

# 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

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**Abstract:** Off shore distribution of juvenile (ocean age .0) Alaskan pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon with thermal otolith marks caught by midwater trawl in the North Pacific varies by geographic region. This may reflect differences in the width of the continental shelf. A few juvenile southeastern Alaska hatchery chum salmon were caught south of major exit corridors, counter to the predominant northward migration pattern. The northern Shelikof Strait may be an important summer migration corridor for juvenile pink salmon. The ocean range of central Alaska pink salmon extends further to the southwest (to 42°N, 165°W) than shown by high-seas tag experiments, and some maturing chum salmon caught in the coastal waters off Prince William Sound in May, are from an early southeastern Alaska hatchery run (peak harvest in mid-July). We conclude that sufficient numbers of thermally-marked hatchery salmon can be recovered during coastal and offshore salmon surveys to provide significant new stock-specific information on ocean distribution and migration patterns of salmon.

## INTRODUCTION

In 1995, the Ocean Carrying Capacity (OCC) program at the Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, initiated a comprehensive program 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). The work is part of an international research effort coordinated through the North Pacific Anadromous Fish Commission (NPAFC) to investigate the physical and biological factors that may be responsible for density-dependent marine growth and survival of salmon (e.g., Kaeriyama 1989, 1996; Helle and Hoffman 1995, 1998; Bigler et al. 1996; Myers et al. this volume).

The primary research emphasis of the OCC program is on the coastal marine phase of juvenile salmon (ocean age .0) in the Alaska Coastal Current (ACC), and a secondary emphasis is on immature and maturing salmon in the Alaska Gyre. From 1996 to 1999, the OCC program focused on broad-scale ship-

board surveys in coastal and offshore waters in spring and summer (Carlson et al. 1996, 1997, 1998a, b, 1999). The major objectives of the surveys were to learn more about the ocean distribution of salmon in the ACC and Gulf of Alaska (GOA), their migration pathways in relation to the continental shelf or slope and distance from shore, the relative abundance and co-occurrence of salmon species, their stock identity or river system of origin, ocean growth, and food habits.

This is the first US program to use large, mid-water rope trawls, towed at high speeds (5.0 kts), to capture salmon at sea, a technique pioneered by Russian researchers and further developed by the OCC program in cooperation with Canadian scientists (e.g., Shuntov et al. 1993; Auke Bay Laboratory, unpublished data). The use of rope trawls greatly enhances our ability to conduct intensive sampling of salmon over broad areas of the North Pacific Ocean in relatively short periods of time, even in moderately rough weather and poor sea conditions.

In recent years, some of the most important scientific advances in ocean salmon research have come through the pioneering, cooperative efforts of the OCC and other NPAFC-related research programs to

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apply new stock-identification technologies to investigations of distribution, migration, growth, and diet of specific stocks or regional populations of salmon (e.g., thermal otolith marks: Farley and Munk 1997; Farley et al. 1999; Farley and Carlson this volume; Urawa et al. this volume; data storage tags: Walker et al. 2000; genetics: Guthrie et al. this volume; Urawa et al. this volume). Thermal marking of salmon otoliths is a relatively new stock identification technique that is now being used by commercial fisheries managers in Alaska to provide information on the contribution of individual hatchery stocks to commercial and cost recovery salmon fisheries (Hagen et al. 1995). Farley and Munk (1997) reported the first recoveries of thermally marked hatchery salmon caught during OCC salmon surveys in the GOA in July and August 1996.

In this paper, we summarize information on the recoveries of thermally marked Alaskan hatchery pink (*O. gorbuscha*) and chum (*O. keta*) salmon during 1996–1999 OCC field surveys. We report new information on salmon distribution and migration patterns in the ACC and Gulf of Alaska, compare our results to previous conceptual models of ocean distribution and migration patterns of salmon, and briefly discuss the factors that may influence these patterns.

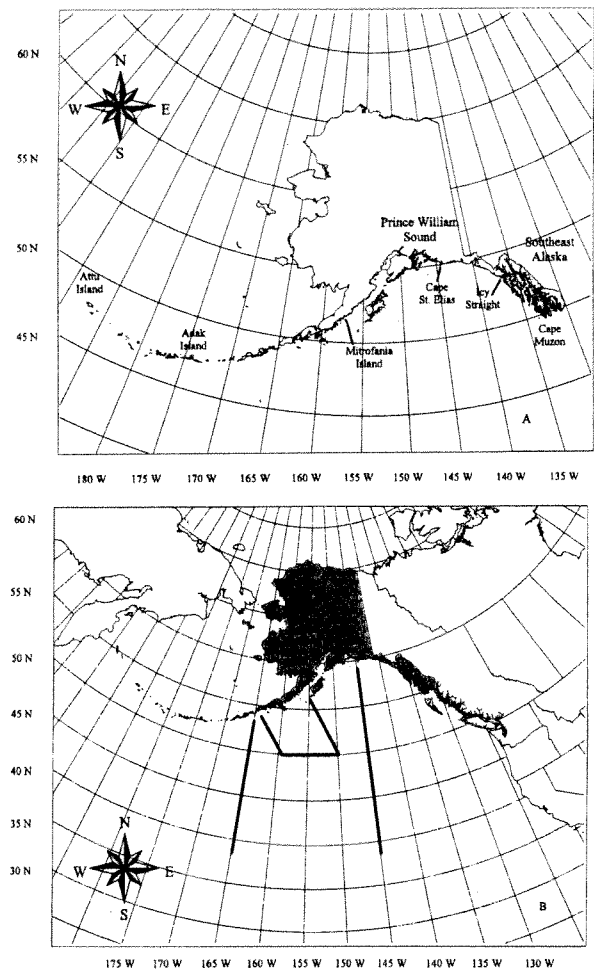
## MATERIALS AND METHODS

### Surveys

During spring (April and May) of 1998 and 1999 and summer (July and August) of 1996–1998, the OCC program conducted five surveys to describe the distribution of juvenile, immature, and maturing salmon in the ACC and GOA. The summer surveys focused on sampling juvenile salmon in coastal waters. During the summers of 1996 and 1998, the coastal surveys began in southern Southeast Alaska (Cape Muzon), and sampled coastal waters to as far west as Adak Island (Carlson et al. 1996; Carlson et al. 1998b; Fig. 1A). During 1997, the survey began at Cape St. Elias, and sampled coastal waters to Attu Island (Carlson et al. 1997). Transects sampled during the summer surveys were perpendicular to the coast and 110–220 km apart. Fish sampling along each transect generally occurred from near shore to at least 185 km off shore.

The spring surveys focused on sampling immature and maturing salmon in offshore waters of the Gulf of Alaska and northeastern North Pacific (Carlson et al. 1998a; Carlson et al. 1999; Fig. 1B). During May 1998, the OCC survey sampled waters south and then east along the 50°N latitude line to 150°W. The survey continued south along the 145°W longi-

**Fig. 1.** Survey area sampled by the OCC program during (A) July–August 1996–1998 (coastal waters of the North Pacific Ocean; Cape Muzon to Attu Island), and transects sampled during (B) April–May 1998 and 1999.



tude line beginning at 59°N and ending at 38°N. During May 1999, the OCC survey sampled waters south along the 165°W longitude line from 52°N to 38°N, then continued north along the 145°W longitude line from 38°N to 59°N. Fish sampling along each of the longitudinal lines generally occurred at every degree latitude.

All surveys were conducted aboard a contracted 38 m stern trawler (F/V *Great Pacific*). The fishing gear was a midwater rope trawl, model 400/580, made by Cantrawl Pacific Ltd.<sup>1</sup> of Richmond, B.C. The net was 198 m long, had hexagonal mesh in the wings and body, and a 1.2 cm mesh liner in the codend. The net was fished with three 60 m, 1.9 cm bridles attached at a single point to steel alloy 5 m midwater trawl doors, each weighing 463 kg. The net was towed at 5 kts at or near surface, with floats on the headrope and 260 m of warp line on each

<sup>1</sup>Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

door. The net was monitored using a Simrad 300 net sounder, which showed a typical spread of 52 m horizontally and 18 m vertically. All tows lasted 30 to 60 minutes and covered 2.8 to 11.1 km. During the summer surveys, all sampling was done during daylight hours; all but 7 tows during the spring surveys were completed during daylight hours.

Catches were brought aboard, and the codend was emptied onto a sorting table. Juvenile (first ocean year; ocean age .0), immature (second or third ocean year; ocean age .1 or older), and maturing salmon were identified and sorted by species. Standard biological measurements including fork length, body weight, and sex as well as scale samples from the preferred area (to document age and growth) were taken from subsamples of all salmon species. Otoliths from pink and chum salmon were saved to identify hatchery origin for salmon with thermally induced otolith marks.

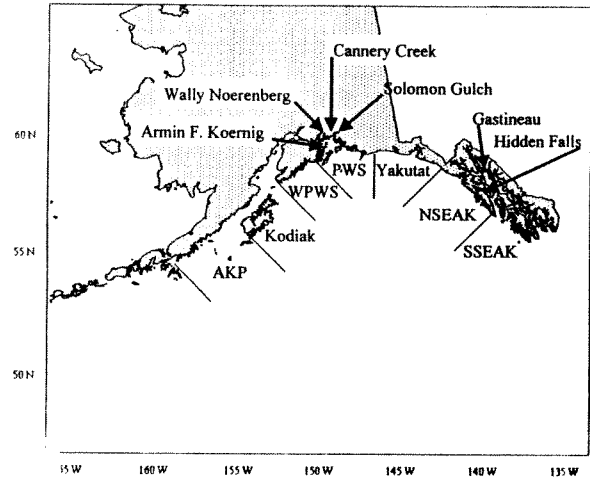
### Stock Identification Techniques

Salmon otoliths were analyzed to determine stock-specific distribution and migration. Left and right sagittal otoliths were removed from salmon heads, 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 hatcheries. For this study, we compared otolith thermal mark patterns from pink and chum salmon collected during the surveys to voucher specimens collected from Gastineau and Hidden Falls hatcheries located in Southeast Alaska and Armin F. Koernig, Cannery Creek, Solomon Gulch, and Wally H. Noerenberg hatcheries located in Prince William Sound (Fig. 2). All otoliths were read independently by a second reader to assure accuracy and confidence in the readings (Hagen et al. 1995). Disagreements between otolith readers were resolved by the most experienced otolith reader.

### Data Analysis

Catches (numbers of fish) were pooled over years for juvenile salmon in summer coastal surveys (1996–1998) and for immature and maturing salmon in spring offshore surveys (1998–1999), and summarized graphically to show variation by species, maturity-group, region, and distance off shore. For graphical displays of juvenile salmon data, we divided the area along the coast into seven regions (Fig. 2). The distributions of thermally marked salmon from Southeast Alaskan and Prince William Sound hatch-

**Fig. 2.** Regions defined for the coastal waters of the Gulf of Alaska sampled by the OCC program during July–August 1996–1998. (Regions include: Southern Southeast Alaska (SSEAK); Northern Southeast Alaska (NSEAK); Yakutat; Prince William Sound (PWS); Western Prince William Sound (WPWS); Kodiak; and Alaska Peninsula (AKP)) and approximate locations of Prince William Sound (Armin F. Koernig, Wally Noerenberg, Cannery Creek, and Solomon Gulch) and Southeast Alaska (Gastineau and Hidden Falls) hatcheries.



eries are represented as percentages of the total catch in each region. Catch per unit effort (CPUE), calculated as catch per 1-hour trawl, was used as a measure of relative abundance of salmon. Information on ocean ranges of thermally marked hatchery salmon stocks was compared to known ranges from high seas tag recovery experiments (1956–present, data archived at the University of Washington, School of Aquatic and Fishery Sciences, Fisheries Research Institute, Seattle).

## RESULTS

### Summer Coastal Surveys

During the summer (1996–1998) surveys, a total of 245 trawl stations were sampled along 54 transects. A total of 47,856 salmon representing five species (and including all life-history stages (juvenile, immature, and maturing) were captured (Table 1). The vast majority of the salmon captured during the summer coastal surveys were juvenile salmon, including pink (50%), chum (12%), sockeye (*O. nerka*; 8%), coho (*O. kisutch*; 5%), and chinook (*O. tshawytscha*; < 1%) salmon. Immature and maturing salmon were also captured during the surveys including immature chum (10%), sockeye (4%), and chinook (< 1%) salmon and maturing pink (5%), chum (1%), sockeye (< 1%), coho (< 1%), and chinook (< 1%) salmon.

Juvenile salmon were distributed along the continental shelf from southern Southeast Alaska (Cape Muzon) to Mitrofanina Island, west of Kodiak Island (Fig. 1). Juvenile pink and chum salmon catches

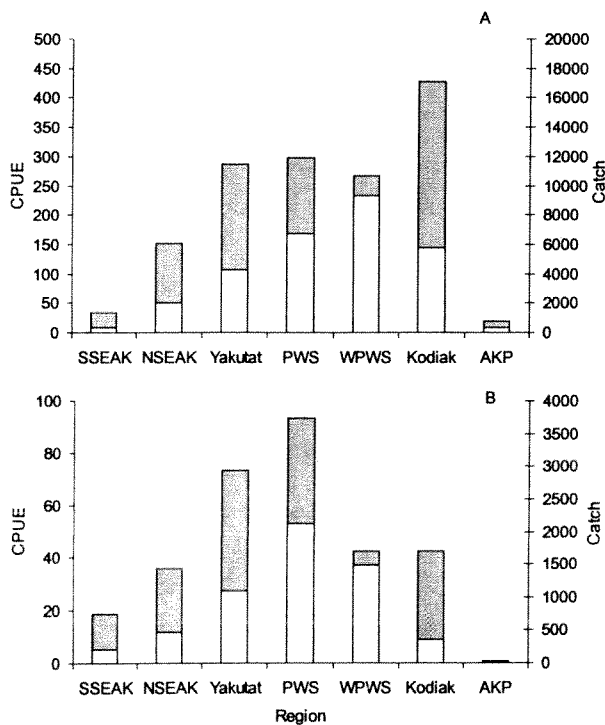
**Table 1.** Number of juvenile (J), immature (I), and maturing (M) salmon captured during summer (1996–1998) in the coastal waters of the North Pacific Ocean.

Year	Pink		Chum			Sockeye			Coho		Chinook		
	J	M	J	I	M	J	I	M	J	M	J	I	M
1996	4,701	1,438	1,932	2,059	260	1,414	411	132	1,405	178	31	99	17
1997	788	548	323	1,802	185	322	698	54	357	49	19	43	13
1998	18,594	541	3,487	1,105	128	2,296	1,019	28	842	120	349	51	18
Total	24,083	2,527	5,742	4,966	573	4,032	2,128	214	2,604	347	399	193	48

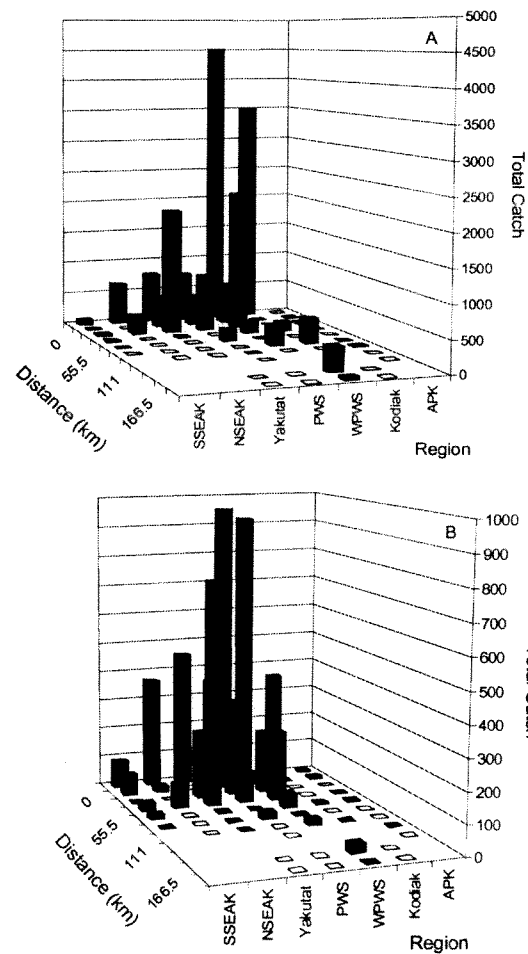
were generally largest in regions west of known exit corridors for juvenile salmon leaving inside waters of southeastern Alaska (Icy Strait) and Prince William Sound (Figs. 3A and B). CPUE for juvenile pink and chum salmon generally followed catch patterns for these fish around the coast except for juvenile pink salmon in the Kodiak Island region where the CPUE was larger (Figs. 3A and B).

Juvenile pink and chum salmon distribution varied by region and by species. Off the coast of Southeast Alaska (southern Southeast Alaska (SSEAK) and northern Southeast Alaska (NSEAK) regions), juvenile pink and chum salmon were distributed from near shore to 93 km off shore (Figs. 4A and B). In the Yakutat region, juvenile pink salmon were generally distributed near shore to 56 km off shore, whereas, juvenile chum salmon were distributed near

**Fig. 3.** Catch per unit effort (CPUE; clear bar) and total catch (gray bar) by region (regions include: Southern Southeast Alaska (SSEAK); Northern Southeast Alaska (NSEAK); Yakutat; Prince William Sound (PWS); Western Prince William Sound (WPWS); Kodiak; and Alaska Peninsula (AKP)) for juvenile (A) pink and (B) chum salmon caught in the coastal waters of the Gulf of Alaska by the OCC program during July–August 1996–1998.



**Fig. 4.** Total catch of juvenile (A) pink and (B) chum salmon by distance offshore and coastal region (regions include: Southern Southeast Alaska (SSEAK); Northern Southeast Alaska (NSEAK); Yakutat; Prince William Sound (PWS); Western Prince William Sound (WPWS); Kodiak; and Alaska Peninsula (AKP)) in the Gulf of Alaska during summer (1996–1998). Dark bars indicate total catch; empty bars indicate area sampled but no juvenile pink salmon were caught.



shore to 111 km off shore. In the western Prince William Sound (WPWS) region, both juvenile pink and chum salmon were distributed from near shore to 185 km off shore. In the Kodiak Island and Alaska Peninsula (AKP) regions, juvenile pink salmon were generally distributed near shore to 111 km off shore, whereas juvenile chum salmon were distributed near shore to 130 km off shore.

The largest catches of juvenile pink and chum salmon varied by distance off shore, region, and species (Figs 4A and B). In the SSEAK and NSEAK regions, the largest catches of juvenile pink and chum salmon occurred near shore. In the Yakutat, Prince William Sound (PWS), and WPWS regions, the largest catches of juvenile pink salmon occurred between near shore and 37 km off shore; whereas, the largest catches of juvenile chum salmon in this area occurred between near shore and 56 km off shore. Juvenile pink and chum salmon catches declined in the Kodiak Island and AKP regions. The largest catches of juvenile pink and chum salmon occurred nearshore in the Kodiak Island region, while in the AKP region there was no particular pattern in juvenile pink or chum salmon catch.

Distribution of juvenile hatchery pink and chum salmon from Southeast Alaska and Prince William Sound varied little between species (Figs. 5A and B). Juvenile hatchery pink salmon from Southeast Alaska were distributed from the Yakutat region to the WPWS region while juvenile chum salmon were distributed from the NSEAK to the WPWS region. Juvenile pink and chum salmon from Prince William Sound hatcheries were distributed from the WPWS region to the AKP region.

The percentage of Southeast Alaska and Prince William Sound hatchery pink and chum salmon in our catch varied between regions (Figs 5A and B). The percentage of Southeast Alaska hatchery pink salmon in our catch ranged from less than 1% in the PWS and WPWS regions to 1% of our catch in the Yakutat region. The percentage of chum salmon from Southeast Alaska hatcheries was larger than that for juvenile hatchery pink salmon from that area, ranging from 1% in the NSEAK region to 28% in the PWS region. The percentage of Prince William Sound hatchery pink and chum salmon in our catch ranged from 17% and 10%, respectively, in the Kodiak Island region to 30% for each species in the WPWS region.

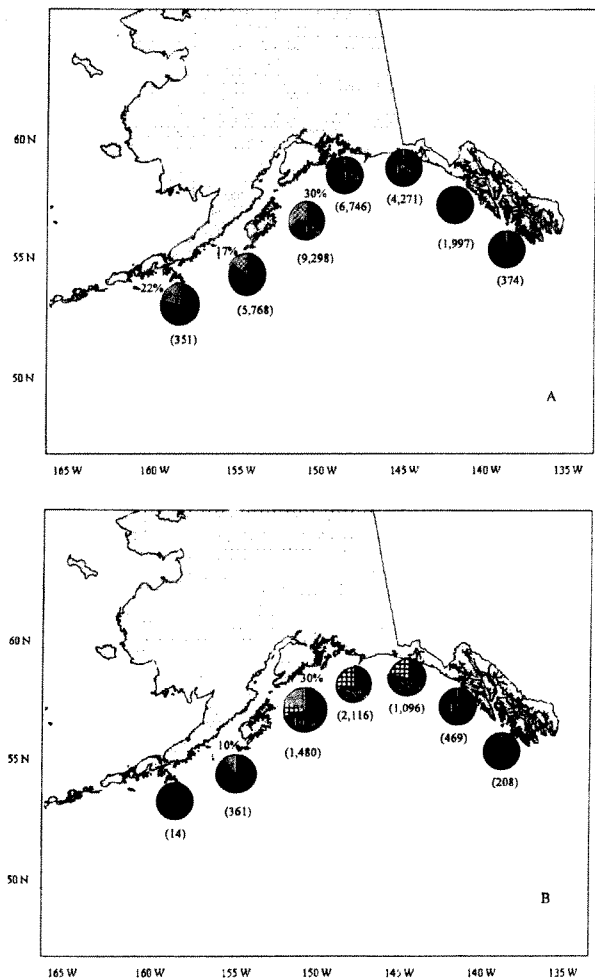
**Spring Offshore Surveys**

During the spring (1998 and 1999) surveys, 121 trawl stations were sampled and a total of 2,643 salmon representing five species were captured (Table 2). Salmon captured during the surveys included

immature chum (16%), sockeye (32%), and chinook (4%) and maturing pink (11%), chum (22%), sockeye (13%), coho (2%) and chinook (< 1%) salmon.

Maturing pink salmon were distributed along the 145°W longitude line from 41° N to 55°N and along the 165°W longitude line from 39°N to 48°N (Figs. 6A and B). The largest CPUE of pink salmon occurred between 45°N and 50°N along the 145°W

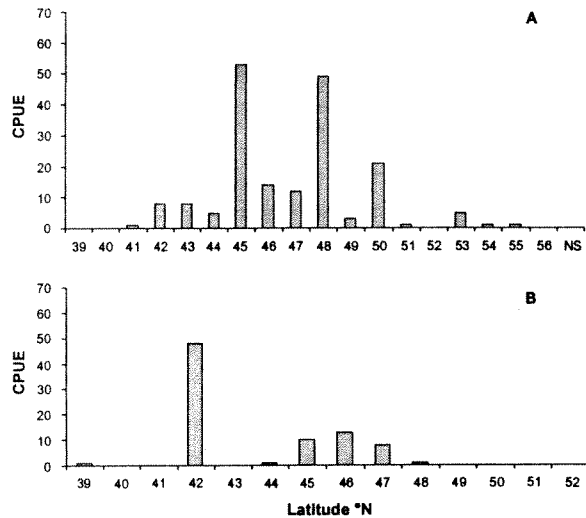
**Fig. 5.** Distribution and percentage of thermally marked juvenile (A) pink and (B) chum salmon (pie chart; solid black area—percentage not marked; solid gray area—percentage (written outside of pie chart) of thermally marked Prince William Sound hatchery pink or chum salmon in our catch; squared area—percentage (written inside solid black area) of thermally marked Southeast Alaska hatchery pink or chum salmon in our catch) by the OCC program during July–August 1996–1998.



**Table 2.** Number of immature (I) and maturing (M) salmon captured during spring (1998–1999) in offshore waters of the North Pacific Ocean.

Year	Pink		Chum		Sockeye		Coho	Chinook	
	M	I	M	I	M	I	M	I	M
1998	109	184	322	602	141	36	84	6	
1999	183	236	254	247	196	22	19	2	
Total	292	420	576	849	337	58	103	8	

**Fig. 6.** Catch per unit effort (CPUE) for maturing pink salmon along the (A) 145°W longitude line and (B) 165°W longitude line during spring 1998 and 1999. (NS is defined as the area sampled from near shore to 100 km offshore.)

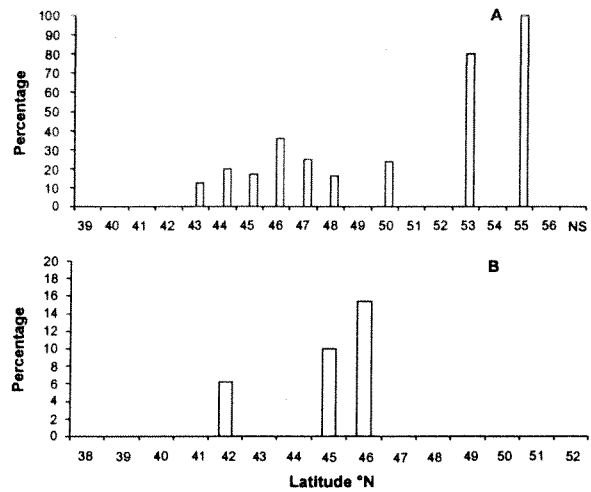


longitude line and at 42°N along the 165°W longitude line. All of the thermally marked maturing pink salmon caught during the spring surveys were from Prince William Sound hatcheries. These fish were distributed between 43°N and 55°N along the 145°W longitude line and from 42°N to 46°N along the 165°W longitude line (Figs. 7A and B). The percentage of Prince William Sound pink salmon in our catch ranged from 11% at 43°N to 100% at 55°N along the 145°W longitude line and from 6% at 42°N to 15% at 46°N along the 165°W longitude line.

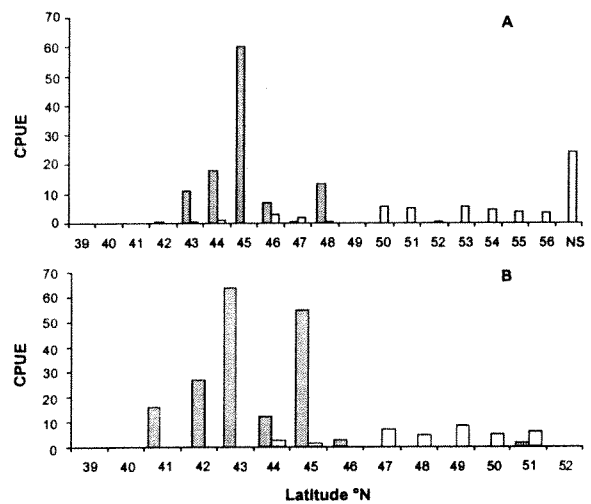
Immature chum salmon were distributed in the southern half of both longitudinal transects while maturing salmon were distributed in the northern half of each longitudinal transect (Figs. 8A and B). Immature chum salmon were distributed along the 145°W longitude line from 42°N to 48°N and along the 165°W longitude line from 41°N to 51°N. The largest CPUE for immature chum salmon occurred at 45°N along the 145°W longitude line and south of 47°N along the 165°W longitude line. Maturing chum salmon were distributed between 43°N and nearshore (NS) with the largest CPUE occurring north of 50°N along the 145°W longitude line. Maturing chum salmon captured along the 165°W longitude line were distributed between 44°N and 51°N with the largest CPUE occurring north of 46°N.

All of the immature and maturing hatchery chum salmon caught during the spring surveys were distributed east of the 165°W longitudinal line. Immature hatchery chum salmon from Southeast Alaska and Prince William Sound hatcheries were distributed between 43°N and 48°N along the 145°W longitude line (Fig. 9). The percentage of immature hatchery chum salmon from Southeast Alaska in our catch along the 145°W longitude line ranged from 23% at 43°N to 7% at 48°N. The percentage of immature

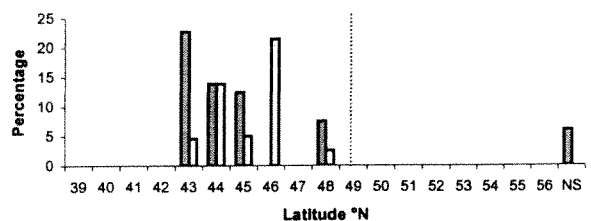
**Fig. 7.** Percentage of thermally marked pink salmon along the (A) 145°W longitude line and (B) 165°W longitude line from Prince William Sound (clear bar) hatcheries in our catch during spring 1998 and 1999. (NS is defined as the area sampled from near shore to 100 km offshore.)



**Fig. 8.** Catch per unit effort (CPUE) for immature (solid bar) and maturing (clear bar) chum salmon along the (A) 145°W longitude line and (B) 165°W longitude line during spring 1998 and 1999. (NS is defined as the area sampled from near shore to 100 km offshore.)



**Fig. 9.** Percentage of thermally marked immature and maturing chum salmon along the 145°W longitude line from Southeast Alaska (solid bar) and Prince William Sound (clear bar) hatcheries in our catch during spring 1998 and 1999. (NS is defined as the area sampled from near shore to 100 km offshore. Dotted line indicates break between immature (left side) and maturing salmon (right side) in our catch.)



hatchery chum salmon from Prince William Sound in our catch along the 145°W longitude line ranged from 21% at 46°N to 3% at 48°N. Almost all of the maturing hatchery chum salmon were from Southeast Alaska hatcheries and were found in the nearshore (NS) waters of the 145°W longitude line.

## DISCUSSION

A conceptual model of oceanic migration patterns of juvenile salmon from Southeast Alaska and Prince William Sound suggests that these stocks migrate in a narrow band around the coastal waters of the Gulf of Alaska (Hartt and Dell 1986). Various ocean surveys in the coastal region of Southeast Alaska estimated the coastal migration corridor of juvenile salmon to be from near shore waters to as far as 74 km off shore (Hartt and Dell 1986; Jaenicke and Celewycz 1994; and Murphy et al. 1999). We found juvenile pink and chum salmon to 93 km off shore in SSEAK but only to 56 km off shore in NSEAK suggesting regional off shore distribution patterns for juvenile pink and chum salmon.

The regional off shore distribution differences for juvenile pink and chum salmon may be influenced by the regional differences in the width of the shelf along the coast. The distance across the shelf in the SSEAK region is approximately 75 km, whereas the distance across the shelf in the NSEAK region is approximately 45 km. The continental shelf broadens to span a distance of nearly 200 km in the region directly west of Prince William Sound. Coincidentally, juvenile pink and chum salmon in our catch were distributed well off shore in the WPWS region, and were found along the entire shelf from near shore to 185 km off shore. However, a variety of factors such as coastal current, sea temperature, food availability, and body size may also affect off shore distribution of juvenile salmon.

A conceptual model of oceanic migrations for Southeast Alaska and Prince William Sound pink and chum salmon stocks also suggests that these stocks migrate in a counter-clockwise direction around the coastal waters of the GOA (Hartt and Dell 1986). Almost all of the thermally marked salmon we collected during the summer surveys were distributed west of major exit corridors for juvenile salmon leaving inside waters of Southeast Alaska (Icy Strait) and Prince William Sound. This suggests a counter-clockwise migration of these stocks around the coastal waters of the Gulf of Alaska. However, there were four thermally marked chum salmon from Southeast Alaska hatcheries located in the coastal waters of the GOA south of Icy Strait. Two possible explanations for this include: (1) these salmon migrated south after entering the coastal waters via Icy Strait; or (2) these salmon migrated south while still

in inside waters and entered the coastal waters via Dixon Entrance.

As mentioned in the previous section, CPUE for juvenile pink and chum salmon generally followed catch patterns for these fish around the coast except for the Kodiak Island region, where CPUE was larger. The large CPUE in the Kodiak Island region is an artifact of our 1998 sampling design. During our 1998 summer survey, we sampled four stations along the northern entrance to Shelikof Strait that were not sampled during the 1996 or 1997 summer surveys. The large juvenile pink and chum salmon CPUE for this region is the result of the large catches of juvenile pink and chum salmon in Shelikof Strait coupled with fewer trawl hauls in the Kodiak Island region when compared to the WPWS region. Overall, 90% of the juvenile pink salmon catch in the coastal region of Kodiak Island occurred in northern Shelikof Strait. The large catches of juvenile pink salmon in northern Shelikof Strait were not expected, and may indicate the importance of this area as a migration corridor for juvenile pink salmon during summer.

The percentage of juvenile Southeast Alaska hatchery pink salmon in our catch seemed low in comparison to the percentage of juvenile Prince William Sound hatchery pink salmon in our catch. Of the two hatcheries thermally marking salmon in Southeast Alaska, only Gastineau Hatchery is thermally marking pink salmon. The low percentage ( $\leq 1\%$ ) of juvenile pink salmon from Southeast Alaska in our catch may be due to the low numbers of thermally marked pink salmon being released from Gastineau Hatchery. For example, during 1998 Gastineau Hatchery released 9 million thermally marked pink salmon, whereas Prince William Sound hatcheries released approximately 543 million thermally marked pink salmon (Kristen Munk, Alaska Department of Fish and Game, P.O. Box 25526, Juneau, Alaska, 99802-5526, personal communication).

All of the maturing pink salmon with thermal otolith marks captured during our spring surveys were from Prince William Sound hatcheries. High seas tag recoveries of maturing pink salmon (1956–present) indicated that central and southwestern Alaska pink salmon stocks were widely distributed in the GOA during spring, and were found as far south as 44°N and as far west as 160°W. Thermally marked pink salmon from Prince William Sound hatcheries caught during our spring surveys were found as far south as 42°N and as far west as 165°W, which is a southwestward range extension for central Alaska pink salmon.

Chum salmon caught during our spring surveys were widely distributed north and south along the central and western GOA transects. Past surveys during May indicated a more southerly distribution of immature chum salmon and a more northerly distribution for maturing chum salmon in the central and

western GOA (Neave et al. 1976). This is consistent with the distribution patterns of immature and maturing chum salmon caught during our spring surveys. Our largest catches of immature chum salmon were located further south in both the central and western GOA than was found in previous studies, while the largest catches of maturing chum salmon were located further north.

High seas tagging experiments conducted during 1956 to 1971 indicated a dominance of Asian stocks in the western GOA and a dominance of North American stocks in the central GOA during spring (Neave et al. 1976). More recently, genetic stock identification techniques (GSI) performed on immature and maturing chum salmon caught in the central and western GOA during winter 1996, indicated that various regional stocks of North American and Asian chum salmon intermingled in the central GOA, while Asian stocks were dominant in the western GOA (Urawa et al. 1997; Urawa and Ueno 1997). The tagging and GSI results are supported by the thermal mark results for chum salmon captured during our spring surveys. All of the thermally marked chum salmon from Prince William Sound and Southeast Alaska hatcheries were located in the central GOA; whereas, none of the chum salmon caught in the western GOA during our spring surveys were from Alaska hatcheries.

Almost all of the maturing hatchery chum salmon caught during our spring surveys were from Southeast Alaska hatcheries, and were located in the coastal waters off Prince William Sound. High-seas tagging experiments of maturing chum salmon in the coastal waters west of Prince William Sound indicated the presence of southeastern Alaska stocks during June; those tagged during May were located in oceanic waters in the central GOA (Neave et al. 1976). In general, the peak nearshore abundance of chum salmon returning to southeastern Alaska occurs during the first two weeks of August, while peak harvest in the northern districts of southeastern Alaska occurs around August 5 (Clark and Weller 1986). However, peak harvest of Gastineau hatchery chum salmon occurs during mid July ([www.alaska.net/~dipac/](http://www.alaska.net/~dipac/)) and may explain the earlier (spring) coastal distribution of these stocks.

## CONCLUSIONS

Our results demonstrate that sufficient numbers of thermally marked hatchery salmon can be recovered during coastal and offshore salmon surveys to provide significant new stock-specific information on their ocean distribution and migration patterns. We plan to continue applying this valuable new tool to international salmon research efforts coordinated through the NPAFC. Because the number of thermal otolith mark patterns available for use is limited, the

NPAFC is playing an important role in coordinating the application and use of these marks for salmon research in international waters (NPAFC 1999). We encourage all agencies planning to use otolith marking techniques for salmon research and management to cooperate in this important international effort.

## ACKNOWLEDGMENTS

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