The NOAA Pre-season 2017 Pink Salmon Harvest Forecast for Southeast Alaska

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**The views expressed are those of the author and do not necessarily represent those of NOAA*

Background:

Researchers from the Auke Bay Laboratories (ABL) of the Alaska Fisheries Science Center (AFSC) have provided pre-season forecasting information to stakeholders of the pink salmon resource of Southeast Alaska (SEAK) since 2004. These forecasting metrics and models are derived from an ongoing time series of data collected by the Southeast Coastal Monitoring (SECM) project which began in 1997. The SECM project conducts surveys annually in the vicinity of Icy Strait and the Gulf of Alaska to collect oceanographic data in May, June, July, and August, and to index juvenile salmon metrics using surface trawls (~20×20 m width×depth) during the latter three months.

In 9 of the past 13 years, NOAA's pre-season pink salmon harvest models have performed well, giving estimates that averaged within 10% of actual harvests. However, four harvest years departed from this accuracy (i.e., 2006, 2013, 2015, and 2016) and represent years of anomalously low (12 and 18 M), high (95 M), and moderate (35 M) harvest (Table 1). Nonetheless, most forecasts have enabled stakeholders to anticipate harvest better than previous forecasting methods. Additionally, NOAA shares SECM juvenile pink salmon catch data (CPUE) with Alaska Department of Fish and Game (ADFG) colleagues who use these data to help refine their pink salmon harvest forecast model for SEAK based on an exponential smoothing method derived from brood year strength trends. Researchers continue to explore new approaches to integrate the SECM data time series and other ecosystem indicators to improve forecast model accuracy and provide the resource stakeholders with the best available pre-season data to help optimize economic efficiency and promote resource sustainability.

Recent anomalous ocean conditions and forecast outcomes:

Anomalously warm ocean conditions, heralded in by the warm ocean BLOB in 2014, have presumably contributed to declining pink salmon production in SEAK over the past two years. In fact, over the 2015 and 2016 harvest years, NOAA's pre-season pink salmon harvest forecast models have underperformed, with harvest levels 19 and 13 M fish below forecasts, respectively. A prevailing paradigm for pink salmon production is that early marine conditions effectuate year class strength, with warm springs fostering good growth, rapid offshore migration, and increased survival. This is consistent with observations that peak juvenile CPUE from the SECM sampling in June or July has been strongly correlated with SEAK pink salmon harvest the following year and has contributed to the success of the forecast models for most years. However, in years with persistent warm temperatures, the open ocean basin may pose elevated risks to the continued survival of juvenile pink salmon via: 1) altered trophic interactions of southern species migrating northward (predation and/or competition), 2) higher energetic stress from increased metabolic demands, 3) more extensive foraging needed to compensate for increased competition, predator avoidance, or lower food quality/availability and 4) an overall shift in ocean migration patterns or restricted ranges influenced by thermal barriers. Most of the SECM ecosystem indicators are derived from spring and summer conditions in Icy Strait so SECM sampling may be less effective at detecting later season drivers of juvenile survival, which may explain the lower forecast accuracy in recent years of extended warm periods. Warm ocean conditions have also persisted into 2016, so we continue to explore suitable indicators of later ocean conditions, and subsequently, juvenile survival, in order to improve forecast accuracy.

Ecosystem conditions observed in 2016:

The four SECM surveys conducted in May, June, July, and August revealed 2016 to be the warmest year in the 20-yr SECM time series in Icy Strait (Figure 1). Despite this continued warming trend, other juvenile pink salmon metrics were encouraging. In fact, most of the 2016 variables considered for the 2017 pink salmon harvest forecast are in the upper ranges of favorable states, as indicated by a green color. Specifically, six Eco-rank variables ($CPUE_{cal}$, $CPUE_{ttd}$, Peak migration month, pink catch composition, predation index, and the NPI) were significantly correlated with harvest and characterize conditions in 2016 as the third best rank over the time series (Figures 1, 2). Of particular note is the record high North Pacific Index (NPI) value in 2016 which is the only basin scale parameter significantly correlated to SEAK pink salmon harvest. ***As an outlook, the average Eco-rank score of the six significant variables in 2016 was 4.2, corresponding to a pink salmon harvest of 69 M fish in 2017*** (Figure 2).

Other open ocean ecosystem variables associated with juvenile pink salmon after they migrate seaward from Icy Strait were also assessed in 2016 to give better insight or inform the SEAK pink salmon harvest outlook for 2017. These metrics include: 1) the relative CPUE of juvenile pink salmon between Icy Strait and the Gulf of Alaska (GOA); 2) the North Pacific Gyre Oscillation (NPGO) index which, when positive, is related to increased nutrient levels in the GOA (Di Lorenzo) which subsequently lead to increased primary production; 3) annual seabird metrics (kittiwake productivity) on Middleton Island in the central GOA, because annual differences in summer diets or chick production from 1997-2016 could be due to shifts associated with the past three BLOB years that also may affect juvenile pink salmon; and 4) the examination of gut contents of juvenile pink salmon in Icy Strait and the GOA to detect any evidence of harmful algal blooms that may impair the ability of fish to adequately migrate, forage, or avoid predators.

1) Relative juvenile pink salmon CPUE: From 2010 to 2015, there was a strong linear relationship between the June/ July GOA juvenile CPUE and the Icy Strait juvenile CPUE, with distinct clustering of even (low catch rates) and odd (higher catch rates) years (Figure 3). However in 2016 there was a departure from the previous trend, with the highest GOA CPUE over the entire time series and Icy Strait catch rates falling between those observed during even and odd years. The GOA sampling encompasses a 3-30 mile offshore section of trawl stations from Whale Bay to Icy Point within a larger region of sampling further offshore. Anecdotally, the anomalously high juvenile catch rates in the GOA may suggest greater production / survival in the southern and coastal stocks of SEAK, and are ***consistent with a high pre-season pink salmon harvest forecast for 2017***.

2) NPGO: The spring (March-May) NPGO metric from 1997-2016 is positively correlated with SEAK pink salmon harvest over the 1998-2016 harvest years (Cor. 0.45, $p=0.052$, Figure 1). Although the NPGO was close to being significant, we chose not to include it in the Eco-rank model because it did not meet our criteria for selection of $p<0.05$. This metric will continue to be monitored in the future because it does correspond to the direction of error in our largest forecast deviations (i.e., 2005 and 2012). The NPGO metric for 2016 was in the lower third range of the 20 year time series (0.0) and if used solely as a bivariate predictor it would suggest only ***a moderate pre-season pink salmon harvest forecast of 37 M fish in 2017***.

3) Seabird productivity in the GOA: The annual productivity of kittiwakes on Middleton Island in the Central GOA in summer was considered as a possible seabird metric that would give insight to the extent of prey resources available to juvenile pink salmon migrating northward from SEAK. This information was shared with us by Scott Hatch of the Institute for Seabird Research and Conservation. The time series shows kittiwake chick productivity with metrics that include: 1) chicks produced per nest, 2) The difference in laying date between fed and unfed chicks, and 3) the difference in fledging date between fed and unfed chicks. These three metrics were marginally significant (p=0.05-0.08) with SEAK harvest (not accounting for multiple comparisons). These metrics indicated poor productivity associated with the warmer "BLOB" temperatures of 2014 and 2015, and also into 2016. Using the 2016 kittiwake chick per nest data alone to do a preseason pink salmon forecast for SEAK would suggest ***a poor pre-season pink salmon harvest forecast of 27 M fish in 2017.***

4) Harmful algal bloom (HAB): Preliminary HAB data from gut content analysis of juvenile pink salmon was shared with us courtesy of Kathi Lefebvre of the Northwest Alaska Fisheries Science Center. These fish were sampled in Icy Strait in July of the years 1997 to 2016. The levels (ng/g) of both Domoic acid and Saxitoxin were examined from the samples and low levels were detected each year, with some spike years noted; however, 2016 was not a high level year. The full complement Icy Strait samples are currently being analyzed for seasonal levels of toxicity, and additional coastal samples from Icy Point are also being examined from 2014 to 2016.

Model selection criteria for the 2017 SEAK pink salmon harvest forecast:

For the 2017 forecast, the models examined were stepwise linear regressions based on three different juvenile pink salmon catch rate metrics as a main factor (i.e., $CPUE_{cal}$, $CPUE_{ttd}$, or Eco-rank) and a suite of potential auxiliary predictors. Several factors went into the decision-making process for the final NOAA pink salmon forecast model for the 2017 SEAK harvest. The first was an evaluation of several SECM forecast models for statistical validity, comparing candidate models for the highest adjusted R^2 (best fit with the data), and the lowest AICc (over parameterization value). The second evaluation factor was using a jackknife analysis (fitting a model with all but one of the historical years and predicting the harvest for the omitted year, successively until all years have been predicted) to compare forecasting performance of the candidate models. The third evaluation factor was to examine the 2017 forecast from each candidate model in the context of other ecosystem indicators.

For all three main prediction parameters, addition of a 2016 spring/summer temperature parameter significantly improved model fit and lowered the resultant forecast (Table 2). The two temperature parameters were from averages across the eight stations in Icy Strait: the first was an average of the one meter temperatures in May in the upper 20 meters of the water column ($May_{20mtemp}$) and the second was the averages across May, June, July, and August termed the Icy Strait Temperature Index ($ISTI_{20mtemp}$). The Eco-rank + $May_{20mtemp}$ model had the best statistical fit, but the $CPUE_{cal}$ + $ISTI_{20mtemp}$ model had the best jackknife performance. Ecosystem indicator signals were mixed: NPI indicates a strong return, NPGO a moderate-weak return, and chicks/nest a weak return. The $CPUE_{ttd}$ + $May_{20mtemp}$ model also indicates a weak return. For the 2016 forecast, the $CPUE_{cal}$ + $ISTI_{20mtemp}$ model also performed better in the jackknife analysis than did the Eco-rank + $May_{20mtemp}$ model, even though the better had a better statistical fit. Because of (1) the better jackknife performance, (2) the mixed signals from other ecosystem indicators, and (3) the intermediate forecast within the range of forecasts from the models considered, the $CPUE_{cal}$ + $ISTI_{20mtemp}$ was selected as the "best" model. This model predicts a ***46.2 M pink salmon harvest forecast for SEAK in 2017, with an 80% bootstrap confidence interval of 39-50 M***.

The historical NOAA pink salmon forecast model estimates and outcomes are shown in figure 4. We will of course continue to track the performance of all CPUE-based forecast models and these newer ecosystem metrics during the ensuing year.

The NOAA presentation information from the 2016 Southeast Alaska Purse Seine Task Force meeting will be made available soon on the SECM pink salmon forecasting and the SECM project websites: http://www.afsc.noaa.gov/ABL/EMA/EMA_PSF.htm and http://www.afsc.noaa.gov/ABL/EMA/EMA_SECM.htm

If this research is of value to you, feel free to contact any of these NOAA/AFSC managers:

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Table 1. Historical preseason pink salmon forecast models using step-wise regressions to determine Southeast Alaska pink salmon harvest.

Forecast harvest year	Model terms	Forecast prediction millions	Harvest outcome millions	Harvest deviation (Outcome - prediction) millions
2004	Peak $CPUE_{cal}$	47.2	45.3	-1.9
2005	Peak CPUEcal	59.1	59.1	0.0
2006	Peak CPUEcal	35.2	11.6	-23.6
2007	Peak $CPUE_{cal}$ + May_{20temp}	40.2	44.8	4.6
2008	Peak $CPUE_{cal}$ + May_{20temp}	16.1	15.9	-0.2
2009	Peak $CPUE_{cal}$ + May_{20temp} + $ENSO_1$ + MLD	44.4	38.0	-6.4
2010	Peak $CPUE_{cal}$ + May_{20temp} + ENSO	26.8	24.0	-2.8
2011	Peak $CPUE_{cal}$	56.2	58.9	2.7
2012	Peak $CPUE_{cal}$ + May_{20temp}	18.8	21.3	2.5
2013	Peak $CPUE_{cal\,+}$ ISTI	53.8	94.7	40.9
2014	Peak $CPUE_{cal\,+}$ ISTI	29.9	37.2	7.3
2015	Peak $CPUE_{cal\,+}$ ISTI	54.5	35.1	-19.4
2016	Eco-rank + May_{20temp}	30.4	17.8	-12.6

Table 2. Forecast models using step-wise regressions for the 2017 SEAK pink salmon harvest. The final model chosen for the NOAA pre-season forecast is in bold text.

SECM pre-season forecast models	Jackknife % forecast deviation average/median	Adj. R^2	AICc	Regression *P value*	Prediction for 2017 (80% PI)
$CPUE_{cal}$ + $ISTI_{20mtemp}$	**22/18**	**71%**	**156.0**	**< 0.001**	**46.2 M (28-64 M)**
Eco-rank + $May_{20mtemp}$	28/26	79%	150.0	< 0.001	55.9 M (40-72 M)
$CPUE_{ttd}$ + $ISTI_{20mtemp}$	30/25	69%	158.0	< 0.001	28.1 M (9-47 M)
$CPUE_{cal}$	31/14	59%	156.0	< 0.001	61.4 M
$CPUE_{ttd}$	35/23	55%	158.0	< 0.001	46.6 M
Eco-rank	29/20	67%	150.0	< 0.001	69.0 M

Primary research data and ecosystem metrics used for NOAA pink salmon forecasts for Southeast Alaska. Details on column letter fields on next page.

PARENT pink salmon brood year					Chronological BIOLOGICAL and OCEAN ecosystem variables											FORECAST	ANNUAL RANK		HARVEST	
	ADULT BROOD YEAR					FRY	JUVENILE SECM DATA					STRAIT	OCEAN			ACCURACY	RANK of 6 sig. variables		pink salmon	
	A	B	C	D		E	F	G	H	I	J	K	L	M	N	O	P		Q	
Brood year (BY)	SEAK pink salmon harvest (M)	(% northern in SEAK harvest)	SEAK pink salmon escapement index	(% northern in total SEAK index)	Ocean entry year (BY lagged 1 yr later)	Auke Creek fry outmigration (1,000s) Latitude 58°N, near Juneau	Juvenile peak pink (CAL) CPUE June or July	Juvenile peak pink (TTD) CPUE June or July	Peak seaward migration month	Proportion of pink in trawl hauls in June-July-Aug	Adult coho predation impact Coho total #s/J-pink CPUE	Upper 1-20 m avg. Icy Strait temperature "ISTI" May, June, July and August	North Pacific Grye Oscillation (March, April, May)	North Pacific Index (- 1000) (June, July, Aug)	SeaBird productivity in the Gulf of Alaska kittiwake chicks/nest on Middletone Is.	NOAA forcast deviations from harvest in millions (-red=forecast too high, +green= forecast too low)	*Average rank score of the six variables*	Ranking of the average rank scores	SEAK pink salmon harvest year (BY lagged 2 yrs. later)	SEAK pink salmon harvest (M) (response variable)
Year 0	Harvest		Escapement		Year 1	Fry	Juvenile					Temps	Ocean basin			Year 2			Production	
Data source	*ADFG$_1$*	*ADFG$_1$*	*ADFG$_2$*	*ADFG*		*NOAA$_1$*	*NOAA$_2$*	*NOAA$_2$*	*NOAA$_2$*	*NOAA$_2$*	*NOAA$_2$ ADFG$_3$*	*NOAA$_2$*	*NPGO$_4$*	*CGD$_5$*	*ISRC$_5$*	*NOAA$_2$*	↓	↓		*ADFG$_1$*
1996	64.6	34%	18.1	17%	**1997**	31.1	2.5	2.2	July	17%	1.5	9.5	-0.7	15.6	0.32	na	*12.8*	13	1998	42.4
1997	28.9	60%	14.8	47%	**1998**	60.8	**5.6**	**5.3**	June	42%	**0.8**	9.7	0.6	18.1	0.36	na	*2.3*	1	1999	77.8
1998	42.4	51%	14.3	44%	**1999**	53.5	1.6	1.4	July	**10%**	3.9	9.0	1.7	15.8	0.21	na	*16.3*	18	2000	20.2
1999	77.8	59%	**27.3**	50%	**2000**	132.1	3.7	3.3	July	25%	1.0	9.0	**2.2**	16.9	0.99	na	*7.0*	6	2001	67.0
2000	20.2	50%	10.8	39%	**2001**	61.5	2.9	2.6	July	28%	2.0	9.5	2.2	16.8	1.03	na	*9.3*	9	2002	45.3
2001	67.0	41%	18.6	22%	**2002**	150.1	2.8	2.5	July	26%	2.5	8.6	1.3	15.6	0.97	na	*12.7*	12	2003	52.5
2002	45.3	47%	16.6	49%	**2003**	95.1	3.1	2.7	July	22%	1.8	9.8	1.2	16.1	0.50	-2	*10.0*	10	2004	45.3
2003	52.5	51%	20.0	44%	**2004**	**169.6**	3.9	3.4	June	31%	1.4	9.7	0.2	15.1	0.18	0	*6.8*	5	2005	59.1
2004	45.3	47%	15.7	54%	**2005**	87.9	2.0	1.7	Aug	26%	3.3	10.2	**-1.3**	15.5	0.37	-24	*16.0*	17	2006	11.6
2005	59.1	53%	19.9	51%	**2006**	65.9	2.6	2.3	June	26%	1.9	8.9	-0.5	17.0	0.47	+5	*8.8*	8	2007	44.8
2006	**11.6**	58%	10.2	72%	**2007**	81.9	**1.2**	**1.0**	Aug	15%	3.7	9.3	0.1	15.7	0.42	0	*18.2*	20	2008	15.9
2007	44.8	40%	17.6	29%	**2008**	117.6	2.5	2.2	Aug	29%	2.1	**8.2**	1.5	16.1	0.78	-6	*12.2*	11	2009	38.0
2008	15.9	34%	**9.5**	14%	**2009**	34.8	2.1	2.7	Aug	27%	1.7	9.5	0.4	**15.1**	0.20	-3	*13.2*	15	2010	24.0
2009	38.0	43%	12.7	31%	**2010**	121.6	3.7	5.0	June	**61%**	0.9	9.6	1.6	17.6	0.78	+3	*2.8*	2	2011	58.9
2010	24.0	47%	11.2	43%	**2011**	30.9	1.3	1.6	Aug	25%	**4.1**	8.9	1.1	15.7	0.50	+3	*17.2*	19	2012	21.3
2011	58.9	61%	14.3	**81%**	**2012**	61.8	3.2	4.3	July	48%	1.1	8.7	1.6	16.7	0.87	+41	*6.2*	4	2013	94.7
2012	21.3	41%	11.0	13%	**2013**	51.2	1.9	2.6	July	13%	2.9	9.2	0.7	16.0	1.00	+7	*14.0*	16	2014	37.2
2013	**94.7**	43%	25.2	44%	**2014**	47.4	3.4	4.6	July	53%	2.0	9.4	-0.3	15.8	0.45	-19	*7.5*	7	2015	35.1
2014	37.2	**30%**	13.8	**11%**	**2015**	**14.2**	2.2	1.8	June	19%	2.6	9.9	-1.2	15.7	0.21	-13	*13.0*	14	2016	17.8
2015	35.1	**64%**	11.2	64%	**2016**	100.1	3.9	3.1	June	50%	1.6	**10.3**	0.0	**18.9**	**0.08**	?	*4.2*	3	2017	?
				Bivariate 2017 harv. predictions			*61 M*	*47 M*	*57 M*	*62 M*	*53 M*		*37 M*	*88 M*	*27 M*	→	*69 M*			
Harvest correlations	0.34	0.30	0.31	0.50		0.37	**0.78**	**0.76**	**-0.50**	**0.56**	**-0.80**	-0.24	0.45	**0.62**	0.44	→	**-0.86**	**Pearson correlation "r"**		
Probability value=	0.15	0.20	0.19	0.03*		0.12	**0.00***	**0.00***	**0.03***	**0.01***	**0.00***	0.32	0.05	**0.01***	0.06	→	**0.00***	**(* = significant @ p<0.05)**		

__Data sources__: ADFG (S. Heinl$_1$, A. Piston$_2$, and L. Shaul$_3$); NPGO=North Pacific Gyre Ocillation (E. Di Lorenzo, http://www.o3d.org/npgo/); CGD = Climate & Global Dynamics (J. Hurrell, http://www.cgd.ucar.edu/cas/jhurrell/indices.data.html), & NOAA Auke Bay Laboratories (J. Joyce$_1$ - Auke Creek research station & E. Fergusson/J. Orsi$_2$ - Southeast Coastal Monitoring project); ISRC = Institute for Seabird Research and Conservation (S. Hatch$_6$).

Figure 1. Ecosystem metrics from SECM and other indices in relation to pink salmon harvests in Southeast Alaska, 1998-2016. See back page.

Figure 1. Sources and descriptions of the ecosystem metrics used. In general for each column, upper third best values shaded green, middle third values shaded yellow, and lowest third values shaded red. Yellow fields at the bottom represent significant bivariate correlations with Southeast pink salmon harvest. The lower gray fields are the bivariate 2017 harvest predictions from certain significant correlations.

Column letter	Source	Description
A	ADFG	Southeast Alaska pink salmon harvest of the parent brood year
B	ADFG	Proportion of harvest from A that occurred in the northern region
C	ADFG	Southeast Alaska pink salmon escapement index
D	ADFG	Proportion of escapement index from C that occurred in the northern region
E	NOAA	Auke Creek wild pink salmon fry production
F	NOAA	Peak June or July average catch of juvenile pink salmon per trawl calibrated among most vessels ($CPUE_{cal}$)
G	NOAA	Peak June or July average catch of juvenile pink salmon per trawl track distance ($CPUE_{ttd}$)
H	NOAA	Peak seaward migration month of juvenile pink salmon: early departures are more conducive to stronger subsequent adult returns and vice versa
I	NOAA	Proportion of juvenile pink salmon in the catches over the entire season in relation to the other species of salmon A higher percentage of pink salmon in the catch indicates a strong relative abundance compared to other salmon species and a high frequency of occurrence
J	NOAA	Adult coho salmon predator impact is the total abundance of adult coho (wild and hatchery commercial catch, M) divided by the peak abundance of juvenile pink salmon in June or July ($CPUE_{ttd}$). A high ratio of retuning adults to outmigrating juvenile pink salmon is undesirable and vice versa
K	NOAA	The upper 20 m water temperature index from Icy Strait (ISTI) representing 1-m temperature readings from eight stations to a 20 m depth averaged over the months of May, June, July, and August: 640 measurements each year
L	NPGO	North Pacific Gyre Oscillation (March-May) in the juvenile ocean year http://www.o3d.org/npgo/
M	NPI	North Pacific Index average value June, July, and August. The North Pacific Index (NP index or NPI) is the area-weighted sea level pressure over the region 30°N-65°N, 160°E-140°W. The NP index is defined to measure interannual to decadal variations in the atmospheric circulation. The NPI is inversely related to the Aleutian Low and may influence coastal down welling in the Gulf of Alaska and the width of the Alaska Coastal Current http://www.cgd.ucar.edu/cas/jhurrell/indices.data.html
N	ISRC	Institute for Seabird Research and Conservation. The annual productivity of kittiwakes on Middleton Island, Gulf of Alaska. Kittiwake chick per nest data. Insight to the extent of prey resources available northward from SEAK
O	NOAA	Harvest deviations from NOAA forecast models 2004-2016, see Table 1
P	NOAA	Average rank score of six significant variables in columns, and overall rank of year over past 20 years
Q	ADFG	Southeast Alaska pink salmon harvest, the production response variable

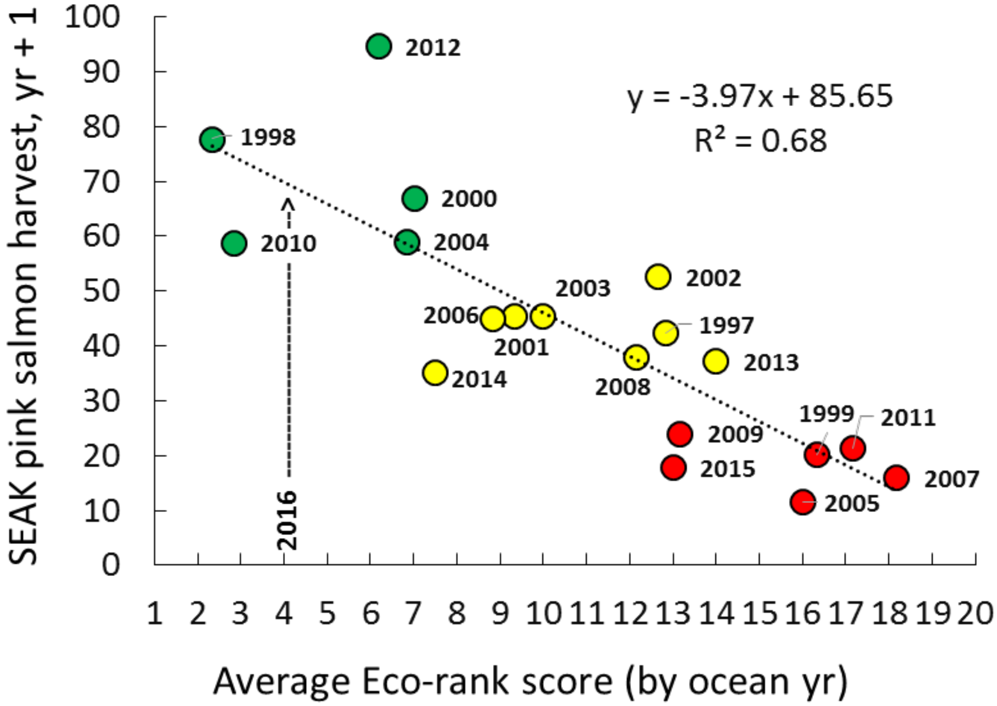

Figure 2. Average Eco-rank scores for seven ecosystem variables over the past 19 ocean years and subsequent pink salmon harvests (ocean year +1) to Southeast Alaska. The average EcoRank score for 2016 is 4.2 and if accurate would correspond to a 69 M pink salmon harvest in 2017.

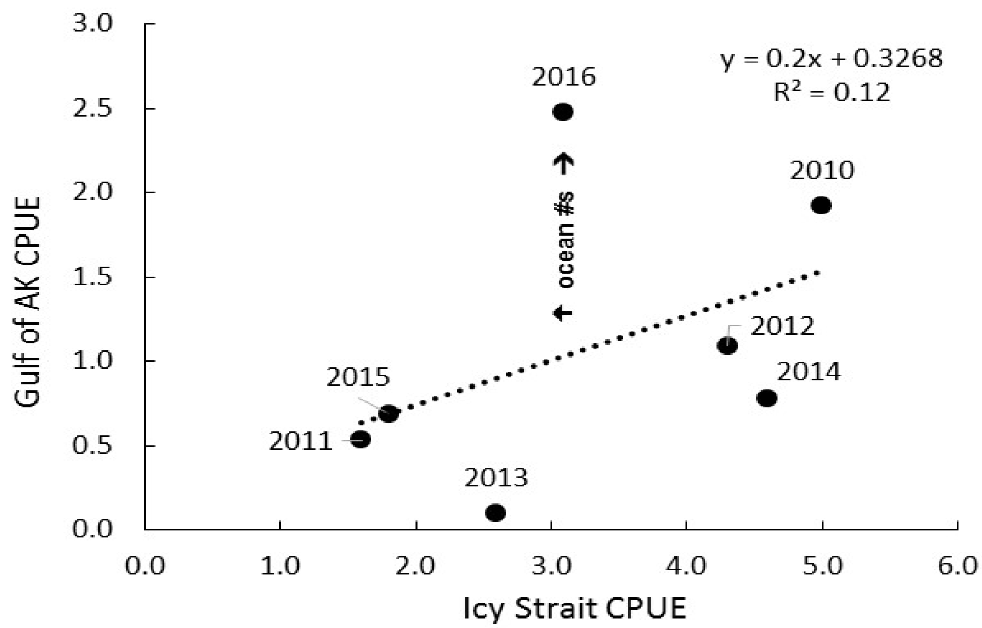

Figure 3. Relative abundance of juvenile pink salmon between Icy Strait and Gulf of Alaska based on surface trawl catch per unit effort (CPUE), July 2010-16. Pink CPUE in the GOA for 2016 was highest on record, and the highest proportional difference with Icy Strait of any year, suggesting favorable production of coastal and southern pink salmon stocks returning in 2017.

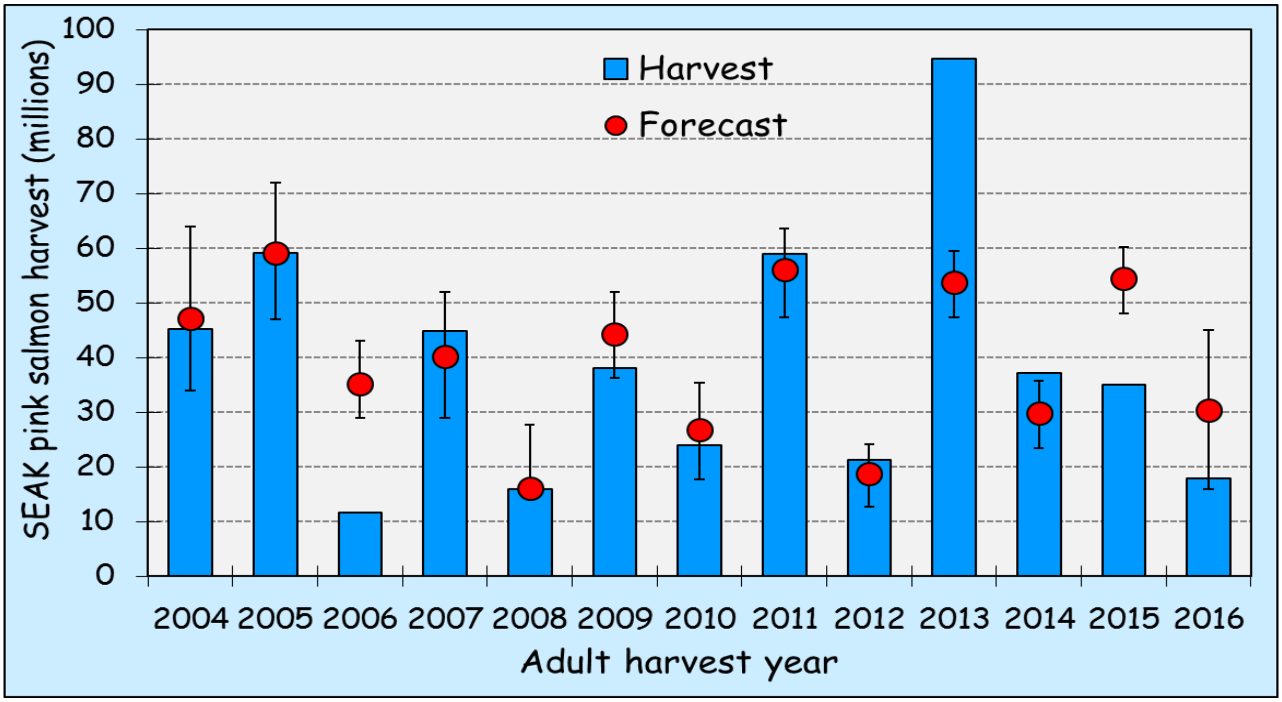

Figure 4. NOAA pink salmon harvest forecast model estimates (red dots) and harvest outcomes (blue bars) in Southeast Alaska, 2004-2016. The actual tabular data is in Table 1. Prediction intervals are shown above and below the red forecast model estimates.