Recent Harvest Trends of Pink and Chum Salmon in Southeast Alaska: Can Marine Ecosystem Indicators Be Used as Predictive Tools for Management?

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Pink and chum salmon are the principal salmon harvest components in Southeast Alaska (SEAK) commercial fisheries and were valued at greater than $75 million from 2008 to 2010 (ADFG 2011). The combined harvests of both species in SEAK generally increased from about 10 to 50 million fish from 1960 to 2000. However, production trends have also varied annually, and over the last decade there has been evidence for a downward trend in harvest for both species. Stock structure also differs dramatically between species. Of the salmon harvested from 1997 to 2010, 98% of pink salmon were unmarked, presumably wild stocks, whereas 74% of chum salmon were identified as hatchery stocks (McNair 1998, 1999, 2000, 2001, 2002; Farrington 2003, 2004; White 2005, 2006, 2007, 2008, 2009, 2010, 2011). Recent variations in SEAK salmon production could be linked to ocean or freshwater conditions, species interactions, management or enhancement practices, or a combination thereof.

To better understand links between marine ecosystem factors and recent pink and chum salmon production in SEAK, data from a regional ocean sampling survey (the Southeast Coastal Monitoring [SECM] project) and corresponding ocean basin-scale indices were examined over the years 1997–2010. Pink and chum salmon have in common the life history trait of migrating to sea as fry, with strong dependence on the littoral marine habitat followed by rapid migration through seaward corridors as juveniles en route to the Gulf of Alaska (GOA). Regional and ocean basin metrics associated with salmon were compared to the harvest and survival response variables for pink and chum salmon in SEAK. Metrics were chosen to align with salmon early ocean life, which has been identified as a critical period of high and variable mortality (Parker 1968; Karpenko 1998; Kaeriyama et al. 2007; Wertheimer and Thrower 2007). At this time, juvenile salmon are vulnerable to marine conditions that influence year-class strength through factors such as growth, predator abundance, and seaward migration size and timing. Identifying a set of marine ecosystem indicators useful as predictive tools for forecasting returns would benefit salmon management in SEAK, particularly when sibling models are not possible, as is the case for pink salmon.

Objectives of this study were to determine whether (1) ecosystem metrics associated with juvenile pink and chum salmon are related to recent trends in SEAK salmon production, and (2) ecosystem metrics can be used as predictive tools for salmon management.

Metrics used for this study were obtained primarily from the SECM project and ocean basin-scale data sources. These ecosystem metrics were also selected to reflect time scales that affect each cohort prior to harvest. The SECM project metrics were obtained from surface trawl samples of juvenile salmon migrating to the ocean (yr_1), plankton nets, and oceanographic data taken at monthly intervals from May to August in the northern region of SEAK (58°N, 135°W; Orsi et al. 2000, 2011). The SECM project metrics used were: upper 20-m integrated water temperature in May, average mixed layer depth (MLD) in June-July, average zooplankton biomass displacement volume (Bongo net 333-µm mesh) in June-July, peak fish CPUE (Ln[catch+1]) in June or July, fish energy density ($kcal \cdot g^{-1}$ WW) in July, fish size (FL, mm) on 24 July (growth proxy), seasonality (peak migration month June–August), stomach fullness (percent body weight) in July, and fish condition factor residuals in June–July. The ocean basin and regional metrics were selected as potential factors affecting juvenile salmon prior to and during their ocean residence, such as in winter (November–March, yr_{-1}) and summer (June–Aug, yr_1). These metrics included GOA (45–58°N, 130–156°W) sea surface temperatures in winter and summer (Kalnay et al. 1996), the North Pacific Index (NPI; winter and summer; Trenberth and Hurrell 1994), the Pacific Decadal Oscillation (PDO; winter and summer; Mantua et al. 1997), the Multivariate El Niño Southern Oscillation Index (MEI; winter and summer; Wolter and Timlin 1993, 1998), and the US Geological Survey monthly river discharge levels for the Mendenhall River, SEAK, in spring/summer (March–Aug, yr_1; USGS 2011).

Harvest and survival data were the response variables chosen for pink and chum salmon production in SEAK (Figs. 1 and 2). The harvest data was assumed to represent total return for each species and was lagged appropriately: conditions affecting juvenile salmon during their ocean entry year (yr_1) were lagged one year to adults in harvest for pink salmon (yr_{1+1}) and three years to adults in harvest for chum salmon (yr_{1+3}). This permitted comparisons of 13 years of pink harvests and 10 years of chum salmon harvests. Marine survival data from three hatcheries' salmon releases and one wild salmon

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stock in SEAK were used. Pink salmon survival rates were available from Auke Creek (wild fish) and the Armstrong Keta Incorporated hatchery. Chum salmon survival rates were available from the Douglas Island Pink and Chum and Hidden Falls hatcheries. For each species of salmon, survival rates were averaged to develop an index, and complete brood year survival indices were compared for 13 years for pink salmon and 9 years for chum salmon.

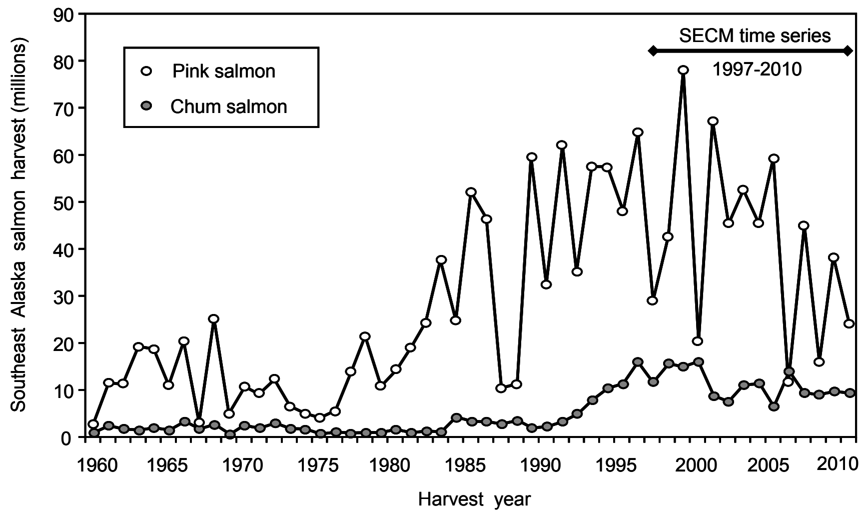

Fig. 1. Historical harvests of pink and chum salmon in the commercial fisheries of Southeast Alaska (SEAK), 1960–2010. The Southeast Coastal Monitoring (SECM) project time series (1997–2010) for juvenile pink and chum salmon is identified. The SEAK salmon harvest data provided courtesy of S. Heinl, Alaska Department of Fish and Game.

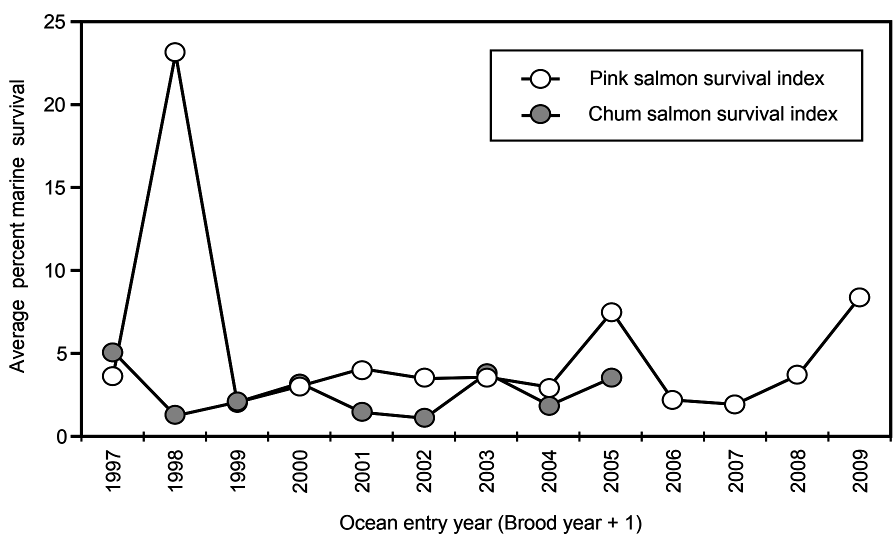

Fig. 2. Marine survival indices for pink and chum salmon (two stocks each) in the northern region of Southeast Alaska from 1998 to 2010. The pink salmon survival index is the average marine survival of Auke Creek (wild) and Armstrong Keta Incorporated (AKI, hatchery) stocks. Auke Creek data provided courtesy of J. Joyce, Auke Bay Laboratories, and the AKI data provided courtesy of B. Watson. The chum salmon survival index is the average marine survival of two hatchery stocks: Hidden Falls, Northern Southeast Regional Aquaculture Association (NSRAA) and Douglas Island Pink and Chum (DIPAC). The NSRAA data provided courtesy of C. Blair and the DIPAC data provided courtesy of R. Focht.

Pink and chum salmon responded differently to SECM project and ocean basin metrics. For pink salmon, significant ($p \leq 0.02$) correlations included: juvenile CPUE with both harvest ($r = 0.92$) and survival ($r = 0.67$), seasonality with harvest ($r = -0.74$), NPI_{summer} with harvest ($r = 0.62$), and MEI_{winter} with survival ($r = 0.73$) (Tables 1 and 2). For chum salmon, the PDO_{summer} was the only metric significantly ($p \leq 0.04$) correlated to both harvest ($r = 0.63$) and survival ($r = 0.72$). These results suggest that a critical period prior to the SECM sampling exists for juvenile pink salmon in particular, and that chum salmon are more influenced by ocean basin metrics. Other metrics were not significantly correlated with harvest or survival of either species.

Table 1. Pearson's correlation coefficients (*r*) and *p*-values for biophysical parameters collected during the Southeast Coastal Monitoring (SECM) project's juvenile salmon time frame (1997–2009) and associated year class strength of adult pink salmon (1998–2010) and chum salmon (2001–2010) in the northern region of Southeast Alaska. Significant ($p < 0.05$) correlations are in bold. SECM project parameters are defined in the text.

	Pink salmon				Chum salmon			
	Harvest (13 years)		Survival (13 years)		Harvest (10 years)		Survival (9 years)	
SECM project parameters	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Integrated 20-m temp (May)	-0.04	(0.91)	0.50	(0.08)	0.24	(0.48)	0.27	(0.48)
Mixed layer (June–July)	-0.46	(0.12)	-0.07	(0.83)	-0.20	(0.55)	0.23	(0.55)
Zooplankton (June–July)	0.18	(0.56)	-0.36	(0.22)	0.26	(0.43)	0.06	(0.89)
CPUE (Peak: June or July)	**0.92**	**(0.00)**	**0.67**	**(0.01)**	0.10	(0.76)	-0.02	(0.97)
Energy density (July)	-0.16	(0.60)	0.07	(0.82)	0.36	(0.28)	0.30	(0.44)
Size-at-time (24 July)	0.26	(0.39)	0.39	(0.19)	0.36	(0.28)	0.43	(0.25)
Seasonality (June–August)	**-0.74**	**(0.00)**	-0.24	(0.44)	0.33	(0.33)	0.28	(0.47)
Fullness (% body wt)	-0.00	(1.00)	-0.12	(0.70)	0.11	(0.76)	-0.19	(0.63)
Condition residual	0.33	(0.27)	0.25	(0.42)	0.58	(0.54)	0.30	(0.44)

Table 2. Pearson's correlation coefficients (*r*) and *p*-values for basin-scale biophysical parameters within the Southeast Coastal Monitoring (SECM) project's juvenile salmon time frame (1997–2009) and associated year class strength of adult pink (1998–2010) and chum salmon (2001–2010). Abbreviations are defined in text and data sources are footnoted. Basin-scale parameters are temporally aligned with juvenile ocean entry year (brood year + 1), or the year prior to ocean entry year (yr_{-1}); the spring is April and May; the summer is June to August; and the winter is November to March. Significant ($p < 0.05$) correlations are in bold.

	Pink salmon				Chum salmon			
	Harvest (13 years)		Survival (13 years)		Harvest (10 years)		Survival (9 years)	
Basin-scale parameters	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
[1]SST (winter, yr_{-1})	0.16	(0.60)	0.15	(0.64)	0.27	(0.42)	0.13	(0.75)
[1]SST (summer)	0.11	(0.72)	0.19	(0.53)	0.37	(0.26)	0.52	(0.15)
[2]NPI (winter, yr_{-1})	-0.50	(0.08)	-0.32	(0.28)	-0.35	(0.28)	-0.01	(0.98)
[2]NPI (summer)	**0.62**	**(0.02)**	0.54	(0.06)	-0.01	(1.00)	-0.29	(0.45)
[3]PDO (winter, yr_{-1})	0.24	(0.44)	0.33	(0.27)	0.35	(0.36)	0.13	(0.70)
[3]PDO (summer)	-0.04	(0.91)	0.01	(0.97)	**0.63**	**(0.04)**	**0.72**	**(0.03)**
[4]MEI (winter, yr_{-1})	0.29	(0.34)	**0.73**	**(0.01)**	-0.05	(0.90)	-0.14	(0.72)
[4]MEI (summer)	0.10	(0.74)	-0.00	(0.99)	0.57	(0.07)	0.57	(0.11)
[5]River (spring–summer)	-0.01	(0.98)	0.17	(0.59)	-0.01	(0.98)	0.27	(0.48)

[1] Kalnay et al. (1996) www.esrl.noaa.gov/psd/data/timeseries/,
[2]Trenberth and Hurrell (1994) www.cgd.ucar.edu/cas/jhurrell/indices.info.html#np,
[3]Mantua et al. (1997) www.atmos.washington.edu/~mantua/abst.PDO.html,
[4]Wolter and Timlin (1993) www.esrl.noaa.gov/psd/enso/mei/table.html,
[5]USGS (2011) Mendenhall River discharge waterdata.usgs.gov/nwis/monthly

This paper examined the relationships of juvenile pink and chum salmon and their associated ecosystem metrics with recent trends in salmon production in SEAK. The highly significant correlation between juvenile pink salmon CPUE and subsequent adult harvest is a relationship that has been successfully incorporated into salmon forecast models for SEAK since 2004 (Wertheimer et al. 2009, 2011). In seven of the past eight years, the SECM pink salmon forecasts have been within 7% of the actual harvests, and all models included CPUE (Fig. 3) as the principal parameter. Since 2007, several models have used additional parameters in a step-wise regression approach to explain error. Forecasting pink salmon abundance has historically been problematic because information from a prior year class is not available as a leading indicator to detect brood year strength. In contrast, forecasting chum salmon has not been attempted because none of the SECM project metrics have been significantly correlated. However, the PDO_{summer} basin-scale index appears to show promise as a tool for future SEAK chum salmon forecasts.

Results from this study indicate ecosystem metrics can be used as predictive tools for pink salmon forecasting in SEAK. Further refinement of forecast methods using ocean basin metrics may permit more robust models to be developed and allow the detection of anomalous years or climate changes that may impact year class strength and give insight to controlling mechanisms within marine ecosystems.

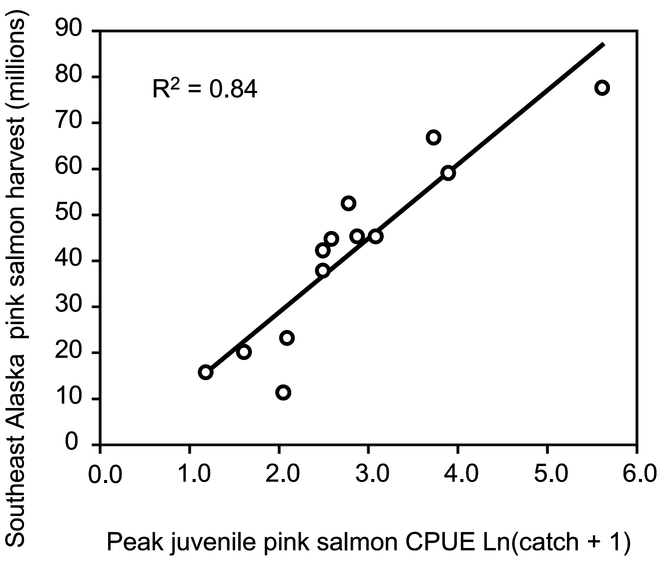

Fig. 3. The relationship between peak juvenile pink salmon CPUE Ln(catch+1) in June or July and the common property harvest of adults in the ensuing year in Southeast Alaska (1997–2009).

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