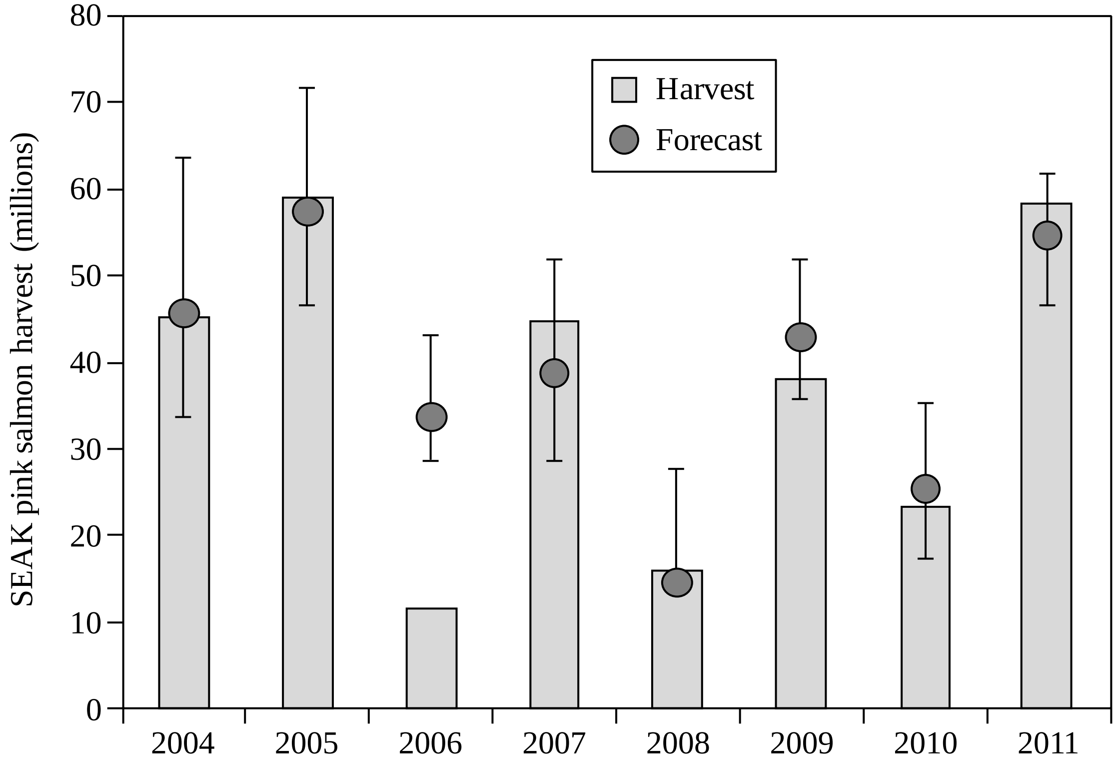

Figure 2.—Southeast Coastal Monitoring (SECM) pink salmon harvest forecasts for Southeast Alaska (SEAK; symbols), associated 80% confidence intervals (lines), and actual SEAK pink salmon harvests (colored bars), 2004-2011.

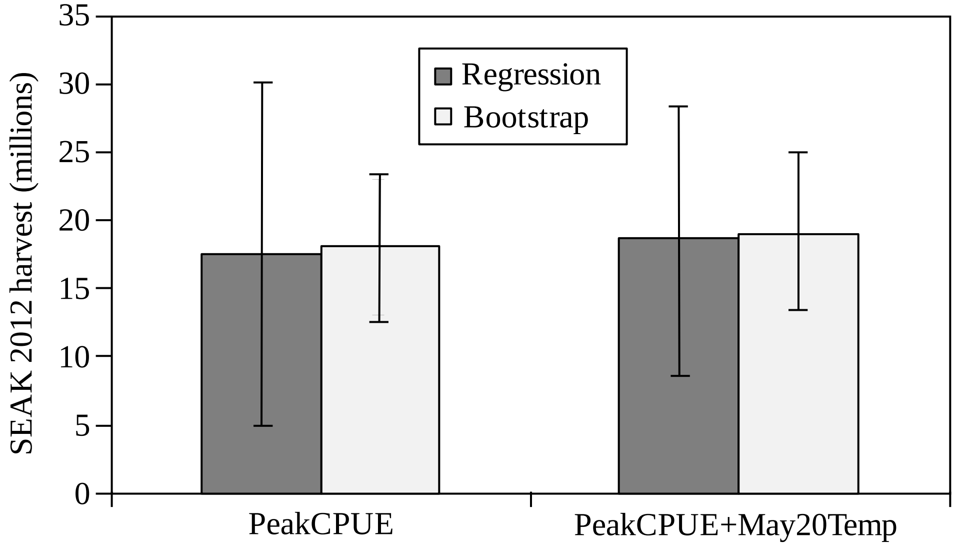

Figure 3.—Parametric regression (dark bars) and bootstrap (light bars) with 80% confidence intervals (lines) for predictions of Southeast Alaska (SEAK) pink salmon harvest in 2012 from two models incorporating juvenile Peak CPUE data in 2011. See text for descriptions of parameters included in models.