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Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Biophysical Parameters: 2016 Returns and 2017 Forecast

by

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

Abstract

The Southeast Alaska Coastal Monitoring (SECM) project has been sampling juvenile salmon (*Oncorhynchus* spp.) and associated biophysical parameters in the northern region of Southeast Alaska (SEAK) annually since 1997 to better understand effects of environmental change on salmon production. A pragmatic application of the annual sampling effort is to forecast the abundance of adult salmon returns in subsequent years. Since 2004, peak juvenile pink salmon catch-per-unit-effort ($CPUE_{cal}$), adjusted for highly-correlated biophysical parameters, has been used to forecast adult pink salmon harvest (*O. gorbuscha*) in SEAK. The 2016 SEAK harvest was 18.4 million fish, the lowest even-year harvest since 2008. The SECM forecast was for a relatively strong harvest of 30.4 M fish, but ended up 65% higher than the actual harvest. The harvest was within the 80% prediction interval of the forecast, however. This is the fourth of 13 forecasts from 2004-2016 that have deviated more than 20% from the actual harvest. The poorer than expected returns of pink salmon in SEAK was consistent with poor pink salmon harvests for Alaska in general. Statewide harvest of pink salmon totaled 39 M fish, the lowest in 40 years. Most (89%) of the harvest was in southern SEAK, suggesting adverse ocean conditions had more affected on more northern and western pink salmon stocks entering the Gulf of Alaska. For the 2017 forecast, model selection included a review of ecosystem indicator variables and consideration of additional biophysical parameters to improve the simple single-parameter juvenile CPUE forecast model. Two measures of CPUE were examined for forecast efficacy: $CPUE_{cal}$, the time series of CPUE calibrated for changes in sampling vessels; and $CPUE_{ttd}$, catch per distance trawled. An alternative model using the regression of harvest and the average ranks of select ecosystem indicators, was also considered. The "best" forecast model for 2017 included two parameters, the $CPUE_{cal}$ and an index of spring/summer water temperatures in Icy Strait. The 2017 forecast from this model, using juvenile salmon data collected in 2016, was 46.2 M with an 80% bootstrap prediction interval of 28–64 M fish.

Introduction

The Southeast Alaska Coastal Monitoring (SECM) project has been sampling juvenile salmon (*Oncorhynchus* spp.) and associated biophysical parameters in northern Southeast Alaska (SEAK) annually since 1997 to better understand effects of environmental change on salmon production (e.g., Orsi et al. 2013a, Orsi and Fergusson 2014, 2015). A pragmatic application of the information provided by this effort is to forecast the abundance of adult salmon returns in subsequent years. Mortality of juvenile pink (*O. gorbuscha*) and chum (*O. keta*) salmon is high and variable during their initial marine residency, and is thought to be a major determinant of year-class strength (Parker 1968; Mortensen et al. 2000; Willette et al. 2001; Wertheimer and Thrower 2007). Sampling juveniles after this period of high initial mortality may therefore provide information that can be used with associated environmental data to more accurately forecast subsequent adult year-class strength.

Because of their short, two-year life cycle, pink salmon are a good species to test the utility of indexes of juvenile salmon abundance in marine habitats for forecasting. Also, sibling recruit models are not available for this species because no leading indicator information exists (i.e., only one age class occurs in the fishery). Spawner/recruit models have also performed poorly for predicting pink salmon returns, due to high uncertainty in estimating spawner abundance and high variability in marine survival (Heard 1991; Haeseker et al. 2005). The exponential smoothing model that the Alaska Department of Fish and Game (ADFG) employs using the time series of annual harvests has provided more accurate forecasts of SEAK pink salmon than spawner/recruit analyses (Plotnick and Eggers 2004; Eggers 2006). Wertheimer et al. (2006) documented a highly significant relationship between annual peak juvenile pink salmon catch-per-unit-effort (CPUE) from the SECM research in June or July and the SEAK harvest. These CPUE data used as a direct indicator of run strength have been supplemented with associated biophysical data in some years (e.g., Wertheimer et al. 2013, 2014, 2015), or used as auxiliary data to improve the ADFG exponential smoothing model (Piston and Heinl 2015, 2016, 2017). Recently, efforts have been made to incorporate climate change scenarios into stock assessment models (Hollowed et al. 2011) and to examine relationships of ecosystem metrics to salmon production (Miller et al. 2013; Orsi et al. 2012, 2013b, 2016). The SECM project has developed a 20-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 2016 SEAK pink salmon harvest and on the development of a prediction model for the 2017 forecast.

Methods

Study Area

This paper uses prior year information on juvenile salmon and their associated biophysical (biological and physical) parameters to forecast adult pink salmon harvest (Table 1). Pink salmon spawning aggregates originate from over 2,000 streams throughout the SEAK region (Baker et al. 1996), and are comprised of 97% wild stocks (Piston and Heinl 2017). Data on juvenile pink salmon abundance, size, and growth, and associated biophysical parameters have been collected by the SECM project annually since 1997; detailed descriptions of the sampling locations and data collections have been reported in annual NPAFC documents (e.g., Orsi et al. 2013a; Orsi and Fergusson 2014, 2015). The SECM data used in the forecasting models are from eight stations along two transects across Icy Strait in the northern region of SEAK, sampled monthly from May to August 1997-2016 (Figure 1).

Data Descriptions and Sources

Parameters considered for forecasting models included pink salmon harvest as the dependent (response) variable and 19 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 (2016), and included the total harvest for SEAK except for a small number of fish taken in the Yakatat area (Figure 1). One caveat for using harvest as the dependent variable in juvenile salmon CPUE forecast models is that juvenile salmon CPUE should be an index of total run (harvest plus escapements to the spawning streams) rather than harvest alone. In contrast to harvest data, the escapement index of pink salmon in SEAK is not a precise measure of actual escapement. Wertheimer et al. (2008) examined the use of scaled escapement index data with harvest data to develop an index of total run; however, this total run index did not improve the fit of the CPUE forecast model, because it was highly correlated with harvest (r = 0.99). In addition, a forecast of total run must assume an average exploitation rate (percent of fish harvested in relation to the total return) to predict harvest, i.e., the equivalent of assuming that harvest directly represents total run strength. For these reasons, the use of accurate and precise harvest data as a proxy for total run is preferred for developing the forecast models.

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

<u>Juvenile pink salmon metrics</u>

Four indexes of juvenile pink salmon abundance or phenology in northern SEAK were evaluated. One index parameter was the average Ln(CPUE+1) for catches in either June or July, whichever month had the highest average in a given year, y, where effort was a standard trawl haul ($CPUE_{cal}$, Table 1). The $CPUE_{cal}$ data was adjusted using calibration factors to account for differences in fishing power among vessels (Wertheimer et al. 2010; Orsi et al. 2013). This parameter has been previously identified to have the highest correlation with harvest and to provide the best performance for forecasting harvest (Wertheimer et al. 2006, 2012, 2013). The second parameter, evaluated for the first time in Wertheimer et al. (2014), was the average (Ln(catch+1)/trawl track distance) for catches in either June or July, whichever month had the highest average in a given year, y ($CPUE_{ttd}$, Table 1). This parameter is evaluated as an alternative to the current need to calibrate $CPUE_{cal}$ for changes in vessel fishing power. The third parameter was the percentage of juvenile pink salmon represented in the total annual catch of all five species of juvenile salmon, a proxy for the relative abundance and distribution of pink salmon each year. The fourth 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) average annual residuals derived from the regression relationship of all paired Ln(weights) and Ln(lengths) for pink salmon collected during SECM sampling from 1997–2016 (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. 2013a). Adult coho salmon are returning from the GOA to SEAK concurrent with the outmigration of juvenile pink salmon from SEAK to the GOA, and could have an effect on survival variation "downstream" of the SECM juvenile CPUE assessment. A time series of SEAK coho salmon total returns (Leon Shaul, Alaska Department of Fish and Game, personal communication) was used as a measure of the degree of potential predation. A second predator index was defined as the numbers of returning adult coho salmon in year y divided by the $CPUE_{ttd}$ in year y. This predator index reflected the ratio of adult coho salmon to juvenile pink salmon each year; and the potential likelihood of predation occurring irrespective of other factors such as timing and distributions of either species and the availability of alternative prey resources.

Zooplankton metrics

One measure of zooplankton standing crop was evaluated as indicators of secondary production that could influence pink salmon harvest (Table 1): average June and July 333-µm bongo net standing crop (displacement volume divided by water volume filtered, ml/m^3), an index of integrated mesozooplankton to 200-m depth (June/July Zooplankton Total Water Column).

Local and basin-scale physical metrics

Five physical measures were chosen to represent local conditions in the northern region of SEAK that could be linked to the growth and survival of juvenile salmon: 1) May upper 20-m integrated average water temperature (°C) adjusted to a standard date of May 23 (May 20-m Integrated Water Temperature); 2) June upper 20-m integrated average water temperature (°C, June 20-m Integrated Water Temperature); 3) the annual Icy Strait Temperature Index (°C, ISTI, see below); 4) June average mixed-layer depth (MLD, June Mixed-layer Depth); and 5) July 3-m salinity (PSU, July 3-m Salinity). The ISTI was calculated as the summer grand average of the 20-m integrated water column temperature, using the monthly averages of ≥ 160 temperatures taken at 1-m increments for May, June, July and August each year.

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

Ecosystem Ranks Index

Beginning in 2014, an ecosystem indicator rank index (ERI) was developed using a suite of six ecosystem metrics and their average rank scores each year (Wertheimer et al. 2015; Orsi et al. 2016). These six ecosystem metrics were the parameters in Table 1 that were significantly correlated with SEAK pink salmon harvest over the SECM time series: 1) $CPUE_{cal}$, 2) $CPUE_{ttd}$, 3) peak migration month, 4) proportion of pinks in hauls, 5) adult coho predation index, and 6) the North Pacific Index. For each of these variables, an average rank score was assigned for each ocean year, and ranked from "best" (lowest rank score) to "worst" (highest rank score). These ranks were then averaged (without weighting) for the six parameters. The annual rank score was then correlated with the pink salmon harvest (Table 1). The ERI includes three parameters using measures of CPUE ($CPUE_{cal}$; $CPUE_{ttd}$; Coho Abundance/$CPUE_{ttd}$), and so is not independent of the previous models based on CPUEcal or $CPUE_{ttd}$. The ERI was considered as an alternative to CPUE for developing forecast models for 2016 and 2017.

Forecast Model Development

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

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

Where Y is either Ln(CPUE+1) or ERI, and γ is the coefficient for biophysical parameter X. Backward/forward stepwise regression with an alpha value of $P < 0.05$ was used to determine whether a biophysical parameter was entered into the model. In separate runs, we used $CPUE_{cal}$ and $CPUE_{ttd}$ for the CPUE variable.

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

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

The fourth step for selecting the “best” forecast model was to evaluate model forecasts in the context of auxiliary run strength indicators. Parameters that had significant bivariate correlation with the SEAK harvest (Table 1) or that were significant auxiliary variables in the stepwise regression model, were ranked for each of the 20 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 2015 were considered for selecting the best regression model to forecast the 2016 harvest.

Results

2016 Forecast Efficacy

In 2016, the SECM forecast of 30.4 M pink salmon had a deviation of 65% higher than the actual 2015 harvest of 18.4 M fish (Table 2). Harvest in 2016 was inside the 80% confidence interval (14.4 M – 46.4 M) for the forecast (Figure 2).

2016 Forecast

Correlations with Harvest

Bivariate correlations were computed between SEAK pink salmon harvests for 2004-2016 using 20 potential prediction variables (Table 1). Six of these variables were significantly ($P \leq 0.05$) correlated with SEAK pink salmon harvest; five of the six were or included measures of juvenile pink salmon abundance or timing. Three measures of pink salmon abundance were significantly and positively associated with harvest: $CPUE_{cal}$, $CPUE_{ttd}$, and the percentage of pinks in the catches of juvenile salmon (*r* = 0.78, *r* = 0.74, and *r* = 0.55, respectively). The predation index of adult coho salmon abundance/ $CPUE_{cal}$ was highly and negatively correlated with harvest (*r* = -0.80). This may be indicative of a strong predator effect, but the significant negative correlation may also be driven by the inverse of $CPUE_{cal}$ in the denominator of the index. Seasonality was negatively correlated with harvest (*r* = -0.55), indicating early (June) peak CPUE is associated with higher harvests and late (August) peak CPUE is associated with lower harvests. One basin scale variable, the NPI, was positively correlated with harvest (*r* = 0.62), indicating that relaxed downwelling and expansion of the ACC is associated with higher harvests. Another basin scale index, the spring NPGO, had an *r* of 0.45, close to the significance criterion (*P* = 0.52), suggesting the strength of the North Pacific gyre in spring may also influence pink salmon run-strength.

The ERI, which is a composite of the six variables meeting the significance criterion, had the highest correlation with harvest, *r* = -0.83. This correlation was also highly significant ($P <$ 0.001).

CPUE Forecast Models

We used the stepwise regression approach with two measures of juvenile abundance, the standard $CPUE_{cal}$ and the alternative $CPUE_{ttd}$ to examine the relationship between SEAK harvest of pink salmon with an index of juvenile abundance and the other biophysical parameters listed in Table 1. For $CPUE_{cal}$, a two-parameter model including ISTI explained 71% of the variability in the harvest data (Adjusted R^2), compared to 59% for the simple linear regression with $CPUE_{cal}$ (Table 3). The AIC_c was lower for the two-parameter model, indicating that this model is not over-parameterized. The 2017 forecasts using 2016 juvenile Peak CPUE were 61.4 M for the simple $CPUE_{cal}$ model and 46.2 M for the two-parameter model.

The stepwise regression procedure identified a three-parameter model with the best fit for the $CPUE_{ttd}$, which included May 20-m temperatures and adult coho abundance. The $CPUE_{ttd}$ models had slightly poorer fits to the harvest data for both one-parameter and two-parameter models than did the $CPUE_{cal}$ models. The two-parameter model including May 20-m temperatures explained 69% of the variability in the harvest data (Adjusted R^2), compared to 55% for the simple linear regression with $CPUE_{ttd}$ (Table 3). The AIC_c was also lower for the two-parameter model for $CPUE_{ttd}$ than the corresponding one-parameter model, but was higher than the two-parameter $CPUE_{cal}$ model (158.0 vs 156.0). However, the three-parameter model explained 82% of the variability and had an AIC_c of 149.7 The 2017 point forecasts using 2016 juvenile $CPUE_{ttd}$ were lower than for $CPUE_{cal}$, 46.6 M for the simple $CPUE_{ttd}$ model, 28.2 M for the two-parameter $CPUE_{ttd}$ model, and 29.0 for the three parameter model.

The ERI model had the best fits to the harvest data for both the one-parameter and two-parameter models, but was not as good as the three-parameter $CPUE_{ttd}$ model (Table 3). The one-parameter model explained 66% of the variability in the harvest data, and the two-parameter model with ERI and May 20-m temperatures explained 78%. The AIC_c was lowest for the two-parameter ERI model in comparison to the ERI one-parameter model and the CPUE models, but was higher than the three-parameter $CPUE_{ttd}$ model, 152.5 vs 149.7 (Table 3). The 2017 point forecasts were higher for the respective ERI models, 37.1 M for the one-parameter ERI model, and 30.3 million for the two-parameter ERI model.

The jackknife analysis comparing the one- and two- parameter models for each of the three predictor variables showed that $CPUE_{cal}$ models generally had the lowest average and median absolute deviations of hindcast harvests to actual harvests (Table 4). The $CPUE_{ttd}$ models were generally the highest, with the ERI models intermediate.

Table 5 and 6 list annual values and ranks of the six parameters in the 20-yr SECM time series that were significantly correlated with SEAK harvest ($CPUE_{cal}$, $CPUE_{ttd}$, Seasonality, % pink salmon juveniles, coho predation index, and NPI), as well as the significant auxiliary variables in the two-parameter regression models (ISTI and 20-m May temperatures). Four of these parameters have a positive association with harvest, while the predation index, seasonality, and the temperature parameters have a negative association with harvest. In 2016, $CPUE_{cal}$, $CPUE_{ttd}$, and % Pinks were above average for the time series (Table 5) and in the first, second, and first quartile of ranks respectively (Table 6). Seasonality was a “1” (June peak), which is the “best” value possible. The predation index was below average, and in the third quartile of ranks. The NPI was above average, and in the first quartile of ranks; it was the highest value of the 20-yr time series. The temperature indexes were also both above average and in the first quartile of ranks. For both ISTI and 20-m May temperature, the values were the highest observed in the time series.

Discussion

2016 Forecast Efficacy

The 2016 harvest of 18.4 M pink salmon in SEAK was the lowest harvest in SEAK since 2008, and reversed the trend of generally increasing even-year harvest since the very poor return in 2006. The SECM forecast was for a harvest of 30.4 M fish. The 2016 forecast was the fourth time the forecast has substantially deviated from the actual harvest over the 13 years (2004-2016) that predictions have been made from SECM juvenile pink salmon data. Nine of 13 forecasts over this time period have been within 20% of the actual harvest, with an average forecast deviation of 9%. The ability of association of the CPUE index to predict harvest one year later in most of the years suggests that marine survival after the early marine recruitment and survival for SEAK pink salmon tends to be relatively stable. Interannual variation in overwinter mortality after the early marine period may also contribute to variability in year-class strength of Pacific salmon (Beamish and Mahnken 2001; Moss et al. 2005). The poor performance of the CPUE model in forecasting the very poor 2006 harvest, the record 2013 harvest, and the poorer than expected 2015 and 2016 harvests suggest that “downstream” variation can cause both large negative and positive deviations after the

SECM sampling period. The Northeastern Pacific Ocean was anomalously warm in the summer of 2005, and as a result juvenile salmon may have encumbered higher energetic demands related to ocean temperature, as well as increased interactions with unusual migratory predators and competitors documented to occur at this time, such as Humboldt squid (*Dosidicus gigas*), blue sharks (*Prionace glauca*).
Ocean conditions in the Gulf of Alaska for the 2015 return were again characterized by anomalously warm water temperatures. In both 2014 and 2015, when the pink salmon juveniles entered the Gulf of Alaska, an area of warm water labeled the "warm blob" (Bond et al. 2015) formed in the North Pacific, and was augmented by an onset of El Niño conditions. These conditions may have affected salmon food resources or predator complexes.

The pattern of pink salmon returns in SEAK and elsewhere in Alaska indicate that the warm ocean conditions affected pink salmon production across broad geographic scales. Harvests of pink salmon throughout Alaska were around 39 M fish (ADFG 2016), the lowest in forty years. Northern SEAK was particularly weak, making up 11% of the SEAK harvest as opposed to the average 40% of the SEAK harvest. This north/south difference is the opposite of what was observed in 2015 when Southern SEAK was weak, while in Northern SEAK, harvests and escapements were actually above average, and to the north and west along the Gulf of Alaska coastline, pink salmon returns were very strong. Harvests of pink salmon were the highest ever recorded in Prince William Sound, and the third highest for Kodiak in 2015 (Brenner and Munro 2016).

Information on environmental conditions affecting juvenile pink salmon migrating through SEAK waters to the GOA could potentially improve forecast accuracy for the juvenile CPUE prediction model, and could help avoid large forecast error due to variability in survival that occurs after the CPUE data are collected. Incorporating biophysical data in the $CPUE_{cal}$ forecast models since 2007 has improved forecasts relative to the simple $CPUE_{cal}$ model in seven of ten years (Table 7), with an average deviation of 23% versus 30%. In 2016, incorporating temperature data into the $CPUE_{cal}$ model moved the forecast substantially in the right direction, reducing forecast deviation from 88% to 30%. The same effect was seen for the ERI model, the model selected for the 2016 forecast (Wertheimer et al. 2015). Incorporating temperature data in the ERI model reduced the forecast deviation from 102% for the single parameter model to 65%.

One problem with seeking a "silver-bullet" of environmental data for improving forecasts is that the signal for physical conditions that may affect survival in the GOA "downstream" from the inside waters of SEAK, e.g. NPI or temperature during the pink salmon's winter or following spring at sea, have not occurred or are not available in time for preseason forecasting in November or December preceding the harvest year. However, the results from 2016 demonstrate that water temperature indices during the juvenile marine period do have strong effects and can be used to improve forecasts of run strength.

The ADFG forecast for pink salmon in SEAK has been based on an exponential smoothing model since 2004 (Eggers 2006). This model uses the trend from previous harvests to predict future harvest, which assumes that year-class performance responds to persistent patterns of environmental conditions. However, no mechanisms are identified or metrics used to adjust the trend analysis for shifts in freshwater or marine environmental patterns. Thus, the trend analysis predicted a large return (52 M) in 2006, whereas the actual return was very poor (12 M; Table 7). As a result, since 2006, the ADFG forecast has used the SECM $CPUE_{cal}$ data to modify the exponential smoothing model forecast (e.g., Heinl 2012; Piston and Heinl 2013). The ADFG forecast for SEAK pink salmon returning in 2016 was 43 M for the unmodified and 34 M for the modified exponential smoothing models (Piston and Heinl 2016). These forecasts were 135% and 85% above the actual harvest, respectively (Table 2). Thus, the incorporation of the juvenile data substantially improved the ADFG forecast in 2016. The modified trend analysis forecasts have improved on the original trend model in six of ten years since implementation (Table 7). The average absolute deviation (and range) for the modified model from 2007-2016 has been substantially better than the unadjusted model, 31% (range, 4-85%) versus 43% (range, 6-134%). This overall improved performance for the ADFG model further demonstrates the utility of the juvenile pink salmon abundance index for forecasting year-class strength. In this case, the CPUE is used to modify and adjust a time-series analysis of harvest trends, a very different approach to the SECM forecast approach that uses the CPUE as the main predictive parameter. Although the two modeling approaches are fundamentally different, they have performed similarly for 2007-2016 (Table 7).

2017 Forecast

For the 2017 forecast, we examined the use of two alternative abundance-index parameters to the forecast model based on the $CPUE_{cal}$ parameter. These alternative models were based on either the $CPUE_{ttd}$ or the average of select ecosystem-indicators' annual ranks (ERI model). The $CPUE_{ttd}$ measure of juvenile pink salmon catch has the advantage of not depending on past vessel calibration studies to adjust for differences in fishing power among sampling vessels. The ERI model integrates a number of abundance and ecosystem indicators to provide a quantitative prediction of subsequent harvest.

For all three abundance-index parameters, the "best" models in terms of statistical fit included indices of spring and/or summer temperatures (Table 3). For two-parameter models of abundance index plus temperature, the ERI model had better statistical fit to the harvest data than the either $CPUE_{cal}$ or $CPUE_{ttd}$ model, but the three parameter $CPUE_{ttd}$ model including temperature and adult coho abundance explained the most (82%) of the variability in harvest data. In terms of AIC_c, the two-parameter $CPUE_{cal}$ model was higher, and the three-parameter $CPUE_{ttd}$ and ERI models were virtually equal (149.7 vs. 150.0).

Although the statistical fit for the $CPUE_{cal}$ was not as good, it performed better in the jackknife analyses than the ERI or $CPUE_{ttd}$ models. In 2015, we selected the ERI model for the 2016 forecast based on better statistical fit, even though the $CPUE_{cal}$ model had better jackknife performance (Wertheimer et al. 2015). Relative to the actual 2016 returns, the selected ERI model overforecast the harvest by 65%, while the corresponding $CPUE_{cal}$ forecast had a deviation of 31%, suggesting that the jackknife analysis is a better measure of performance than statistical fit, given the models have relatively similar statistical power.

We considered the prediction outcomes of the "best" models for each abundance parameter in relation to a suite of ecosystem indicators in choosing the final 2017 forecast model (Tables 6, 7). The signals from these ecosystem indicators were decidedly mixed. For the abundance indexes, $CPUE_{cal}$ in 2016 was tied for the second highest in the time series, indicating an excellent run. However, $CPUE_{ttd}$ in 2016 was ranked seventh in the time series, in the second quartile of abundances, indicating a run closer to average. The NPI was the highest observed in the time series, again indicating a strong return. But the temperature indexes, which have a negative association with run strength, were also the highest in the time series, suggesting substantial depression in run strength due to high ocean temperatures. This potential temperature effect was clearly seen in the lower forecasts when temperature indexes are included in the models (Table 3).

The predictions for the "best"models for the three abundance parameters ranged from 29 M to 54 M fish, with $CPUE_{cal}$ + ISTI intermediate at 46M. We considered model averaging as a method to integrate the forecasts of competing models (Burnam and Anderson 2002) as opposed to choosing among them based on informed but subjective judgement. We used the R package for multi-model inference, weighting by AIC_c values (Barton 2013) to derive an "average" forecast of 51 M, towards the high end of the range defined by the three models.

In the end, we reverted to subjectively choosing among the models. We did not choose the model average because it was skewed towards the high end of the range of forecasts. We selected the $CPUE_{cal}$ + ISTI forecast for three reasons: 1) it had the best performance in jackknife hindcasts of historical harvests; 2) it was intermediate in the range of forecasts in relation to forecasts from the alternative abundance parameters; and 3) it provided a good statistical fit to the harvest data, albeit somewhat poorer than the two-parameter ERI model and the three-parameter $CPUE_{ttd}$ model. Based on this selection, the SECM forecast for the 2017 SEAK pink salmon harvest is 46.2 M, with an 80% prediction interval of 28 M–64 M.

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Table 1. Correlation coefficients for juvenile pink salmon biophysical parameters and ecosystem metrics in year *y* for 1997-2015 with adult pink salmon harvest in Southeast Alaska (SEAK) in year *y* + 1. Parameters with statistically significant correlations are in bold text; the probabilities were not adjusted for multiple comparisons.

Parameter	***r***	***P*-value**
Juvenile pink salmon abundance		
$CPUE_{cal}$	**0.78**	**<0.001**
$CPUE_{ttd}$	**0.76**	**<0.001**
Seasonality	**-0.47**	**0.041**
Percentage of Juvenile Pinks	**0.57**	**0.011**
Juvenile pink salmon growth and condition		
Pink Salmon Size July 24	-0.14	0.575
Condition Index	0.12	0.648
Energy Content	-0.20	0.416
Predator Indexes		
Adult Coho Abundance	-0.24	0.324
Adult Coho Abundance/$CPUE_{cal}$	**-0.80**	**<0.001**
Zooplankton standing crop		
June/July Average Zooplankton Total Water Column	0.18	0.457
Local-scale physical conditions	-	
May 20-m Integrated Water Temperature	-0.05	0.835
June 20-m Integrated Water Temperature	-0.32	0.183
Icy Strait Temperature Index (ISTI)	-0.23	0.335
June Mixed-layer Depth	-0.15	0.532
July 3-m Salinity	-0.02	0.948
Basin-scale physical conditions		
Pacific Decadal Oscillation (PDO, y-1)	-0.14	0.571
Northern Pacific Index (NPI, y**)**	**0.62**	**0.004**
ENSO Multivariate Index (MEI, Nov (*y-1)*-March (*y*))	0.19	0.439
North Pacific Gyre Oscillations	0.45	0.052
Ecosystem Indicators Rank Index (ERI)	**-0.83**	**<0.001**

Table 2. Southeast Coastal Monitoring (SECM) and Alaska Department of Fish and Game (ADFG) forecasts for 2016 pink salmon harvest in Southeast Alaska (SEAK). The ADFG forecasts are from Piston and Heinl (2016). NA = not applicable.

	Pink salmon (M of fish)	**Deviation from actual harvest**
SECM forecast	30.4	65%
ADFG forecast (w/ $CPUE_{cal}$ data)	34.0	85%
ADFG forecast (w/o $CPUE_{ttd}$ data)	44.0	134%
Actual harvest	18.4	NA

Table 3. Regression models relating juvenile pink salmon catch-per-unit-effort ($CPUE_{cal}$ and $CPUE_{cal}$) and the Ecosystem Ranks Index in year *y* to adult harvest in Southeast Alaska (SEAK) in year *y* +1, for *y* = 1997-2015. R^2 = coefficient of determination for model; AIC_c = Akiake Information Criterion (corrected); *P* = statistical significance of regression equation. Adult harvest is the total for SEAK harvest (except Yakutat).

Model	**Adjusted R^2**	**AIC_C**	**Regression *P* -value**	**2016 Prediction (M)**
$Ln(CPUE_{cal})$	59%	161.5	<0.001	61.4
$Ln(CPUE_{cal})$ + ISTI	71%	156.0	<0.001	46.2
$Ln(CPUE_{ttd})$	55%	163.2	<0.001	46.6
$Ln(CPUE_{ttd})$ + May20Temp	69%	158.0	<0.001	28.2
$Ln(CPUE_{ttd})$ + May20Temp +Acoho	82%	149.7	<0.001	29.0
Ecosystem Ranks	66%	157.6	<0.001	68.9
Ecosystem Ranks+May20Temp	78%	150.0	<0.001	55.9

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**
$Ln(CPUE_{cal})$	30.6	13.8
$Ln(CPUE_{ttd})$	35.0	22.7
Ecosystem Ranks	28.7	19.5
$Ln(CPUE_{cal})$ + ISTI	22.0	18.0
$Ln(CPUE_{ttdl})$ + May20Temp	30.0	25.0
Ecosystem Ranks+ May20Temp	28.0	26.0

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 2017 harvest.

Juvenile year y	**Harvest year y+1 (M)**	**Ln ($CPUE_{cal}$)**	**Ln ($CPUE_{ttd}$)**	**Seasonality**	**%Pinks**	**Coho Predation Index**	**NPI Index**	**ISTI**	**May 20m temp**
1997	42.5	2.5	2.22	July	17	1.54	15.6	9.5	7.3
1998	77.8	5.6	5.32	June	42	0.80	18.1	9.6	7.8
1999	20.2	1.6	1.39	July	10	3.92	15.8	9.0	6.5
2000	67.0	3.7	3.34	July	25	0.95	17.0	9.0	6.6
2001	45.3	2.9	2.64	July	28	2.01	16.8	9.4	7.1
2002	52.5	2.8	2.48	July	26	2.48	15.6	8.6	6.4
2003	45.3	3.1	2.74	July	22	1.76	16.1	9.8	7.4
2004	59.1	3.9	3.39	June	31	1.42	15.1	9.7	7.6
2005	11.6	2.0	1.72	Aug	26	3.28	15.5	10.3	8.3
2006	44.8	2.6	2.27	June	26	1.91	17.0	8.9	6.7
2007	15.9	1.2	0.97	Aug	15	3.70	15.7	9.3	7.0
2008	38.0	2.5	2.18	Aug	29	2.13	16.1	8.3	6.1
2009	23.4	2.1	2.68	Aug	27	1.72	15.1	9.6	7.3
2010	59.0	3.7	5.01	June	61	0.94	17.6	9.6	8.3
2011	21.3	1.3	1.64	Aug	25	4.07	15.7	8.9	6.7
2012	94.7	3.2	4.26	July	48	1.12	16.7	8.7	6.7
2013	37.2	1.9	2.67	July	12	2.85	16.0	9.2	6.5
2014	35.0	3.4	4.47	July	57	1.99	15.8	9.4	7.7
2015	18.4	2.2	1.84	June	19	2.57	15.7	9.8	7.6
2016	TBD	3.9	3.10	June	50	1.58	18.9	10.3	8.4
Average	**43.9**	**2.8**	**2.80**	**July**	**30**	**2.14**	**16.3**	**9.3**	**7.2**

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 2017 harvest.

Juvenile year y	Harvest y+1	$CPUE_{cal}$	$CPUE_{ttd}$	Seasonality	% Pinks	Coho Predation Index	NPI Index	ISTI	May 20m temp
1997	10	12	14	2	17	15	16	9	9
1998	2	1	1	1	5	20	2	6	4
1999	16	18	19	2	20	2	11	14	18
2000	3	4	6	2	13	18	4	15	16
2001	7	9	11	2	8	9	6	8	11
2002	6	10	12	2	10	7	16	19	19
2003	7	8	8	2	15	12	8	4	8
2004	4	2.5	5	1	6	16	19	5	7
2005	19	16	17	3	10.5	4	18	2	3
2006	9	11	13	1	10.5	11	4	17	14
2007	18	20	20	3	18	3	13	12	12
2008	11	12	15	3	7	8	8	20	20
2009	14	15	9	3	9	13	19	10	10
2010	5	5	2	1	1	19	3	7	2
2011	15	19	18	3	13	1	13	16	13
2012	1	7	4	2	4	17	7	18	15
2013	12	17	10	2	19	5	10	13	17
2014	13	6	3	2	2	10	11	11	5
2015	17	14	16	1	16	6	13	3	6
2016	TBD	2.5	7	1	3	14	1	1	1

Table 7. Southeast Alaska (SEAK) pink salmon harvest (in millions of fish, M) and associated forecasts from Southeast Coastal Monitoring (SECM) juvenile $CPUE_{cal}$ models and Alaska Department Fish and Game (ADFG) exponential smoothing models. Accuracy of the forecast is shown in parentheses. For SECM, both the simple $CPUE_{cal}$ and the multi-parameter $CPUE_{cal}$ models are shown. Similarly for ADFG, both the exponential smoothing model with (2007–2016) and without the addition of the SECM juvenile $CPUE_{cal}$ data are shown.

		SECM $CPUE_{cal}$ models				**ADFG Exp. smoothing models**			
Year	**SEAK harvest (M)**	**$CPUE_{cal}$ only**		**Multi-parameter CPUE**		**Trend analysis only**		**Trend analysis w/juvenile data**	
2004	45	47	(4%)	NA		50	(11%)	NA	
2005	59	59	(0%)	NA		49	(17%)	NA	
2006	12	35	(209%)	NA		52	(333%)	NA	
2007	45	38	(16%)	40	(10%)	58	(29%)	47	(4%)
2008	16	18	(13%)	16	(1%)	29	(81%)	19	(19%)
2009	38	37	(3%)	44	(17%)	52	(37%)	41	(8%)
2010	23	31	(33%)	29	(15%)	22	(6%)	19	(19%)
2011	59	55	(5%)[1]	45	(24%)[1]	46	(22%)	55	(6%)
2012	21	17	(17%)	18	(12%)	23	(8%)	17	(20%)
2013	95	48	(49%)	54	(43%)	52	(44%)	54	(43%)
2014	37	30	(20%)	30	(20%)	22	(41%)	22	(41%)
2015	35	56	(59%)	54	(57%)	46	(31%)	58	(66%)
2016	18	35	(88%)	24	(31%)[2]	43	(134%)	34	(85%)

[1]Single-parameter model was used for 2011 forecast (Wertheimer et al. 2011).
[2]Two-parameter ERI model was used for 2016 forecast (Wertheimer et al. 2015)..

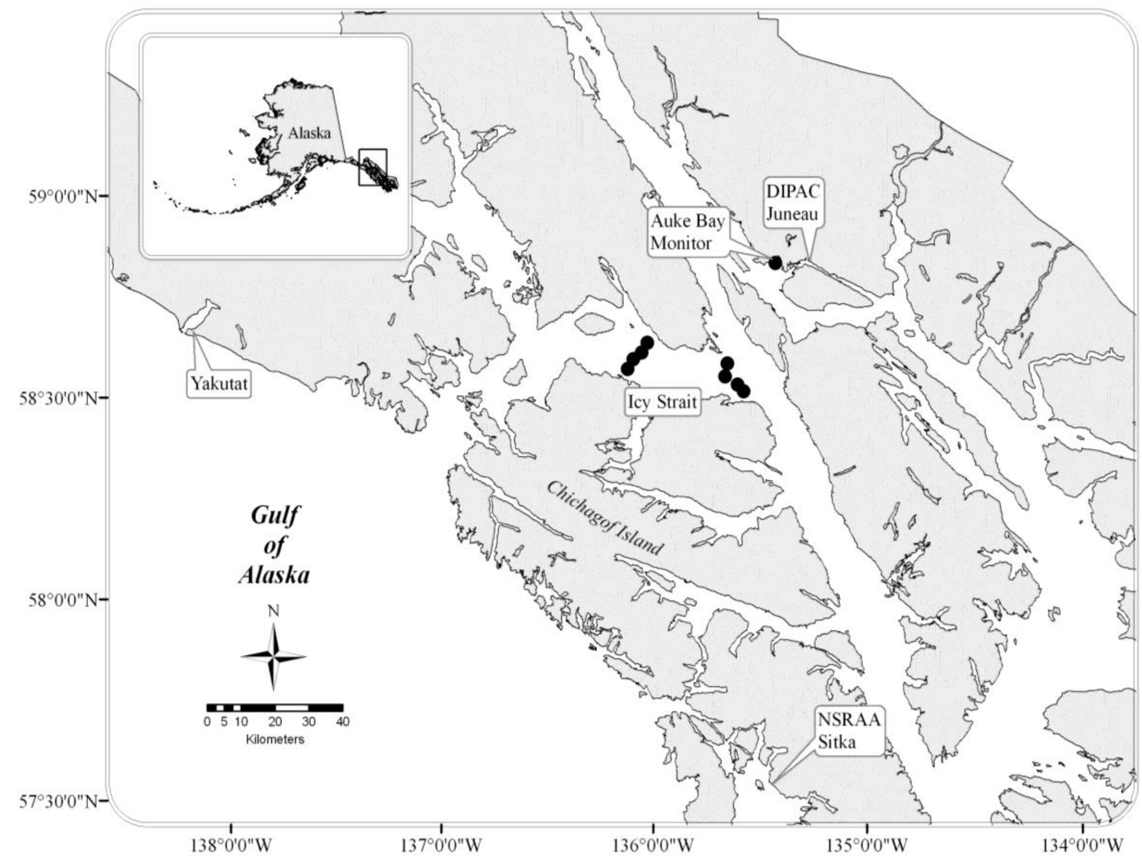

Figure 1. Stations sampled for juvenile pink salmon and associated biophysical parameters along the Icy Strait transects in the northern region of Southeast Alaska for the development of pink salmon harvest forecast models. Stations were sampled monthly from May to August 1997–2016. Oceanography was conducted in all months and surface trawling for juvenile salmon occurred from June to August.

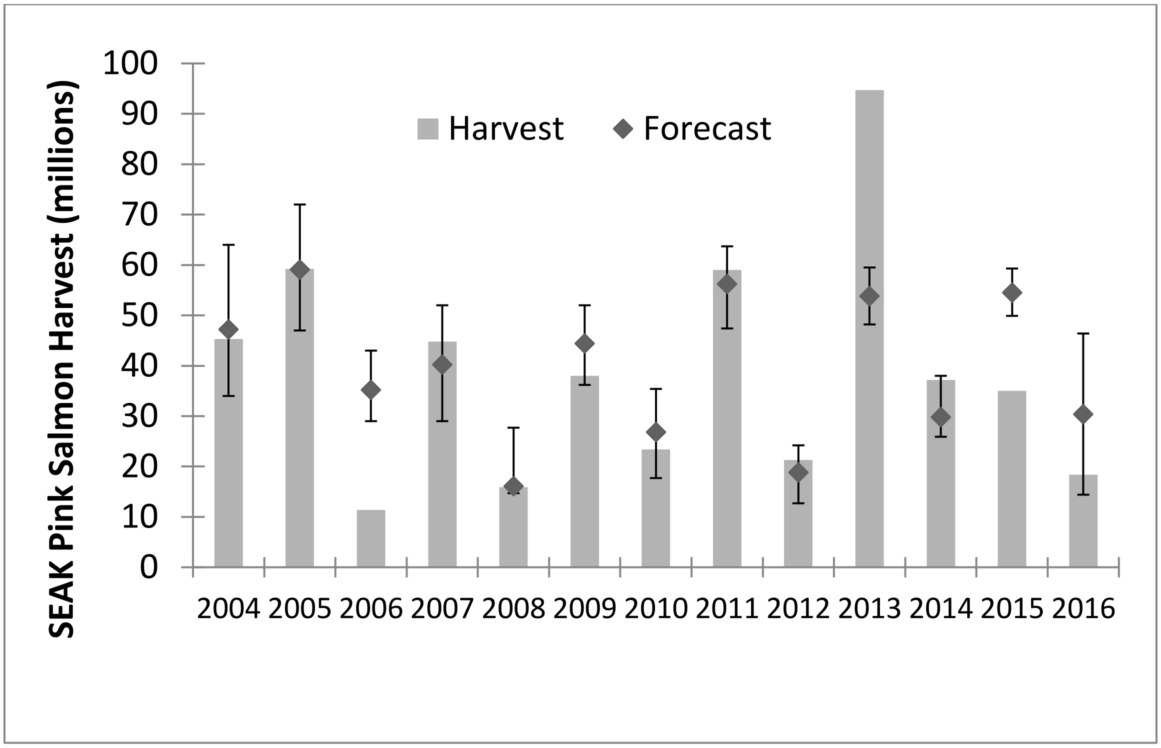

Figure 2. Southeast Coastal Monitoring (SECM) project pink salmon harvest forecasts for Southeast Alaska (SEAK; symbols), associated 80% confidence intervals (lines), and actual SEAK pink salmon harvests (grey bars), 2004–2016.