Spatial Variations in Early Marine Growth and Condition of Thermally Marked Juvenile Pink and Chum Salmon in the Coastal Waters of the Gulf of Alaska

Edward V. Farley, Jr. and **H. Richard Carlson†**
NOAA, NMFS, Alaska Fisheries Science Center, Auke Bay Laboratory,
11305 Glacier Hwy., Juneau, Alaska 99801-8626 USA

Farley, Jr., E.V., and H.R. Carlson. 2000. Spatial variations in early marine growth and condition of thermally marked juvenile pink and chum salmon in the coastal waters of the Gulf of Alaska. N. Pac. Anadr. Fish Comm. Bull. No. 2: 317–323.

Keywords: Salmon, ocean, condition, thermal-otolith-mark

Abstract: We examined spatial variations in early marine growth and condition factor of juvenile Prince William Sound hatchery pink (*Oncorhynchus gorbuscha*) and Southeast Alaska hatchery chum (*O. keta*) salmon collected in the coastal waters of the Gulf of Alaska (GOA) during July–August 1996. Mean lengths and weights of juvenile Prince William Sound hatchery pink salmon and Southeast Alaska hatchery chum salmon increased as fish migrated westward along the coast; the smallest individuals were found at Cape Spencer and Cape Puget which are near the exit corridors for juvenile chum salmon leaving inside waters of Southeast Alaska and juvenile pink salmon leaving inside waters of Prince William Sound. Condition factor was significantly lower for hatchery origin chum and pink salmon caught at Cape Spencer and Cape Puget, respectively, than at the next transect located further along the migratory pathway for these salmon.

INTRODUCTION

During 1995, scientists at the Auke Bay Laboratory, National Marine Fisheries Service, Ocean Carrying Capacity (OCC) program initiated a comprehensive study to describe the role and spatial distribution of salmon in the marine ecosystem, and to test for density dependence in the growth rate of Pacific salmon (*Oncorhynchus* spp.) during various periods of ocean residency (National Marine Fisheries Service 1995). One objective of this ongoing study is to collect and analyze otoliths from juvenile pink and chum salmon caught in the coastal waters of the Gulf of Alaska (GOA) and identify hatchery origin of these fish. Since the beginning of our study, recoveries of thermally marked pink (*O. gorbuscha*) and chum (*O. keta*) salmon at sea have provided unique information on stock-specific early marine migration, distribution, and growth of these salmon (Farley and Munk 1997, 1998; Farley et al. 1999)

In this paper, we summarize growth and condition factor of thermally marked pink and chum salmon caught in the coastal waters of the Gulf of Alaska during July and August 1996. We report new information on stock-specific size and condition factor patterns for juvenile pink and chum salmon from Prince William Sound and Southeast Alaska hatcheries, respectively, and briefly discuss the factors that may influence these patterns.

METHODS

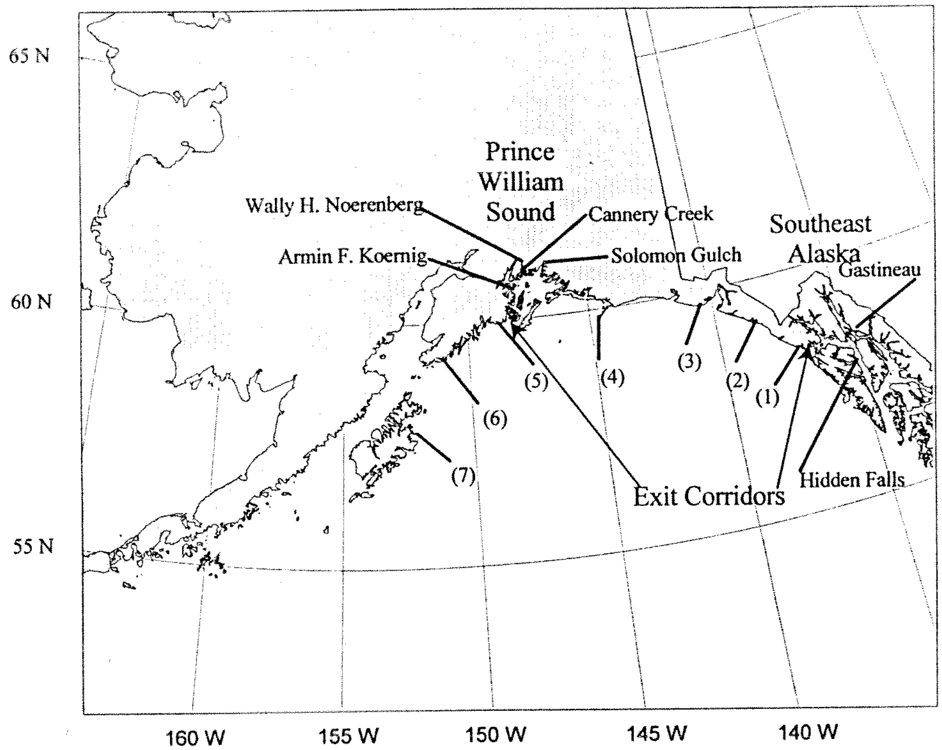
Juvenile pink and chum salmon captured during the July–August 1996 survey (See Carlson et al. this volume for details on sampling methods) were frozen whole and shipped to the laboratory for analysis. In the laboratory, juvenile salmon were thawed and standard length (measured from tip of snout to posterior end of caudal peduncle) and weight were recorded for subsamples of juvenile pink and chum salmon. Left and right sagittal otoliths were removed, and the left sagittal otoliths mounted, using thermal resin, on petrographic slides and then ground to expose the primordia. If left sagittal otoliths were not available or were overground, then the right sagittal otoliths were used.

Otolith microstructure was examined under a compound microscope, and the microstructure patterns were compared to thermal mark patterns from voucher specimens collected from the hatcheries before release. For this study we compared otolith thermal mark patterns from juvenile chum salmon caught during our survey to voucher specimens collected from Gastineau and Hidden Falls hatcheries located in Southeast Alaska (Fig. 1). Otolith thermal mark patterns from juvenile pink salmon caught during the summer survey were compared with voucher specimens collected from Armin F. Koernig, Cannery Creek, Solomon Gulch, and Wally H. Noerenberg

† deceased

All correspondence should be addressed to E.V. Farley, Jr.
e-mail: ed.farley@noaa.gov

Fig. 1. Transects sampled in the North Pacific Ocean during July–August 1996 by the Ocean Carrying Capacity program and locations of Southeast Alaska and Prince William Sound hatcheries. (1) Cape Spencer; (2) Cape Fairweather; (3) Ocean Cape; (4) Cape St. Elias; (5) Cape Puget; (6) Gore Point; (7) Cape Chiniak.



hatcheries located in Prince William Sound (Fig. 1). We will refer to each of these hatcheries as a separate 'stock' throughout the rest of the paper. All otoliths were read independently by a second reader to minimize reader error and provide confidence in readings (Hagen et al. 1995). When disagreements between otolith readers occurred, they were resolved by the most experienced reader.

Data included standard length (L, mm) and weight (W, g) for each hatchery pink and chum salmon stock. We tested for significant differences between length and weight of the four Prince William Sound (PWS) hatchery pink salmon stocks and two Southeast Alaska hatchery chum salmon stocks to determine whether these data could be pooled by species across hatchery stocks. Length and weight for both species were significantly different ($p < 0.01$) between hatchery stocks; therefore, these data were not pooled. A length-weight regression, $\ln(W_{i,j}) = \alpha_0 + \beta\ln(L_{i,j})$ where i represents species and j represents hatchery stock, was performed for each hatchery pink and chum salmon stock. A condition factor (K) was defined as the ratio of the weight of each fish to its expected weight based on the length-weight regressions for that hatchery (Perry et al. 1996). Juvenile pink and chum salmon characteristics (L, W, and K) were grouped by transect and differences in salmon characteristics were examined graphically using box-plots (Cleveland 1993). The Tukey-Kramer multiple comparison method (Kramer 1956) was used to calculate 95% confidence intervals (expressed as Lower Bound (L-Bound) and Upper Bound (U-Bound)) for all pairwise differences between fish characteristic (L, W, and K) means at each transect. Confidence intervals that exclude 0 suggest the pairwise difference was significant. Statistical analyses were conducted using the S-Plus 2000 statistical system (MathSoft, Inc. 1999).

RESULTS

Thermal Mark/Recoveries

Subsamples of otoliths from the total catch of juvenile pink and chum salmon were analyzed for hatchery thermal marks (see Farley and Munk 1997 for details). Transects sampled along the coastal GOA that contained sufficient numbers (≥ 10; but we did use one sample of 3) of thermally marked salmon for statistical analyses included Cape Puget, Gore Point, and Cape Chiniak for PWS hatchery pink salmon stocks and Cape Spencer, Cape Fairweather, Ocean Cape, and Cape St. Elias for Southeast Alaska hatchery chum salmon stocks (see Fig. 1 for transect locations). Numbers of thermally marked salmon by species, hatchery, and transect are given in Table 1.

Growth and Condition

Growth (length and weight) and condition factor of PWS hatchery pink and Southeast Alaska hatchery chum salmon stocks varied among transects (Figs. 2 and 3). Median size of pink and chum salmon increased from east to west along the coast starting at transects near exit corridors (Cape Spencer near Southeast Alaska and Cape Puget near PWS). In general, the multiple comparison procedure showed that differences in length and weight of each of the hatchery pink and chum salmon stocks between transects were significant ($p < 0.05$; Tables 2 and 3). The length-weight regression indicated that weights were significantly related to lengths for each hatchery pink and chum salmon stock (Table 4). The condition factor based on the ratio of actual Vs expected weight at length for each of the PWS hatchery pink and Southeast Alaska chum salmon stocks was significantly lower at transects near exit corridors (Cape Puget and Cape Spencer, respectively) than at the next transect further east along their migratory path (Tables 2 and 3).

Table 1. Number of thermally marked Prince William Sound hatchery pink salmon and Southeast Alaska hatchery chum salmon caught during July and August 1996 at each transect in the coastal waters of the Gulf of Alaska. (Prince William Sound hatcheries include: Armin F. Koerning (AFK), Cannery Creek (CC), Solomon Gulch (SG), and Wally H. Noerenberg (WHN); Southeast Alaska hatcheries include: Gastineau Hatchery (GH) and Hidden Falls (HF).)

	Hatchery					
	AFK	CC	SG	WHN	GH	HF
Pink Salmon						
Cape Puget	50	40	96	57		
Gore Point	80	33	154	86		
Cape Chiniak	17	3	38	17		
Totals	147	76	288	160		
Chum Salmon						
Cape Spencer					30	51
Cape Fairweather					10	24
Ocean Cape					96	48
Cape St. Elias					69	11
Total					205	134

Fig. 2. Box plots of juvenile chum salmon length, weight, and condition factor from Gastineau (GH) and Hidden Falls (HF) hatcheries. Transect numbers correspond to: 1—Cape Spencer; 2—Cape Fairweather; 3—Ocean Cape; and 4—Cape St. Elias. The line within the box represents the median, the upper and lower edges define the 75th and 25th percentiles (interquartile distance), the whiskers represent values that fall within 1.5 times the interquartile distance, and the separate lines represent outliers.

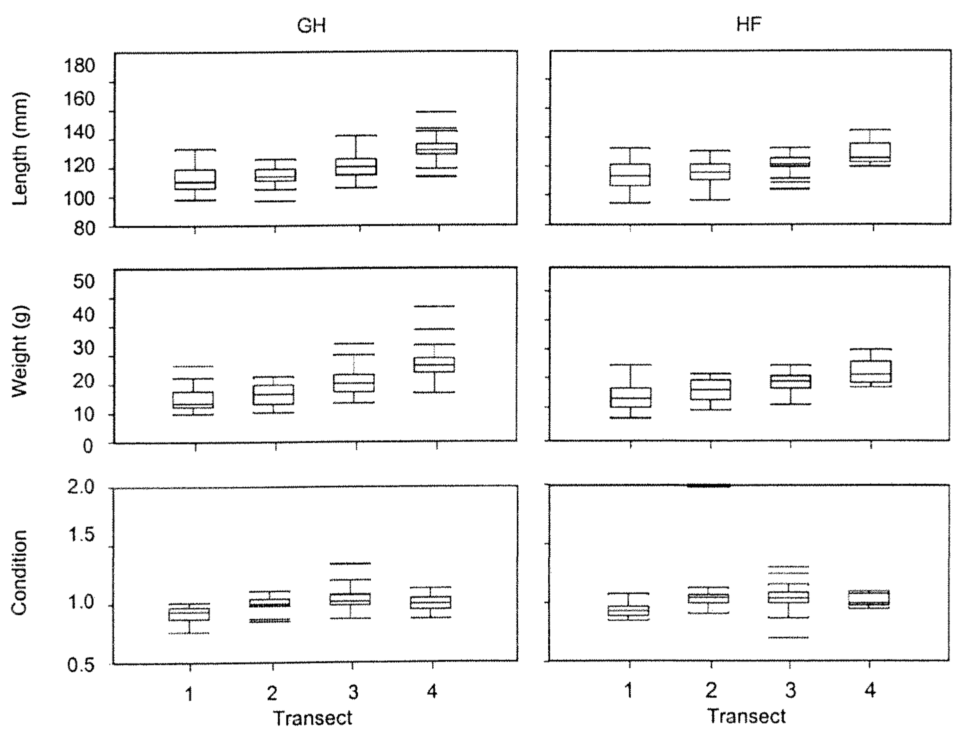


Fig. 3. Box plots of juvenile pink salmon length, weight, and condition factor from Armin F. Koernig (AFK), Cannery Creek (CC), Solomon Gulch (SG), and Wally H. Noerenberg (WHN) hatcheries. Transect numbers correspond to: 5—Cape Puget; 6—Gore Point; and 7—Cape Chiniak. The line within the box represents the median, the upper and lower edges define the 75th and 25th percentiles (interquartile distance), the whiskers represent values that fall within 1.5 times the interquartile distance, and the separate lines represent outliers.

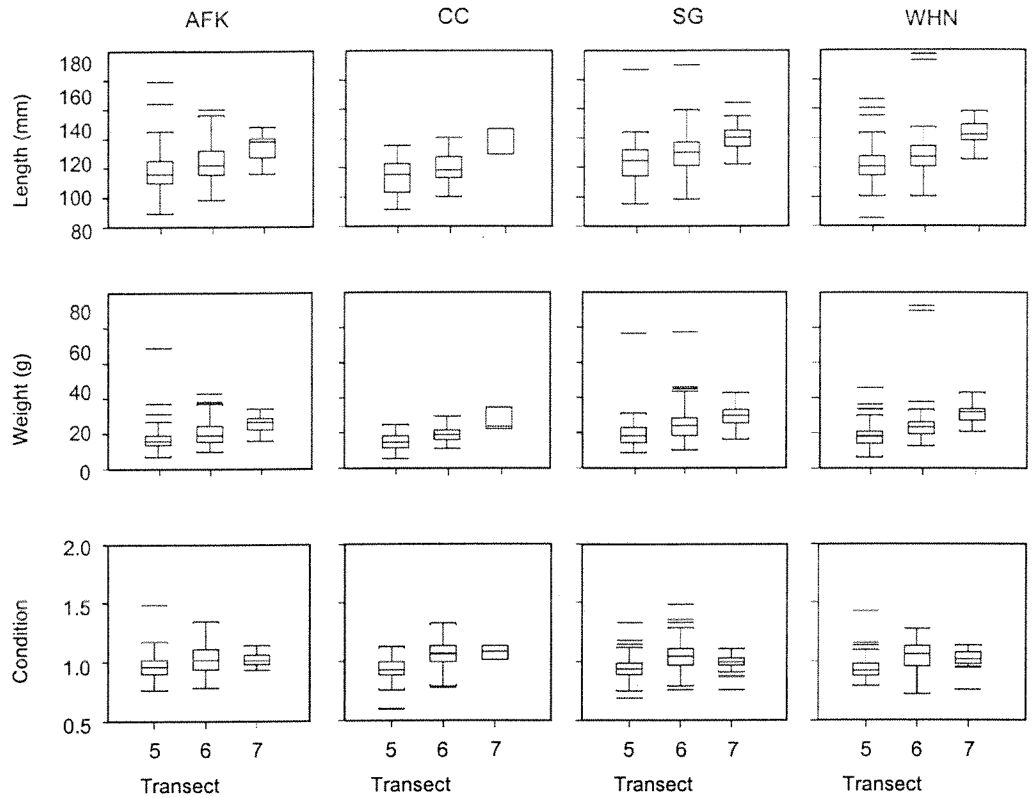


Table 2. Multiple comparison results for length, weight, and condition factor for Prince William Sound hatchery pink salmon caught during July and August 1996 in the coastal waters of the Gulf of Alaska by the OCC program with 95% simultaneous confidence intervals (Lower Bound—L-bound; Upper Bound—U-bound) for specified linear combinations, by the Tukey-Kramer method. (Confidence intervals that exclude 0 (**Bold**) indicate significant differences between transects).

	Armin F. Koernig		Cannery Creek		Solomon Gulch		Wally Noerenberg	
Transect	L-bound	U-bound	L-bound	U-bound	L-bound	U-bound	L-bound	U-bound
a. *Length*								
Cape Puget - Gore Point	-11.00	0.04	-11.90	0.86	**-9.31**	**-1.79**	**-12.00**	**-0.77**
Cape Puget - Cape Chiniak	**-24.80**	**-7.30**	**-37.00**	**-4.40**	**-22.40**	**-11.30**	**-29.70**	**-11.50**
Gore Point - Cape Chiniak	**-18.90**	**-2.16**	-31.60	1.26	**-16.50**	**-6.07**	**-22.90**	**-5.42**
b. *Weight*								
Cape Puget - Gore Point	**-6.60**	**-0.16**	**-6.67**	**-1.38**	**-7.58**	**-2.71**	**-9.46**	**-1.62**
Cape Puget - Cape Chiniak	**-14.00**	**-3.80**	**-18.50**	**-5.01**	**-14.00**	**-6.81**	**-19.00**	**-6.33**
Gore Point - Cape Chiniak	**-10.40**	**-0.63**	**-14.50**	**-0.94**	**-8.65**	**-1.86**	**-13.20**	**-1.05**
c. *Condition*								
Cape Puget - Gore Point	**-0.10**	**-0.01**	**-0.21**	**-0.01**	**-0.13**	**-0.07**	**-0.15**	**-0.06**
Cape Puget - Cape Chiniak	-0.13	0.02	-0.37	0.13	-0.09	0.00	**-0.15**	**0.00**
Gore Point - Cape Chiniak	-0.07	0.07	-0.27	0.24	**0.01**	**0.10**	-0.04	0.10

Table 3. Multiple comparison results for length, weight, and condition factor for Southeast Alaska hatchey chum salmon caught during July and August 1996 in the coastal waters of the Gulf of Alaska by the OCC program with 95% simultaneous confidence intervals (Lower Bound—L-bound; Upper Bound—U-bound) specified linear combinations, by the Tukey-Kramer method. (Confidence intervals that exclude 0 (**Bold**) indicate significant differences between transects).

	Gastineau Hatchery		Hidden Falls Hatchery	
Transect	L-bound	U-bound	L-bound	U-bound
a. *Length*				
Cape Spencer - Cape Fairweather	-8.52	6.18	-6.69	3.67
Cape Spencer - Ocean Cape	**-12.40**	**-3.96**	**-12.00**	**-3.55**
Cape Spencer - Cape St. Elias	**-23.90**	**-15.10**	**-21.90**	**-8.02**
Cape Fairweather - Ocean Cape	**-13.70**	**-0.32**	**-11.50**	**-1.02**
Cape Fairweather - Cape St. Elias	**-25.20**	**-11.50**	**-21.10**	**-5.85**
Ocean Cape - Cape St. Elias	**-14.50**	**-8.16**	**-14.20**	**-0.22**
b. *Weight*				
Cape Spencer - Cape Fairweather	-5.62	2.42	**-4.87**	**-0.17**
Cape Spencer - Ocean Cape	**-8.01**	**-3.40**	**-7.02**	**-3.19**
Cape Spencer - Cape St. Elias	**-13.90**	**-9.07**	**-11.80**	**-5.47**
Cape Fairweather - Ocean Cape	**-7.76**	**-0.45**	**-4.96**	**-0.21**
Cape Fairweather - Cape St. Elias	**-13.60**	**-6.15**	**-9.57**	**-2.65**
Ocean Cape - Cape St. Elias	**-7.51**	**-4.03**	**-6.69**	**-0.34**
c. *Condition*				
Cape Spencer - Cape Fairweather	**-0.14**	**-0.01**	**-0.21**	**-0.06**
Cape Spencer - Ocean Cape	**-0.16**	**-0.08**	**-0.16**	**-0.05**
Cape Spencer - Cape St. Elias	**-0.12**	**-0.04**	-0.17	0.02
Cape Fairweather - Ocean Cape	-0.10	0.02	-0.04	0.10
Cape Fairweather - Cape St. Elias	-0.07	0.06	-0.05	0.16
Ocean Cape - Cape St. Elias	**0.01**	**0.07**	-0.07	0.12

Table 4. Regression results for salmon weight versus length, for juvenile Prince William Sound hatchery pink salmon stocks and Southeast Alaska hatchery chum salmon stocks collected during July and August 1996 in the coastal waters of the Gulf of Alaska by the OCC program. Coefficients (*alpha*$_0$) and (*beta*) are from the regression model, *n* represents the number of data points, r^2 is the proportion of variance explained by the regression, and *p* represents the probability value for the regression.

Pink Salmon	*n*	r^2	*P*	α_0	β
Armin F. Koernig	147	0.91	< 0.001	-12.31	3.17
Cannery Creek	76	0.77	< 0.001	-10.31	2.75
Solomon Gulch	288	0.90	< 0.001	-12.68	3.25
Wally Noerenberg	160	0.89	< 0.001	-11.85	3.08
Chum Salmon					
Gastineau	205	0.92	< 0.001	-12.27	3.18
Hidden Falls	134	0.92	< 0.001	-12.25	3.18

DISCUSSION

Prince William Sound hatchery pink salmon stocks and Southeast Alaska chum salmon stocks caught along the coastal waters of the Gulf of Alaska during July and August 1996 displayed spatial variations in growth and condition factor. The smallest PWS hatchery juvenile pink salmon were caught at Cape Puget, while the smallest Southeast Alaska hatchery chum salmon were caught at Cape Spencer. Condition factor for each of the Southeast Alaska hatchery chum salmon and PWS hatchery pink salmon stocks was also significantly lower at these two transects than at the next transect located further along the migratory pathway for these salmon. This result may be related to reduced growth, feeding intensity, or survival of juvenile hatchery pink and chum salmon while entering the coastal GOA from inside waters.

Condition factor for fishes has been measured differently by different authors (Perry et al. 1996; Lambert and Dutil 1997). Lambert and Dutil (1997) measured condition factor using somatic weight (total weight of fish less stomach and gonad weights) instead of total weight of each fish, since feeding intensity and gonad maturation can vary significantly and independently of condition within and between stocks. The condition factor used in our study was measured as the ratio of actual weight to expected weight based on the length-weight regressions for each hatchery stock (similar to Perry et al. 1996). The hatchery pink and chum salmon captured during our survey were juveniles, thus differences in gonad weight of individuals could be considered negligible; however, differences in stomach content weights could vary significantly between transects and hatchery stocks. Juvenile pink and chum salmon captured at Cape Puget and Cape Spencer had less food in their stomachs than those fish captured at transects further along the coast (Mary Auburn-Cook, National Marine Fisheries Service, Auke Bay Laboratory, Juneau, AK 99801, personal communication) suggesting that the lower condition factor in our study may be related to feeding intensity.

Feeding intensity of juvenile hatchery pink and chum salmon captured during our survey may be impacted by differences in size and/or species of zooplankton along the coastal GOA. Zooplankton data collected during NMFS Marine Salmon Investigation surveys in inside waters of northern Southeast Alaska (Icy Strait) and in the coastal waters of the GOA near Cape Spencer during July indicated that zooplankton found in inside waters were generally smaller and in some instances of different species than zooplankton in the coastal waters (Joe Orsi, National Marine Fisheries Service, Auke Bay Laboratory, Juneau Alaska 99801, personal communication). As mentioned earlier, Cape Spencer as well as Cape Puget are located near exit corridors for juvenile salmon leaving inside waters of Southeast Alaska and Prince William Sound, respectively. The significantly lower condition factor for juvenile salmon at Cape Spencer, and perhaps Cape Puget may indicate a period of adjustment for juvenile salmon leaving inside waters and entering the oceanic waters of the GOA before they can actively feed on larger and different prey items found in the oceanic waters of the GOA.

Feeding intensity of PWS and Southeast Alaska hatchery pink and chum salmon stocks entering the coastal waters of the GOA may also be related to their hatchery origins. Condition factor was positively related to stomach fullness for juvenile chum salmon captured off the coastal waters of northern Vancouver Island, B.C. during early summer 1992 but negatively related to stomach fullness for those captured off of southern Vancouver Island, B.C. (Perry et al. 1996). The authors speculated that juvenile chum salmon captured on the southern end of Vancouver Island during their survey were most likely from the Nitinat hatchery which had released approximately 40 million chum salmon into the ocean during spring 1992. Pink salmon caught in the same area, however, exhibited a significant positive relationship between condition factor and stomach fullness, suggesting that Nitinat Hatchery chum salmon, and perhaps other hatchery salmon, may not be as competent at feeding on wild zooplankton as fish that have survived longer in the marine environment (Perry et al. 1996).

Spatial variations in zooplankton abundance may also explain the differences in feeding intensity of Southeast Alaska hatchery chum and PWS hatchery pink salmon stocks entering the GOA. Zooplankton biomass in the coastal waters of the GOA near Cape Spencer (Icy Point) during July was lower than in inside waters (Icy Strait) of northern Southeast Alaska (Murphy et al. 1999). Large numbers of juvenile salmon leaving inside waters of Southeast Alaska and entering the coastal waters near Cape Spencer may exceed the carrying capacity of this area, suggesting the possibility that feeding intensity in the vicinity of Cape Spencer is density dependent.

CONCLUSIONS

Our study examined spatial variations in size and condition factor for four PWS hatchery pink and two Southeast Alaska hatchery and chum salmon stocks caught in the coastal waters of the GOA during July and August 1996. We have suggested that the significantly lower condition factor for these hatchery pink and chum salmon when they enter the GOA may be related to feeding intensity of these juvenile salmon. We speculate that the lower feeding intensity of juvenile salmon at exit corridors is related to zooplankton abundance, high density, or a transitional period either before juvenile salmon leave inside waters and enter the ocean, or before hatchery raised juvenile salmon actively feed in the marine environment. Testing these hypotheses requires a time series of observations on migration routes, feeding success, condition, and growth (in inside and outside waters along the GOA) for hatchery and wild stocks of salmon.

ACKNOWLEDGMENTS

Captain C. Bronson and the crew of the F/V *Great Pacific* are acknowledged for their fine efforts and technical assistance in all aspects of the field survey, especially with new fishing strategies and methods of rope-trawling for salmon. Technical support was also provided by the RACE Division of the Alaska Fisheries Science Center, in particular D. King. We gratefully acknowledge the cooperation and contribution of all scientists who participated in the 1996 shipboard survey, including K. Myers, C. Guthrie, R. Haight, and H. Jaenicke. We thank the Alaska Department of Fish and Game, especially K. Munk, for providing thermal otolith-mark data.

REFERENCES

Carlson, H.R., E.V. Farley, and K.W. Myers. This volume. The use of thermal otolith marks to determine stock-specific ocean distribution and migration patterns of Alaskan pink and chum salmon in the North Pacific Ocean, 1996–1999. N. Pac. Anadr. Fish Comm. Bull. No. 2.

Cleveland, W.S. 1993. Visualizing Data. AT&T Bell Laboratories, New Jersey.

Farley, E.V., Jr., and K. Munk. 1997. Incidence of thermally marked pink and chum salmon in the coastal waters of the Gulf of Alaska. Alaska Fish. Res. Bull. 4: 181–187.

Farley, E.V., Jr., and K. Munk. 1998. Incidence of thermally marked pink, chum, and sockeye salmon in the coastal waters of the Gulf of Alaska. (NPAFC Doc. 341) 18p. Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, Juneau, Alaska.

Farley, E.V., Jr., K. Munk, and P.T. Hagen. 1999. Incidence of thermally marked pink, chum, and sockeye salmon in the coastal waters of the Gulf of Alaska, 1998. (NPAFC Doc. 446) 24p. Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, Juneau, Alaska.

Hagen, P., K. Munk, B. Van Alen, and B. White. 1995. Thermal mark technology for inseason fisheries management: a case study. Alaska Fish. Res. Bull. 2: 2143–2155.

Kramer, C.Y. 1956. Extension of multiple range tests to group means with unequal numbers of replications. Biometrics 12: 309–310.

Lambert, Y., and J.D. Dutil. 1997. Can simple condition indices be used to monitor and quantify seasonal changes in the energy reserves of Atlantic cod (*Gadus morhua*)? Can. J. Fish. Aquat. Sci. 54(Suppl. 1): 104–112.

MathSoft, Inc. 1999. S-Plus 2000: Modern statistics and advanced graphics. Guide to Statistics, Vol. 1. Seattle, WA.

Murphy, J.M., A.L.J. Brase, and J.A. Orsi. 1999. Survey of juvenile Pacific salmon in the northern region of southeastern Alaska, May–October 1997. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-105.

National Marine Fisheries Service. 1995. Ocean carrying capacity program: an implementation plan for the Gulf of Alaska. (NPAFC Doc. 119) 34p. Auke Bay Laboratory, Alaska Fisheries Science Center, Juneau, Alaska.

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. Fish. Oceanogr. 5: 73–88.