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# Distribution, Migration Pathways, and Size of Western Alaska Juvenile Salmon Along the Eastern Bering Sea Shelf

**Edward V. Farley, Jr., James M. Murphy, Bruce W. Wing, Jamal H. Moss, and Angela Middleton**

Abstract: The size, condition, distribution, and migration pathways of juvenile Pacific salmon (pink, chum, sockeye, coho, and Chinook salmon) were examined along the eastern Bering Sea shelf during August through October 2002. Juvenile salmon were widely distributed across the eastern Bering Sea shelf, but species-specific distributional patterns were found. Juvenile sockeye and chum salmon were large during 2002, suggesting that growth rates were high during their first summer at sea. Seaward migratory pathways for juvenile salmon from Bristol Bay and the Kuskokwim and Yukon rivers were inferred from their size distributions along the eastern Bering Sea shelf, and differ from earlier migration models.

## INTRODUCTION

Pacific salmon (*Oncorhynchus* spp.) returns (catch + escapement) to rivers draining into the eastern Bering Sea have been inconsistent, and at times very weak. During 2000, low returns of Chinook (*O. tshawytscha*) and chum (*O. keta*) salmon to the Yukon River, Kuskokwim River, and Norton Sound areas prompted the State of Alaska to restrict commercial and subsistence fisheries and to declare a fisheries disaster for the region. Weak salmon returns to these river systems followed several years of low sockeye (*O. nerka*) salmon returns to Bristol Bay, which was declared a fisheries disaster region during 1998 by both the State of Alaska and the U.S. Department of Commerce. Causes for the poor salmon returns are not known; however, the regional scale of the decline of these stocks indicates that the marine environment may play a critical role.

Ocean conditions are known to significantly affect salmon survival, particularly during the first few months after leaving freshwater (Holtby et al. 1990; Friedland et al. 1996; Beamish and Mahnken 2001; Beamish et al. 2004). The assumption is that growth of juvenile salmon in the estuarine and nearshore marine environments is directly linked to their marine survival. Thus, years with favorable environmental conditions and increased growth rates of juvenile salmon may reduce susceptibility of the salmon to size-selective predation (Fisher and Pearcy 1988; Holtby et al. 1990) and/or improve survival during their first winter at sea (Beamish and Mahnken 2001; Beamish et al. 2004), ultimately increasing total returns from the brood year.

Mechanisms affecting marine survival of eastern Bering Sea salmon stocks are poorly understood due to the lack of basic biological information about the early marine life history of salmon in this region. Earlier studies of juvenile salmon migration in the eastern Bering Sea were generally focused within Bristol Bay (Hartt and Dell 1986; Isakson et al. 1986; Straty 1974). Information on juvenile salmon in the Arctic, Yukon, and Kuskokwim (AYK) region is limited to a 1986 study of juvenile salmon that was restricted to a few sample stations around the Yukon River delta (Martin et al. 1986). Summaries of these studies can be found in Brodeur et al. (2003).

During 2002, scientists from Canada, Russia, Japan, and the United States, member nations of the North Pacific Anadromous Fish Commission (NPAFC), cooperated in the design and execution of a field survey of salmon across the entire Bering Sea. The research, designated as Bering-Aleutian Salmon International Survey (BASIS), was developed to clarify the mechanisms of biological response by salmon to climate change. Research cruises were conducted during summer and fall 2002 (Murphy et al. 2003; Temnykh et al. 2003).

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In this paper, we summarize information from the U.S. BASIS research cruise along the eastern Bering Sea shelf from August to October 2002. We report new information on size, condition, and distribution of juvenile salmon on the eastern Bering Sea shelf. Seaward migration pathways of juvenile salmon were examined using a Generalized Additive Model (GAM), for which variation in size (length) of juvenile salmon is assumed to be a function of time spent at sea (i.e., size increases along the migratory pathway away from the location of ocean entry).

## METHODS

### Survey

The Auke Bay Laboratory's Ocean Carrying Capacity (OCC) survey of the eastern Bering Sea was conducted during 2002 (20 August–7 October) aboard the chartered fishing vessel *Sea Storm* (38 m in length). Stations sampled during the survey were along longitudinal (161°W to 168ºW) and latitudinal lines (60ºN to 65ºN; Figure 1). Fish were collected using two midwater rope trawls, Models 400/580 and 300, made by Cantrawl Pacific Limited[1] of Richmond, B.C. Stations in relatively deeper waters along the long 162°W to 166°W transects were sampled using a midwater trawl Model 400/580. Stations in relatively shallow waters along long 167°W and 168°W, and lat transects north of 60°N were sampled using a midwater trawl Model 300. Both nets were 198 m long, had hexagonal mesh in wings and body, and had a 1.2-cm mesh liner in the codend. The Model 400/580 and 300 rope trawls were towed at 3.5 to 5 knots, at or near surface, and had typical spreads of 41 m horizontally and 14 m vertically, and 56 m horizontally and 12 m vertically, respectively.

The trawls were fished with Noreastern Trawl Systems[1] 5-m alloy doors, 60-m bridles, and 180–200 fathoms of warp line behind the boat. Buoys were secured to the wing tips (2-A5 and 4-A4 buoys) and 2 buoys were attached to the net sounder to help maintain the headrope near the surface. Wing-tip buoys could be seen floating near the surface when trawling and were used to ensure the headrope was at the surface. A Simrad FS900[1] net sounder was used to determine the net opening (height and width) during each trawl set.

Stations were sampled during daylight hours (0730–2100, Alaska Daylight Savings Time) and all tows lasted 30 min and covered 2.8 to 4.6 km. Salmon and other fishes captured during the tow were sorted by species and counted. We tested for a correlation between catch per unit effort (number of salmon caught during a 30 minute tow) and time of day and found no relationship ($r < 0.20$; $P > 0.01$). Standard biological measurements including fork length (nearest mm) and body weight (nearest g) were taken on board. Scale samples to document freshwater age of juvenile sockeye salmon were taken from the preferred area (Clutter and Whitesel 1956) and non-preferred areas (when a preferred scale was not available). Juvenile sockeye salmon were aged at the Alaska Department of Fish and Game's (ADF&G) Mark, Tag, and Otolith Laboratory in Juneau, Alaska. Subsamples of all juvenile salmon species were wrapped in a labeled plastic bag, frozen, and shipped to the laboratory for further processing.

### Geographical Regions

The eastern Bering Sea was separated into two regions based on distribution and probable stock- and species-

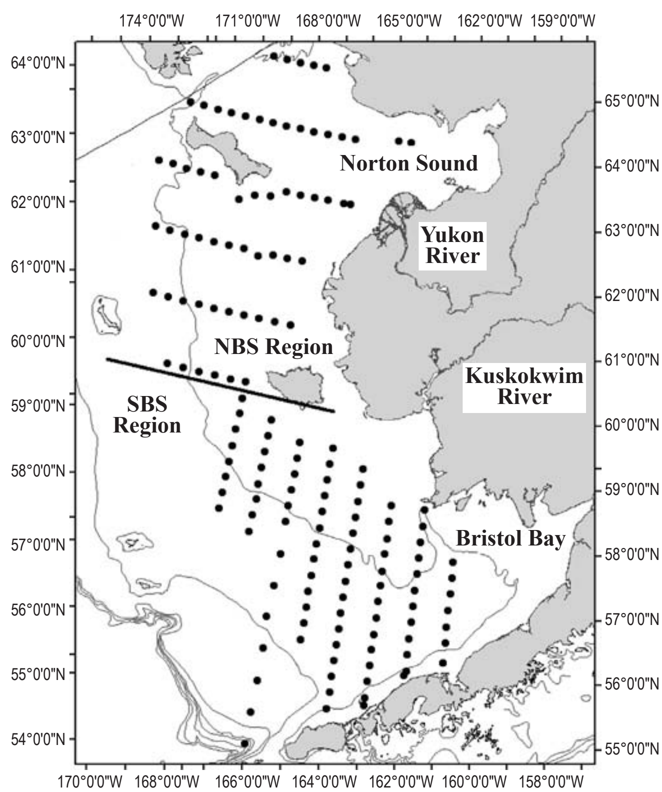



Figure 1. Station locations (●) sampled within the Northern Bering Sea (NBS, stations along 60°N and north) and Southern Bering Sea (SBS, stations south of 60°N) regions during the August–October 2002 BASIS research cruise.

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

specific migration routes for juvenile salmon (Figure 1). The southeastern Bering Sea (SBS) region was defined as the area south of lat 60°N (does not include catches made along 60°N) to the Alaska Peninsula, and the area west of long 161°W to 168°W. The northeastern Bering Sea (NBS) region was defined as the area between lat 60°N (includes catches made along lat 60°N) and lat 65°N, and from the eastern shoreline of Alaska to long 173°W or the U.S.-Russian border. Sample times for these regions differ by nearly one month. The SBS region was sampled from 20 August through 18 September; whereas, the NBS region was sampled from 19 September through 7 October.

## Size and condition

Estimates of size [mean and standard deviation length (mm) and weight (g)] and condition were calculated as indices of health for juvenile salmon. A length-weight regression line,

$$\ln(W) = \alpha_{s,i} + \beta_{s,i}\ln(L) \quad (1)$$

where $L$ represents length (mm) of a fish, $W$ represents weight (g) of a fish, $s$ represents species ($s$ = pink (*O. gorbuscha*), chum, sockeye, coho (*O. kisutch*), and Chinook salmon) and $i$ represents age (juvenile sockeye salmon only, $i$ = 1 or 2) was fit to length and weight and age for each species and age group of salmon. Condition factor ($k$) was defined as the ratio of the weight of each fish to its expected weight based on the length-weight regression for each species (Perry et al. 1996). Differences in mean condition factor by species between regions were tested using a standard 2 sample $t$-test.

## Size, distance, and Julian date relationships

Size, distance, and date relationships were tested using Generalized Additive Models (GAM). The power of the GAMs is their ability to include non-parametric smooth terms in the relationship between the response and predictor variables. Smooth terms are particularly useful when modeling spatial data where parametric relationships between the response variable and space do not necessarily exist. Three variables: distance from shore (north shore, south shore, or east shore), distance from river mouth, and Julian date, were included in GAM models of juvenile salmon length. Distance variables were fit to the length data to capture the spatial distribution in juvenile salmon length using a non-parametric spline smoother with the equivalent of four degrees of freedom (see Chambers and Hastie (1992) for details). Julian date was included in the GAM model to account for growth during the course of the survey. Growth during the survey was assumed to be linear, therefore the Julian date was assumed to be linearly related to fish length. Due to the confounding effects of time and distance, it is unlikely that the relationship between time and length represents the actual growth rate. However, when a significant positive relationship existed between fish length and time, the Julian date term was included in the model to ensure that spatial patterns in length were not the result of growth during the survey. Initial fits were obtained through ordinary least squares and the parametric fits were then replaced with smoothed, non-parametric fits of the partial residuals for each term. The final fit to the data was obtained through iteratively reweighted least squares by iteratively computing and smoothing the residuals for each distance term until convergence.

We chose to limit our GAM relationships to areas that contained sufficient sample sizes of juvenile salmon which may reflect stock-specific migration corridors. For juvenile chum and Chinook salmon, we analyzed relationships for salmon possibly leaving the Kuskokwim (juvenile chum salmon caught north of lat 58°N in the SBS region) and Yukon rivers (juvenile salmon caught between lat 60°N and 63°N in the NBS region). For juvenile sockeye salmon, we analyzed distance relationships for juvenile sockeye salmon caught in the SBS region that were likely from Bristol Bay lake systems. Juvenile pink salmon caught in the NBS region between lat 60°N and 63°N and juvenile coho salmon in the SBS region north of lat 58°N were also included in the distance analyses. We used lat 59.30°N, long 162.30°W and lat 63.00°N, long 165.00°W for Kuskokwim and Yukon river locations in models of river distance and length for juvenile chum, pink, coho, and Chinook salmon, and lat 57.30°N, long 160.00°W for the Bristol Bay location in the models for juvenile sockeye salmon. Distances from shore were defined as distance south from the lat 60°N transect for chum, Chinook, and coho salmon distributed west of long 162°W within the SBS region, and north of the Alaska Peninsula for sockeye salmon distributed within this region. Distance from shore for chum, pink, and Chinook salmon located within the NBS region was defined as the distance west from the eastern shoreline. Initial results were similar for both length and weight; therefore, we use length to summarize results for relationships with distance from shore and river.

## RESULTS

### Survey

During the survey, 152 trawl stations were sampled beginning at the southern end of long 161ºW and ending on the western end of lat 65ºN (Figure 1). A total of 10,629 Pacific salmon were captured including juvenile pink (5.9%), chum (43.4%), sockeye (42.6%), coho (*O. kisutch*; 3.8%), and Chinook (3.0%) salmon; less than 2% of the catch consisted of older immature and mature chum, sockeye, and Chinook salmon. Approximately 570,000 other marine fish were captured during the survey. These included (in order of highest to lowest catch) young-of-the-year (YOY) walleye pollock (*Theragra chalcogramma*–73.8%); juvenile and adult Pacific herring (*Clupea pallasi*–18.5%); rainbow smelt (*Osmerus mordax*–2%); YOY Pacific cod (*Gadus macrocephalus*–2%); Pacific sandfish (*Trichodon trichodon*–2%); larval, juvenile, and adult Pacific sand lance (*Ammodytes hexapterus*–2%); and less than 1% of the following; crested sculpin (*Blepsias bilobus*); sturgeon poacher (*Podothecus acipenserinus*); Bering wolffish (*Anarhichas orientalis*); larval, juvenile, and adult capelin (*Mallotus villosus*); juvenile prowfish (*Zaprora silenus*); northern rock sole (*Lepidopsetta peracuata*); lamprey (Petromyzontidae); sablefish (*Anoplopoma fimbria*); juvenile Atka mackerel (*Pleurogrammus monopterygius*); starry flounder (*Platichthys stellatus*); rock greenling (*Hexagrammos lagocephalus*); salmon shark (*Lamna ditropis*); and YOY saffron cod (*Eleginus gracilis*).

### Size and condition

The average length, weight, condition factor, and regression results for juvenile salmon by region is summarized in Table 1. Weight of all juvenile salmon species was significantly related to length ($P < 0.001$). Condition factor was not significantly different (*t*-test, $P > 0.8$) between regions for juvenile chum and Chinook salmon and not significantly different (*t*-test, $P > 0.8$) between ages for juvenile sockeye salmon. Condition factor was significantly different (*t*-test, $P < 0.01$) for juvenile pink salmon, with fish in the northern region in higher condition factor.

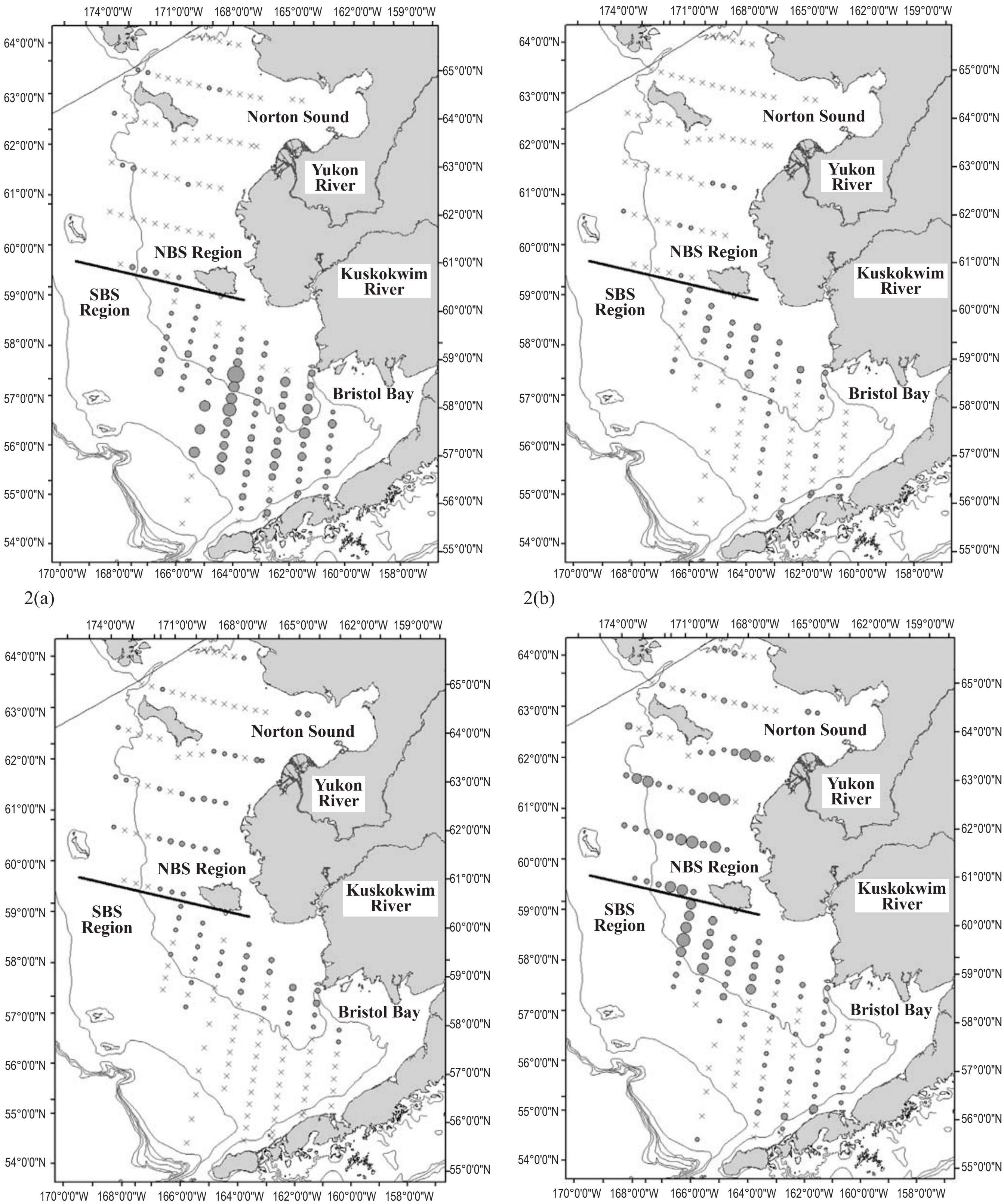
### Distribution of juvenile salmon

Juvenile sockeye salmon were widely distributed along transects within the SBS region (Bristol Bay area), with the highest catch rates occurring north of lat 57°N along the long 165°W transect (Figure 2a). Very few juvenile sockeye salmon were located in the NBS region, with the largest catch rates occurring along the lat 60°N transect. Age analysis for juvenile sockeye salmon indicated that 58% were age-1.0 and 42% were age-2.0. Both age-1.0 and -2.0 juvenile sockeye salmon were found along all transects in the SBS region; however, the percentage of age-1.0 sockeye salmon was higher along transects east of long 164°W (Figure 3).

In contrast to the offshore distribution of sockeye salmon, juvenile coho and Chinook salmon were mainly distributed nearshore (Figures 2b and c). The

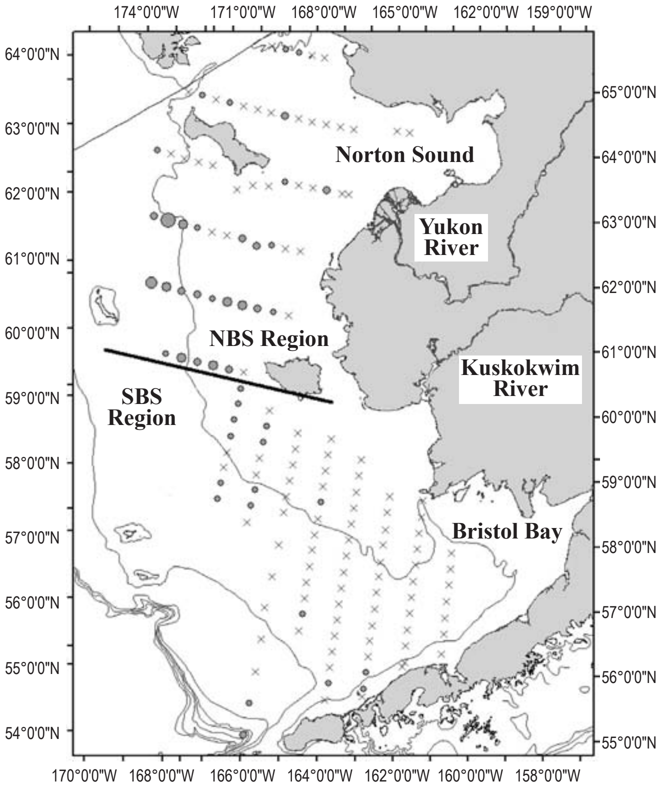
Table 1. Number sampled (*n*), average (Avg) and standard deviation (SD) of length (mm), weight (g), condition factor by region, and regression results for juvenile salmon weight versus length for juvenile pink, chum, sockeye (age 1.0 and 2.0), coho, and chinook salmon collected in the northern Bering Sea (NBS) and southern Bering Sea (SBS) regions during the BASIS research cruise, 20 August–7 October, 2002. Coefficients are for the model $\log_e W=\alpha+\beta\log_e L$, where $W$ and $L$ are the weight (g) and length (mm) of a species, and $R^2$ is the proportion of variance explained by the regression. The probability value ($P$) for the regression was <0.001 for all models. Dash (-) indicates no salmon caught.

| Region | Species | | Length (mm) | | Weight (g) | | Condition | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *n* | Avg | SD | Avg | SD | Avg | SD | $R^2$ | $\alpha_0$ | $\beta$ |
| NBS | Pink | 390 | 215.8 | 15.5 | 101.8 | 23.9 | 0.999 | 0.065 | 0.93 | -13.0 | 3.27 |
| | Chum | 1,095 | 205.3 | 15.1 | 92.9 | 21.9 | 1.002 | 0.062 | 0.94 | -12.8 | 3.25 |
| | Sockeye | | | | | | | | | | |
| | Age 1.0 | - | - | - | - | - | - | - | - | - | - |
| | Age 2.0 | - | - | - | - | - | - | - | - | - | - |
| | Coho | - | - | - | - | - | - | - | - | - | - |
| | Chinook | 105 | 227.2 | 33.2 | 153.0 | 58.4 | 1.002 | 0.064 | 0.99 | -12.9 | 3.29 |
| SBS | Pink | 44 | 188.8 | 31.0 | 66.8 | 32.5 | 0.947 | 0.107 | 0.95 | -12.7 | 3.20 |
| | Chum | 1,046 | 184.6 | 21.4 | 69.2 | 25.1 | 1.003 | 0.072 | 0.96 | -12.3 | 3.16 |
| | Sockeye | | | | | | | | | | |
| | Age 1.0 | 1,276 | 188.4 | 29.0 | 75.6 | 37.8 | 1.003 | 0.072 | 0.98 | -12.8 | 3.26 |
| | Age 2.0 | 620 | 214.1 | 37.1 | 115.9 | 54.4 | 1.002 | 0.065 | 0.99 | -12.6 | 3.23 |
| | Coho | 228 | 291.5 | 25.7 | 326.3 | 84.2 | 1.002 | 0.061 | 0.96 | -12.0 | 3.14 |
| | Chinook | 193 | 208.3 | 26.8 | 122.2 | 61.3 | 1.002 | 0.059 | 0.97 | -11.1 | 2.97 |




2(a) 2(b) 2(c) 2(d)

Figure 2. Distribution [shown by graduated symbol of catch per unit effort (CPUE)] of juvenile (a) sockeye, (b) coho, (c) Chinook, (d) chum, (e) and pink salmon collected during the 20 August–7 October, 2002 BASIS research cruise (x = 0, maximum CPUE, ●, = 1,001–1,250).



2(e)

highest catch rates of juvenile coho salmon within the SBS region occurred north of lat 58°N and along the Alaska Peninsula west of the Kuskokwim River. Juvenile coho salmon were sparsely scattered throughout the NBS region, with highest catch rates occurring nearshore along the lat 62°N transect and further offshore along the lat 61°N and 60°N transects. Juvenile Chinook salmon were mainly distributed north of lat 58°N in the SBS region with the largest catch rates occurring nearshore along the northern end of the long 163°W and 162°W transects. Juvenile Chinook salmon were widely scattered within the NBS region, with the largest catch rates occurring in Norton Sound. There were 3 coded-wire tag recoveries of juvenile Chinook salmon from the Yukon Territory, Whitehorse Rapids Salmon Hatchery, 2 within Norton Sound at lat 64.06°N, long 164.31°W station, and 1 offshore of the Yukon River at lat 63.00°N, long 165.58°W (Myers et al. 2003).

Juvenile chum salmon were mainly distributed north of lat 58°N within the SBS region directly west of the Kuskokwim River (Figure 2d). Several large catches also occurred along the Alaska Peninsula. The highest catch rates of juvenile chum salmon in the NBS region occurred offshore of the western Alaska shoreline south of the Yukon River. Catch rates declined farther offshore along each transect with the exception of the lat 62°N transect, where catch rates increased west of long 169.30°W.

Most of the juvenile pink salmon were distributed in the NBS region rather than the SBS region, with the highest catch rates occurring offshore, west of long168°W along the lat 60°N, 61°N, and 62°N transects (Figure 2e). Juvenile pink salmon were scattered throughout the SBS region, with highest catch rates occurring north of lat 58°N and along the Alaska Peninsula.

## GAM relationships

An Analysis of Variance *F*-test (Chambers and Hastie 1992) was used to compare models with and without Julian date. The addition of Julian date to the GAM models did not significantly improve the model fit ($P > 0.05$) for juvenile salmon in the SBS and NBS regions with the exception of age-1.0 juvenile sockeye salmon in the SBS region (Table 2). Convergence was not possible for the model for Chinook salmon in the NBS region with the addition of Julian date. These results indicate that juvenile salmon growth during the survey did not significantly contribute to the spatial patterns in the size of juvenile salmon. Therefore, seaward migration pathways were developed using size and distance relationships; however, Julian date was left in the model fit for age-1.0 juvenile sockeye salmon in the SBS region to account for growth during the survey.

## Seaward migration pathways

In general, length of juvenile salmon increased with the distance from freshwater rearing locations (Figures 4a–e; 5a–c). The length of juvenile age-1.0 and -2.0 sockeye salmon increased with distance from river mouth and displayed a bell shaped curve offshore from the southern shoreline of the SBS region, with the largest fish distributed within middle Bristol Bay and the smallest fish along the southern and northern shorelines (Figures 4a and b). Juvenile chum, coho, and Chinook salmon length within the SBS region increased with distance from the Kuskokwim River mouth. However, only chum and coho salmon length increased from the northern shoreline; whereas juvenile Chinook salmon length displayed more of a bell shaped curve with lengths increasing from nearshore to 100 km offshore, then decreasing thereafter (Figures 4c, d, and e). The length of juvenile chum and Chinook salmon within the NBS region increased with distance from shore, but appeared to have a bimodal pattern with distance from the Yukon River mouth (Figures

5a and b). In contrast, juvenile pink salmon size in the NBS region generally increased with distance from the Yukon River, but appeared bimodal with distance from the eastern shoreline (Figure 5c).

The above size distributions for juvenile salmon along the eastern Bering Sea shelf suggest the following seaward migration pathways (Figure 6). Upon leaving freshwater lake systems around Bristol Bay, juvenile sockeye salmon migrate west along the northern and southern sides of Bristol Bay, moving offshore and away from their freshwater rearing habitats as they grow. Juvenile chum and coho salmon migrate westward along the northern end of the SBS region (south of lat 60°N) upon entering the eastern Bering Sea from the Kuskokwim River, gradually moving offshore (southwest) as they grow. Juvenile Chinook salmon from the Kuskokwim River also appear to migrate westward along the northern end of the SBS region; however, the decreasing size with distance from the northern shoreline suggests the presence of other stocks farther offshore. Juvenile chum and Chinook salmon from the Yukon River migrate southwesterly. The presence of 2 coded wire tag juvenile Whitehorse Rapids Salmon Hatchery Chinook salmon caught within Norton Sound also suggests that some juvenile Chinook salmon from the Yukon River migrate north into Norton Sound. The bimodal offshore distribution for juvenile pink salmon, particularly along the lat 62°N transect (Figure 2e), and bimodal length with distance from shore (Figure 5c) suggests mixed stock distributions of juvenile pink salmon south of lat 63°N. A general southwesterly migration pathway along the NBS shelf appears plausible, with either the presence of separate stocks of juvenile pink salmon from western Alaska or a mixture of western Alaska stocks nearshore and Russian stocks (southeasterly migration) offshore.

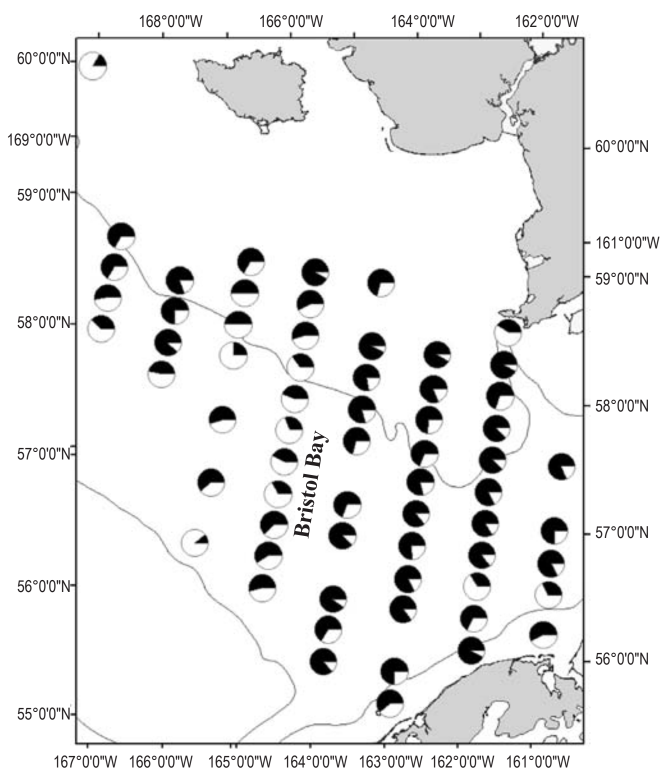



Figure 3. Distribution and percent composition of age-1.0 (dark) and age-2.0 (clear) juvenile sockeye salmon collected in the southeastern Bering Sea (SBS) region during the 20 August–7 October, 2002 BASIS research cruise.

Table 2. The Analysis of Variance *F*-statistic and the probability (*P*) of *F* used to indicate whether the addition of Julian date significantly improves the model fit over the models of size and distance.

| Region | Species | *F* | *P* |
|---|---|---|---|
| NBS | Pink | 1.11 | 0.29 |
| | Chum | 2.43 | 0.12 |
| | Chinook | Non-convergence | |
| SBS | Chum | 0.13 | 0.72 |
| | Sockeye Age-1.0 | 21.14 | 0.001 |
| | Sockeye Age-2.0 | 0.93 | 0.34 |
| | Coho | 3.60 | 0.06 |
| | Chinook | 0.14 | 0.71 |

## DISCUSSION

The first step toward understanding mechanisms associated with highly variable marine survival rates of Pacific salmon is to provide basic biological information during their most critical life history stages. This study presents the first examination of the large-scale distribution and migration patterns of juvenile salmon from a systematic survey along the eastern Bering Sea shelf during fall (August–October) 2002. Ocean conditions during the first months after juvenile salmon enter the ocean are known to significantly affect their survival (Holtby et al. 1990; Friedland et al. 1996; Beamish and Mahnken 2001; Beamish et al. 2004). Therefore, the distribution, migration, size, and condition information from our survey is important in that it provides the spatial scales over which to compare ocean conditions to these biological factors, thus linking juvenile salmon biology to factors that may affect their marine survival.

The size and condition of juvenile salmon captured during the fall survey indicated the western Alaska juvenile salmon were better fed than other Alaskan juvenile salmon available for comparison prior to winter. Juvenile pink, chum, sockeye, and coho salmon in the SBS region were, on average, 20–40 mm longer and

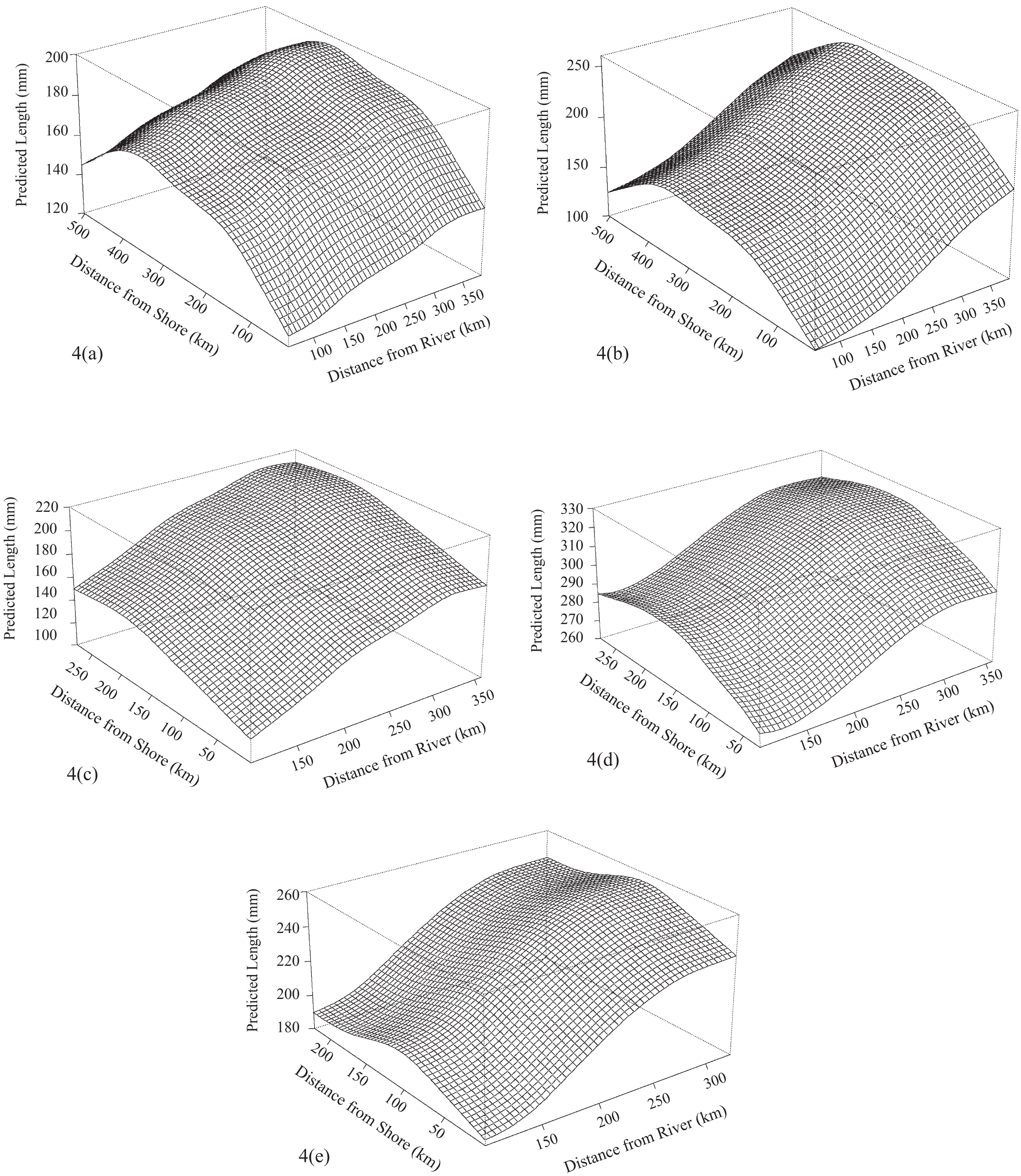



Figure 4. Predicted length (mm) versus distance from river and shore for juvenile (a) sockeye age 1.0, (b) sockeye age 2.0, (c) chum, (d) coho, and (e) Chinook salmon collected in the southern Bering Sea (SBS) region during the 20 August–7 October, 2002 BASIS research cruise. Locations for river distance include lat 57.30°N, long 160.00°W for juvenile sockeye salmon age-1.0 and -2.0 and lat 59.30°N, long 162.30°W (mouth of Kuskokwim River) for juvenile chum, coho, and Chinook salmon. Distances from shore were defined as distance (km) south of the lat 60°N transect to capture locations for chum, coho, and Chinook salmon and north of the Alaska Peninsula for age-1.0 and -2.0 juvenile sockeye salmon.

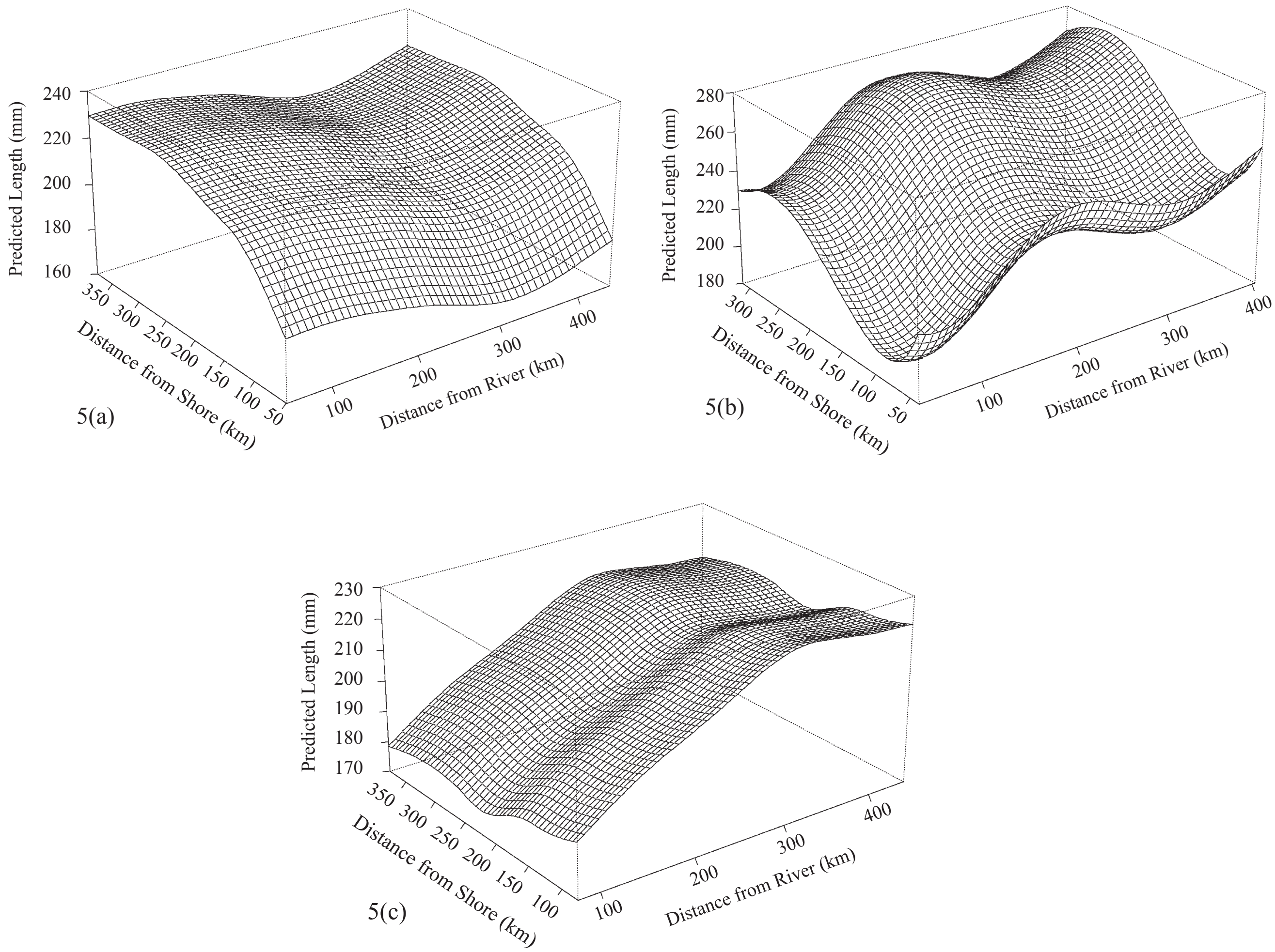



Figure 5. Predicted length (mm) versus distance from river and shore for juvenile (a) chum, (b) Chinook, and (c) pink salmon collected in the northern Bering Sea (NBS) region during the 20 August–7 October, 2002 BASIS research cruise. River distance was calculated as distance from lat 63.00°N, long 165.00°W (mouth of Yukon River) and distances from shore were defined as distance west from the eastern shoreline.

27–163 g heavier than those juvenile salmon caught in southeastern Alaska during late August 2002 (see Orsi et al. 2003 for details). Juvenile chum and pink salmon length and weight were comparable to those of juvenile age-1.0 sockeye salmon, suggesting that their early marine growth rates are greater than those of age-1.0 juvenile sockeye salmon that spent an additional year in a freshwater lake. Also, both age-1.0 and -2.0 juvenile sockeye salmon caught during 2002 in the SBS region were larger (average difference 15 mm and 50 mm, respectively) than those caught during previous OCC eastern Bering Sea research cruises (see Farley et al. 2000, 2001). Juvenile salmon that attain a larger size prior to winter will likely have a survival advantage (Beamish and Mahnken 2001; Beamish et al. 2004), thus, the large size of juvenile salmon observed during our 2002 survey is expected to result in higher over-winter marine survival.

Juvenile coho and Chinook salmon were distributed nearshore, but not found in the deeper, offshore waters. One possible explanation for the absence of juvenile coho and Chinook salmon within the deeper, offshore waters is that their vertical distribution increases as bottom depth increases, potentially making them unavailable to the surface trawl. Although we do not have data on the actual vertical distribution of juvenile salmon in our survey, we can infer some general patterns from other surveys. Juvenile coho and Chinook salmon can occur in water depths down to 50-m, but juvenile coho salmon maintain their highest densities in the upper 15-m of the water column (Beamish et al. 2000); whereas juvenile Chinook

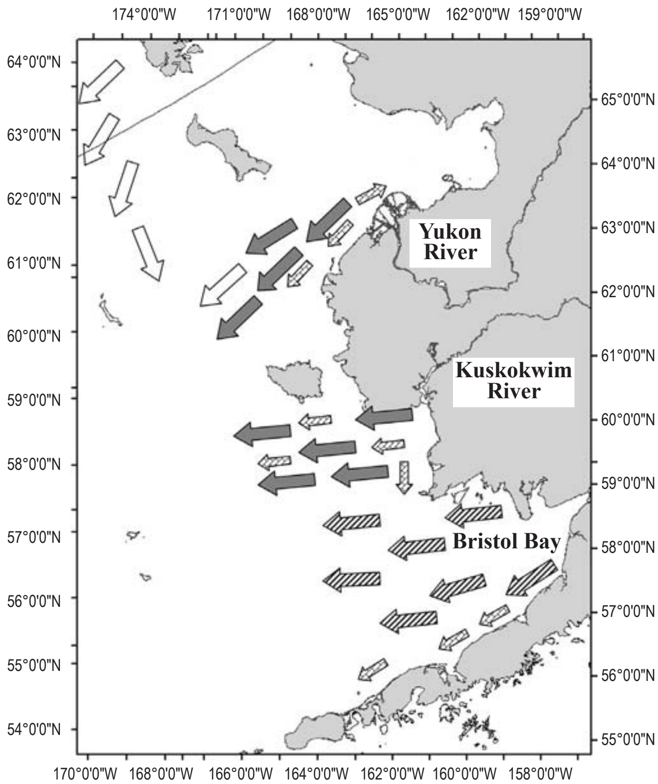



Figure 6. Seaward migration pathways for juvenile pink (clear arrow), chum (solid arrow), sockeye (slashed line arrow), coho, and Chinook (boxed line arrow) salmon along the eastern Bering Sea shelf during August through October 2002.

salmon are distributed deeper, but are still present in the upper 15-m of the water column (Orsi and Wertheimer 1995). Therefore, the absence of juvenile coho and Chinook salmon in deeper, offshore waters of our survey does not necessarily indicate a bias in our sampling gear but rather that they appear to prefer the nearshore, shallow locations.

Relationships between juvenile salmon size with distance from shore and distance from river help identify stock-specific migration routes in the eastern Bering Sea. Upon entering oceanic waters, juvenile salmon in the eastern Bering Sea generally remain nearshore (Straty 1974, Martin et al. 1986). Early marine growth for juvenile salmon is rapid, and those at the vanguard of ocean entry will have had more time to grow. Assuming migration distance and size are primarily a function of time spent at sea, the largest juvenile salmon from a point of ocean entry will be found farthest along the migration path.

We used GAM models to describe the relationship of size and distance, either from shore, or to river of possible freshwater origin, to investigate ocean migration pathways for juvenile salmon. The models in the SBS region suggest that juvenile sockeye salmon migrate west along the northern and southern sides of Bristol Bay upon leaving freshwater, offshore and away from their home streams. This finding contrasts to an earlier conceptual model that juvenile sockeye salmon from all Bristol Bay river systems migrate west in a narrow coastal band from nearshore to approximately 50 km along the coastal waters of the Alaska Peninsula (Straty 1974). Gradual offshore movement of juvenile sockeye salmon was speculated to occur west of Port Moller. Under the earlier model, the smallest juvenile sockeye salmon would occur near the southern coastline along the Alaska Peninsula, and the largest fish along the northern extent of their distribution.

The differences in juvenile sockeye salmon offshore distribution observed during the late 1960s, early 1970s, and during our survey have at least two possible explanations. First, juvenile sockeye salmon seek or aggregate in warmer sea surface temperatures to promote optimal migration, growth, and survival rates (Straty 1974). Mid-June to early July sea surface temperatures, particularly offshore within Bristol Bay, were cool during 1967–1971 (see Straty (1974) for examples). As a result, juvenile sockeye salmon may have avoided cold sea surface temperatures found offshore in Bristol Bay during the late 60s and early 70s, instead preferring the relatively warmer surface waters found nearshore along the Alaska Peninsula. The climate record for the Bering Sea indicates a warming trend since the late 1970s, particularly since 2000 (Overland and Stabeno 2004). The extensive offshore distribution of juvenile salmon during our survey may be the result of warmer offshore sea surface temperatures during early summer. This provides opportunities for rapid offshore migration of juvenile salmon, thus increasing the width and extent of their offshore distribution and potential forage opportunities during summer and fall.

Second, the nearshore preference of juvenile salmon observed during the earlier surveys may have been apparent rather than real due to the differences in fishing gear between the two surveys. A 200-fathom, small-mesh purse seine was used to define the seaward migration route of juvenile salmon (Straty 1974). Purse seines are effective at capturing juvenile salmon at sea (Hartt and Dell 1986); however, they are generally designed for nearshore sampling, can take a long time to deploy, and can only be fished in minimal wind and a relatively calm sea state (J. Orsi, National Marine Fisheries Service, Auke Bay Laboratory, Juneau, AK, personal communication). During the summer, the sea state in the eastern Bering Sea can often exceed 2-m, especially in offshore areas, limiting the use of purse seines in offshore sampling. On the other hand, rope trawls greatly enhance our ability to conduct intensive sampling of salmon in relatively short periods of time, even in moderately rough weather and poor sea conditions. The extensive coverage of our survey, particularly in offshore locations along the eastern Bering Sea shelf, and large catches of juvenile salmon are proof as to the effectiveness of rope trawls for salmon surveys.

The presence of a bell-shaped curve relationship between length of juvenile Chinook salmon and distance from the northern shoreline in the SBS region indicates the possibility of the presence of other Chinook salmon stocks. A possible explanation for the observed size of juvenile Chinook salmon and distance relationship in the SBS region is that the largest catch rates of juvenile Chinook salmon occurred along the northern end of the long 163°W transect. Smaller fish along these transects are likely the vanguard of juvenile Chinook salmon populations from Nushagak River. Alternatively, these fish may have recently entered marine waters from the Kuskokwim River and distributed themselves nearshore along Kuskokwim Bay.

The bimodal size patterns for juvenile chum and Chinook salmon also indicates mixed stocks in the NBS region. Fall Yukon juvenile chum salmon are larger and generally migrate to the ocean several weeks earlier than summer Yukon chum salmon (Martin et al. 1986). Earlier outmigration, larger size, and rapid movement away from the Yukon River by the fall Yukon stocks could account for the bimodal signature in the size and distance from Yukon River. Alternatively, the bimodal nature of size with distance from the Yukon River for juvenile Chinook may be explained by differences in peak outmigrations of juvenile Chinook from the Yukon River (Martin et al. 1986).

We suggested that the seaward migration pathway for juvenile Yukon River Chinook salmon is southwesterly along the western Alaska coastline. Three adipose fin-clipped juvenile Chinook salmon (brood year 2001) caught in Norton Sound and offshore of the Yukon River during October 2002, and another adipose fin clipped Chinook salmon (brood year 2001) caught at lat 56.44°N, long 167.00°W during February 2003, were from the Whitehorse Rapids Salmon Hatchery located in Yukon Territory, Canada, that releases Chinook salmon smolt into the Yukon River (Myers et al. 2003). The timing and locations of these adipose fin-clipped Chinook salmon indicate that juvenile Chinook salmon may initially migrate into Norton Sound upon leaving the Yukon River, eventually migrating south during late fall and winter.

The size and distribution of juvenile pink salmon in the NBS region also suggests the presence of mixed stocks. Pink salmon have a fixed 2-year life span, thus odd- and even-year stocks exist (Heard 1991). In western Alaska rivers, the even-year return is generally larger, but along the east coast of Russia, returns are generally strong for both even and odd years (Heard 1991). The largest catches of juvenile pink salmon occurred offshore in the NBS region. Based on pink salmon life history characteristics, bimodal offshore distribution, and size, we speculate that the juvenile pink salmon caught offshore in the NBS region are of Russian origin and those caught nearshore are of western Alaska origin.

Processes linking juvenile salmon survival to ocean conditions occur in the habitats the salmon encounter during their early marine life history. Along the eastern Bering Sea shelf, juvenile coho and Chinook salmon prefer nearshore habitats whereas juvenile sockeye prefer offshore habitats. These distributional differences may be linked to ocean conditions as well as preferred prey resources that maximize growth during early marine residency. Future analyses will link prey to the growth of juvenile salmon using bioenergetic models of growth rate potential.

## LITERATURE CITED

Beamish, R. J., and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Progress in Oceanography 49:423–437.

Beamish, R. J., C. Mahnken, and C. M. Neville. 2004. Evidence that reduced early marine growth is associated with lower marine survival of coho salmon. Transactions of the American Fisheries Society 133(1):26–33.

Beamish, R. J., D. McCaughran, J. R. King, R. M. Sweeting, and G. A. McFarlane. 2000. Estimating the abundance of juvenile coho salmon in the Strait of Georgia by means of surface trawls. North American Journal of Fisheries Management 20:369–375.

Brodeur, R. D., K. W. Myers, and J. H. Helle. 2003. Research conducted by the United States on the early ocean life history of Pacific salmon. Pages 89–131 *in* P. Symons, editor. A review of the research on the early marine period of Pacific salmon by Canada, Japan, Russia, and the United States. North Pacific Anadromous Fish Commission, Bulletin 3, Vancouver, Canada.

Chambers, J. M., and Hastie, T. J. 1991. Statistical Models in S. London. Chapman and Hall.

Clutter, R. I, and L. W. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. International Pacific Salmon Fisheries Commission Bulletin 9.

Farley, E. V., Jr., R. E. Haight, C. M. Guthrie, and J. E. Pohl. 2000. Eastern Bering Sea (Bristol Bay) coastal research on juvenile salmon, August 2000. Report to the North Pacific Anadromous Fish Commission. NPAFC Document 499. NPAFC, STE 502, 899 West Pender St. Vancouver, B.C., Canada, V6C 3B2.

Farley, E. V., Jr., C. M. Guthrie III, S. Katakura, and M. Koval. 2001. Eastern Bering Sea (Bristol Bay) coastal research (August and September 2001) on juvenile salmon. Report to the North Pacific Anadromous Fish Commission. NPAFC Document 560. NPAFC, STE 502, 899 West Pender St. Vancouver, B.C., Canada, V6C 3B2.

Farley, E. V., Jr. B. Wing, A. Middleton, J. Pohl, L. Hulbert, J. Moss, M. Trudel, E. Parks, T. Hamilton, C. Lagoudakis, and D. McCallum. 2003. Eastern Bering Sea (BASIS) coastal research (August – October 2002) on juvenile salmon. Report to the North Pacific Anadromous Fish Commission. NPAFC Document 678. NPAFC, STE 502, 899 West Pender St. Vancouver, B.C., Canada, V6C 3B2.

Fisher, J. P., and W. G. Pearcy. 1988. Growth of juvenile coho salmon (*Oncorhynchus kisutch*) off Oregon and Washington, USA, in years of differing coastal upwelling. Canadian Journal of Fisheries and Aquatic Sciences 45:1036–1044.

Friedland, K. D., R. E. Haas, and T. F. Sheehan. 1996. Postsmolt growth, maturation, and survival of two stocks of Atlantic salmon. Fishery Bulletin 94:654–663.

Hartt, A. C., and M. B. Dell. 1986. Early oceanic migrations and growth of juvenile Pacific salmon and steelhead trout. International North Pacific Fisheries Commission Bulletin 46.

Hastie, T., and R. Tibshirani. 1995. Generalized Additive Models. Encyclopedia of Statistical Sciences.

Heard, W. R. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*). Pages 120–230 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver, Canada.

Holtby, L. B., B. C. Andersen, and R. K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 47:2181–2194.

Isakson, J. S., J. P. Houghton, D. E. Rogers, and S. S. Parker. 1986. Fish use of inshore habitats north of the Alaska Peninsula June–September 1984 and June–July 1985. Final Report, Outer Continental Shelf Environmental Assessment Program, Research Unit 659.

Martin, D. J., C. A. Simenstad, D. A. Milward, E. C. Volk, M. L. Stevenson, P. Nunes, M. Savoie, and R. A. Grotefendt. 1986. Distribution, seasonal abundance, and feeding dependencies of juvenile salmon and non-salmonid fishes in the Yukon River Delta. Final Report, Outer Continental Shelf Environmental Assessment Program, Research Unit 660, Dames & Moore, Seattle.

Murphy, J., N. Davis, O. Ivanov, M. Rohr, S. Elmajjati, and W. Barber. 2003. Cruise report of the 2002 F/V *Northwest Explorer* BASIS survey in the Bering Sea, September–October. Report to the North Pacific Anadromous Fish Commission. NPAFC Document 676 (Rev. 1). NPAFC, STE 502, 899 West Pender St. Vancouver, B.C., Canada, V6C 3B2.

Myers, K. W., A. G. Celewycz, and E. V. Farley, Jr. 2003. High seas salmonid coded-wire tag recovery data, 2003. Report to the North Pacific Anadromous Fish Commission. NPAFC Document 701. NPAFC, STE 502, 899 West Pender St. Vancouver, B.C., Canada, V6C 3B2.

Orsi, J. A., E. A. Fergusson, M. V. Sturdevant, B. L. Wing, W. R. Heard, A. C. Wertheimer, and D. G. Mortensen. 2003. Survey of juvenile salmon in the marine waters of southeastern Alaska, May–August 2002. Report to the North Pacific Anadromous Fish Commission. NPAFC Document 702. NPAFC, STE 502, 899 West Pender St. Vancouver, B.C., Canada, V6C 3B2.

Orsi, J. A., and A. C. Wertheimer. 1995. Marine vertical distribution of juvenile Chinook and coho salmon in southeastern Alaska. Transactions of the American Fisheries Society 124:159–169.

Overland, J. E., and P. J. Stabeno. 2004. Is the climate of the Bering Sea warming and affecting the ecosystem? EOS, Transactions, American Geophysical Union 85:309–312.

Perry, R. I., N. B. Hargreaves, B. J. Waddell, and D. L. Mackas. 1996. Spatial variations in feeding and condition of juvenile pink and chum salmon off Vancouver Island, British Columbia. Fisheries Oceanography 5:73–88.

Straty, R. R. 1974. Ecology and behavior of juvenile sockeye salmon (*Oncorhynchus nerka*) in Bristol Bay and the eastern Bering Sea. Pages 285–320 *in* D. W. Hood and E. J. Kelley, editors. Oceanography of the Bering Sea with emphasis on renewable resources. Proceedings of the International Symposium on Bering Sea Study, Institute of Marine Sciences Occasional Publication 2, University of Alaska, Fairbanks.

Temnykh, O. S., A. N. Starovoytov, I. I. Glebov, G. V. Khen, A. Y. Efimkin, A. M. Slabinsky, and V. V. Sviridov. 2003. The results of trawling survey in the epipelagic layer of the Russian Economic Zone in the Bering Sea during September–October, 2002. Report to the North Pacific Anadromous Fish Commission, NPAFC Document 682. NPAFC, STE 502, 899 West Pender St. Vancouver, B.C., Canada, V6C 3B2.

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