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Variation in Abundance and Condition of Juvenile Chum Salmon (*Oncorhynchus keta*) in the Eastern Gulf of Alaska in Relation to Environmental Variables

Michael L. Kohan[1], Joseph A. Orsi[2], Franz Mueter[1] and Megan V. McPhee[1]

[1]*University of Alaska Fairbanks, School of Fisheries and Ocean Sciences, 17101 Point Lena Loop Rd, Juneau, AK 99801, USA*
[2]*NOAA Fisheries, Alaska Fisheries Science Center, Ted Stevens Marine Research Institute, Auke Bay Laboratories, 17109 Point Lena Loop Road, Juneau, AK 99801, USA*

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Commercial ex-vessel value of the chum salmon harvest in Southeast Alaska (SEAK) has increased 64% in the past five years to an annual harvest value close to 83 million dollars in 2012 (ADFG 2013), making it the most valuable commercial salmon fishery (in terms of ex-vessel price) in the region. Harvest of chum salmon has increased since the early 1990s due to the increase in hatchery production, which accounts for 73% of the region's commercial catch on average (Piston and Heinl 2011). However, a recent downward trend in wild chum salmon escapement indices (Piston and Heinl 2011) and the high variation in brood-year survival of hatchery chum salmon releases (Wertheimer and Thrower 2007) highlight the importance of trying to better understand the mechanisms affecting marine survival of chum salmon stocks in SEAK.

The mechanisms affecting marine survival of chum salmon are most influential during early marine residency when juvenile salmon experience high growth (Healey 1982a; Mortensen et al. 2000) and high mortality (Parker 1962). Juvenile chum salmon are highly dependent upon their early marine environment due to a short residence in freshwater rearing streams (Healey 1982b). After a rapid growth period, juvenile chum salmon in northern SEAK predominantly take a seaward migration corridor travelling from inshore waters through Icy Strait and out into the eastern Gulf of Alaska (EGOA; Orsi et al. 2000, 2004). In the EGOA, salmon distribution, abundance, and survival are presumably influenced by inter-annual variability in ocean physical processes.

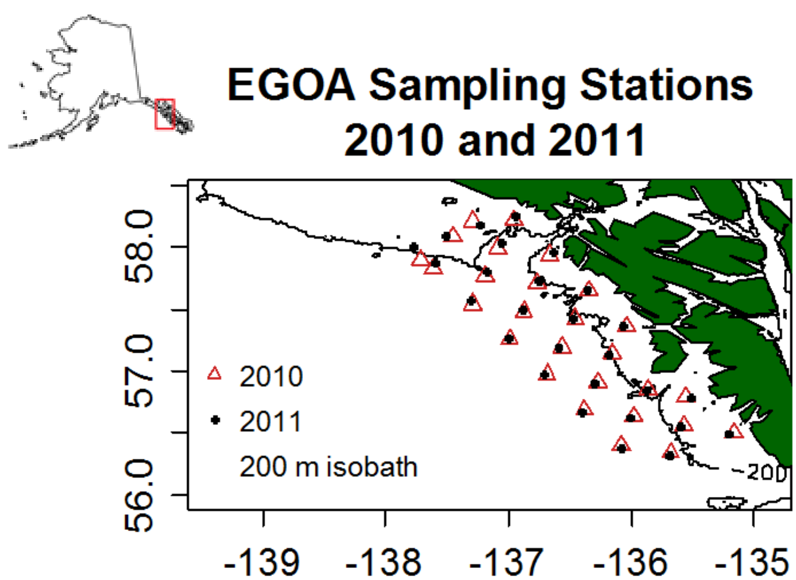

Fig. 1. Location of stations sampled in the eastern Gulf of Alaska (EGOA) in July, 2010 and 2011. Open triangles represent stations sampled in 2010 and black circles represent stations sampled in 2011.

Variability in ocean processes in the EGOA is affected by the Aleutian Low pressure system, a dominant feature of the atmospheric pressure system during the winter in the North Pacific Ocean. Multi-decadal variability in the Aleutian Low affects the abundance of Pacific salmon in the EGOA (Beamish and Bouillon 1993). Inter-annual variability in ocean processes in the GOA is affected by basin-scale processes such as the El Niño Southern Oscillation (ENSO) reflected in the

All correspondence should be addressed to M. Kohan.
e-mail: mlkohan@alaska.edu

variation of sea surface temperature (SST). The Multivariate ENSO Index (MEI) is a basin-scale variable that integrates El Niño and La Niña events with longer-term variations in the coupled ocean-atmosphere system, including variability in the Aleutian Low (Wolter 1987). Indirectly, climate variability can constrain early marine growth in chum salmon by altering the distribution and abundance of prey communities and by increasing residence time in shallow littoral zones, thus delaying offshore migration timing and increasing vulnerability to nearshore predators. Faster growing individuals avoid being prey to gape-limited predators (Sogard 1997) resulting in higher marine survival (Healy 1982a; Beamish and Mahnken 2001; Ruggerone et al. 2003; Ruggerone and Goetz 2004).

Directly, thermal conditions can constrain growth by influencing metabolic responses and subsequent allocation of energy in a juvenile salmon. The metabolic response to the thermal condition determines if energy is allocated to basal or active metabolism rather than somatic growth or lipid storage (Beauchamp et al. 2007).

This study examined variation in juvenile chum salmon abundance and condition in relation to marine factors in the EGOA. Specifically, the objectives of this study were to (1) examine differences in abundance and condition of juvenile chum salmon between stocks of different origin, (2) describe the spatial and temporal variability in abundance (CPUE) and condition of juvenile chum salmon, and (3) examine the relationship between abundance and condition of juvenile chum salmon and marine environmental factors.

Twenty-seven stations on a grid were sampled off the coast of northern SEAK during July, 2010 and 2011 (Fig. 1). In 2010 stations were sampled from north to south, and in 2011 stations were sampled from south to north. At each station, juvenile salmon samples were collected with 30-minute surface trawls targeting the top 20 meters. Associated oceanographic variables were also collected, including vertical profiles of conductivity and temperature.

Surface water temperatures in the upper 3 m were significantly different between years (ANOVA, $p = 0.001$) averaging 11.70°C (SD = 0.39) in 2010 and 12.59 °C (SD = 1.25) in 2011. In both years, stations sampled in early July (northern stations in 2010 and southern stations in 2011) had lower temperatures than stations sampled later in the month (Fig. 2; ANOVA, $p < 0.001$). Sea surface salinities (SSS) and Chl-*a* values were not found to differ significantly between sampling year or station location.

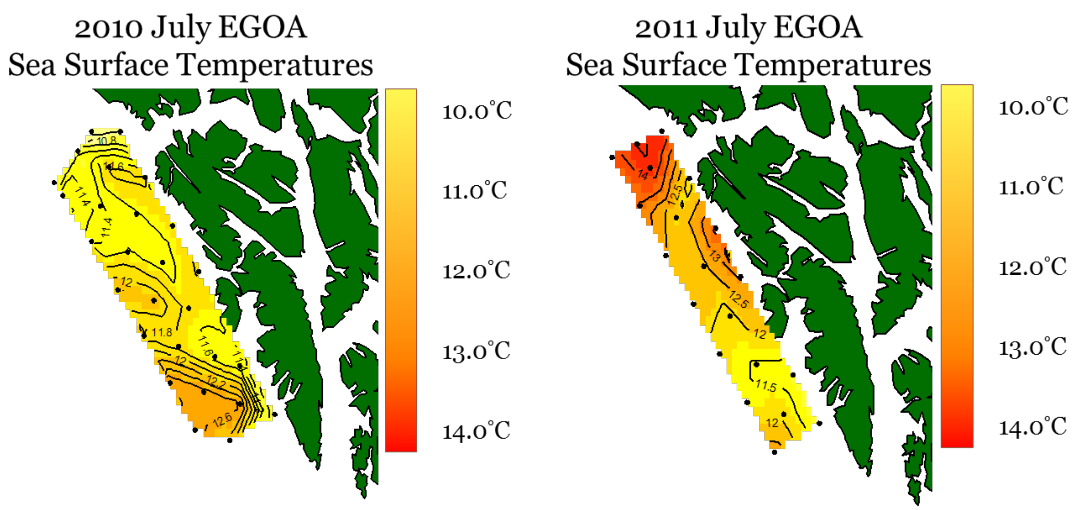

Fig. 2. Interpolated sea surface temperatures (SST) in the vicinity of the survey area in the eastern Gulf of Alaska (EGOA) in July, 2010 and 2011. Black circles represent stations sampled for SST in 2010 (n = 27, left panel) and 2011 (n = 20, right panel). Contour lines depict temperature gradients.

On average, juvenile chum salmon of the pooled stock groups were larger in 2011 (mean FL = 124.09 mm, SE = 2.26) than in 2010 (mean FL = 121.6 mm, SE = 2.03). Wild juvenile chum salmon had a larger mean length than those originating from hatcheries for both sampling years combined (ANOVA, $p < 0.001$). However, within sampling years, wild stocks were only significantly larger than hatchery stocks in 2011 (ANOVA: 2011 $p < 0.001$; 2010 $p = 0.309$; Table 1).

Two measures of condition were used in comparing the physiological status of juvenile chum salmon in the EGOA: whole-body energy density and weight-at-length residuals. Energy density values and residuals from a regression of ln-transformed weight on ln-transformed length were pooled for both years of sampling. Energy density was higher in chum samples collected in 2011 (4892.97 J/g, SE = 64.27) than in fish collected in 2010 (4688.22 J/g, SE = 75.93).

Table 1. Stock, sample size, and average fish length (mm) for juvenile chum salmon collected in the eastern Gulf of Alaska (EGOA) in July, 2010 and 2011. Stock identified as wild or originating from regional hatcheries in Southeast Alaska (SEAK).

Year	Stock	Sample Size	Min Length (mm)	Max Length (mm)	Length (mm)	Standard Error
2010	WILD	36	85	145	124.22	3.58
2010	NSRAA	19	87	191	128.74	4.12
2010	DIPAC	33	101	126	111.82	1.22
2010	SSRAA	2	152	178	171.5	0.5
2011	WILD	35	96	189	137.6	4.96
2011	NSRAA	71	109	188	115	1.70
2011	DIPAC	5	98	125	109	4.51
2011	SSRAA	5	171	172	168.2	4.45

NSRAA: Northern Southeast Regional Aquaculture Association.
DIPAC: Douglas Island Pink and Chum.
SSRAA: Southern Southeast Regional Aquaculture Association.

The weight-at-length residuals representing the condition of juvenile salmon varied between stations and stocks, but without a clear spatial or temporal trend. While we found significant between-station variability, there was no evidence that the variability in abundance or condition of juvenile chum salmon in the EGOA was related to variability in SST, SSS, or Julian day (linear mixed-effects model, $p > 0.05$).

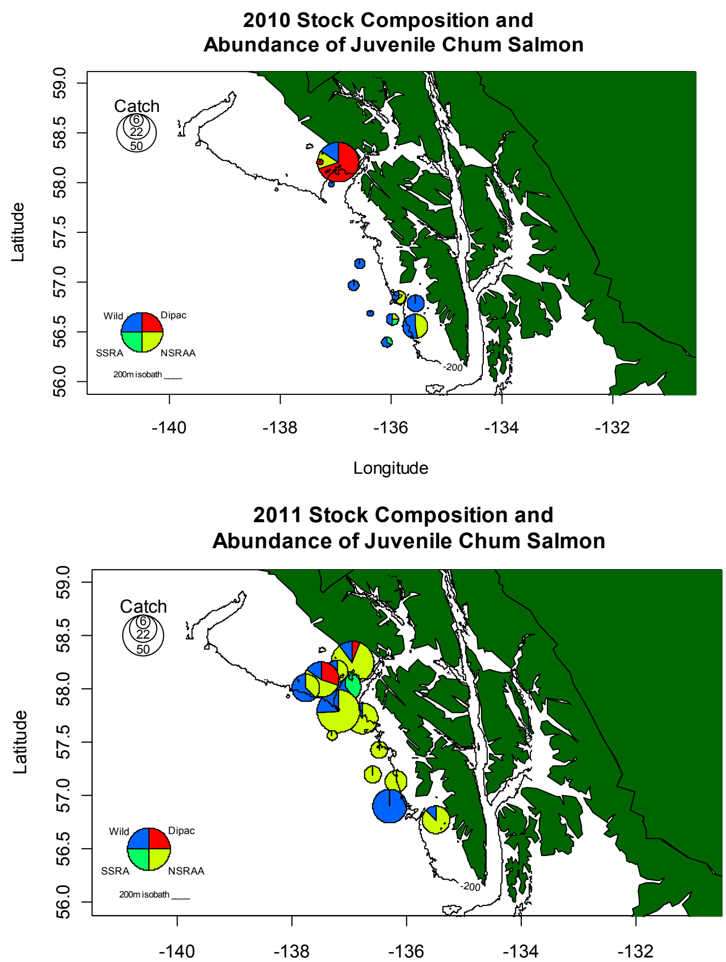

Fig. 3. Wild-hatchery chum salmon stock composition and abundance by station in the eastern Gulf of Alaska (EGOA) surveys conducted in July, 2010 and 2011. Circle radius indicates sample size (up to 50 juvenile chum salmon per station). Stocks are identified in Table 1.

In both years, juvenile chum salmon caught in the EGOA in July originated predominantly from three regional hatcheries in SEAK: Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum (DIPAC), and Southern Southeast Regional Aquaculture Association (SSRAA; Fig. 3). For the unmarked wild chum salmon stocks, CPUE was higher in 2011 than 2010. The DIPAC was the only stock with fewer fish in the catch in 2011 than 2010. However, differences in catch composition could be due to temporal and spatial differences in the sampling design between the two years.

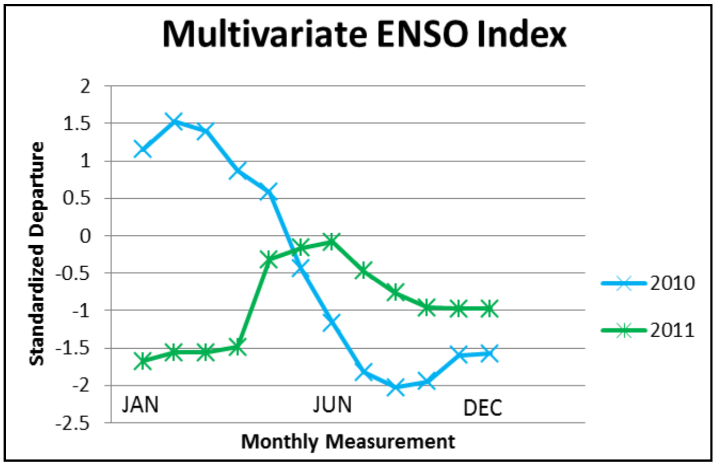

Fig. 4. Comparison of the standardized departures from the mean monthly measurements of the multivariate ENSO index for 2010 and 2011 in the eastern Gulf of Alaska (EGOA; Wolter 2013).

Physical climate indices in the marine environment differed between years. Both the Aleutian Low Pressure Index, measuring the Aleutian Low pressure system, and the MEI characterized 2010 as a weak El Niño year, whereas 2011 was characterized as a weak La Niña year with an anomalously cold winter (Beamish et al. 1997). These measurements of large-scale environmental processes identify 2010 and 2011 as being contrasting years, with high values of the MEI in 2010 corresponding to a warm winter and followed by a drastic decline through the summer to a cold fall and subsequent winter (low MEI values, Fig. 4).

As the thermal regime shifted from 2010 to 2011, so did the abundance and condition of juvenile chum salmon. In general, juvenile chum salmon were less abundant but had higher energy content and were larger in size in 2011, following an anomalously cold winter in the EGOA. A weak Aleutian Low in the EGOA in the winter of 2011 resulted in colder winter/spring SSTs, relaxed downwelling, and reduced onshore transport of prey species in the coastal habitat (Wickett 1967).

Differences in juvenile chum salmon condition and abundance in 2010 and 2011 coincided with years representing positive and negative anomalies of the coupled ocean-atmosphere system. This suggests that previous winter environmental conditions at both the basin and regional scale have potential to be used as predictive tools for forecasting juvenile chum salmon year class strength in SEAK. Future work will use regression models to examine the relationship between juvenile chum salmon condition and associated ecosystem metrics over the years 1997-2011 in northern SEAK.

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