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Juvenile Pink and Chum Salmon Distribution, Diet, and Growth in the Northern Bering and Chukchi Seas

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Abstract: Loss of non-seasonal sea ice and a general warming trend in the Bering Sea has altered the composition, distribution, and abundance of marine organisms inhabiting the region. Juvenile pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon were found in significant numbers throughout the Chukchi Sea and Bering Strait regions during early autumn 2007, reflecting significant utilization of Arctic marine habitat by Pacific salmon. Linear models of juvenile pink and chum salmon body size corrected for Day of Year were parameterized to estimate daily growth rates and habitat-specific differences in body size using 6 years of survey data. Model results revealed that juvenile pink salmon inhabiting the eastern Bering Sea grew at an average rate of 1.17 mm•day^{-1} and juvenile chum salmon grew at a rate of 1.21 mm•day^{-1}. The U.S. BASIS survey area was expanded northward to include the Chukchi Sea during 2007, where larger juvenile pink and chum salmon were found in higher abundances relative to pink and chum inhabiting the eastern Bering Sea. Food habits analyses revealed that juvenile pink and chum salmon fed upon high energy prey in the Chukchi Sea, and that the majority of chum salmon encountered there were from either Alaskan or Russian stocks.

Keywords: pink salmon, chum salmon, Chukchi Sea, eastern Bering Sea, growth

INTRODUCTION

Loss of non-seasonal sea ice and a general warming trend in the Bering Sea has altered the composition, distribution, and abundance of marine organisms inhabiting the region (Grebmeier et al. 2006). Juvenile pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon were found in significant numbers throughout the Chukchi Sea and Bering Strait regions during early autumn, reflecting significant utilization of Arctic marine habitat. Marine migration rate plays a key role in the distribution of juvenile salmon within the Bering Sea (Farley et al. 2005). Bering-Aleutian Salmon International Survey (BASIS) research cruises have determined that juvenile pink and chum salmon are consistently distributed the greatest distance from shore as compared with other Pacific salmon species, reflecting high dispersal rates and minimal utilization of nearshore estuarine habitat. Pink salmon consume large amounts of food in order to sustain rapid growth during the early marine life-history stage (Healey 1980); and offshore movements of chum salmon generally coincide with a decline in nearshore food resources and a period when fish attain a body size that allows them to capture and consume prey resources located farther from shore (Simenstadt and Salo 1982).

Environmental conditions can limit or enhance growth during the early marine life-history stage, which influences over-winter survival and recruitment (Farley et al. 2009; Moss et al. 2009). Climate can affect salmon growth and survival directly through physiological influences such as the effect of water temperature on metabolism, or indirectly through altering migration pathways and the availability of prey resources. The effect of ocean temperature and prey quality on juvenile pink salmon growth rate has been quantified for Gulf of Alaska stocks (Cross et al. 2008), and early marine growth shown to affect over-winter survival during the first year of marine life (Moss et al. 2005). In addition to the potential for thermal conditions to constrain growth, there is also evidence that salmon are food-limited during the offshore migration in the Bering Sea and North Pacific Ocean (Ruggerone et al. 2003; Aydin et al. 2004; Kaeriyama et al. 2004), and that climate variability could alter the distribution and abundance of prey resources.

All five species of Pacific salmon are distributed in the epipelagic waters of the eastern Bering Sea during their first marine summer and fall (Farley et al. in press). Early marine growth is known to positively influence marine survival, and salmon populations that have typically inhabited the Bering Sea are expanding their range into Arctic waters. Therefore, the objective of this study is to document and describe the distribution of juvenile pink and chum salmon in the Chukchi

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Sea, and to quantify differences in habitat-specific growth across the Bering and Chukchi seas. In order to accomplish these goals, linear models of juvenile pink salmon body size and Day of Year are parameterized to estimate daily growth rates and to quantify habitat-specific differences in body size. Variability in water temperature and food habits of juvenile pink and chum salmon in the northern Bering and Chukchi seas are also reported.

MATERIALS AND METHODS

Biological Sampling

Juvenile pink and chum salmon were collected in the Bering Strait region and Chukchi Sea aboard the NOAA fisheries research vessel *Oscar Dyson* from September 2^{nd} – September 29^{th} 2007 (Fig. 1), using a midwater rope trawl (model 400/580) made by Cantrawl Pacific Limited of Richmond, B.C., Canada (Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.). The net is approximately 198 m long, has hexagonal mesh in the wings and body, and a 1.2-cm mesh liner in the codend, and has a mouth opening of approximately 55 m horizontally and 15 m vertically. It was towed at or near the surface for 30 minutes at speeds between 3.5 and 5 knots at each station, retrieved, and the contents emptied onto a sorting table on deck. Nekton samples were then moved to an onboard laboratory by conveyer belt where standard biological measurements including fork length and body weight were recorded.

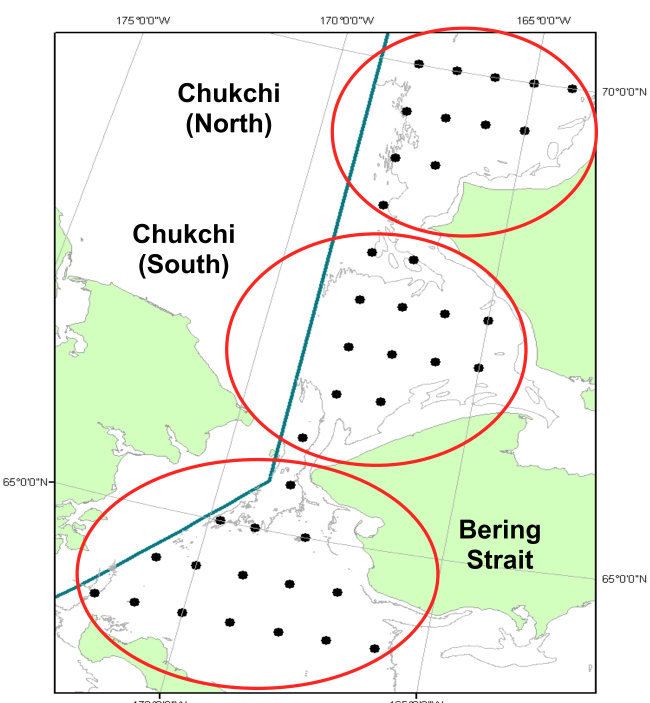

Fig. 1. Survey station locations sampled in the Bering Strait region, southern Chukchi Sea, and northern Chukchi Sea.

Food habits of juvenile pink and chum salmon were examined on board by removing and pooling the contents of the entire food bolus from the stomachs of up to 10 randomly selected individuals. Stomach contents were weighed to the nearest 0.001 g, sorted, and identified to the lowest feasible taxonomic group. Individual prey groups were weighed and divided by the total weight of prey contained in the stomachs and the proportional contributions of each prey group to the diet were calculated.

Growth Rate Estimation and Habitat-specific Differences in Body Size

Variation in juvenile salmon length and body weight across ocean habitats can provide insight into how juvenile salmon respond to environmental conditions. However, a number of confounding factors such as water temperature, prey availability, and prey quality can act to limit direct interpretations of habitat quality to growth rate or body size. The effect of growth during the course of a survey is an important confounding factor in the U.S. BASIS survey, which was in excess of 50 days during 2007. To correct for the effect of growth during the survey a simple linear regression model with Gaussian error was used to model length as a function of Day of Year (growth rate term) and habitat type with habitat terms estimated as dummy variables or factors for each type of habitat (Venables and Ripley 1999), which was performed using six years (2002–2007) of survey data on body size. The interaction between habitat type and growth rate was not considered, as three of the five habitat categories contained a date range of less than five days. This was considered inadequate to describe habitat-specific growth rates. Habitat types selected for the analysis included two from the eastern Bering shelf region: coastal (bottom depth < 50 m) and middle (100 > bottom depth > 50 m), and three from the Arctic region: Bering Strait (64.0–65.5ºN) (bottom depth < 100 m), southern Chukchi Sea (66.0–68.0ºN) (bottom depth < 100 m), and northern Chukchi Sea (68.5–70.0ºN) (bottom depth < 100 m) (Fig. 1).

RESULTS

Spatial Distribution and Growth

Higher densities of juvenile pink and chum salmon were observed within the vicinity of the Bering Strait and the Chukchi Sea as compared with the eastern Bering Sea during 2007 (Fig. 2). Relatively high densities of pink and chum were also encountered on the eastern Bering Sea shelf within the vicinity of St. Lawrence Island (63.5ºN, -170.0ºW), south of St. Lawrence to the Pribilof Islands (57.0ºN, -170.0ºW), and west of Nunivak Island (60.0ºN, -166.0ºW) (Fig. 2). Sea surface temperatures in the northern Chukchi Sea (10.8ºC) were higher on average than the other two areas sampled

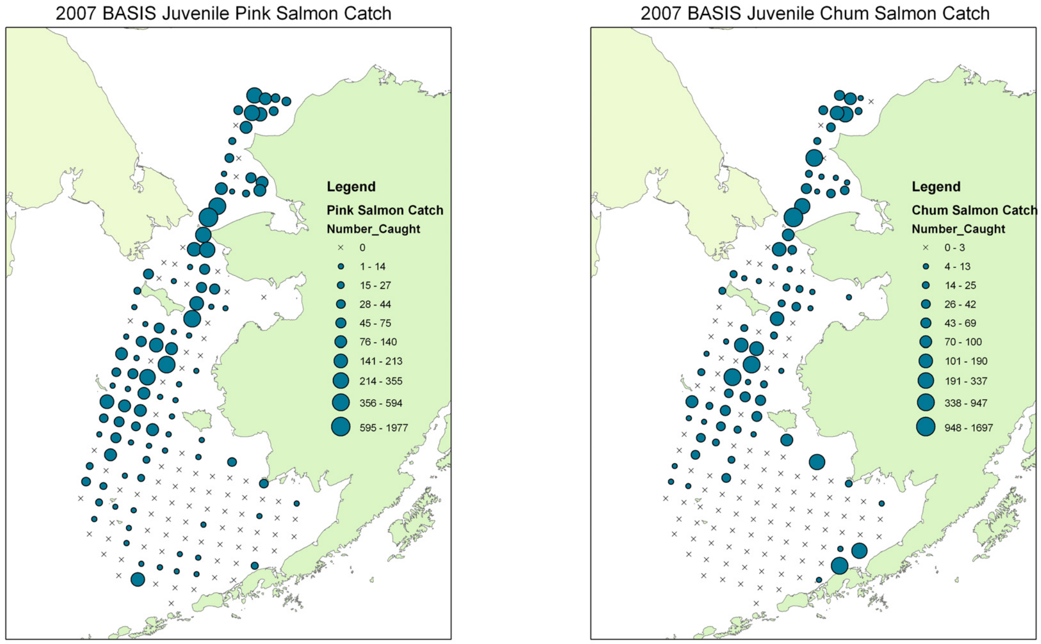

Fig. 2. Relative abundance of juvenile pink and chum salmon inhabiting the eastern Bering Sea, Bering Strait, and Chukchi Sea during late August and early September 2007. Circle size represents catch per unit effort for a 30-minute surface trawl.

in 2007. The southern Chukchi Sea temperatures averaged 9.3ºC, and those for the Bering Strait region averaged 8.7ºC. Juvenile pink salmon grew less on average (1.17 mm•day^{-1}) than chum salmon (1.21 mm•day^{-1}) during 2007 (Fig. 3). Pink salmon grew at rates comparable to the six-year mean (1.18 mm•day^{-1}) during 2007, whereas juvenile chum salmon grew at above average rates (1.48 mm•day^{-1}). During 2007, pink and chum salmon inhabiting the Bering Strait and Chukchi Sea were also larger on average than those inhabiting the lower latitudes of the eastern Bering Sea (Fig. 4).

Juvenile Pink and Chum Salmon Food Habits

Juvenile pink and chum salmon preyed heavily upon high-energy content prey including fish (5,011 J•g^{-1}), euphausiids (3,110 J•g^{-1}), and appendicularia (3,177 J•g^{-1}) (Tables 1, 2). Pink and chum salmon inhabiting the northern Chukchi Sea preyed most heavily upon fish (> 0.61 of diet by weight). Chum salmon inhabiting the southern Chukchi Sea and northern Bering Sea preyed most heavily upon euphausiids (42%, 36% of diet by weight, respectively), while pink salmon preyed most heavily upon crab megalopa (69%, 39% of diet by weight, respectively) (Table 1).

DISCUSSION

Climate-induced changes in the Bering Sea have caused a thinning and reduction of sea ice and a northward redistribution of subarctic species (Hunt et al. 2002; Overland et al. 2004; Grebmeier et al. 2006). The recent temperature increase in Arctic waters can be attributed to a lack of sea

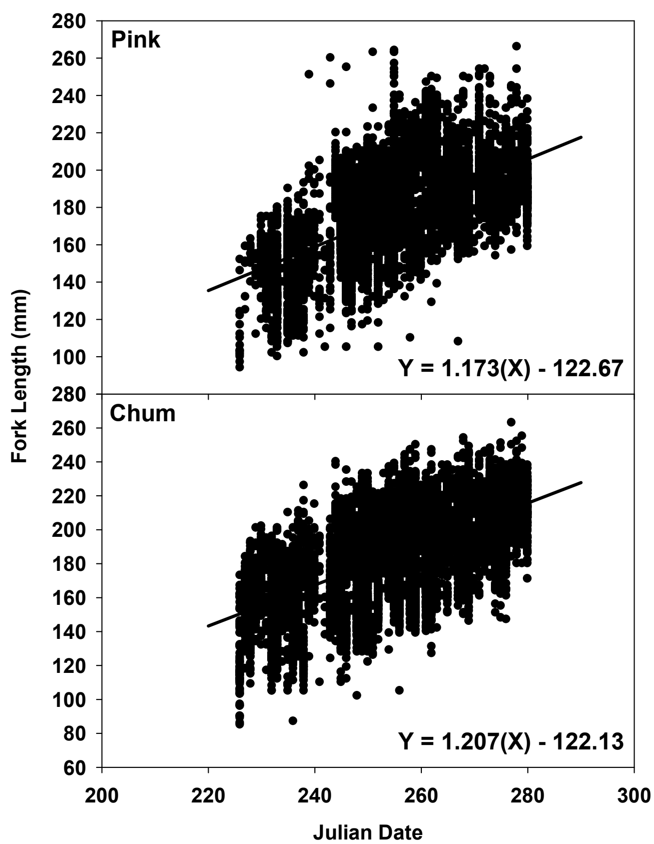

Fig. 3. Linear models representing daily growth of juvenile pink (n = 6,828) and chum (n = 8,769) salmon collected in U.S. BASIS surveys from 2002–2007.

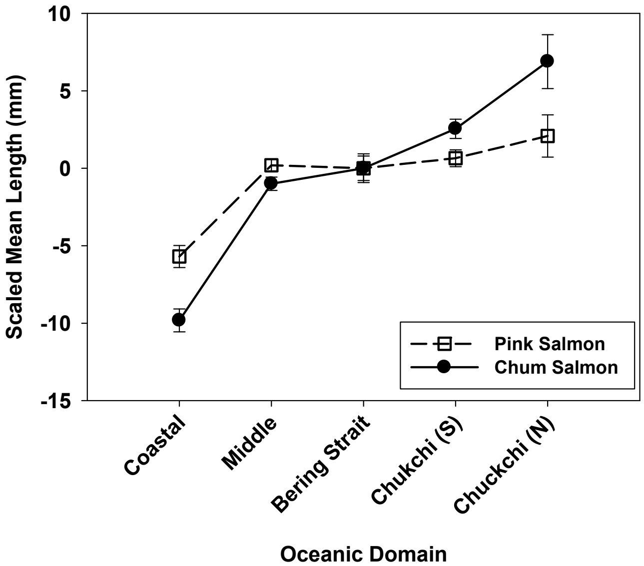

Fig. 4. Estimated average fork length (mm) of juvenile pink and chum salmon by oceanic domain (habitat) during the U.S. BASIS cruise in 2007. Standard error estimates of average length are included.

ice that would normally reflect solar radiation, compared to darker, ice-free ocean water that absorbs solar radiation. Such climate-induced changes may affect salmon feeding and overwintering grounds by influencing inter- and intra-specific competition related to the availability and quality of ocean habitat (Welch et al. 1998). Climate-induced changes may also influence the interactions among the wide variety of salmon stocks in the North Pacific Ocean. During 2007, sea surface temperatures were greatest in the northern Chukchi Sea, followed by temperatures in the southern Chukchi Sea and the Bering Strait. Higher water temperatures combined with a longer photoperiod during summer months could have allowed for longer daily foraging bouts, and more energetically favorable conditions for growth compared to cooler, deeper, eastern Bering Sea waters. It has previously been suggested that cool spring sea surface temperatures lead to slower growth and marine survival of juvenile salmon, and that warmer spring sea surface temperatures lead to more rapid growth (Farley et al. in press). Further, it has been shown that the fastest growing juvenile pink salmon experience higher survival to adulthood (Moss et al. 2005; Cross et al. 2008). Therefore, the combination of increased light and higher water temperatures in the Chukchi Sea is likely resulting in increased lower trophic level productivity, which

Table 1. Prey composition of juvenile pink and chum salmon captured in the northern Chukchi Sea, southern Chukchi Sea, and the Bering Strait region during early autumn 2007.

Prey	Pink salmon			Chum salmon		
	Chukchi North	Chukchi South	Bering Strait	Chukchi North	Chukchi South	Bering Strait
Copepoda	0.008	0.010	0.228	0.009	0.001	0.042
Amphipoda	0.000	0.005	0.015	0.000	0.057	0.058
Euphausiacea	0.268	0.250	0.130	0.241	0.418	0.361
Pteropoda	0.000	0.002	0.000	0.000	0.000	0.000
Chaetognatha	0.000	0.000	0.010	0.000	0.000	0.004
Appendicularia	0.038	0.005	0.006	0.025	0.150	0.214
Coelenterata	0.000	0.000	0.000	0.000	0.174	0.193
Megalopa	0.075	0.687	0.389	0.032	0.192	0.027
Fish	0.611	0.041	0.222	0.693	0.008	0.101

Table 2. Prey energy density (wet weight) and percent indigestible values of prey identified in juvenile pink and chum salmon diet.

Prey	Percent indigestible	Energy content ($J \cdot g^{-1}$)	Literature sources
Copepoda	9.04	2,624.2	Davis et al. 1998, Boldt and Haldorson 2002
Amphipoda	12.99	2,465.6	Davis et al. 1998, Boldt and Haldorson 2002
Euphausiacea	10.35	3,110.2	Davis et al. 1998, Boldt and Haldorson 2002
Pteropoda	10.00	2,612.1	Model default value
Chaetognatha	8.50	2,213.0	Davis et al. 1998, Boldt and Haldorson 2002
Appendicularia	10.00	3,177.2	Davis et al. 1998, Boldt and Haldorson 2002
Coelenterata	10.00	1,975.8	Davis et al. 2003, Model default value
Megalopa	8.50	2,980.4	Nishiyama 1977, Boldt and Haldorson 2002
Fish + Squid	8.98	5,010.6	Nishiyama 1977, Boldt and Haldorson 2002

is cascading up the food chain to fishes that prey upon zooplankton.

A closer examination of habitat-specific differences in length showed that pink and chum salmon body size increased from coastal waters seaward across the eastern Bering Sea shelf. Similar differences in size patterns have been reported for pink and chum inhabiting the Gulf of Alaska (Farley et al. 2005; Cross et al. 2008). Chum salmon growth rates were above average in 2007, which may have been the result of earlier ocean entry and seaward migration than that in a 'typical' year. The observed growth rate differences suggest that environmental conditions in the northern Chukchi Sea were better for supporting growth, which could be due to the presence of higher quality prey, as well as more energetically favorable water temperatures and a longer photoperiod for these visually foraging fish. High quality prey items in the northern Chukchi Sea likely enhanced juvenile pink and chum salmon growth as well, and given a potential for high growth rates in the Chukchi Sea, juvenile pink and chum salmon that inhabit this region will likely benefit from the shallow shelf habitat. The combined effects of prey quality, prey availability, and water temperature which support chum salmon growth and survival in Arctic waters should be further investigated using bioenergetics models. Bioenergetics model simulations can be used to reveal the combined influence of biophysical factors such as juvenile pink and chum salmon physiology, prey quality, and thermal experience.

Juvenile chum salmon captured in the Bering Strait region were primarily from northern Russia (Kondzela et al. 2009), and may have been passively transported from coastal Siberia to the eastern Bering Strait by the Anadyr Current. Climate-based effects on the Arctic and northern Bering Sea ecosystem may cause a trophic feedback loop and increase competition for zooplankton prey (Aydin et al. 2000). The ability to predict the effects of climate change on the growth and survival of marine organisms is needed, and results from this study suggest that juvenile pink and chum salmon inhabiting the Arctic are currently benefiting from present conditions.

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