High-Seas Ocean Distribution of Alaskan Hatchery Pink Salmon Estimated by Otolith Marks

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Keywords: Pink salmon, stock origin, distribution, otolith thermal mark, Gulf of Alaska

To investigate the ocean distribution of Alaskan hatchery pink salmon (*Oncorhynchus gorbuscha*), we examined otoliths for thermal marks from maturing pink salmon caught in the Gulf of Alaska and central North Pacific Ocean in the summers of 1998–2000. Pink salmon captured in the Gulf of Alaska were identified as originating from hatchery locations in Prince William Sound (PWS), Alaska. Large numbers of Alaskan hatchery pink salmon have been thermally marked and released (Geiger and Munk 1998). Thermal marks are an effective tool for stock identification in high-seas and coastal waters (Farley and Munk 1997; Kawana et al. 1999a; Carlson et al. 2000; Urawa et al. 2000a). Salmon otoliths are thermally marked by exposing fish to alternating (relatively lower and higher) temperatures (Volk et al. 1990), whereby a "thermal ring" (dark ring) is induced by exposure to the lower temperature (Munk et al. 1993). Different thermal marks are made by varying the number and spacing of thermal rings in the RBr notation in Alaskan hatcheries (Munk and Geiger 1998).

Thermally-marked pink salmon were released from four PWS hatcheries: Armin F. Koernig Hatchery (AFK), Wally H. Noerenberg Hatchery (WHN), Cannery Creek Hatchery (CCH), Solomon Gulch Hatchery (SGH), and one southeast Alaskan hatchery: Gastineau Hatchery (GH). For pink salmon brood years 1996, 1997, and 1998, the numbers of thermally-marked fry released were 489.60, 551.08, and 607.80 million, respectively. More than 98% of thermally-marked pink salmon were released from PWS hatcheries, where 100% of all hatchery pink salmon released were thermally marked. Each hatchery stock had unique thermal mark patterns coded in RBr notation, with the exception of brood year 1996 where RBr code (1:1.4) was used for both GH and one of two stocks of AFK (Geiger and Munk 1998; Hagen et al. 1999). Pink salmon were caught by gillnets (non-selective varied research mesh, traditional commercial mesh, and experimental mesh) during June and July along two offshore transects (145°W and 165°W) in the Gulf of Alaska by the T/S *Oshoro maru* and one offshore transect (180°) in the central North Pacific Ocean by the R/V *Wakatake maru*. The total catches were 813, 1297, and 574 maturing pink salmon in 1998, 1999, and 2000, respectively (Walker et al. 1998; Kawana et al. 1999b; Yamaguchi et al. 1999; Urawa et al. 2000b; Yamaguchi et al. 2000). Fork length (mm), body weight (g), sex, and gonad weight (g) were recorded and sagittal otoliths were collected from 383, 778, and 349 pink salmon in 1998, 1999, and 2000, respectively. Scales were also collected for age determination. The catch per unit effort (CPUE) was calculated as total catch (number of fish) per one set of the non-selective gillnet (30 tans, 1 tan = 50 m long and approximately 6 m depth; Takagi 1975; Walker et al. 1998; Kawana et al. 1999b; Yamaguchi et al. 1999; Urawa et al. 2000b; Yamaguchi et al. 2000). A gonadosomatic index (GSI) was calculated as 100 × gonad weight (g) / body weight (g) to examine maturity. Fork length, body weight, gonad weight, and GSI were compared by Kruskal-Wallis test and Scheffe's test . The left sagittal otoliths were mounted on individually labeled glass slides using thermoplastic cement. If the left otolith was missing or ground through the primordia, then the right otolith was used. Otoliths were ground to expose the primordia, and examined under a microscope. Thermal marks were recorded in the RBr notation. If the same RBr code was used for a brood year class at different hatcheries, then microstructural patterns were compared with voucher specimens that were collected from the hatcheries before release.

One hundred and fifty-one thermal marks were found among 1,510 maturing pink salmon examined (Table 1). Along the 145°W transect, 25 thermally-marked fish were found (8.1%, n = 307) in 1998, 86 marked fish were found (15.1%, n = 568) in 1999, and 34 marked fish were found (12.0%, n = 284) in 2000. The thermally-marked salmon were from three of four pink salmon hatcheries in PWS: AFK (n = 57), CCH (n = 39), and WHN (n = 49). Along the 165°W transect, only four thermally-marked fish were found (5.3%, n = 76) in 1998, and two marked fish were found (2.6%, n = 78) in 1999. Their origins were AFK (n = 3), CCH (n = 2), and WHN (n = 1). Along the 180° transect, no thermally-marked fish were found in 1999 (n = 132) and 2000 (n = 65). Marked pink salmon released from SGH and GH were not found along either transect. PWS hatchery pink salmon were widely distributed from 49°N to 56°N along the 145°W transect and from 47°N to 50°N along the 165°W transect, but not

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Table 1. Composition of pink salmon hatchery origins caught along the 145°W, 165°W, and 180° transects during June and July 1998–2000. PWS, Prince William Sound; A, Armin F. Koernig Hatchery; C, Cannery Creek Hatchery; W, Wally H. Noerenberg Hatchery.

Latitude	1998					1999					2000				
	PWS			Other	%	PWS			Other	%	PWS			Other	%
(N)	A	C	W	unmarked	PWS	A	C	W	unmarked	PWS	A	C	W	unmarked	PWS
145°W transect															
56°00'	3	3	4	62	12.5	10	6	11	117	18.8	3	3	0	20	23.1
55°00'	3	4	3	50	16.7	10	4	7	74	22.1	3	5	4	38	24.0
54°00'	-	-	-	-	-	12	2	6	76	20.8	1	3	4	49	14.0
53°00'	-	-	-	-	-	1	2	3	56	9.7	1	0	1	27	6.9
52°00'	1	0	0	27	3.6	2	3	2	47	13.0	1	0	1	33	5.7
51°00'	1	0	1	58	3.3	2	0	1	56	5.1	0	0	0	42	0
50°00'	0	2	0	16	11.1	0	1	1	56	3.4	2	1	0	40	7.0
49°00'	0	0	0	69	0	-	-	-	-	-	1	0	0	9	10.0
48°00'	-	-	-	-	-	-	-	-	-	-	0	0	0	1	0
Total	8	9	8	282	8.1	37	18	31	482	15.1	12	12	10	250	12.0
165°W transect															
50°00'	1	0	0	17	5.6	2	0	0	42	4.5	-	-	-	-	-
48°30'	0	2	0	4	33.3	-	-	-	-	-	-	-	-	-	-
47°00'	0	0	1	29	3.3	0	0	0	19	0	-	-	-	-	-
45°30'	0	0	0	22	0	0	0	0	12	0	-	-	-	-	-
44°00'	-	-	-	-	-	0	0	0	3	0	-	-	-	-	-
											-	-	-	-	-
Total	1	2	1	72	5.3	2	0	0	76	2.6	-	-	-	-	-
180° transect															
47°30'	-	-	-	-	-	0	0	0	83	0	0	0	0	11	0
47°00'	-	-	-	-	-	0	0	0	36	0	0	0	0	17	0
46°00'	-	-	-	-	-	0	0	0	8	0	0	0	0	21	0
45°00'	-	-	-	-	-	0	0	0	3	0	0	0	0	7	0
44°00'	-	-	-	-	-	0	0	0	1	0	0	0	0	3	0
43°00'	-	-	-	-	-	0	0	0	0	0	0	0	0	4	0
42°00'	-	-	-	-	-	0	0	0	1	0	0	0	0	1	0
41°00'	-	-	-	-	-	-	-	-	-	-	0	0	0	1	0
Total	-	-	-	-	-	0	0	0	132	0	0	0	0	65	0

along the 180° transect. However, 83% of total CPUEs of PWS hatchery pink salmon along the three transects caught by non-selective gillnets were represented by catches in northern waters (54–56°N) of the 145°W transect (Fig. 1). Among the three hatchery stocks caught along the 145°W transect, differences in the body and gonad measurements were not significant ($p > 0.05$; Kruskal-Wallis test, by year and sex). Among three sampling years along the 145°W transect, fork lengths and body weights of PWS hatchery females in 1998 were significantly different from 1999 and 2000 ($p < 0.001$, Scheffe's test), but no significant difference was observed among males ($p > 0.05$, Table 2). There was also a significant difference in GSI of PWS hatchery males between 1998 and 2000 ($p < 0.05$, Table 2).

All thermally-marked pink salmon detected in the present study were from PWS. In April and May, PWS hatchery pink salmon were distributed in southern (43–48°N, 145°W and 42–46°N, 165°W) and northern (50–55°N, 145°W) waters in 1998 and 1999 (Carlson et al. 2000). But in June and July, they were absent from the southern waters and became increasingly abundant in the northern part (54–56°N) of the 145°W transect corresponding to

Fig. 1. Catch per unit effort (CPUE) of thermally-marked pink salmon released from Prince William Sound hatchery caught along the 145°W (left) and 165°W (right) transects in the Gulf of Alaska during June and July 1998–2000. The CPUE values are based on the catch (number of fish) per one set of a non-selective varied research mesh gillnets (30 tans).

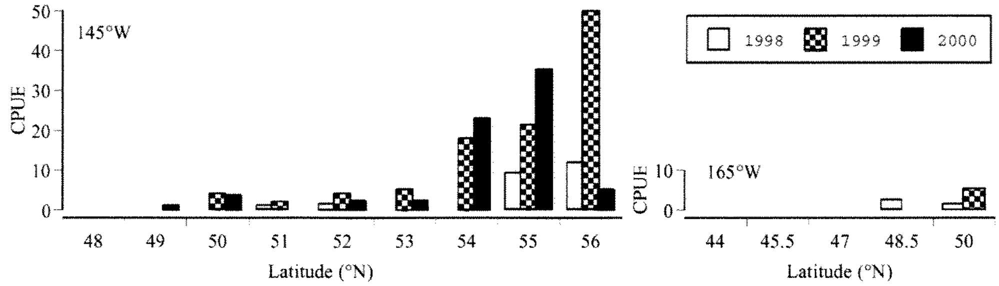

Table 2. A comparison of body and gonad measurements of maturing thermally-marked Prince William Sound hatchery pink salmon caught along the 145°W transect in the Gulf of Alaska during July 1998–2000. Values are given as the mean ± SD. Numbers in parentheses are sample sizes. FL, fork length (mm); BW, body weight (g); GW, gonad weight (g); GSI, gonadosomatic index = 100 × gonad weight (g) / body weight (g).

								Probability		
Sex	Measurement	1998		1999		2000		1998–1999	1998–2000	1999–2000
Female	FL	483 ± 24	(12)	448 ± 15	(48)	439 ± 35	(15)	p < 0.001	p < 0.001	p > 0.05
	BW	1328 ± 227	(12)	1066 ± 122	(47)	979 ± 169	(15)	p < 0.001	p < 0.001	p > 0.05
	GW	47 ± 21	(12)	44 ± 12	(48)	35 ± 10	(15)	p > 0.05	p > 0.05	p > 0.05
	GSI	3.54 ± 1.41	(12)	4.08 ± 0.78	(47)	3.62 ± 0.87	(15)	p > 0.05	p > 0.05	p > 0.05
Male	FL	460 ± 16	(13)	442 ± 22	(38)	449 ± 27	(19)	p > 0.05	p > 0.05	p > 0.05
	BW	1111 ± 123	(13)	1036 ± 140	(38)	1013 ± 218	(19)	p > 0.05	p > 0.05	p > 0.05
	GW	14 ± 6	(13)	19 ± 8	(38)	21 ± 13	(19)	p > 0.05	p > 0.05	p > 0.05
	GSI	1.26 ± 0.53	(13)	1.82 ± 0.72	(38)	2.01 ± 0.97	(19)	p > 0.05	p < 0.05	p > 0.05

their northward homeward migration. Year-to-year differences were observed in the body size of PWS hatchery females because half of the sampled fish in 1998 were larger in fork length or body weight than any fish in 1999 and 2000. This may be a result of differences in sample sizes or characters of PWS hatchery pink salmon caught in 1998. In this study, maturing pink salmon were sampled in the Gulf of Alaska during their homeward migration, and incidence of otolith thermal marks was used to identify their hatchery origin. Our results show that high-seas stock identification, abundance, and migration timing data are available prior to commencement of commercial harvest, and therefore may aid the management of PWS hatchery pink salmon.

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