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Stock-Specific Distribution of Juvenile Sockeye Salmon in the Eastern Gulf of Alaska

by

Marc Trudel[1], Jamal H. Moss[2], Strahan Tucker[1], John R. Candy[1], and Terry D. Beacham[1]

[1]Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC, Canada
V9T 6N7

[2]Auke Bay Laboratories
Ted Stevens Marine Research Institute
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
17109 Point Lena Loop Road
Juneau, Alaska 99801-8625, USA

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ABSTRACT

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Describing stock-specific migration behaviour is an important first step that is required to understand the effects of climate change and ocean conditions on the marine survival of Pacific salmon (*Oncorhynchus* spp.). In this study, we examined stock-specific distribution of juvenile sockeye salmon (*O. nerka*) in the Eastern Gulf of Alaska. Approximately 45% of the juvenile sockeye salmon analyzed in this study were caught beyond the 1,000 m isobath. DNA analyses revealed that the spatial distribution of juvenile sockeye salmon differed among stocks. A significant positive relationship between station depth and sockeye salmon size was observed only for Fraser River sockeye salmon. However, this relationship was weak, indicating that offshore movement of juvenile sockeye salmon was not strongly influenced by body size. These results suggest that juvenile sockeye may be leaving the continental shelf earlier than previously believed and further east than the Aleutian Islands.

INTRODUCTION

Fraser River sockeye salmon represents one of the most lucrative fishery in British Columbia. However, this fishery was closed from 2007 to 2009 as adult returns were much lower than was predicted by the stock-recruitment models currently used by Fisheries and Oceans Canada (DFO) to manage this fishery. The poor returns observed during these years represent a continuation of long-term decline that started in the early 1990's for most Fraser River sockeye salmon stocks (Peterman and Dorner 2011). Interestingly, Fraser River sockeye experienced in 2010 the highest return on record in nearly 100 years immediately following the worst adult return in 2009.

Although the exact causes of these declines are unknown, the parallel decline observed in adult return and the marine survival of Chilko Lake sockeye salmon, the only indicator stock for which freshwater and marine survival can be partitioned in this system, suggests that these declines are due, at least in part, to changes in the marine environment (Marmorek et al. 2011; Thomson et al., submitted). Furthermore, Barkley Sound and Columbia River sockeye salmon, two stocks that have different ocean entry points from Fraser and migrate directly into the Northern California Current System, experienced a similar decline to Fraser River during the last two decades (Peterman and Dorner 2011). However, their returns were respectively near and well above the long-term average in 2009, suggesting that divergent stock-specific migration behaviour may affect their survival.

In order to understand the effects of ocean conditions on the marine survival of Pacific salmon, we must first determine where they migrate to in the ocean, how much time they spend in these areas, and then determine the ocean conditions they encounter (Trudel et al. 2009; Tucker et al. 2009, 2011). On the continental shelf of the west coast of North America, juvenile sockeye salmon generally undertake a rapid northwestward migration (Hartt and Dell 1986; Tucker et al. 2009) and are believed to exit the continental shelf late in the summer or fall near the Aleutians (Welch et al. 2002). However, surveys conducted by the Auke Bay Laboratories in the Eastern Gulf of Alsaka revealed the presence of aggregations of juvenile sockeye salmon well beyond the 500 m isobath (J. Moss, unpublished data), suggesting that sockeye may be leaving the continental shelf earlier than previously believed and further east than the Aleutian Islands. Here, we report the results on the DNA analyses performed on the juvenile sockeye salmon caught in these surveys to examine stock-specific distribution of these fish in the Eastern Gulf of Alaska.

METHODS

Fish collection

Juvenile salmon were collected on July 2nd-24th, 2010, aboard the chartered fishing vessel *F/V Northwest Explorer* as part of the Gulf of Alaska (GOA) Project, a broad-scale fisheries oceanographic survey in the GOA. A midwater rope trawl, Cantrawl model 400 made by Cantrawl Nets LTD of Richmond, BC, Canada, which has been standardized for NPAFC salmon ocean ecology studies. The Cantrawl 400 is a 198-m midwater rope trawl modified to fish at the water surface by stringing buoys along the headrope. The net has a mouth opening 55 m wide x 15 m deep and is comprised of hexagonal mesh wings in the body with a 1.2-cm mesh codend liner at the foot. Trawl catches were sorted by species and catch. Juvenile sockeye salmon were counted and measured (weight and fork length), and frozen immediately. Samples were then transported to the laboratory and thawed for calorimetry, food habits analysis, and removal of genetic tissues.

DNA extractions

DNA was extracted from the issue samples collected from juvenile sockeye salmon caught in the trawl net using the method described by Withler et al. (2000). Juvenile sockeye salmon were surveyed for microsatellite loci (MSL) as well as for a major histocompatibility complex (MHC) locus. Further details on the loci surveyed as well as the laboratory equipment used are outlined by Beacham et al. (2010).

Stock identification

Analyses of mixed-stock samples of juveniles were conducted with a Bayesian procedure (BAYES) as outlined by Pella and Masuda (2001). A modified version of the program was developed as a C-based program (cBAYES) and used in the analysis (Neaves et al. 2005). Approximately 240-population species-specific baseline comprised of approximately 50,000 individuals ranging from Bristol Bay to California was used in the estimation of stock composition for each individual fish (Tucker et al. 2009; Beacham et al. 2010). In the analysis, eight 200,000-iteration Monte Carlo Markov chains of estimated stock compositions were produced, with an uninformative prior where each chain was started with a randomly selected population set at 0.90 . Estimated stock compositions were considered to have converged when the shrink factor was less than 1.2 for the ten chains (Pella and Masuda 2001). The last 1,000 iterations from each of the ten chains were then combined, and the mean and standard deviations of estimated stock compositions determined. The model determined probablity of assignment to baseline populations which were then summed into regional groupings. Identification of individual fish to region of origin was determined as the one with the highest probability of assignment. Individual fish were left without an assigned region of origin if the highest probability of assignment was less than 50%.

RESULTS AND DISCUSSION

Stock proportion

DNA analyses were performed on 165 juvenile sockeye salmon. DNA was not successfully amplified on enough microstalite markers for accurate stock assignments in 4 juvenile sockeye salmon. In addition, two juvenile sockeye salmon were excluded, as the allocation probability to a specific region was below 50%. Hence, a total of 159 juvenile sockeye salmon were retained for the remaining analyses.

Most of the juvenile sockeye salmon caught in the Eastern Gulf of Alaska originated from the Fraser River (34%), followed by the Nass and Skeena Rivers (23%), and Southeast Alaska/transboundary stocks (18%) (Fig. 1). None of the remaining regions contributed more than 8% of the catch (Fig. 1).

Chilko Lake and Stellako River, both located in the Fraser River watershed, were the dominant stocks of the catch with 11% and 9%, respectively. Other large stocks included Fulton Late in the Skeena River (8%), Meziadin Creek in the Nass River (8%), Kynock Creek in the Fraser River watershed (6%), and Osoyoos Lake in the Columbia River (5%). Of special interest was the recovery of a single individual originating from Lake Sakinaw, a stock listed as endangered under the Committee on the Status of Endangered Wildlife in Canada (Irvine et al. 2005).

Within the Fraser River system, Chilko Lake, Stellako River, and Kynock Creek were the dominant stocks with 31%, 28%, and 19%, respectively. The remaining stocks were represented by Gates Creek (11%), Raft Creek (7%), and Weaver Creek (4%). In terms of run timing, this represents 19% early Stuart, 18% early summer runs, 59% summer runs, and 4% late run. The expected contribution of these runs based on escapment were 5% early Stuart, 16% early summer runs, 75% summer runs, and 3% late run (S. Grant, DFO, Annacis Island, British Columbia, Canada, personal communication), indicating that early Stuart was over-represented and summer runs were under-represented in these samples. This may indicate that different stocks of sockeye salmon within the Fraser River watershed are migrating at different rates along the continental shelf (Tucker et al. 2009).

Stock-specifc size and distribution

Overall, fish originating from stocks south of latitude 53ºN were larger than those originating further north (Fig. 2). Lake Washington sockeye were the largest at 208 mm, though sample size for this stock was small (n=5). The northern most stocks (i.e. Southeast Alaska and transboundary rivers) exhibited the smallest size at 137 mm. This suggests that fish originating from northern latitudes recently left inshore waters for the open waters of the continental shelf and Gulf of Alaska (Burgner 1991).

Approximately 45% of the juvenile sockeye salmon analyzed in this study had been caught beyond the 1,000 m isobath (Fig. 3). However, the spatial distribution of juvenile sockeye salmon differed among stocks (Fig. 3). In general, Columbia River sockeye salmon were caught along the 1,000 m isobath, whereas most Fraser River and Nass/Skeena River sockeye salmon were caught beyond the 1,000 m isobath (Fig. 3). Lake Washington and Barkley Sound sockeye salmon were either caught in shallow waters (<200 m) or deep waters (>1,500 m). The majority of the Transboudary/Southeast Alaska sockeye salmon were caught on the continental shelf near Icy Strait, futher indicating that they had recently left inshore waters (Fig. 3). A significant positive relationship between station depth and sockeye salmon size was observed only for Fraser River sockeye salmon (Table 1). However, this relationship was weak, indicating that offshore movement of juvenile sockeye salmon was not strongly influenced by body size.

CONCLUSIONS

The continental shelf off the west coast of North America is thought to represent a migration highway for juvenile salmon (Hartt and Dell 1986; Welch et al. 2002), though the point at which they exit this migratory corridor is unknown. Hartt and Dell (1986) speculated that juvenile salmon would leave the continental shelf sometime in the fall or winter, but could not identify when and where these fish migrated offshore. In contrast, Welch et al. (2002) argued that juvenile salmon remained on the continental shelf until these fish reached the Aleutians. This interpretation was based on the absence of juvenile salmon in trawl surveys conducted beyond the shelf break. However, results from the present study indicate that juvenile sockeye salmon from several stocks are located beyond the shelf break off Southeast Alaska as early as July, indicating that offshore movements occured earlier than previously assumed by Hartt and Dell (1986) and Welch et al. (2002). For the most part, this offshore movement appears to be independent of body size. The cues that juvenile salmon utilize to migrate offshore are currently unknown and warrrant further research but may be linked to the Sitka Eddy (Atwood et al. 2010).

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Table 1. Stock-specific Spearman rank correlation between station depth and sockeye salmon size.

Stock of origin	r	n	p
Transboundary/Southeast Alaska	0.20	29	0.30
Nass/Skeena River	-0.32	37	0.053*
Haida Gwaii	-0.29	6	0.58
Central Coast of British Columbia	-0.30	12	0.35
Fraser River	0.33	54	0.02
Barkley Sound	0.12	6	0.83
Lake Washington	0.90	5	0.08
Columbia River	0.02	8	0.95

*Kendall rank correlation and Pearson's correlation coefficients were not significant.

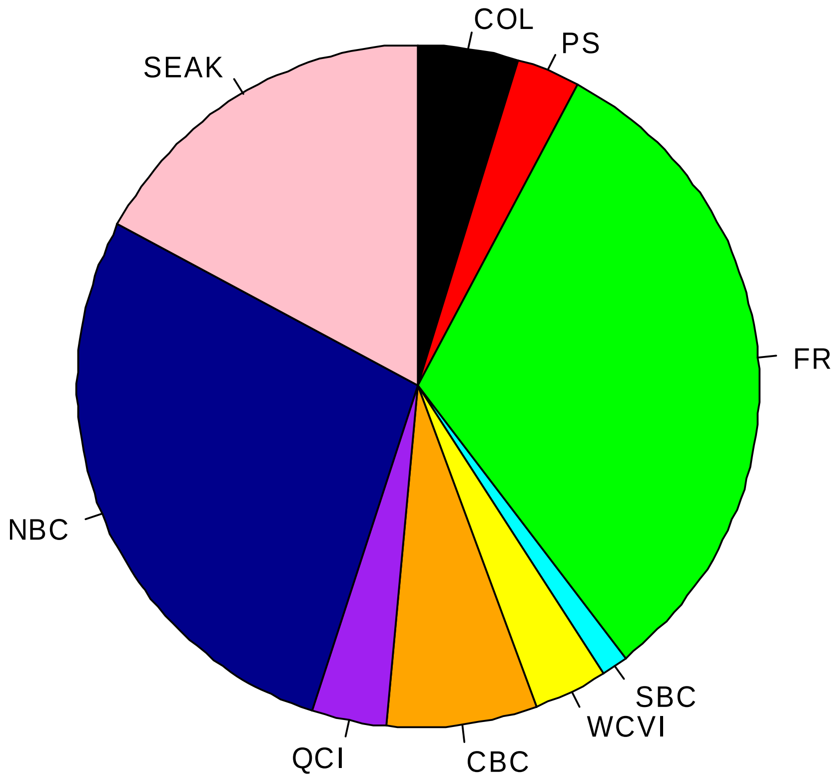

Figure 1. Stock composition of the juvenile sockeye salmon caught in the Eastern Gulf of Alaska on July 2-24, 2010. COL: Columbia River; PS: Lake Washington (Puget Sound); FR: Fraser River; SBC: British Columbia lower mainland; WCVI: Barkley Sound (West Coast of Vancouver Island); CBC: Central Coast of British Columbia; QCI: Haida Gwaii (formerly known as Queen Charlotte Islands); NBC: Nass/Skeena River; SEAK: Southeast Alaska/Transboundary.

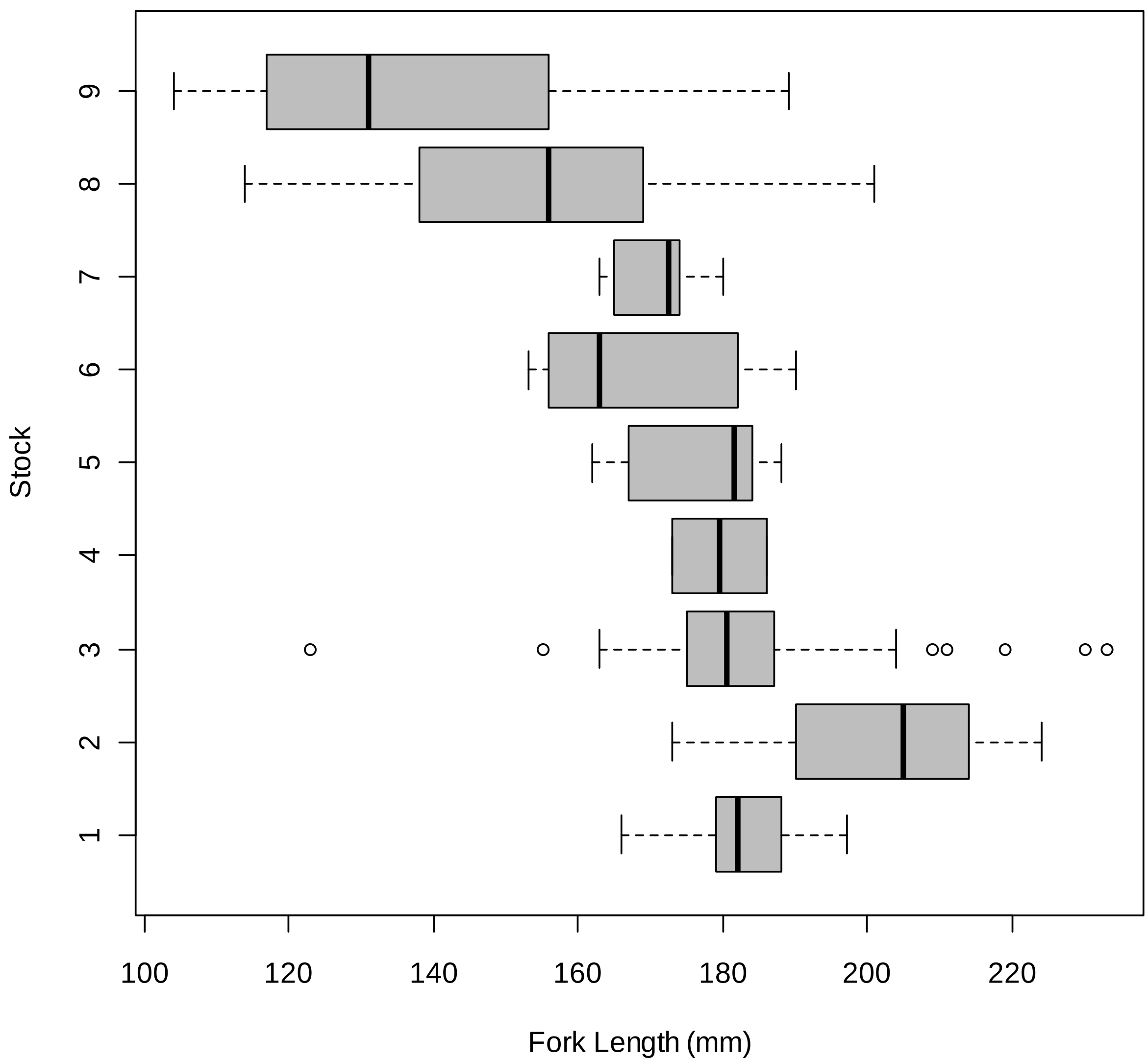

Figure 2. Boxplot of the fork length of juvenile sockeye caught in the Eastern Gulf of Alaska by region of origin. The regions are organized from south (bottom) to north (top). 1: Columbia River; 2: Lake Washington; 3: Fraser River; 4: British Columbia lower mainland; 5: Barkley Sound; 6: Central Coast of British Columbia; 7: Haida Gwaii; 8: Nass/Skeena River; 9: Southeast Alaska/Transboundary. Sample sizes for each region is reported in Table 1.

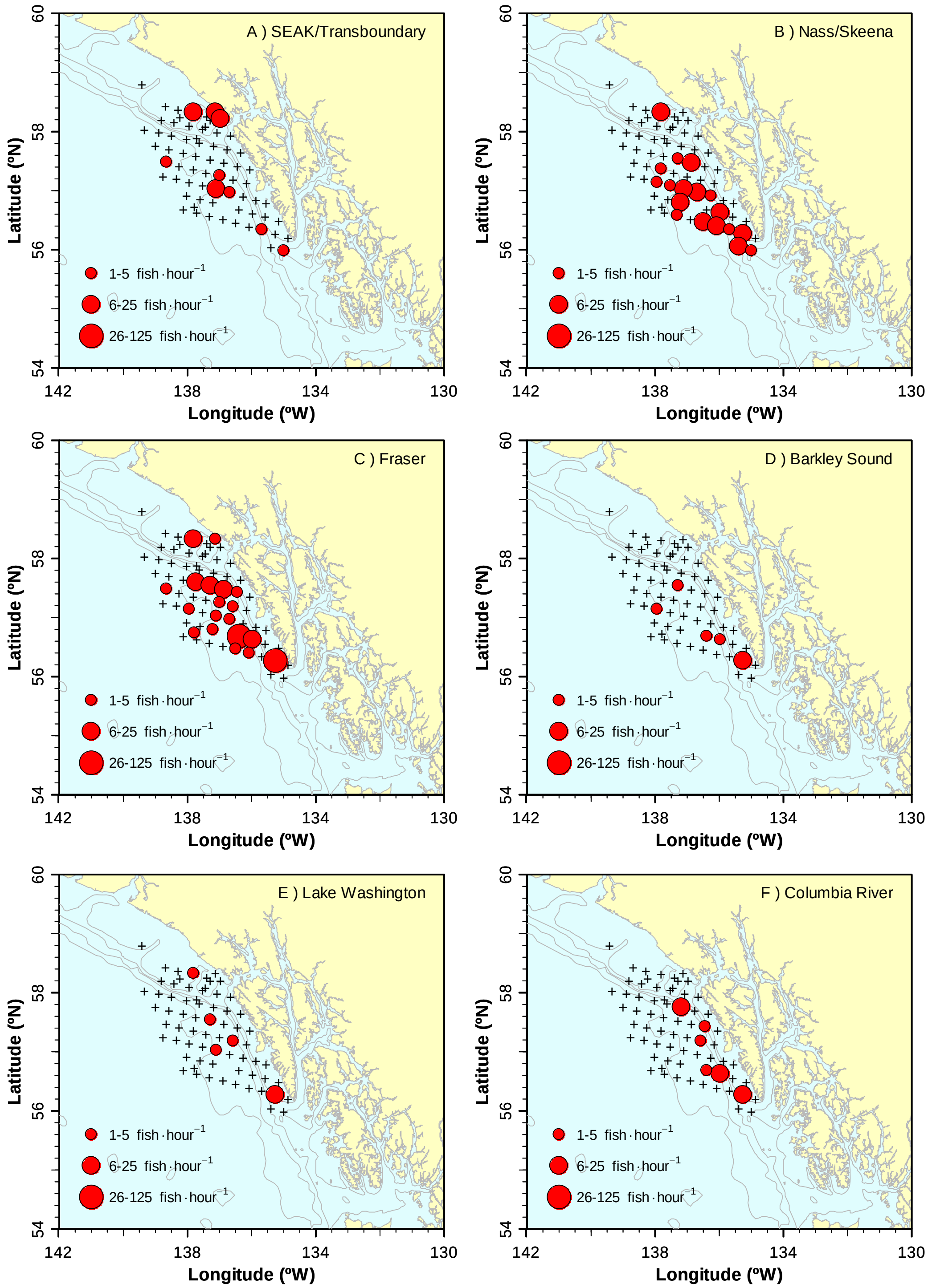

Figure 3. Stock-specific distribution of juvenile sockeye salmon in the Eastern Gulf of Alaska. Symbol size is proportional to catch-per-unit-effort. The contour lines represent the 200 m, 500 m, 1000m, and 2500 m isobath.