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by

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Stock Origin of Chum Salmon caught in Offshore Waters of the Gulf of Alaska during the Summer of 1998

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Abstract

Genetic stock identification (GSI) and thermal otolith marking techniques were used for determining the stock origin of chum salmon (*Oncorhynchus keta*, n=527 fish) caught in two offshore transects (165°W and 145°W) in the Gulf of Alaska during June and July 1998. In the central Gulf of Alaska (49-56°N, 145°W), 49 thermally-marked chum salmon were found (14.5%, n=339 fish). The percentage of thermally-marked fish was higher in southern waters (21.5%, 49-52°N) than in northern waters (8.9%, 53-56°N). Most of these marked fish were released from hatcheries in southeast Alaska (SEAK) and Prince William Sound (PWS), while two fish were from Nitinat Hatchery on southwest Vancouver Island, British Columbia (BC). In the western Gulf of Alaska (45-50°N, 165°W), however, we found only 2 marked chum salmon (1.1%, n=188 fish) that had been released from the Hidden Falls (HF) and Gastineau hatcheries in SEAK. All of the marked chum salmon were immature fish except for a HF fish (age 0.3) caught in the central Gulf of Alaska (56°N, 145°W). For GSI, we used a baseline of protein allozyme characters (19 loci) including 77 North Pacific Rim stocks. The GSI results indicated that North American chum salmon were common in the central Gulf of Alaska (1% Japan, 10% Russia, 15% west Alaska, 25% Alaska Peninsula/Kodiak, 28% SEAK/PWS, 18% BC, 3% Washington stocks), and Asian chum salmon were predominant in the western Gulf of Alaska (25% Japan, 53% Russia, 13% west Alaska, 4% Alaska Peninsula/Kodiak, 1% SEAK/PWS, 3% BC, and 1% Washington stocks).

Introduction

Thermal marking of salmonid otoliths has been well developed as a remarkable tool to determine the hatchery origin of salmon. This technology has been primarily used for stock management in near-shore interception fisheries (Hagen et al., 1995). Now, large numbers of thermally-marked chum and pink salmon are annually released from hatcheries in Alaska, British Columbia, Washington, and Russia. Japan has also started thermal marks, beginning with the 1998 brood year stocks. Many thermally-marked chum and pink salmon are collected in the eastern Bering Sea (Ignell et al., 1997) and coastal waters of the Gulf of Alaska (Farley and Munk, 1997, 1998). Genetic stock identification techniques have been established for estimating stock compositions of high-seas chum salmon (Seeb et al., 1995; Urawa et al., 1997, 1998; Wilmot et al., 1998; Winans et al., 1998; Seeb and Crane, 1999a, 1999b). The present study was conducted to determine stock origin of chum salmon caught in the high seas of the Gulf of Alaska by using genetic and thermal marks.

Materials and Methods

Fish samples

Chum salmon (n=527 fish) were captured in two transects (165°W and 145°W) of the Gulf of Alaska by research gillnet operations of T/V *Oshoro maru* during June and July 1998 (Fig. 1). The fork length, body weight and gonad weight of each fish were recorded, and scales were removed for the age determination. The sagittal otoliths, muscle, heart, and liver were collected from each fish. The sagittal otoliths were dried and kept in cell well plates until the detection of otolith makers. The other tissues (muscle, heart, and liver) were immediately frozen in -80°C freezer, and shipped to the Genetics Section of the National Salmon Resources Center for genetic analysis.

Detection of thermal otolith marks

The left sagittal otoliths were mounted on slide glasses using thermoplastic cement (Buehler Co.), and then ground to expose the primordia. If the left sagittal otoliths were not available, the right sagittal otoliths were used. Otolith microstructures were observed under a light microscope, and the microstructure patterns were compared to the thermal mark patterns of voucher specimens collected from hatcheries before releases. All otoliths were read independently by two readers.

GSI analysis

Samples were examined for protein electrophoretic variation on horizontal starch gels using standard procedures described by Aebersold et al. (1987). Standard nomenclature for loci and alleles was used as outlined in Shaklee et al. (1990). Alleles were compared and standardized for 20 polymorphic loci (Seeb et al., 1995). We used the simplified baseline data set formulated in Seeb et al. (1995) for 69 stock groups that was augmented by Wilmot et al. (1998) to a 77 stock group/20 locus data set. Our analyses are based on a 19-locus baseline (Table 1). We dropped PEPA from our analyses because it was frequently missed in the electrophoretic screening of mixture samples (Winans et al., 1998). Estimates of stock contributions were made with a conditional maximum likelihood algorithm (Pella and Milner, 1987) using the GIRLS program of Masuda et al. (1991). Standard deviations of estimates were estimated by 500 bootstrap resamplings of the baseline and mixture samples. Estimates were made to individual stocks and than pooled to regional stock groups used by Seeb et al. (1995) and Wilmot et al. (1998). The regional stock groups are Japan, Russia, west Alaska (summer run), Yukon River (fall run), Alaska Peninsula/Kodiak, southeast Alaska and Prince William Sound, British Columbia, and Washington. Simulation studies indicated that average estimates were greater than 80% accurate when true group contributions were 100% (Wilmot et al., 1998).

Results

Thermal otolith mark

Thermal otolith marks were detected in 51 chum salmon (9.7% of fish examined; Table 2). All of these marked chum salmon were immature fish except for one maturing fish caught in the central Gulf of Alaska (56°N, 145°W).

In the central Gulf of Alaska (49-56°N, 145°W), 49 thermally otolith marked chum salmon were found (14.5%, n=339 fish). Most of these marked fish were released from 4 hatcheries in southeast Alaska (SEAK) and Prince William Sound (PWS), while two fish were from Nitinat Hatchery on southwest Vancouver Island, British Columbia (BC). The percentage of thermally-marked fish was higher in southern waters (21.5%, 49-52°N) than in northern waters (8.9%, 53-56°N)(Figure 2). The CPUE of thermally-marked fish showed a similar trend (Figure 3). Number of thermally-marked immature chum salmon decreased with an increase of ocean age: 31 fish (36.9%) in age 0.1, 15 fish (7.9%) in age 0.2, and one fish (3.6%) in age 0.3 groups (Figure 4).

In the western Gulf of Alaska (45-50°N, 165°W), thermal marks were found in only 2 chum salmon (1.1%, n=188 fish; Figure 2). These marked fish were released from the Hidden Falls and Gastineau hatcheries in SEAK.

Genetic stock identification

The GSI results indicated that North American chum salmon were common in the central Gulf of Alaska, and Asian chum salmon were predominant in the western Gulf of Alaska (Table 3, Figures 5 and 6).

In the central Gulf of Alaska, Alaskan stocks occupied 72% of immature chum salmon, while the proportion of southern North American stocks (British Columbia and Washington) was high (58%) among maturing fish (Figure 7). A geographical comparison of stock composition in immature chum salmon (Figure 9) indicated that the percentage of SEAK/PWS stocks was higher in the southern waters (49-52°N) than in northern waters (53-56°N). In age 0.1 group, SEAK/PWS stocks were dominant (41%), and west Alaskan stock was rarely present (Figure 10). However, the proportion of SEAK/PWS stocks decreased with an increase of ocean age, and west Alaskan stock accounted for 21% and 17% in Age 0.2 and 0.3 groups, respectively.

In the western Gulf of Alaska, the proportion of Russian and Japanese stocks was 56% and 18% among immature fish and 41% and 34% among maturing fish, respectively (Figure 8). North American stocks were rare except for west Alaskan stock whose proportion was 15% and 12% in immature and maturing groups, respectively.

Discussion

The 1996 winter GSI results showed that various regional stocks of North American and Asian chum salmon intermingled in the central Gulf of Alaska but Asian stocks were dominant in the western Gulf of Alaska (Urawa et al., 1997; Urawa and Ueno, 1997). The present summer GSI results indicate the similar stock composition estimates in the western Gulf of Alaska. In the central Gulf of Alaska, however, North American stocks (central and southwest Alaska and BC) are common in the summer of 1998.

These GSI results are supported by data of thermal otolith marks showing frequent occurrence of marked chum salmon in the central Gulf of Alaska and rare detection in the western waters. Among these marked fish detected (n=51), 49 fish originated from 4 hatcheries in Prince William Sound (PWS) and southeast Alaska (SEAK), where about two hundred million chum fry are annually released after thermally marked (Figure 11; Geiger and Munk, 1998). Other two marked chum salmon were released from Nitinat Hatchery in BC, where about thirty million chum fry are annually treated by thermal marks (Hargreaves et al., 1999). In the Gulf of Alaska we found no marked chum salmon that were released from Washington (Volk and Hagen, 1998) and Russia

(Akinitcheva and Rogatnykh, 1999).

It is noteworthy that 98% of thermally-marked chum salmon were immature when they were caught in the Gulf of Alaska during late June and early July. It may reflect their spawning season: in this period maturing fish have already moved to coastal waters for spawning in PWS and SEAK. The GSI results suggested that maturing chum salmon originating from southern North America (BC and Washington) were still distributed in the central Gulf of Alaska in early July.

Number of thermally-marked chum salmon of PWS/SEAK origins decreased with an increase of ocean age among immature chum salmon in the central Gulf of Alaska (Figure 4). This decrease may partly reflect annual changes in the number of thermally-marked fish released from hatcheries (Figure 11). However, the GSI analysis also showed a similar trend that the proportion of SEAK/PWS stocks was high (41%) in age 0.1 group but decreased to 17% and 6% in age 0.2 and 0.3 groups, respectively. In contrast, west Alaskan chum salmon rarely appeared in age 0.1 group, but occupied 17-21% in older age groups. The proportion of Russian chum salmon also increased to 29% in age 0.3 group. These results suggest that chum salmon stocks along the Gulf of Alaska coasts (SEAK/PWS, Alaska Peninsula and BC) are dominant among fish at the early ocean life in the central Gulf of Alaska, but their predominance may decrease, because other stocks (such as west Alaska and Russia) enter to this water after the second year of their ocean life.

Thermal otolith marking is an effective tool to determine hatchery origins of individual salmon in high seas as well as in coastal waters. However, some duplication of mark codes occur within or between Alaska, British Columbia and Russia, because of limited thermal mark codes (Hagen, 1999) and poor coordination. In the present study, these duplications could be resolved by secondary characters. However, duplicated thermal marks are a challenge even for the experienced observers (Munk, 1999). Thermal marking program has been primarily used for coastal fishery management in Alaska, and then coordination of thermal mark coding has not occurred between counties or states. Now the large numbers of thermally-marked salmon are released from hatcheries in North Pacific Rim counties. This provides a good opportunity to study life histories and population dynamics of hatchery salmon and their relations to wild stocks in the ocean. To avoid duplications of thermal mark patterns between counties at least, we must consider possible coordination under the NPAFC.

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Table 1. Protein coding loci of enzymes used for stock identification of high-seas chum salmon and the tissues and buffers in which they were resolved.

Enzyme	EC No.	Locus	Tissue[*1]	Buffer[*2]
Aspartate aminotransferase	2.6.11	sAAT-1,2*	H, M	ACE7.0, TBE
		mAAT-1*	H	ACE7.0
Aconitae hydratase	4.2.1.3	mAH-3*	H	ACE7.0
Alanine aminotransferase	2.6.1.2	ALAT*	M	TBE
Esterase-D	3.1.1.-	ESTD*	H, M	TBCLE, TBE
Glyceraldehyde-3-phosphate dehydrogenase	1.2.1.12	G3PDH-2*	H	ACE7.0
Glucose-6-phosphate isomerase	5.3.19	GPI-B1,2*	M	TBCLE
		GPI-A*	M	TBCLE
Isocitrate dehydrogenase (NADP+)	1.1.1.42	mIDHP-1*	H, M	ACE7.0
		sIDHP-2*	L	ACE7.0
L-Lactate dehydrogenase	1.1.1.27	LDH-A1*	M	ACE7.0, TBCLE
		LDH-B2*	M	TBCLE
Malate dehydrogenase	1.1.1.37	sMDH-A1*	H, L	ACE7.0, TC4
		sMDH-B1,2*	H, M	ACE7.0
Malic enzyme (NADP+)	1.1.1.40	mMEP-2*	M	ACE7.0
		sMEP-1*	M	ACE7.0
Mannose-6-phosphate isomerase	5.3.1.8	MPI*	H	TBE
Tripeptide aminopeptidase	3.4.-.-	PEPB-1*	H, L, M	ACE7.0, TC4, TBE
Phosphogluconate dehydrogenase	5.4.2.2	PGDH*	H, L, M	ACE7.0

[*1]H, heart; L, liver; M, muscle.
[*2]Buffers and electrophoretic protocol are from Aebersold et al. (1987).

Table 2. A list of thermally-marked chum salmon caught in the Gulf of Alaska in the summer of 1998. FL, fork length; BW, Body weight; GW, gonad weight; Mat, maturity; RBr, Regional band rings showing coding structure of thermal marks (Munk and Geiger, 1998).

No	Date	Lat (N)	Long (W)	Sex	FL (mm)	BW (g)	GW (g)	Mat	Age	RBr	TM ID*
1	08-Jul-98	52°00	145°00	male	400	780	1	IM	0.1	1:1.4	AFK96
2	11-Jul-98	49°00	145°00	male	401	620	1	IM	0.1	1:1.4	AFK96
3	06-Jul-98	54°00	145°00	male	611	2420	3	IM	0.4	2:1.3	DIPAC93
4	06-Jul-98	54°00	145°00	male	525	1680	1	IM	0.3	1:1.4	DIPAC94
5	30-Jun-98	45°30	165°00	female	456	1120	7	IM	0.2	1:1.5	DIPAC95
6	05-Jul-98	55°00	145°00	male	479	1220	1	IM	0.2	1:1.5	DIPAC95
7	06-Jul-98	54°00	145°00	female	506	1520	12	IM	0.2	1:1.5	DIPAC95
8	06-Jul-98	54°00	145°00	female	506	1440	11	IM	0.2	1:1.5	DIPAC95
9	07-Jul-98	53°00	145°00	female	491	1480	12	IM	0.2	1:1.5	DIPAC95
10	07-Jul-98	53°00	145°00	male	514	1540	1	IM	0.2	1:1.5	DIPAC95
11	07-Jul-98	53°00	145°00	female	497	1560	10	IM	0.2	2:1.5	DIPAC95
12	07-Jul-98	53°00	145°00	female	467	1220	13	IM	0.2	1:1.5	DIPAC95
13	08-Jul-98	52°00	145°00	male	506	1460	1	IM	0.2	1:1.5	DIPAC95
14	08-Jul-98	52°00	145°00	female	512	1600	14	IM	0.2	1:1.5	DIPAC95
15	08-Jul-98	52°00	145°00	female	488	1340	11	IM	0.2	1:1.5	DIPAC95
16	06-Jul-98	54°00	145°00	male	378	560	1	IM	0.1	1:1.6	DIPAC96
17	08-Jul-98	52°00	145°00	male	405	740	1	IM	0.2	1:1.6	DIPAC96
18	09-Jul-98	51°00	145°00	male	358	520	1	IM	0.1	1:1.6	DIPAC96
19	09-Jul-98	51°00	145°00	male	384	680	1	IM	0.1	1:1.6	DIPAC96
20	11-Jul-98	49°00	145°00	female	369	540	5	IM	0.1	1:1.6	DIPAC96
21	11-Jul-98	49°00	145°00	male	395	620	2	IM	0.1	1:1.6	DIPAC96
22	29-Jun-98	47°00	165°00	female	467	1300	11	IM	0.2	1:1.3,2.3	HF95
23	04-Jul-98	56°00	145°00	female	529	1820	110	MT	0.3	1:1.3,2.3	HF95
24	06-Jul-98	54°00	145°00	female	477	1180	14	IM	0.2	1:1.3,2.3	HF95
25	08-Jul-98	52°00	145°00	male	504	1640	1	IM	0.2	1:1.3,2.3	HF95
26	08-Jul-98	52°00	145°00	male	482	1280	1	IM	0.2	1:1.3,2.3	HF95
27	05-Jul-98	55°00	145°00	male	368	520	1	IM	0.1	1:1.3,2.4	HF96
28	06-Jul-98	54°00	145°00	female	382	640	5	IM	0.1	1:1.3,2.4	HF96
29	07-Jul-98	53°00	145°00	male	336	460	1	IM	0.1	1:1.3,2.4	HF96
30	08-Jul-98	52°00	145°00	female	388	680	12	IM	0.1	1:1.3,2.4	HF96
31	09-Jul-98	51°00	145°00	male	418	740	1	IM	0.1	1:1.3,2.4	HF96
32	09-Jul-98	51°00	145°00	male	376	600	1	IM	0.1	1:1.3,2.4	HF96
33	10-Jul-98	50°00	145°00	male	392	660	1	IM	0.1	1:1.3,2.4	HF96
34	11-Jul-98	49°00	145°00	female	333	390	3	IM	0.1	1:1.3,2.4	HF96

Table 2. (continued)

No	Date	Lat (N)	Long (W)	Sex	FL (mm)	BW (g)	Gonad (g)	Mat	Age	RBr	TM ID*
35	05-Jul-98	55°00	145°00	female	631	3000	12	IM	0.2	1:1.3+2.3	NIT95
36	08-Jul-98	52°00	145°00	female	405	780	3	IM	0.1	1:1.4	NIT96
37	09-Jul-98	51°00	145°00	female	378	620	7	IM	0.1	1:1.6	PC96E
38	09-Jul-98	51°00	145°00	male	368	560	1	IM	0.1	1:1.6	PC96E
39	11-Jul-98	49°00	145°00	female	418	860	8	IM	0.1	1:1.6	PC96E
40	06-Jul-98	54°00	145°00	male	429	820	1	IM	0.1	1:1.3,2.2	WHN96L
41	08-Jul-98	52°00	145°00	male	428	960	1	IM	0.1	1:1.3,2.2	WHN96L
42	08-Jul-98	52°00	145°00	female	407	740	5	IM	0.1	1:1.3,2.2	WHN96L
43	09-Jul-98	51°00	145°00	male	394	600	1	IM	0.1	1:1.3,2.2	WHN96L
44	09-Jul-98	51°00	145°00	female	379	640	7	IM	0.1	1:1.3,2.2	WHN96L
45	10-Jul-98	50°00	145°00	female	354	460	7	IM	0.1	1:1.3,2.2	WHN96L
46	11-Jul-98	49°00	145°00	female	404	780	10	IM	0.1	1:1.3,2.2	WHN96L
47	11-Jul-98	49°00	145°00	male	423	820	1	IM	0.1	1:1.3,2.2	WHN96L
48	11-Jul-98	49°00	145°00	male	395	640	1	IM	0.1	1:1.3,2.2	WHN96L
49	11-Jul-98	49°00	145°00	female	385	660	9	IM	0.1	1:1.3,2.2	WHN96L
50	11-Jul-98	49°00	145°00	male	390	640	1	IM	0.1	1:1.3,2.2	WHN96L
51	11-Jul-98	49°00	145°00	male	375	620	1	IM	0.1	1:1.3,2.2	WHN96L

*AFK, Armin F. Koering Hatchery; DIPAC, Gastineau Hatchery; HF, Hidden Falls Hatchery; NIT, Nitinat Hatchery; PC, Wally H. Noerenberg Hatchery (Port Chalmers); WHN, Wally H. Noerenberg Hatchery.

Table 3. Regional stock composition estimates (%) of immature and maturing chum salmon determined by genetic stock analysis.

Location of capture	Date of capture	Number of fish	Japan	Russia	Fall Yukon	Western Alaska	Alaska Pen. /Kodiak	Southeast Alaska/PWS	Alaska Total	British Columbia	Washington
Central Gulf of Alaska											
49-52°N, 145°W	8-11 Jul. 98	148	1.4±1.7*[1]	9.5±5.3	0.4±1.0	15.1±4.8	28.8±9.2	27.7±10.2	72.0±10.3	15.5±8.9	1.7±2.9
53-56°N, 145°W	4-7 Jul. 98	190	1.4±1.5	13.7±6.1	0.7±0.9	13.2±4.2	21.6±7.5	20.7±9.4	56.2±10.0	24.5±8.9	4.2±4.6
49-56°N, 145°W	4-11 Jul. 98	338	1.2±1.1	10.1±4.4	0.4±0.6	14.5±3.4	24.7±6.5	28.3±8.9	67.8±8.5	17.5±7.4	3.8±3.3
Western Gulf of Alaska											
45-50°N, 165°W	26-30 Jun. 98	188	24.5±5.3	53.3±7.1	0.3±0.9	13.0±5.2	3.9±3.4	1.0±1.7	18.3±6.0	3.3±2.3	0.7±1.1

*[1] Estimate ± SD.

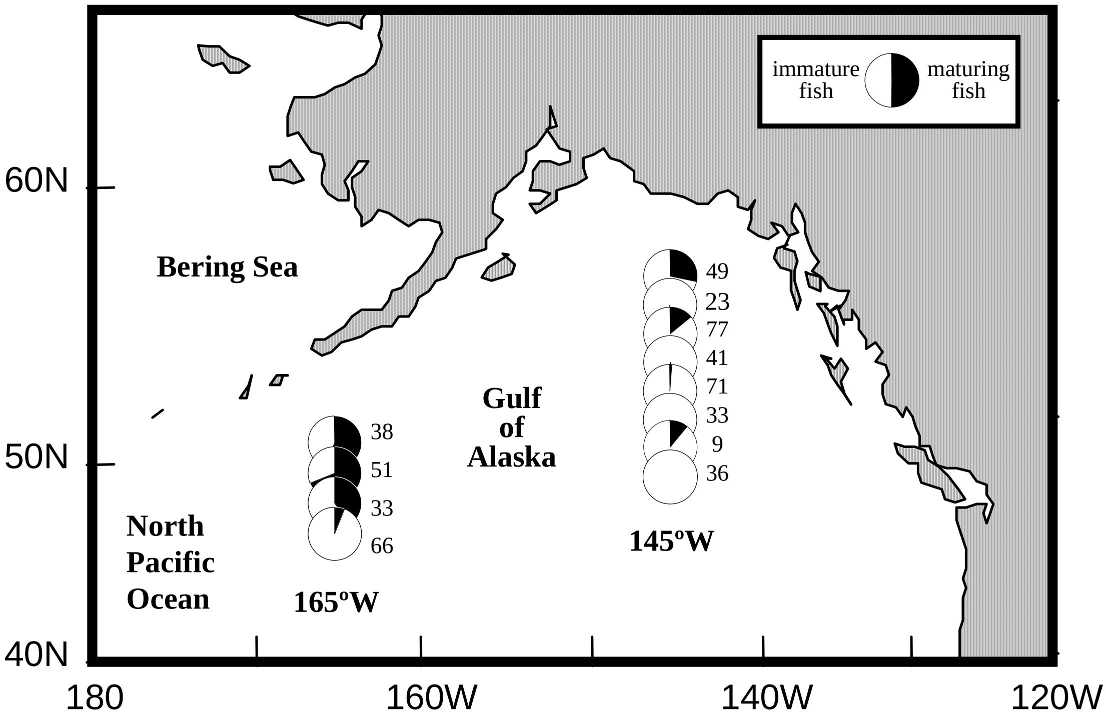

Figure 1. A map showing sampling locations with the ratio of maturing and immature chum salmon caught in 145°W and 165°W transects of the Gulf of Alaska during June and July 1998. Numerals indicate the number of fish samples at each sampling location.

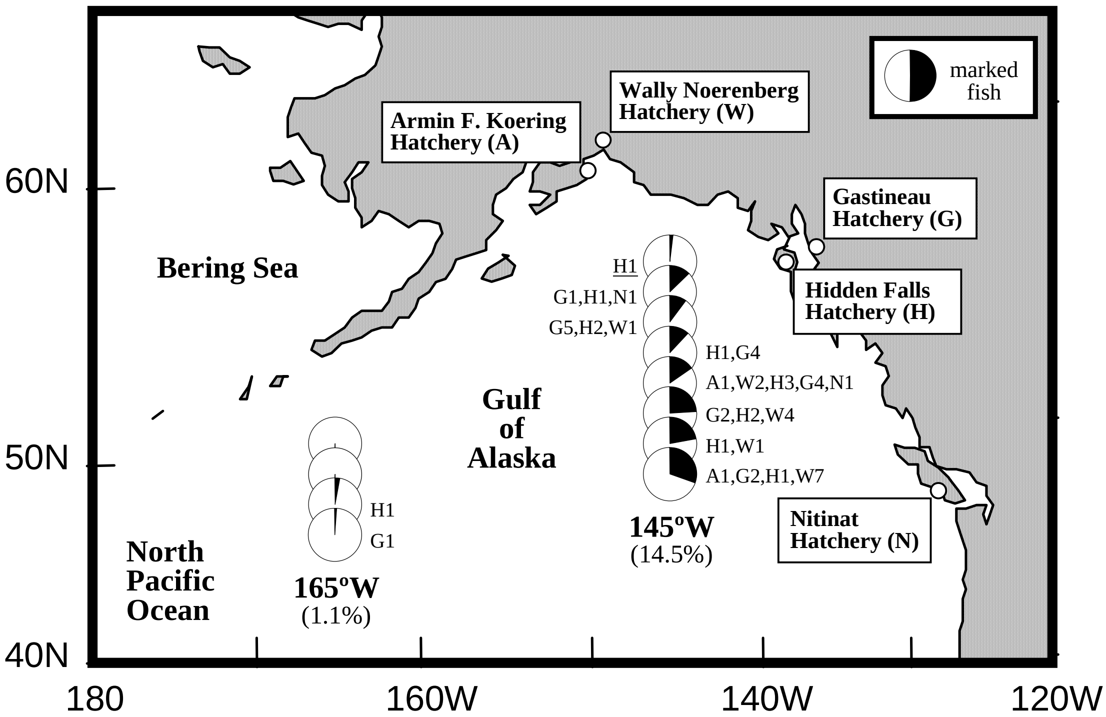

Figure 2. Ratio (%) of thermally otolith marked fish among chum salmon caught in 145°W and 165°W transects of the Gulf of Alaska during June and July 1998. Numerals indicate number of thermally-marked fish. All marked fish are immature except for one maturing fish (56°N, 145°W) indicated by an underline.

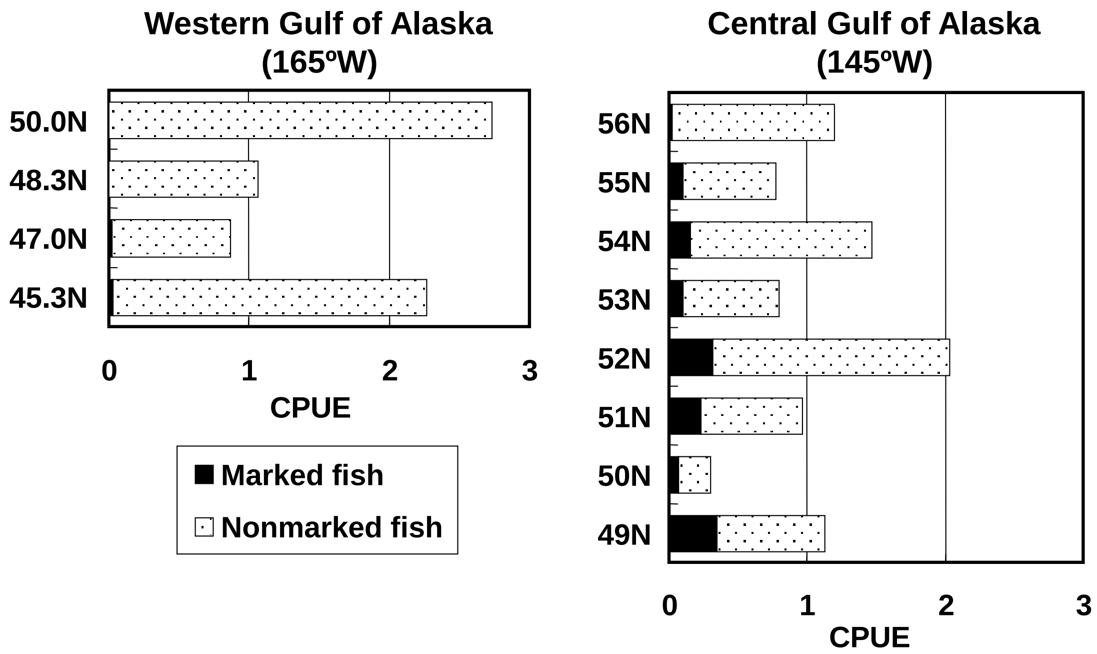

Figure 3. CPUE (fish catch per tan of research gillnet) of thermally marked and nonmarked chum salmon in 145°W and 165°W transects of the Gulf of Alaska in the summer of 1998.

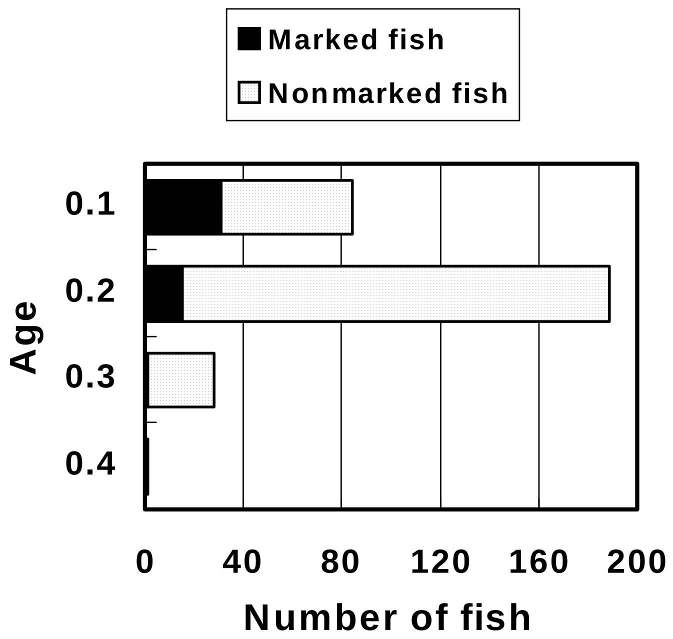

Figure 4. By age composition of thermally-marked fish among immature chum salmon caught in 145°W transect of the Gulf of Alaska in the summer of 1998.

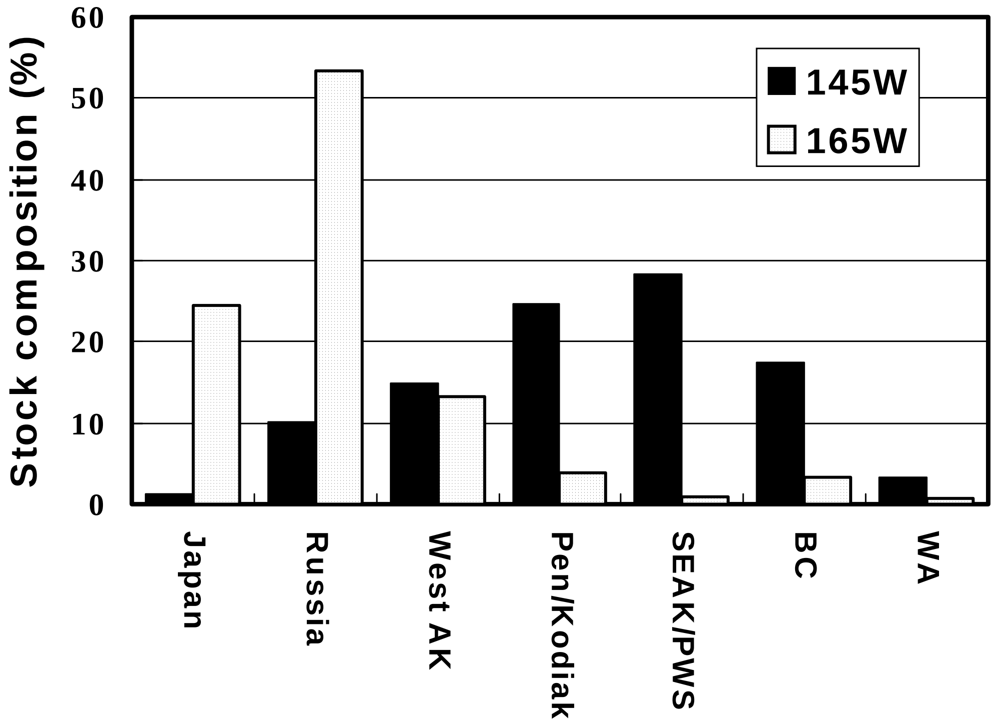

Figure 5. GSI-estimated stock composition (%) of chum salmon caught in 145°W and 165°W transects of the Gulf of Alaska in the summer of 1998.

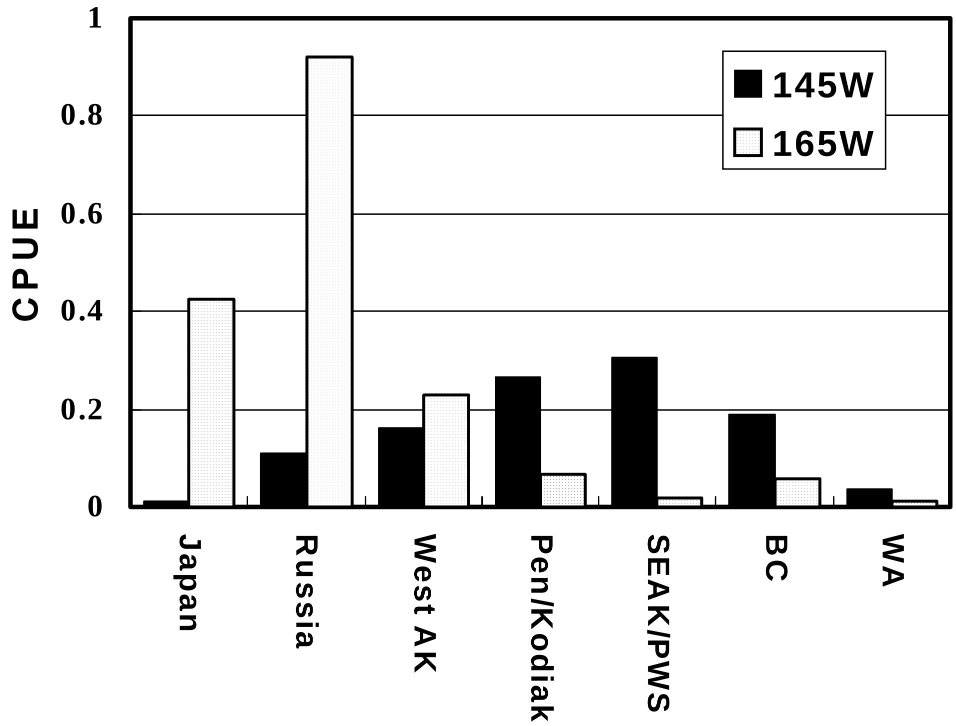

Figure 6. GSI-estimated CPUE (number of fish per tan of research gillnets) of chum salmon caught in 145°W and 165°W transects of the Gulf of Alaska in the summer of 1998 by stocks.

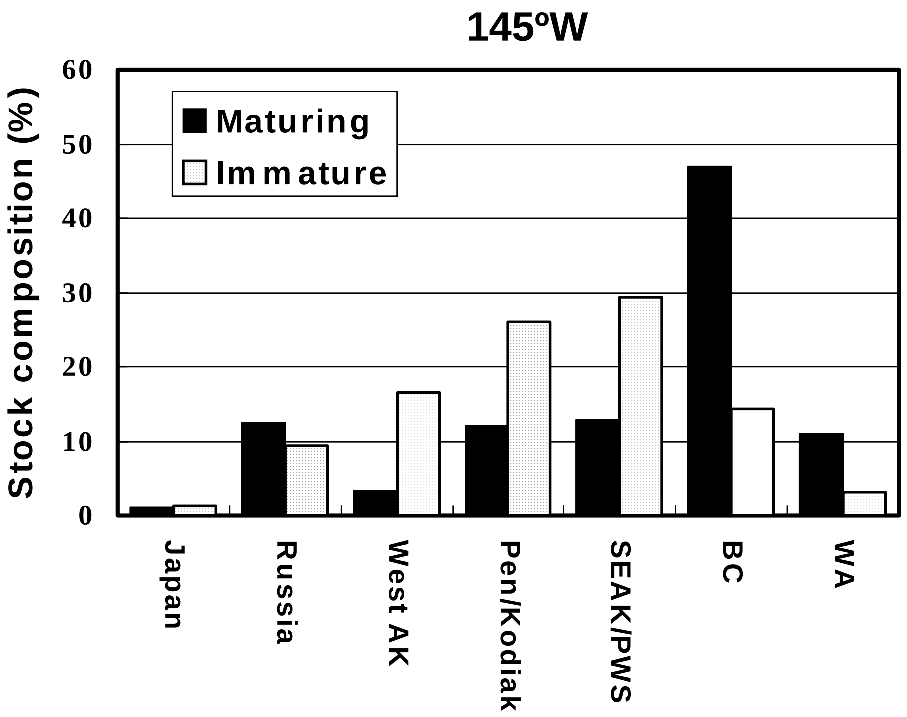

Figure 7. GSI-estimated stock composition (%) of immature and maturing chum salmon caught in 145°W transect of the Gulf of Alaska in the summer of 1998.

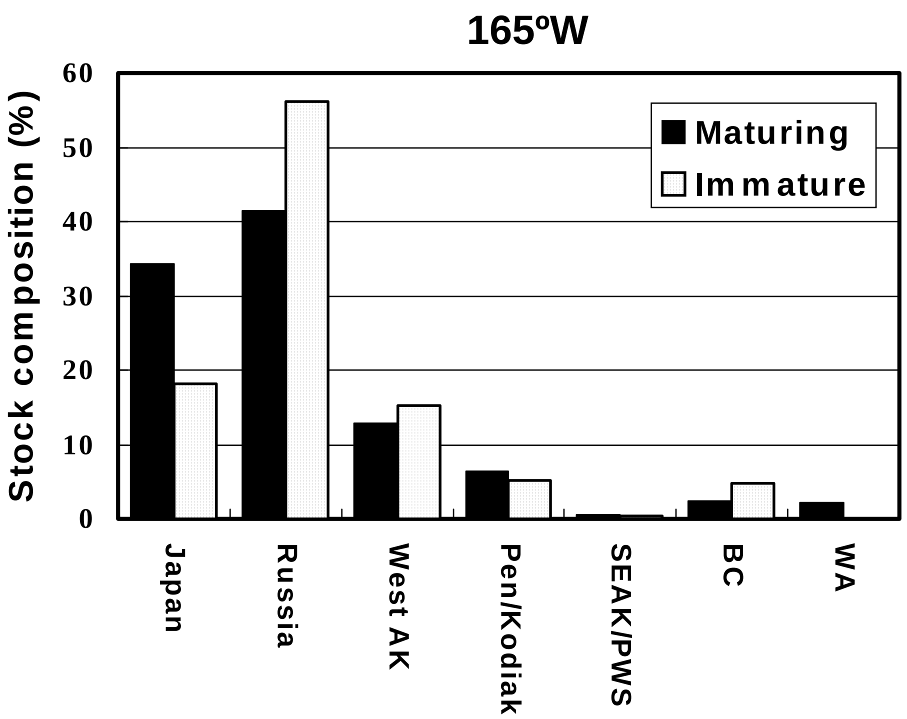

Figure 8. GSI-estimated stock composition (%) of immature and maturing chum salmon caught in 165°W transects of the Gulf of Alaska in the summer of 1998.

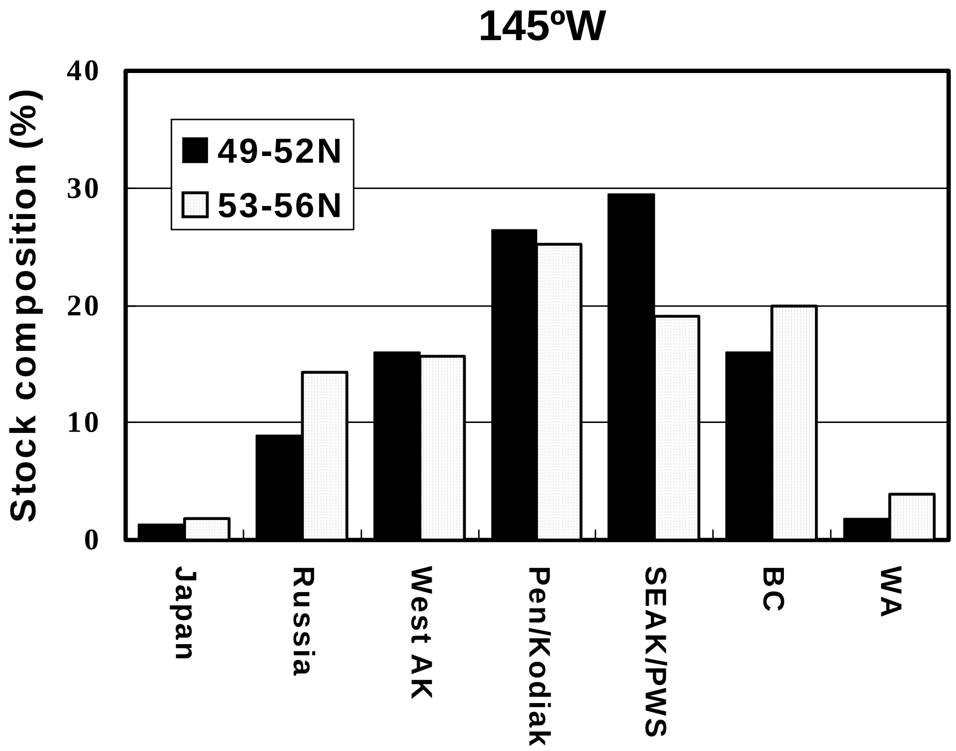

Figure. 9. A comparison of GSI-estimated stock composition (%) of immature chum salmon caught in the southern (49-52°N) and northern (53-56°N) waters of 145°W transect of the Gulf of Alaska in the summer of 1998.

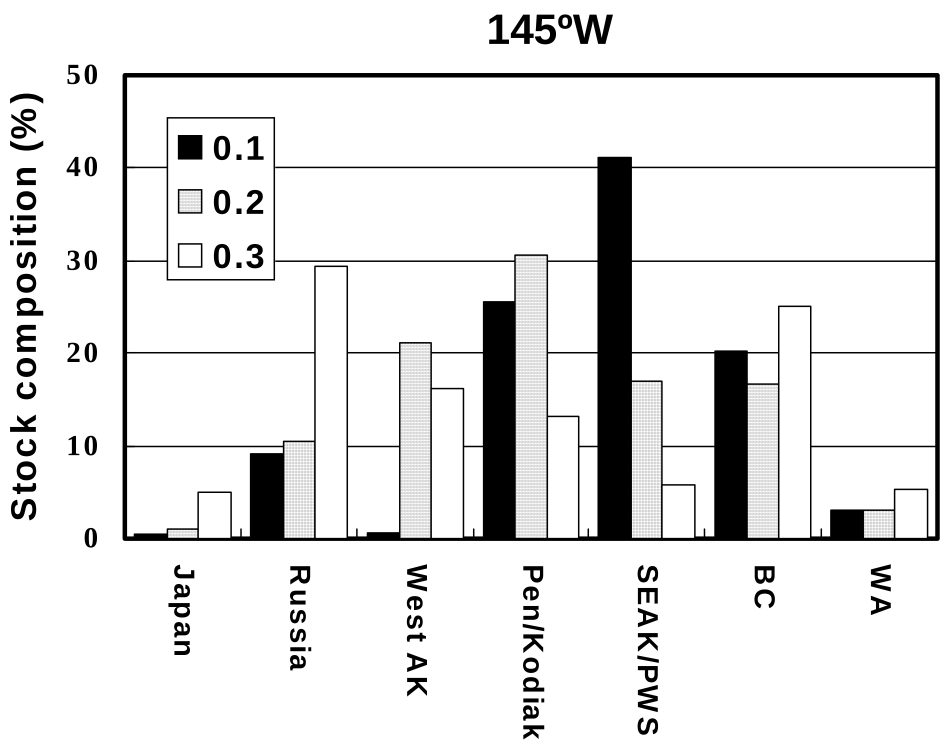

Figure 10. By age stock composition (%) of immature chum salmon caught in 145°W transect of the Gulf of Alaska in the summer of 1998. The compositions were estimated by genetic stock identification.

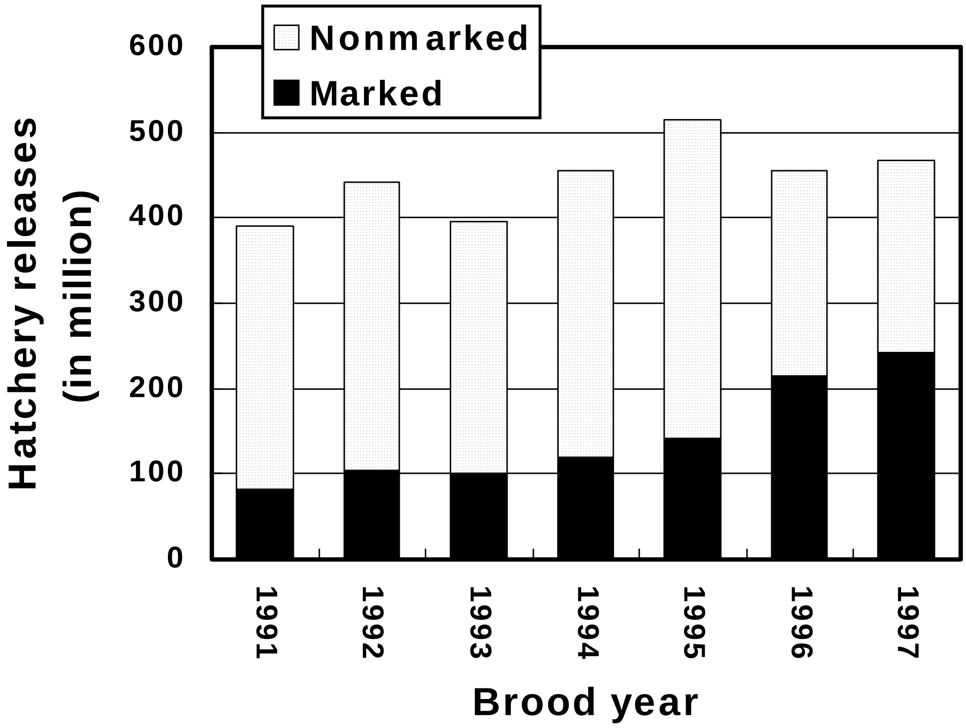

Figure 11. Annual changes in number of thermally otolith marked chum salmon juveniles released from hatcheries in southeast Alaska and Prince William Sound.