Stock-specific Ocean Distribution and Migration of Chum Salmon in the Bering Sea and North Pacific Ocean

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Abstract: Chum salmon (*Oncorhynchus keta*) is a major pelagic fish species in the Bering Sea and North Pacific ecosystems. The stock-specific ocean distribution of chum salmon was estimated by genetic stock identification (GSI) and hatchery otolith marks. Fish were caught by 1-h trawls at 98 stations in the Bering Sea, North Pacific Ocean and Gulf of Alaska during the early summer (June/July) and late summer/early fall (August/September) of 2003. Tissue samples were collected from chum salmon (n = 3,980) and run for 20 allozyme loci to estimate the stock composition of mixtures. In addition, otoliths were collected from chum salmon (n = 4,424) and examined for mark patterns to determine hatchery origin. The GSI-estimates combined with catch data (CPUE) indicated that the ocean distribution patterns of immature chum salmon were different among eleven regional stocks. Japanese stocks were mainly distributed in the Bering Sea during summer and early fall. The distribution of Russian (primarily northern Russian) stocks was similar to that of Japanese chum salmon, but they also spread into the North Pacific Ocean. Northwest Alaska stocks including fall runs in the Yukon River were relatively abundant at the southern edge (50°N) of the Gulf of Alaska and eastern North Pacific Ocean. Alaska Peninsula/Kodiak Island stocks were widely distributed in the Bering Sea and North Pacific Ocean. The southeast Alaska (SEAK)/North British Columbia (BC) stocks were distributed throughout the northern Gulf of Alaska, the eastern North Pacific Ocean and the southern Bering Sea. The distribution of the South BC/Washington stocks was similar to that of the SEAK/North BC stocks, but extended into the central Bering Sea. The samples included otolith-marked chum salmon released from Alaska (n = 66), Canada (n = 3), Japan (n = 23) and Russia (n = 6). The recovery sites of marked fish were largely consistent with the marine distribution of those regional stocks estimated by GSI. The seasonal migration patterns of Japanese chum salmon in the Bering Sea were assessed from the best available information.

Keywords: genetic stock identification, otolith mark, chum salmon, ocean distribution, migration route, Bering Sea, North Pacific Ocean, Gulf of Alaska

INTRODUCTION

The Bering Sea provides major feeding habitats for various salmon stocks originating from Asia and North America. A better understanding of salmon community structure will clarify the mechanisms of the salmon population response to recent environmental changes (Myers et al. 2007). Chum salmon (*Oncorhynchus keta*) is a dominant pelagic fish in the Bering Sea during summer and fall especially after pink salmon (*O. gorbuscha*) have moved to coastal areas for spawning (Nagasawa and Azumaya 2009).

Genetic stock identification (GSI) techniques using allozyme variation were established for estimating stock compositions of high-seas chum salmon (Seeb et al. 1995, 2004; Wilmot et al. 1998; Winans et al. 1998; Seeb and Crane 1999a, 1999b). The previous allozyme analyses suggested that Japanese and Russian stocks were predominant in chum salmon mixtures in the central Bering Sea (Urawa et al. 1997, 1998, 2004; Winans et al. 1998), while North American stocks were predominant in the Gulf of Alaska (Urawa et al. 2000). In addition, mitochondrial DNA (mtDNA) markers were recently used to estimate the stock origins of chum

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salmon in the Bering Sea (Moriya et al. 2007, 2009; Sato et al. 2009a), however the resolution of the mtDNA analysis was limited to identifying only three regional stocks (Japan, Russia and North America).

Otolith marking is an effective tool for determining the hatchery origin of individual salmon in both high seas and coastal waters (Volk and Hagen 2001). Otolith-marked salmon are annually released from hatcheries in Canada, Japan, Korea, Russia and the United States under the coordination of the North Pacific Anadromous Fish Commission (NPAFC) (Josephson 2007). The total number of otolith-marked chum salmon released in 1999–2002 was approximately 1.3 billion juveniles (11.8% of the total hatchery releases in the North Pacific Rim countries).

This study used allozyme and otolith markers to estimate stock origins of maturing and immature chum salmon in the Bering Sea and North Pacific Ocean, including the Gulf of Alaska, during the summer and early fall of 2003, and to determine the ocean distribution and migration patterns of eleven regional stocks.

MATERIALS AND METHODS

Fish Samples

Trawl surveys were conducted at 98 stations in the Bering Sea and North Pacific Ocean by the research vessel *Kaiyo maru* during the early summer (June 28 to July 18) and the late summer/early fall (August 2 to September 19) of 2003 (NPAFC 2004). At each station a trawl net was towed at the surface for one hour at a speed of 5 knots. The average opening of the net during towing was 53 m in width and 54 m in height. A total of 9,600 chum salmon were caught during the two survey periods.

Maturity of fish was determined from gonad weights (Takagi 1961). Age was determined by visual examination of scale samples and designated by the European method, in which the number preceding the period is the number of freshwater annuli (zero for chum salmon) and the number following the period is the number of ocean annuli (Koo 1962).

For GSI, tissue samples (liver, heart and muscle) were collected from 3,980 chum salmon, and immediately deep frozen until allozyme analysis at the National Salmon Resources Center (NASREC) in Sapporo, Japan. In addition, otoliths were collected from 4,424 chum salmon to determine their hatchery origins at the Mark, Tag, and Age Laboratory, Alaska Department of Fish and Game, Juneau, Alaska, USA.

Allozyme Analysis

Tissue 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 (ALAT*, mAAT-1*, sAAT-1,2*, mAH-3*, ESTD*, G3PDH-2*, GPI-A*, GPIB-1,2, mIDHP-1*, sIDHP-2*, LDH-A1*, LDHB-2*, sMDHA-1*, sMDHB-1,2*, mMEP-2*, sMEP-1*, MPI*, PEPA*, PEPB-1*, and PGDH*) (see Table 1 in Kondzela et al. 2002 and Table 2 in Urawa et al. 2006).

Baseline and Statistical Estimates

We used the simplified baseline data set (124 stock groups/20 loci) formulated in Seeb et al. (1997) with additional data from Japan (the Gakko R., Hei R., Katagishi R., Kido R., Koizumi R., Kurobe R., Orikasa R., Naruse R., Sho R., Tedori R., and Uono R. in Honshu, and the Abashiri R., Shikiu R., Shizunai R., Yubetsu R., and Yurrapu R. in Hokkaido) (Urawa et al. 2006). Estimates of stock contributions were made with a conditional maximum likelihood algorithm (Pella and Milner 1987) by using the Statistical Package for Analyzing Mixtures (SPAM version 3.7) developed by Debevec et al. (2000). Standard deviations of stock estimates were estimated by 1,000 bootstrap resamplings of the baseline and mixture samples.

Based on genetic similarity and 100% simulation analysis among baseline stocks, eleven reporting regions were selected. These included five regions in Asia: 1) Japan, 2) Sakhalin, 3) Premorye, 4) Amur, and 5) north Russia (north Okhotsk coast, Kamchatka and Anadyr); and six regions in North America: 6) northwest Alaska summer, 7) fall Yukon, 8) Alaska Peninsula/Kodiak Island, 9) Prince William Sound (PWS), 10) southeast Alaska/north British Columbia (BC), and 11) south BC/Washington. Estimates were made to individual stocks and then pooled into regional stock groups. Simulation studies indicated that most reporting regions showed greater than 90% accuracy when true group contributions were 100% (Table 1).

Stock-specific CPUE (number of fish caught per 1-h trawl) was calculated by using the GSI estimates and catch data of chum salmon.

Otolith Analysis

The left sagittal otoliths were mounted on glass slides using thermoplastic cement, and then ground to expose the primordia. If the left sagittal otolith was not adequate for identification, the right sagittal otolith was used. Otolith microstructures were observed under a light microscope, and the microstructure patterns were compared to the otolith mark patterns of voucher specimens deposited in the NPAFC database (www.npafc.taglab.org). Otolith mark patterns are presented in the uniform hatch code notation (Johnson et al. 2006).

Table. 1. Mean estimated contribution and standard deviations for 1,000 simulations where each region comprises 100% of the mixture (n = 400). Shaded cells are correct allocations and should equal 1.00.

Reporting region	Japan		Sakhalin Island		Premorye		Amur	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1. Japan	0.964	0.020	0.039	0.028	0.151	0.072	0.001	0.003
2. Sakhalin Island	0.005	0.009	0.903	0.037	0.011	0.018	0.002	0.006
3. Premorye	0.004	0.009	0.003	0.007	0.826	0.081	0.000	0.001
4. Amur River	0.001	0.002	0.003	0.005	0.000	0.001	0.961	0.043
5. North Russia	0.006	0.007	0.015	0.014	0.001	0.002	0.012	0.019
6. Northwest Alaska Summer	0.009	0.011	0.017	0.018	0.002	0.006	0.004	0.009
7. Fall Yukon	0.002	0.005	0.002	0.003	0.000	0.001	0.000	0.001
8. Alaska Peninsula/Kodiak	0.007	0.007	0.006	0.006	0.006	0.008	0.017	0.029
9. Prince William Sound	0.000	0.001	0.001	0.002	0.000	0.000	0.000	0.002
10. Southeast Alaska/North BC	0.001	0.002	0.001	0.003	0.001	0.002	0.000	0.000
11. South BC/Washington	0.001	0.002	0.002	0.004	0.000	0.002	0.000	0.000

Reporting region	North Russia		NW Alaska Summer		Fall Yukon		AK Peninsula/Kodiak	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1. Japan	0.010	0.010	0.010	0.010	0.002	0.003	0.006	0.007
2. Sakhalin Island	0.004	0.008	0.002	0.004	0.000	0.001	0.001	0.002
3. Premorye	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.001
4. Amur River	0.003	0.005	0.001	0.002	0.000	0.001	0.002	0.005
5. North Russia	0.902	0.036	0.013	0.014	0.001	0.002	0.013	0.014
6. Northwest Alaska Summer	0.025	0.021	0.895	0.049	0.041	0.040	0.005	0.008
7. Fall Yukon	0.002	0.004	0.064	0.043	0.954	0.040	0.001	0.003
8. Alaska Peninsula/Kodiak	0.040	0.025	0.007	0.008	0.001	0.001	0.935	0.030
9. Prince William Sound	0.004	0.007	0.001	0.002	0.000	0.001	0.010	0.013
10. Southeast Alaska/North BC	0.004	0.007	0.000	0.002	0.000	0.000	0.018	0.019
11. South BC/Washington	0.002	0.004	0.000	0.001	0.000	0.000	0.007	0.009

Reporting region	Prince William Sound		SE Alaska/N BC		S BC/Washington	
	Mean	SD	Mean	SD	Mean	SD
1. Japan	0.001	0.002	0.004	0.005	0.001	0.002
2. Sakhalin Island	0.000	0.001	0.001	0.003	0.000	0.001
3. Premorye	0.000	0.000	0.000	0.002	0.000	0.000
4. Amur River	0.001	0.002	0.001	0.003	0.001	0.002
5. North Russia	0.008	0.011	0.007	0.009	0.001	0.003
6. Northwest Alaska Summer	0.001	0.002	0.002	0.004	0.000	0.001
7. Fall Yukon	0.000	0.001	0.001	0.002	0.000	0.000
8. Alaska Peninsula/Kodiak	0.034	0.024	0.074	0.041	0.010	0.011
9. Prince William Sound	0.938	0.029	0.009	0.013	0.003	0.006
10. Southeast Alaska/North BC	0.006	0.011	0.863	0.052	0.010	0.013
11. South BC/Washington	0.008	0.011	0.036	0.027	0.973	0.017

RESULTS

Abundance, Maturity and Age Composition

Early Summer

Chum salmon were caught at all sampling stations (n = 37) in the Bering Sea and adjacent North Pacific Ocean during June and July 2003 (Fig. 1A). The highest CPUE (number of fish caught per one-hour trawl) was recorded in the eastern North Pacific Ocean (51°N, 165–170°W). Most (94%) chum salmon were immature in the North Pacific Ocean, while the percentage of maturing fish averaged 25% in the Bering Sea (Fig. 1B). The age composition of immature chum salmon was 15.9% age 0.1, 41.8% age 0.2, 36.6% age 0.3 and 4.2% age 0.4 in the Bering Sea, and 39.6% age 0.1, 39.6% age 0.2, 17.4% age 0.3 and 2.7% age 0.4 in the

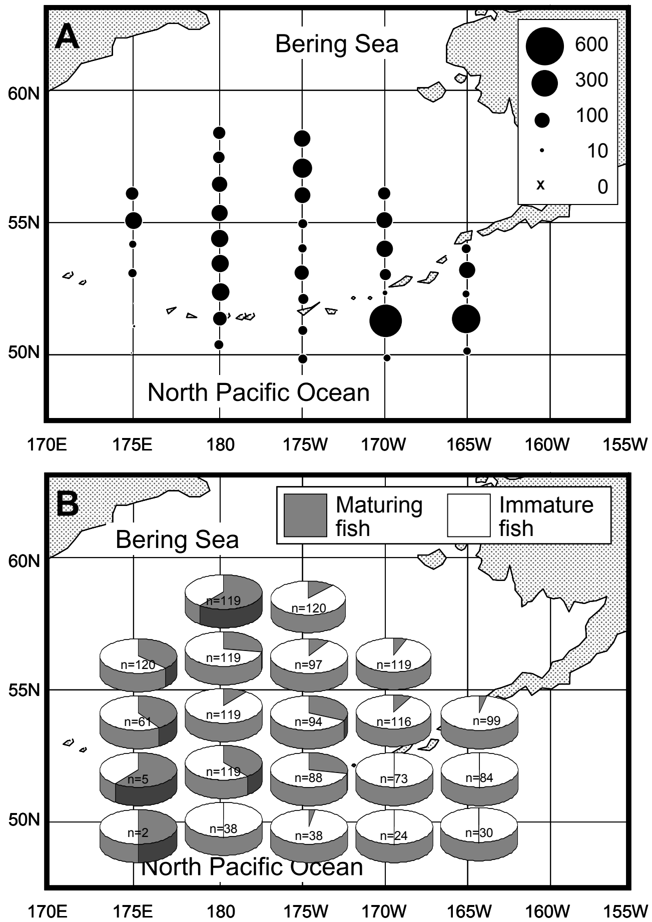

Fig. 1. CPUE distribution (A) and percent composition of maturing and immature fish (B) of chum salmon caught in the Bering Sea and North Pacific Ocean during June and July 2003. CPUE = number of fish caught per 1-h trawl, n = number of samples.

North Pacific Ocean. Therefore the major age-classes were 0.2 and 0.3 fish in the Bering Sea, and 0.1 and 0.2 in the North Pacific Ocean. Young chum salmon (age 0.1) were most prevalent in the central North Pacific Ocean (50–52°N, 175°E–175°W) and southern Bering Sea (52–54°N, 180–175°W).

Late Summer/Early Fall

In August and September, chum salmon were widely distributed in the Bering Sea and North Pacific Ocean except for the central Gulf of Alaska (50–53°N, 145°W), and they were most abundant in the southern Bering Sea (Fig. 2A). The majority of chum salmon were immature at every station (Fig. 2B). The age composition of immature chum salmon was 44.9% age 0.1, 38.6% age 0.2 and 14.4% age 0.3 in the Bering Sea, and 32.6% age 0.1, 45.5% age 0.2 and 19.4% age 0.3 in the North Pacific Ocean and Gulf of Alaska. Thus age 0.1 and 0.2 fish were predominant over the entire area. Young chum salmon (age 0.1) showed a trend of occurring in marginal habitat: north in the Bering Sea, and south in the eastern North Pacific Ocean and the Gulf of Alaska.

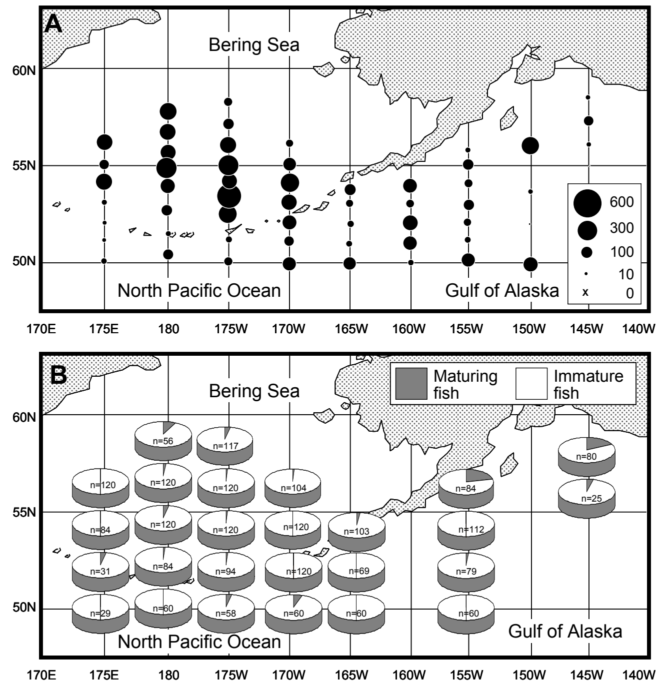

Fig. 2. CPUE distribution (A) and percent composition of maturing and immature fish (B) of chum salmon caught in the Bering Sea, North Pacific Ocean and Gulf of Alaska during August and September 2003. CPUE = number of fish caught per 1-h trawl, n = number of samples.

Stock-specific Distribution Estimated by GSI

Early Summer

The GSI-estimated stock composition of maturing chum salmon was 45–71% Japanese and 21–42% Russian stocks in the Bering Sea (Fig. 3A, Table 2). Russian stocks comprised 52% of maturing fish in the central North Pacific Ocean (50–52°N, 175°E–175°W). The percentage of North American stocks was 37% in the eastern Bering Sea (53–56°N, 170°W), but less than 20% in the other areas. The estimated CPUE of Japanese and Russian maturing chum salmon was extremely high in the Bering Sea (except for the eastern waters), and low in the North Pacific Ocean (Fig. 3B). The majority of Russian maturing fish originated from the Sakhalin and north Russia regions, and they were most abundant in the western and southern Bering Sea (Table 2). The distribution of Japanese maturing fish also shifted west of 175°W in the Bering Sea with the highest CPUE at the central stations (Fig. 3B). Most of North American maturing fish in the Bering Sea originated from the northwest Alaska and Alaska Peninsula/Kodiak Island regions (Table 2).

The estimated stock composition of immature chum salmon in the Bering Sea was similar to that of maturing fish, with Japanese and Russian stocks accounting for 37–68% and 25–45% of fish mixtures, respectively (Fig. 4A, Table 3). In the central and eastern North Pacific Ocean, however, the stock composition was almost equal for the three major

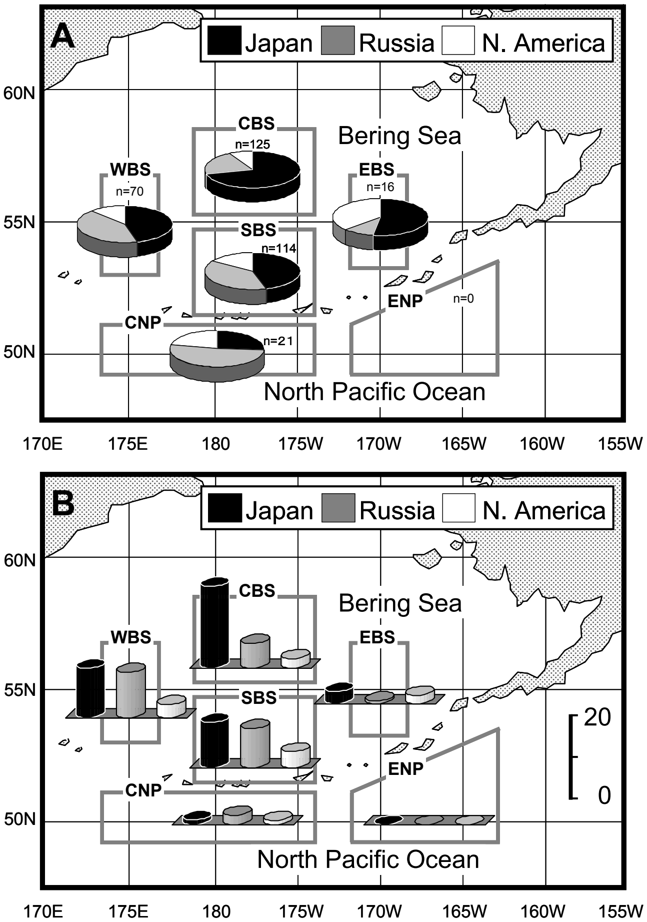

Fig. 3. GSI-estimated stock composition (A) and mean CPUE (B) of maturing chum salmon caught in the Bering Sea and North Pacific Ocean during June and July 2003. CPUE = number of fish caught per 1-h trawl, n = number of samples, CBS = central Bering Sea (55-58ºN, 180-175ºW), EBS = eastern Bering Sea (53-56ºN, 170ºW), SBS = southern Bering Sea (52-54ºN, 180-175ºW), WBS = western Bering Sea (53-56ºN, 175ºE), CNP = central North Pacific Ocean (50-52ºN, 175ºE-175ºW), ENP = eastern North Pacific Ocean (50-53ºN, 165-170ºW).

groups: 25–39% for Japanese, 39–44% for Russian and 23–31% for North American stocks. Japanese immature chum salmon were mainly distributed in the eastern North Pacific Ocean and the Bering Sea, with the highest CPUE in the central Bering Sea (Fig. 4B). Russian immature fish were also abundant in the same areas, but their highest CPUE was recorded in the eastern North Pacific Ocean. North Russian stocks comprised 68–89% of Russian immature fish (Table 3). North American immature stocks (except for fall Yukon and PWS fish) were abundant in the eastern North Pacific Ocean, while they were relatively scarce in the Bering Sea and central North Pacific Ocean (Fig. 4B, Table 3).

Late Summer/Early Fall

Maturing chum salmon were rare in the survey areas during August and September, and thus were not adequate for GSI.

Table 2. GSI-estimated mean stock contribution and standard deviation for maturing chum salmon caught in the Bering Sea, and North Pacific Ocean in 2003. Estimated mean CPUE (number of fish caught per 1-h trawl) is indicated in parentheses. N = number of samples, NWAK = Northwest Alaska summer, AP = Alaska Peninsula, PWS = Prince William Sound, SEAK = Southeast Alaska, NBC = North British Columbia, SBC = South British Columbia, WA = Washington.

Sampling Area/ Date	N	JAPAN	RUSSIA					NORTH AMERICA						
			N. Russia	Premonye	Amur R.	Sakhalin	Total	Fall Yukon	NWAK	AP/Kodiak	PWS	SEAK/NBC	SBC/WA	Total
Western Bering Sea (53-56ºN, 175ºE)														
June 30 - July 1	70	0.459±0.104	0.288±0.080	0.039±0.044	0.009±0.017	0.083±0.044	0.419±0.102	0.000	0.091±0.061	0.027±0.040	0.000	0.003±0.015	0.000	0.122±0.075
		(11.3)	(7.1)	(1.0)	(0.2)	(2.0)	(10.3)	(0.0)	(2.2)	(0.7)	(0.0)	(0.1)	(0.0)	(3.0)
Central Bering Sea (55-58ºN, 180-175ºW)														
July 2-11	125	0.708±0.070	0.104±0.049	0.015±0.026	0.007±0.011	0.086±0.057	0.213±0.077	0.000	0.032±0.032	0.029±0.029	0.002±0.007	0.008±0.015	0.009±0.010	0.079±0.045
		(18.6)	(2.7)	(0.4)	(0.2)	(2.3)	(5.6)	(0.0)	(0.8)	(0.8)	(0.1)	(0.2)	(0.2)	(2.1)
Southern Bering Sea (52-54ºN, 180-175ºW)														
July 4-10	114	0.453±0.091	0.267±0.085	0.008±0.020	0.003±0.009	0.111±0.067	0.389±0.108	0.002±0.006	0.105±0.064	0.034±0.038	0.005±0.013	0.011±0.016	0.002±0.007	0.158±0.080
		(10.3)	(6.1)	(0.2)	(0.1)	(2.5)	(8.9)	(0.0)	(2.4)	(0.8)	(0.1)	(0.2)	(0.0)	(3.6)
Eastern Bering Sea (53-56ºN, 170ºW)														
July 12-14	16	0.526±0.186	0.028±0.064	0.062±0.112	0.000	0.013±0.045	0.103±0.136	0.000	0.042±0.070	0.134±0.127	0.000	0.088±0.096	0.106±0.093	0.371±0.168
		(2.7)	(0.1)	(0.3)	(0.0)	(0.1)	(0.5)	(0.0)	(0.2)	(0.7)	(0.0)	(0.4)	(0.5)	(1.9)
Central North Pacific Ocean (50-52ºN, 175E-175ºW)														
June 29 - July 8	21	0.259±0.167	0.366±0.154	0.092±0.117	0.001±0.010	0.065±0.098	0.523±0.198	0.001±0.007	0.147±0.125	0.007±0.031	0.000	0.008±0.031	0.055±0.061	0.218±0.139
		(1.1)	(1.5)	(0.4)	(0.0)	(0.3)	(2.1)	(0.0)	(0.6)	(0.0)	(0.0)	(0.0)	(0.2)	(0.9)

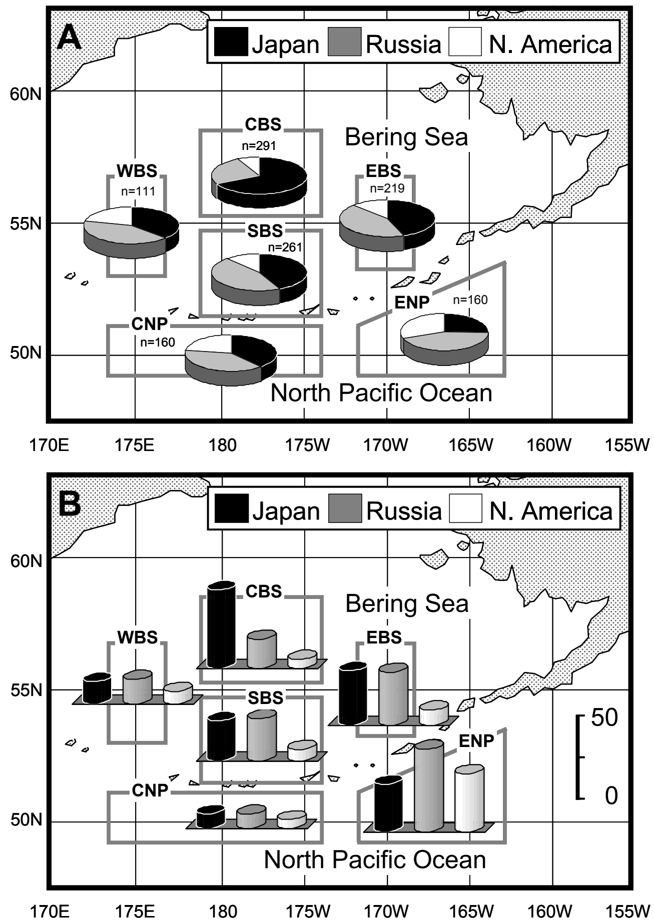

Fig. 4. GSI-estimated stock composition (A) and mean CPUE (B) of immature chum salmon caught in the Bering Sea and North Pacific Ocean during June and July 2003. CPUE = number of fish caught per 1-h trawl, n = number of samples, CBS = central Bering Sea (55-58ºN, 180-175ºW), EBS = eastern Bering Sea (53-56ºN, 170ºW), SBS = southern Bering Sea (52-54ºN, 180-175ºW), WBS = western Bering Sea (53-56ºN, 175ºE), CNP = central North Pacific Ocean (50-52ºN, 175ºE-175ºW), ENP = eastern North Pacific Ocean (50-53ºN, 165-170ºW).

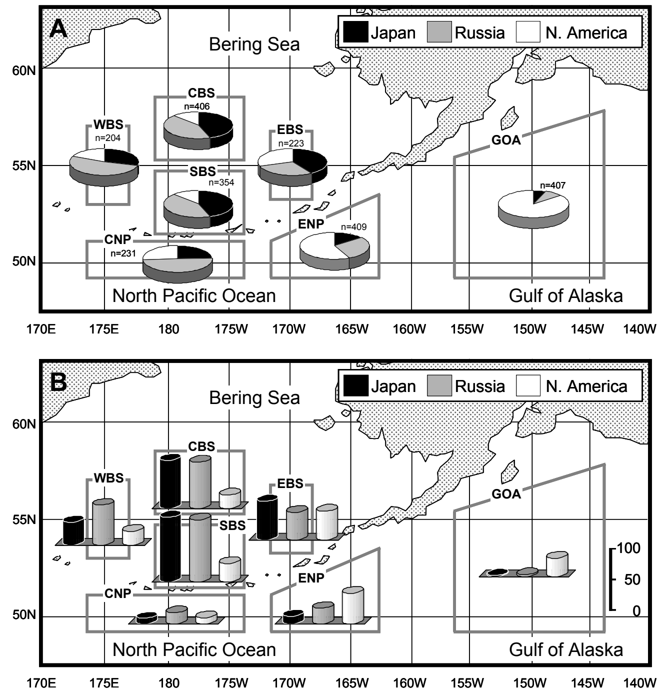

Fig. 5. GSI-estimated stock composition (A) and mean CPUE (B) of immature chum salmon in the Bering Sea, North Pacific Ocean and Gulf of Alaska during August and September 2003. CPUE = number of fish caught per 1-h trawl, n = number of samples, CBS = central Bering Sea (55-58ºN, 180-175ºW), EBS = eastern Bering Sea (53-56ºN, 170ºW), SBS = southern Bering Sea (52-54ºN, 180-175ºW), WBS = western Bering Sea (53-56ºN, 175ºE), CNP = central North Pacific Ocean (50-52ºN, 175ºE-175ºW), ENP = eastern North Pacific Ocean (50-53ºN, 165-170ºW), GOA = Gulf of Alaska (50-58ºN, 145-155ºW).

Asian immature chum salmon predominated in the Bering Sea and central North Pacific Ocean, where the estimated stock composition was 24–45% Japanese, 29–52% Russian and 13–30% North American stocks (Fig. 5A, Table 3). North American immature chum salmon were the major stocks in the eastern North Pacific Ocean (57%) and the Gulf of Alaska (86%). Japanese and Russian stocks were most abundant in the central and southern Bering Sea, whereas North American stocks were most abundant in the eastern Bering Sea and eastern North Pacific Ocean (Fig. 5B).

The GSI-estimated CPUE distribution indicated that Japanese immature chum salmon were mainly distributed in the Bering Sea, and rarely in the Gulf of Alaska (Fig. 6A). They were most abundant in the central and southern Bering Sea. Russian immature chum salmon had a distribution similar to the Japanese stocks, but their distribution extended south to the adjacent North Pacific Ocean (Fig. 6B). Among Russian immature chum salmon, north Russian stocks accounted for 68–86% in all areas (Table 3). Sakhalin stocks appeared mainly in the central and southern Bering Sea, while the abundance of Premorye and Amur River stocks were low in the survey areas.

Fall Yukon chum salmon had a unique distribution, appearing at the southern edge of the sampling areas (50°N) in the eastern North Pacific Ocean and Gulf of Alaska (Fig. 6C). Most of those chum salmon were young age 0.1 fish (2001 brood year). Northwest Alaska summer runs had a wide ocean distribution, and they were relatively abundant in the eastern waters of the Bering Sea and North Pacific Ocean and the Gulf of Alaska (Fig. 6D). Alaska Peninsula/Kodiak Island chum salmon were also widely distributed in the Bering Sea and North Pacific Ocean including the Gulf of Alaska (Fig. 6E). Prince William Sound (PWS) fish were not abundant, although they appeared in the southern Bering Sea, eastern North Pacific Ocean and Gulf of Alaska (Fig. 6F). Southeast Alaska (SEAK)/north BC fish were distributed near the continental shelf waters of the eastern North Pacific Ocean and Gulf of Alaska, and the southern Bering Sea (Fig. 6G). South BC/Washington stocks had a distribution similar to that of SEAK/north BC stocks, except that they also appeared in the central Bering Sea (Fig. 6H).

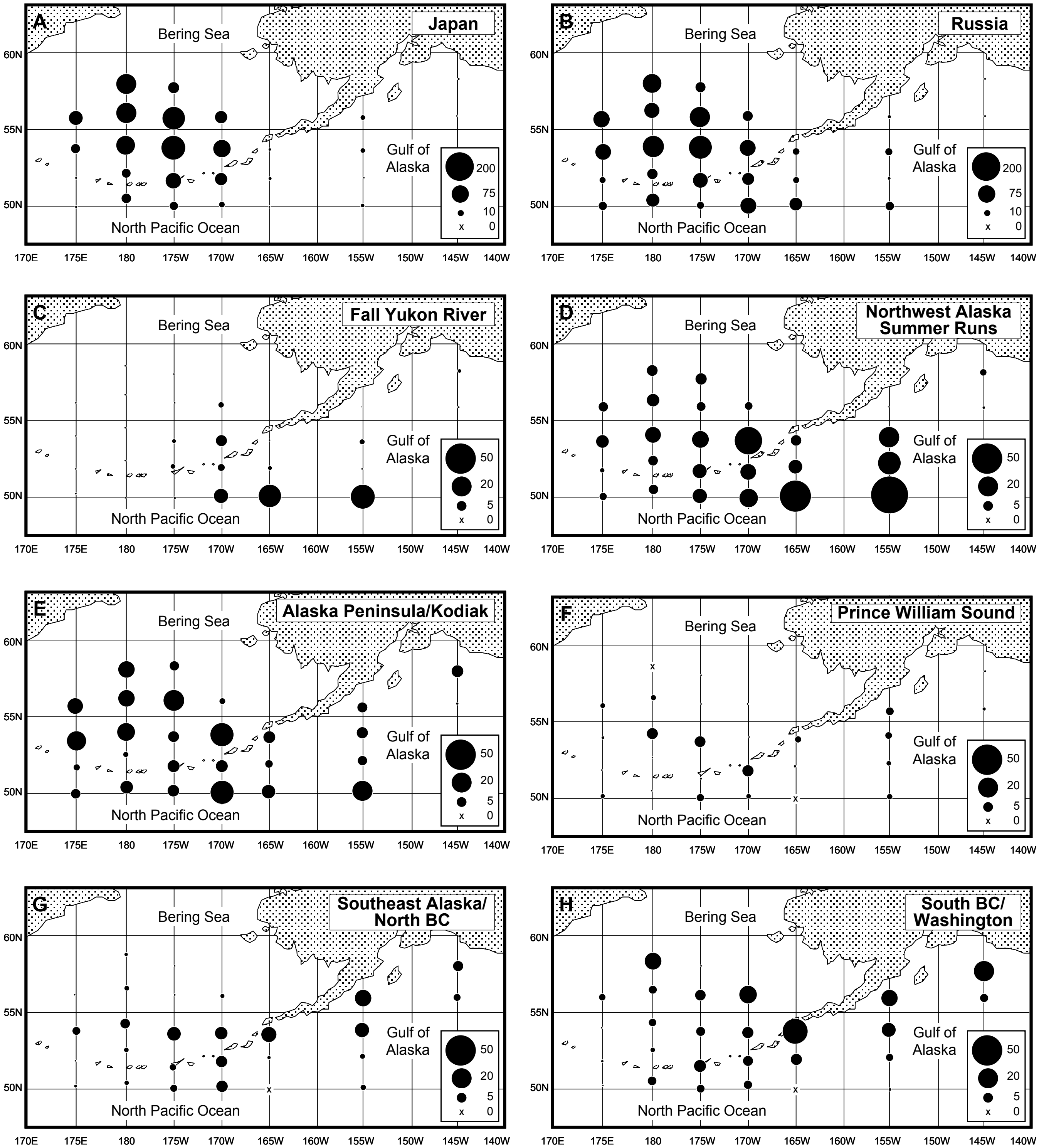

Fig. 6. GSI-estimated CPUE distribution of immature chum salmon in the Bering Sea, North Pacific Ocean and Gulf of Alaska during August and September 2003 by regional stocks. CPUE = number of fish caught per 1-h trawl. Number of mixture samples at each station is indicated in Fig. 2B.

Otolith Mark Recoveries

A total of 107 otolith-marked chum salmon (2.4% of all examined fish) were recovered in the Bering Sea and North Pacific Ocean including the Gulf of Alaska (Figs. 7–9). The biological information on all recovered fish is recorded in Table 4. Hatchery origins of nine fish were not identified, mainly because of duplicate mark patterns among hatchery stocks.

Table 3. GSI-estimated mean stock contribution and standard deviation for immature chum salmon caught in the Bering Sea, North Pacific Ocean and the Gulf of Alaska in 2003. Estimated mean CPUE (number of fish caught per 1-h trawl) is indicated in parentheses. N = number of samples, NWAK = Northwest Alaska summer, AP = Alaska Peninsula, PWS = Prince William Sound, SEAK = Southeast Alaska, NBC = North British Columbia, SBC = South British Columbia, WA = Washington.

Sampling Area/ Date	N	JAPAN	RUSSIA					NORTH AMERICA						
			N. Russia	Premorye	Amur R.	Sakhalin	Total	Fall Yukon	NWAK	AP/Kodiak	PWS	SEAK/NBC	SBC/WA	Total
Western Bering Sea (53-56ºN, 175ºE)														
June 30 - July 1	111	0.374±0.074	0.282±0.073	0.082±0.045	0.001±0.004	0.050±0.050	0.414±0.088	0.000	0.041±0.039	0.087±0.054	0.028±0.037	0.023±0.027	0.033±0.030	0.212±0.067
		(15.1)	(11.4)	(3.3)	(0.0)	(2.0)	(16.7)	(0.0)	(1.7)	(3.5)	(1.1)	(0.9)	(1.3)	(8.6)
Sep 16-18	204	0.298±0.052	0.439±0.064	0.026±0.022	0.044±0.026	0.014±0.023	0.523±0.067	0.000	0.042±0.031	0.114±0.047	0.004±0.009	0.011±0.013	0.008±0.010	0.179±0.056
		(37.3)	(55.0)	(3.2)	(5.5)	(1.8)	(65.6)	(0.0)	(5.2)	(14.2)	(0.5)	(1.4)	(1.0)	(22.4)
Central Bering Sea (55-58ºN, 180-175ºW)														
July 2-11	291	0.676±0.053	0.168±0.042	0.048±0.023	0.000	0.033±0.030	0.249±0.053	0.001±0.002	0.004±0.008	0.047±0.027	0.004±0.009	0.006±0.011	0.015±0.013	0.075±0.030
		(53.7)	(13.4)	(3.8)	(0.0)	(2.6)	(19.8)	(0.1)	(0.3)	(3.7)	(0.3)	(0.5)	(1.2)	(6.0)
Sep 6-15	406	0.446±0.074	0.296±0.059	0.025±0.029	0.015±0.015	0.094±0.047	0.430±0.076	0.000	0.050±0.039	0.067±0.043	0.002±0.006	0.001±0.005	0.004±0.008	0.124±0.057
		(78.9)	(52.2)	(4.4)	(2.6)	(16.7)	(75.9)	(0.0)	(8.9)	(11.9)	(0.3)	(0.1)	(0.7)	(21.9)
Southern Bering Sea (52-54ºN, 180-175ºW)														
July 4-10	261	0.430±0.055	0.400±0.059	0.027±0.023	0.010±0.011	0.013±0.018	0.450±0.062	0.002±0.005	0.078±0.043	0.020±0.020	0.004±0.010	0.013±0.016	0.003±0.006	0.119±0.051
		(27.5)	(25.5)	(1.7)	(0.7)	(0.8)	(28.7)	(0.1)	(5.0)	(1.3)	(0.2)	(0.8)	(0.2)	(7.6)
Sep 8-13	354	0.448±0.056	0.321±0.053	0.016±0.015	0.016±0.014	0.074±0.042	0.427±0.063	0.001±0.003	0.039±0.030	0.038±0.024	0.021±0.019	0.015±0.017	0.010±0.009	0.125±0.042
		(106.5)	(76.4)	(3.7)	(3.8)	(17.6)	(101.6)	(0.2)	(9.4)	(9.1)	(5.1)	(3.7)	(2.4)	(29.8)
Eastern Bering Sea (53-56ºN, 170ºW)														
July 12-14	219	0.445±0.053	0.386±0.061	0.022±0.016	0.000	0.024±0.032	0.431±0.063	0.000	0.017±0.022	0.038±0.029	0.026±0.023	0.007±0.015	0.036±0.026	0.124±0.046
		(37.3)	(32.4)	(1.8)	(0.0)	(2.0)	(36.2)	(0.0)	(1.4)	(3.2)	(2.2)	(0.6)	(3.0)	(10.4)
Sep 3-5	223	0.407±0.054	0.246±0.054	0.028±0.022	0.001±0.003	0.016±0.014	0.291±0.058	0.024±0.016	0.099±0.045	0.068±0.035	0.000	0.024±0.025	0.087±0.031	0.302±0.056
		(63.4)	(38.4)	(4.3)	(0.1)	(2.5)	(45.3)	(3.7)	(15.3)	(10.6)	(0.0)	(3.7)	(13.6)	(47.0)
Central North Pacific Ocean (50-52ºN, 175E-175ºW)														
June 29 - July 8	160	0.387±0.071	0.279±0.072	0.037±0.030	0.022±0.019	0.046±0.034	0.385±0.081	0.000	0.092±0.053	0.101±0.054	0.020±0.022	0.005±0.010	0.010±0.014	0.228±0.074
		(9.8)	(7.1)	(0.9)	(0.6)	(1.2)	(9.7)	(0.0)	(2.3)	(2.6)	(0.5)	(0.1)	(0.2)	(5.8)
Sep 9-19	231	0.242±0.059	0.412±0.074	0.032±0.029	0.024±0.017	0.025±0.028	0.494±0.080	0.000	0.096±0.050	0.061±0.041	0.027±0.034	0.037±0.039	0.043±0.024	0.264±0.070
		(9.0)	(15.2)	(1.2)	(0.9)	(0.9)	(18.3)	(0.0)	(3.5)	(2.3)	(1.0)	(1.4)	(1.6)	(9.8)
Eastern North Pacific Ocean (50-53ºN, 165-170ºW)														
July 14-18	160	0.252±0.045	0.389±0.055	0.009±0.014	0.002±0.005	0.039±0.024	0.438±0.058	0.002±0.005	0.124±0.041	0.073±0.038	0.006±0.012	0.046±0.030	0.058±0.024	0.309±0.056
		(32.5)	(50.0)	(1.1)	(0.3)	(5.0)	(56.5)	(0.3)	(15.9)	(9.5)	(0.8)	(5.9)	(7.5)	(39.8)
Aug 30 - Sep 3	409	0.141±0.038	0.249±0.050	0.025±0.018	0.007±0.007	0.007±0.013	0.289±0.052	0.054±0.020	0.172±0.048	0.075±0.034	0.039±0.028	0.070±0.033	0.160±0.034	0.569±0.054
		(12.4)	(21.8)	(2.2)	(0.6)	(0.6)	(25.3)	(4.7)	(15.1)	(6.5)	(3.5)	(6.1)	(14.0)	(49.9)
Gulf of Alaska (50-58ºN, 145-155ºW)														
Aug 5-17	407	0.057±0.021	0.058±0.032	0.002±0.004	0.007±0.007	0.016±0.014	0.083±0.036	0.029±0.020	0.299±0.039	0.132±0.043	0.036±0.024	0.170±0.049	0.193±0.036	0.859±0.038
		(2.0)	(2.0)	(0.1)	(0.3)	(0.6)	(2.9)	(1.0)	(10.4)	(4.6)	(1.3)	(6.0)	(6.8)	(30.1)

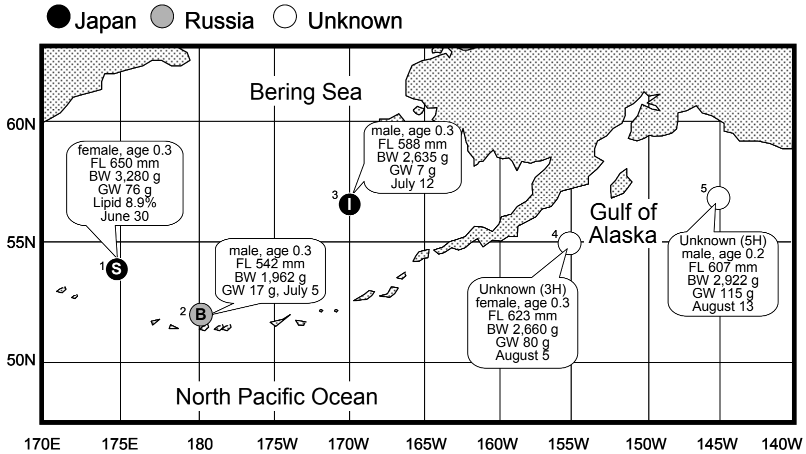

Fig. 7. Distribution of otolith-marked maturing chum salmon in the Bering Sea, North Pacific Ocean and Gulf of Alaska in the summer of 2003. Japanese hatcheries: I = Ichani, S = Shizunai; Russian hatchery: B = Bereznykovsky. Sex, age, fork length (FL), body weight (BW), gonad weight (GW), lipid content of muscle (if available), and catch date are indicated in each column. Numerals indicate sample numbers listed in Table 4.

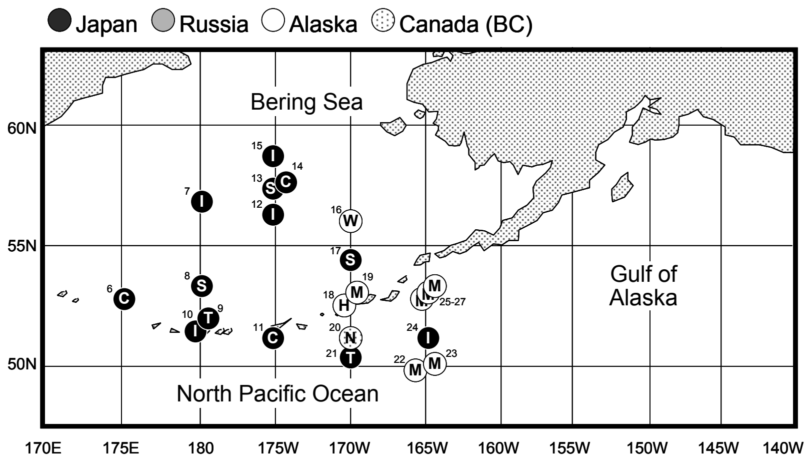

Fig. 8. Distribution of otolith-marked immature chum salmon in the Bering Sea, North Pacific Ocean and Gulf of Alaska in June and July 2003. Japanese hatcheries: C = Chitose, I = Ichani, S = Shizunai, T = Tokushibetsu; Alaskan hatcheries: H = Hidden Falls, M = Macaulay/Gastineau, W = Wally Noerenberg; Canadian hatchery: N = Nitinat. Numerals indicate sample numbers listed in Table 4.

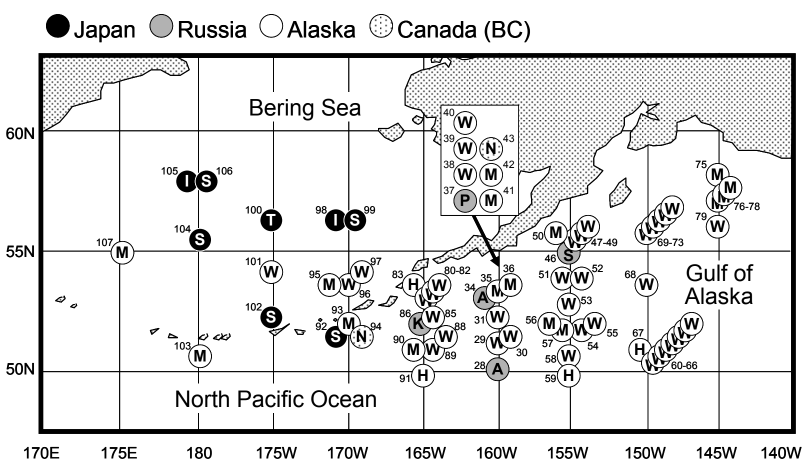

Fig. 9. Distribution of otolith-marked immature chum salmon in the Bering Sea, North Pacific Ocean and Gulf of Alaska in August and September 2003. Japanese hatcheries: I = Ichani, S = Shizunai, T = Tokushibetsu; Russian hatcheries: A = Armansky, K = Ketkinsky, P = Paratunsky, S = Sokolovsky; Alaskan hatcheries: H = Hidden Falls, M = Macaulay/Gastineau, W = Wally Noerenberg; Canadian hatchery: N = Nitinat. Numerals indicate sample numbers listed in Table 4.

Table 4. List of otolith-marked chum salmon caught in the Bering Sea and North Pacific Ocean during the 2003 *Kaiyo maru* trawl survey. Mark patterns are presented in hatch code notation (Johnson et al. 2006). F = female, M = male, IM = immature fish, MAT = maturing fish, NID = not identified.

No	Original hatchery	Hatch code	NPAFC-ID	Date of catch	Location of catch		Fork length (mm)	Body weight (g)	Sex	Ocean age	Maturity
					Latitude	Longitude					
1	Shizunai	2,3H	JP99-03	June 30	53°50’N	174°59'E	650	3,280	F	3	MAT
2	Bereznykovsky	4H	RU99-18	July 5	52°35’N	179°44’E	542	1,962	M	3	MAT
3	Ichani	2,8nH	JP99-09	July 12	56°00’N	170°03’W	588	2,635	M	3	MAT
4	NID	3H	NID	August 5	55°03’N	155°15’W	623	2,660	F	3	MAT
5	NID	5H	NID	August 13	56°53’N	144°45’W	607	2,922	M	2	MAT
6	Chitose	2,5n-3nH	JP01-03	June 30	53°05’N	174°44’E	338	367	F	1	IM
7	Ichani	2,8nH	JP00-08	July 4	55°40’N	179°58’W	410	747	M	2	IM
8	Shizunai	2,6nH	JP01-04	July 5	53°25’N	179°42’W	344	345	M	1	IM
9	Tokushibetsu	2,1n-4nH	JP00-09	July 6	51°34’N	179°44’W	469	1,313	M	2	IM
10	Ichani	2,7nH	JP01-08	July 6	51°34’N	179°44’W	314	329	M	1	IM
11	Chitose	2,5n-3nH	JP01-03	July 8	50°49’N	175°03’W	320	328	F	1	IM
12	Ichani	2,7nH	JP01-08	July 10	55°49’N	175°00’W	344	474	F	1	IM
13	Shizunai	2-3H	JP00-03	July 11	57°03’N	175°20’W	451	1,016	F	2	IM
14	Chitose	2,6nH	JP00-01	July 11	57°03’N	175°20’W	464	1,153	F	2	IM
15	Ichani	2,8nH	JP00-08	July 11	57°49’N	175°00’W	420	847	F	2	IM
16	Wally Noerenberg	3,2H	AK01-14	July 12	56°00’N	170°03’W	365	548	M	1	IM
17	Shizunai	2-3H	JP00-03	July 13	54°02’N	170°34’W	426	827	F	2	IM
18	Hidden Falls	3,3H	AK00-10	July 14	53°19’N	170°32’W	535	1,963	M	2	IM
19	Macaulay/Gastineau	5H4	AK00-07	July 14	53°19’N	170°32’W	494	1,586	F	2	IM
20	Nitinat	3-1H3	CA01-34	July 15	50°50’N	169°48’W	315	372	F	1	IM
21	Tokushibetsu	2,3n-3nH	JP01-01	July 15	49°52’N	170°14’W	332	410	M	1	IM
22	Macaulay/Gastineau	5H4	AK00-07	July 16	50°03’N	165°14’W	444	971	F	2	IM
23	Macaulay/Gastineau	5H5	AK00-08	July 16	50°03’N	165°14’W	480	1,219	M	2	IM
24	Ichani	2,8nH	JP00-08	July 17	51°06’N	165°12’W	451	1,029	M	2	IM
25	Macaulay/Gastineau	6H6	AK99-02	July 18	52°49’N	164°54’W	526	1,574	F	3	IM
26	Macaulay/Gastineau	5H	AK00-05	July 18	52°49’N	164°54’W	503	1,591	M	2	IM
27	Macaulay/Gastineau	5H3	AK00-06	July 18	52°49’N	164°54’W	504	1,514	F	2	IM
28	Armansky	5,3H	RU01-03	August 2	49°49’N	160°00’W	386	669	M	1	IM
29	Wally Noerenberg	3,2H	AK01-14	August 2	50°50’N	160°10’W	381	587	M	1	IM
30	Wally Noerenberg	3,2H	AK01-14	August 2	50°50’N	160°10’W	320	349	F	1	IM
31	Wally Noerenberg	5,2H	AK00-14	August 3	51°54’N	160°15’W	499	1,505	F	2	IM
32	NID	3,3H	NID	August 3	52°51’N	160°10'W	404	767	M	x	IM
33	NID	4H	NID	August 3	52°51’N	160°10'W	436	911	M	2	IM
34	Armansky	5,3H	RU01-03	August 3	52°51’N	160°10'W	470	1,071	F	2	IM
35	Macaulay/Gastineau	6H	AK99-01	August 3	52°51’N	160°10'W	557	1,893	M	3	IM
36	Macaulay/Gastineau	5H4	AK00-07	August 3	52°51’N	160°10'W	487	1,373	F	2	IM
37	Paratunsky	3,2nH	RU01-13	August 4	53°50’N	160°05'W	496	1,361	F	2	IM
38	Wally Noerenberg	5,2H	AK00-14	August 4	53°50’N	160°05'W	507	1,565	M	2	IM
39	Wally Noerenberg	5,2H	AK00-14	August 4	53°50’N	160°05'W	473	1,346	M	2	IM
40	Wally Noerenberg	5,2H	AK00-14	August 4	53°50’N	160°05'W	521	1,575	M	2	IM
41	Macaulay/Gastineau	6H6	AK99-02	August 4	53°50’N	160°05'W	548	1,885	F	3	IM
42	Macaulay/Gastineau	6H	AK99-01	August 4	53°50’N	160°05'W	588	2,348	F	3	IM
43	Nitinat	5H	CA00-22	August 4	53°50’N	160°05'W	488	1,384	M	x	IM
44	NID	4H	NID	August 4	53°50’N	160°05'W	510	1,556	M	2	IM
45	NID	5H	NID	August 4	53°50’N	160°05'W	525	1,707	F	2	IM
46	Sokolovsky	4,3H	RU01-18	August 5	55°03’N	155°15’W	428	1,000	F	1	IM
47	Wally Noerenberg	3,2H	AK01-14	August 5	55°03’N	155°15’W	364	522	M	1	IM
48	Wally Noerenberg	5,2H	AK00-14	August 5	55°03’N	155°15’W	526	1,660	M	2	IM
49	Wally Noerenberg	3,2H	AK01-14	August 5	55°03’N	155°15’W	409	846	F	1	IM
50	Macaulay/Gastineau	5H4	AK00-07	August 5	55°03’N	155°15’W	436	1,019	M	2	IM
51	Wally Noerenberg	5,2H	AK00-14	August 6	54°00’N	155°13’W	539	1,741	M	2	IM
52	Wally Noerenberg	5,2H	AK00-14	August 6	54°00’N	155°13’W	500	1,406	F	2	IM
53	Wally Noerenberg	3H	AK01-15	August 6	53°03’N	155°13’W	452	1,121	F	x	IM
54	Wally Noerenberg	5,2H	AK00-14	August 7	52°08’N	154°52’W	499	1,458	F	2	IM

Table 4 (continued).

No	Original hatchery	Hatch code	NPAFC-ID	Date of catch	Location of catch		Fork length (mm)	Body weight (g)	Sex	Ocean age	Maturity
					Latitude	Longitude					
55	Wally Noerenberg	3,2H	AK01-14	August 7	52º08'N	154º52'W	372	530	F	1	IM
56	Macaulay/Gastineau	5H	AK00-05	August 7	52º08'N	154º52'W	522	1,708	F	2	IM
57	Macaulay/Gastineau	6H	AK99-01	August 7	52º08'N	154º52'W	588	2,374	F	3	IM
58	Wally Noerenberg	3,2H	AK01-14	August 7	51º09'N	154º59'W	409	771	M	1	IM
59	Hidden Falls	3,3H	AK01-13	August 8	50º07'N	154º59'W	387	726	F	1	IM
60	Wally Noerenberg	3,2H	AK01-14	August 9	49º50'N	150º02'W	393	734	F	1	IM
61	Wally Noerenberg	3,2H	AK01-14	August 9	49º50'N	150º02'W	419	859	F	1	IM
62	Wally Noerenberg	3,2H	AK01-14	August 9	49º50'N	150º02'W	400	771	M	1	IM
63	Wally Noerenberg	3,2H	AK01-14	August 9	49º50'N	150º02'W	393	723	F	1	IM
64	Wally Noerenberg	3,2H	AK01-14	August 9	49º50'N	150º02'W	393	765	M	1	IM
65	Wally Noerenberg	3,2H	AK01-14	August 9	49º50'N	150º02'W	355	552	M	1	IM
66	Wally Noerenberg	3,2H	AK01-14	August 9	49º50'N	150º02'W	369	568	M	1	IM
67	Hidden Falls	3,2H	AK01-12	August 9	49º50'N	150º02'W	405	815	F	1	IM
68	Wally Noerenberg	3,2H	AK01-14	August 11	53º50'N	149º59'W	429	936	M	1	IM
69	Wally Noerenberg	5,2H	AK00-14	August 12	55º52'N	150º15'W	511	1,537	M	2	IM
70	Wally Noerenberg	3,2H	AK01-14	August 12	55º52'N	150º15'W	435	978	M	1	IM
71	Wally Noerenberg	5,2H	AK00-14	August 12	55º52'N	150º15'W	549	1,931	M	2	IM
72	Wally Noerenberg	3,2H	AK01-14	August 12	55º52'N	150º15'W	372	581	M	1	IM
73	Wally Noerenberg	3H	AK00-13	August 12	55º52'N	150º15'W	519	1,670	M	2	IM
74	NID	5H	NID	August 12	55º52'N	150º15'W	478	1,241	M	2	IM
75	Macaulay/Gastineau	6H	AK99-01	August 13	57º50'N	144º59'W	580	2,328	M	3	IM
76	Macaulay/Gastineau	5H4	AK00-07	August 13	56º53'N	144º45'W	504	1,446	M	2	IM
77	Macaulay/Gastineau	5H6	AK00-09	August 13	56º53'N	144º45'W	508	1,675	M	2	IM
78	Macaulay/Gastineau	4H5	Ak01-22	August 13	56º53'N	144º45'W	449	1,180	M	1	IM
79	Wally Noerenberg	5,2H	AK00-14	August 14	55º50'N	145º04'W	386	732	M	1	IM
80	Wally Noerenberg	5,2H	AK00-14	August 30	53º29'N	165º00'W	513	1,586	F	2	IM
81	Wally Noerenberg	5,2H	AK00-14	August 30	53º29'N	165º00'W	501	1,269	F	2	IM
82	Wally Noerenberg	5,2H	AK00-14	August 30	53º29'N	165º00'W	496	1,298	F	2	IM
83	Hidden Falls	3,3H	AK00-10	August 30	53º29'N	165º00'W	497	1,401	M	2	IM
84	NID	5H	NID	August 30	53º29'N	165º00'W	562	1,676	M	2	IM
85	Wally Noerenberg	3,4H	AK98-12	August 30	53º11'N	164º59'W	575	2,120	F	4	IM
86	Ketkinsky	3,4H	RU99-15	August 30	53º11'N	164º59'W	520	1,298	M	3	IM
87	NID	5H	NID	August 30	53º11'N	164º59'W	550	2,002	F	3	IM
88	Wally Noerenberg	5,2H	AK00-14	August 31	51º59'N	164º59'W	528	1,580	M	2	IM
89	Wally Noerenberg	3,2H	AK01-14	August 31	51º59'N	164º59'W	409	745	F	1	IM
90	Macaulay/Gastineau	5H3	AK00-06	August 31	51º59'N	164º59'W	564	2,121	M	2	IM
91	Hidden Falls	3,3H	AK00-10	September 2	49º59'N	164º59'W	495	1,251	F	2	IM
92	Shizunai	2-3H	JP00-03	September 3	52º11'N	170º04'W	475	1,141	F	2	IM
93	Macaulay/Gastineau	5H3	AK00-06	September 3	52º11'N	170º04'W	493	1,216	M	2	IM
94	Nitinat	5H3	CA00-23	September 3	52º11'N	170º04'W	543	1,994	M	2	IM
95	Macaulay/Gastineau	6H3	AK99-04	September 4	54º00'N	170º17'W	548	1,940	F	3	IM
96	Wally Noerenberg	3,2H	AK01-14	September 4	54º00'N	170º17'W	412	842	F	1	IM
97	Wally Noerenberg	3H	AK01-15	September 4	54º00'N	170º17'W	400	677	M	1	IM
98	Ichani	2,8nH	JP00-08	September 5	55º59'N	169º57'W	534	1,622	F	3	IM
99	Shizunai	2-3H	JP00-03	September 5	55º59'N	169º57'W	500	1,459	F	2	IM
100	Tokushibetsu	2,3n-3nH	JP01-01	September 7	55º59'N	175º00'W	359	579	F	1	IM
101	Wally Noerenberg	3,2H	AK01-14	September 8	53º59'N	175º00'W	385	595	M	1	IM
102	Shizunai	2,6nH	JP01-04	September 9	51º40'N	175º00'W	372	636	M	1	IM
103	Macaulay/Gastineau	5H6	AK00-09	September 11	50º29'N	179º49'W	490	1,285	F	2	IM
104	Shizunai	2,6nH	JP01-04	September 13	55º29'N	179º42'W	384	690	M	1	IM
105	Ichani	2,8nH	JP00-08	September 15	57º29'N	179º59'E	421	820	F	2	IM
106	Shizunai	2,6nH	JP01-04	September 15	57º29'N	179º59'E	367	519	F	1	IM
107	Macaulay/Gastineau	6H	AK99-01	September 16	55º03'N	175º18'E	537	1,526	M	3	IM

Early Summer

Three otolith-marked maturing chum salmon (age 0.3) were found in the Bering Sea between June 30 and July 12 (Fig. 7). Those marked fish were released from the Ichani and Shizunai hatcheries in Hokkaido, Japan, and the Bereznykovsky Hatchery in Sakhalin, Russia.

Thirteen Japanese immature chum salmon originally released from four hatcheries (Chitose, Ichani, Shizunai and Tokushibetsu) in Hokkaido were recovered in the Bering Sea (n = 10) and adjacent North Pacific Ocean (n = 3) (Fig. 8). In addition, eight Alaskan chum salmon from the Wally Noerenberg (PWS), Hidden Falls and Macaulay hatcheries (SEAK) and one Canadian fish from the Nitinat Hatchery on southern Vancouver Island were found in the eastern waters of the North Pacific Ocean and Bering Sea (Fig. 8).

Late Summer/Early Fall

Two otolith-marked maturing chum salmon (ages 0.2 and 0.3) were found in the northern Gulf of Alaska on August 5 and 13, 2003, but their hatchery origins were not determined due to mark duplication (Fig. 7).

Eight Japanese immature chum salmon released from the Ichani, Shizunai and Tokushibetsu hatcheries (Hokkaido) were caught in the Bering Sea (n = 7) and eastern North Pacific Ocean near the Aleutian Islands (n = 1) (Fig. 9). Five Russian chum salmon released from the Armansky (North Okhotsk), Ketkinsky and Paratunsky (Kamchatka), and Sokolovsky (Sakhalin) hatcheries were recovered in the eastern North Pacific Ocean and Gulf of Alaska (Fig. 9). Thirty-eight fish released from the Wally Noerenberg Hatchery (PWS) were found in the Gulf of Alaska (n = 23), eastern North Pacific Ocean (n = 12), and eastern Bering Sea (n = 3). Nineteen fish from the Macaulay and Hidden Falls hatcheries (SEAK) were recovered in the Gulf of Alaska (n = 9), eastern North Pacific Ocean (n = 7), central North Pacific Ocean (n = 1) and Bering Sea (n = 2). One of them was caught in the western Bering Sea (55º03'N, 175º18'E) (Fig. 9, Table 4). Two Canadian fish from the Nitinat Hatchery were detected in the eastern North Pacific Ocean (Fig. 9).

DISCUSSION

The present GSI study clearly indicated the stock-specific distribution, migration and abundance of maturing and immature chum salmon in the Bering Sea and North Pacific Ocean. Their distribution and migration patterns in the ocean were variable among eleven regional stocks in Asia and North America. Past long-term high-seas tagging experiments have been useful in designating the major ocean distributions of maturing chum salmon (e.g. Yonemori 1975; Neave et al. 1976; Ogura 1994; Myers et al. 1996), however, distributional information for immature fish is sparse due to the limited recoveries of tagged fish over the years. The recent mass otolith marking programs provide a good opportunity to identify the distribution and abundance of hatchery chum salmon in the ocean. For example, the total number of tagging recoveries for immature chum salmon originating from central and southeast Alaska was only 19 fish over 40 years (1956–1995; Myers et al. 1996), whereas 57 immature chum salmon originating from hatcheries in PWS and southeast Alaska were recovered in the open ocean during the single summer and fall period of 2003.

Ocean Distribution and Migration of Japanese Stocks

Past tagging recoveries suggested that Japanese immature chum salmon were distributed along the Aleutian Islands in the North Pacific Ocean during July and August (Yonemori 1975; Neave et al. 1976). However, our GSI study clearly indicated that Japanese immature fish were widely distributed in the Bering Sea during the summer and fall, while a considerable number of fish appeared in the eastern North Pacific Ocean in the early summer (late June and July). On the other hand, most Japanese maturing fish were already present in the central and western waters of the Bering Sea in the early summer, and had disappeared by late summer. Japanese chum salmon inhabit the western North Pacific Ocean during the first winter and the central Gulf of Alaska during the following winters (Urawa and Ueno 1997; Urawa 2000, 2004). Genetic monitoring surveys in salmon fisheries in the Unimak and Shumagin islands (near Unimak Pass in the eastern Aleutian Islands) indicated that the component of Japanese chum salmon stocks increased between mid June and mid July with a peak in late June (Crane and Seeb 2000; Seeb et al. 2004). Young fish (age 0.1) of Japanese origin also migrate from the western North Pacific Ocean into the Bering Sea in the summer (Urawa et al. 1998, 2001). Nagasawa and Azumaya (2009) also reported that age 0.1 chum salmon stayed in the North Pacific Ocean at 5–10°C in June and appeared in the Bering Sea in July. Our results as well as other known information suggest that Japanese maturing chum salmon move from the Gulf of Alaska into the Bering Sea mainly in June, and are followed by immature fish in late June and July.

The ocean distribution of immature chum salmon is affected by water temperatures (Azumaya et al. 2007; Fukuwaka et al. 2007). It is not known exactly how long immature chum salmon stay in the Bering Sea to feed, but sea surface temperature (SST) data suggest that they may migrate out of the Bering Sea to their winter habitat in the Gulf of Alaska by late November when SST decrease to less than 4°C. During the winter period, chum salmon prefer water temperatures between 4°C and 6°C (Ueno et al. 1997). The habitat in this temperature range is more widely available in the Gulf of Alaska than in the western waters of the North Pacific Ocean (Neave et al. 1976; Urawa 2000). For Japanese chum salmon overwintering in the Gulf of Alaska, the shortest homing migration route is through the Bering Sea. In addition, the Bering Sea is one of most productive ecosystems in the world, and provides favorable feeding habitats

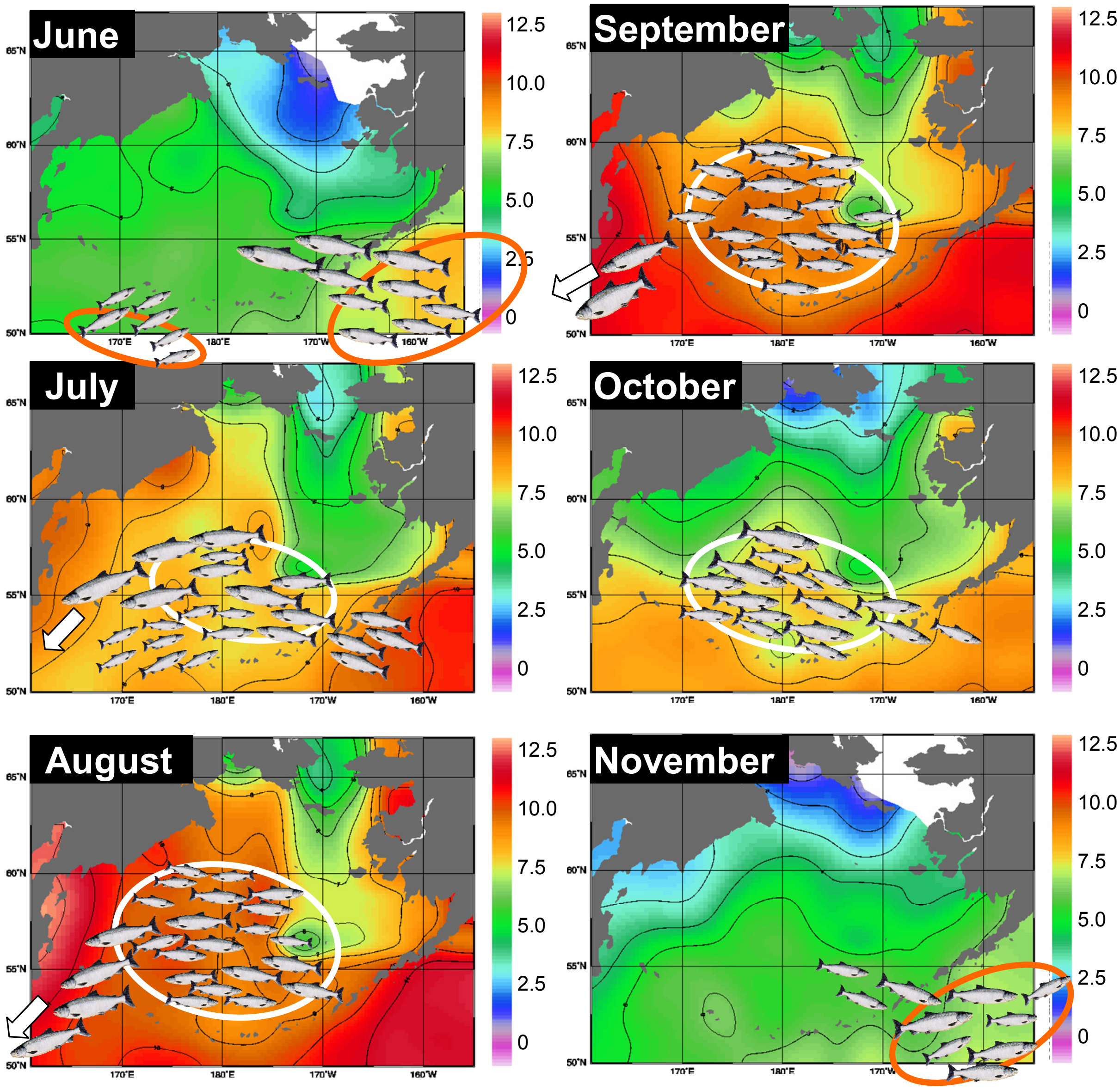

Fig. 10. Estimated migration pattern of Japanese chum salmon in the Bering Sea and North Pacific Ocean with the10-year average of sea surface temperatures (°C; http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/). Orange and white circles indicate the estimated major ocean distributions of Japanese chum salmon during winter and summer/fall, respectively (Urawa 2000, 2004).

for salmon during summer and fall.

In the western Bering Sea within the Russian EEZ, Russian chum salmon were the predominant stocks (over 60%) in May and June, while the percentage of Japanese stocks increased from several percent in May to 60% in August (Seeb et al. 2004). This GSI estimate as well as past tagging experiments (Yonemori 1975; Neave et al. 1976; Ogura 1994; Myers et al. 1996) indicates that Japanese maturing chum salmon migrate in the waters off the Kamchatka Peninsula and the Kuril Islands between July and September, heading southwest to northern Japan where mature salmon runs occur between September and December.

A total of 23 otolith-marked chum salmon released from four Japanese hatcheries in Hokkaido were recovered in this study, and most of those fish were found in the Bering Sea. Sato et al. (2009b) also recorded many otolith marked chum salmon in the Bering Sea (n = 177) and North Pacific Ocean (n = 13) during the spring and summer of 2006 and 2007, most (90%) of which were of Japanese origin. Those otolith mark recoveries support the ocean distribution of Japanese chum salmon estimated by GSI analysis.

The estimated seasonal migration patterns of Japanese chum salmon in the Bering Sea and North Pacific Ocean are summarized in Fig. 10 along with 10-year averages of SST. After overwintering, maturing chum salmon in the Gulf of Alaska migrate into the Bering Sea during June, followed by young fish (age 0.1) from the western North Pacific Ocean and by immature fish from the Gulf of Alaska. Maturing fish migrate out of the Bering Sea by August, while immature fish remain in the Bering Sea to feed. In late October or November when the water temperature decreases in the Bering Sea, immature fish move southeast to the Gulf of Alaska. They migrate between summer feeding grounds in the Bering Sea and winter habitat in the Gulf of Alaska until they return to spawn along the shortest migration route through the Bering Sea.

Ocean Distribution of Russian Stocks

Our GSI analysis suggested that Russian immature chum salmon were abundantly distributed in the Bering Sea similar to the Japanese stocks, but their distribution also spread into the adjacent North Pacific Ocean. Most of the Russian chum salmon in the Bering Sea and North Pacific Ocean were of north Russian (north Okhotsk coast, Kamchatka and Anadyr) origin. Sakhalin immature chum salmon were mainly distributed in the central and southern Bering Sea. Other Russian stocks (Amur River and Premorye) may not be abundant in the Bering Sea. Tagging recoveries (Myers et al. 1996) suggested that immature chum salmon from the Amur River and Sakhalin were mainly present in the western North Pacific Ocean, and immature fish from North Okhotsk coast and Kamchatka were distributed in both the Bering Sea and North Pacific Ocean. Russian immature chum salmon inhabit the central North Pacific Ocean during winter (Urawa and Ueno 1997).

Our study indicated that northern Russian maturing chum salmon were most abundant in the western Bering Sea in the early summer. Tagging experiments indicated that maturing fish from the eastern Kamchatka and Anadyr regions were distributed in the Bering Sea, while other stocks (Amur River, Prymoyre, Sakhalin, northern Okhotsk and western Kamchatka) appeared mainly in the western North Pacific Ocean between May and July (Neave et al. 1976; Ogura 1994; Myers et al. 1996). Because Russian stocks include summer runs, the timing of spawning runs may limit their oceanic distribution to western waters.

Ocean Distribution of North American Stocks

As suggested by past results (Urawa et al. 2000, 2004), our GSI study indicated that North American stocks were predominant in the Gulf of Alaska, but not in the Bering Sea. It is noteworthy that young chum salmon from the Yukon River fall runs appeared at the southern margin (50°N) of our survey areas in the eastern North Pacific Ocean and Gulf of Alaska. Northwest Alaska summer runs also appeared in the same area as well as in the Bering Sea. Other GSI studies estimated that the contribution of northwest Alaska stocks among immature chum salmon in the Gulf of Alaska was 15% in summer 1998 (Urawa et al. 2000), 11–14% (ages 0.2–0.4 only) in January 1996 (Urawa et al. 1997), and 3–16% in February 2006 (Beacham et al. 2009). Most tagged immature chum salmon recovered in northwest Alaska were released in the Gulf of Alaska and around the eastern Aleutian Islands, whereas tagged maturing fish were released in both the Gulf of Alaska and the Bering Sea (Neave et al. 1976; Myers et al. 1996). Thus it may be that young chum salmon migrate from the northwest Alaska coast to the Gulf of Alaska for overwintering, and considerable numbers of fish remain there until maturing, unlike Japanese stocks that migrate seasonally between the Gulf of Alaska and Bering Sea.

Our study confirmed that immature chum salmon from the Alaska Peninsula/Kodiak Island region were widely distributed in the Bering Sea and North Pacific Ocean (east of 175°E), although the tagging recoveries indicated a limited distribution in the northern Gulf of Alaska and around the Aleutian Islands east of 178°W (Neave et al. 1976; Myers et al. 1996).

The ocean distribution of PWS chum salmon was not clear in our GSI study, because of the low abundance of PWS stocks in the survey areas. However, a large number of otolith-marked chum salmon released from the Wally Noerenberg Hatchey (WNH) located in PWS were found in the open ocean. This hatchery annually releases approximately 75–100 million chum salmon fry with otolith marks. According to our recovery records, WNH immature chum salmon were mainly distributed in the Gulf of Alaska and eastern North Pacific Ocean, and some were present in the eastern and southern Bering Sea (east of 175°W).

Both our GSI and otolith mark recoveries indicated that SEAK/North BC immature stocks were widely distributed throughout the northern waters of the Gulf of Alaska and eastern North Pacific Ocean, and the southern Bering Sea. South BC/Washington stocks shared a similar ocean distribution with SEAK/North BC stocks, but they were also distributed in the central Bering Sea. In the Bering Sea, there were few records of tagging recovery for immature and maturing chum salmon originating from central and southeast Alaska, BC and Washington (Myers et al. 1996). Compared with the past tagging recovery records, the present GSI and otolith mark recoveries suggest a wider ocean distribution of chum salmon stocks originating along the Gulf of Alaska and northwest coast of North America than previously acknowledged.

CONCLUSIONS

Our study using genetic and otolith marks provides new information on stock-specific ocean distribution of chum salmon originating from Asia and North America. The distribution patterns apparently differ among regional stocks. Japanese and north Russian chum salmon are predominant in the Bering Sea during summer and fall. North American stocks are mainly distributed in the Gulf of Alaska and eastern North Pacific Ocean, and some stocks also intermingle in the Bering Sea. Japanese chum salmon have a strong seasonal migration pattern between the Bering Sea (summer/fall) and Gulf of Alaska (winter/spring), responding to seawater temperatures. The ocean distribution and migration patterns of salmon may be also affected by the abundance of food organisms, interactions within or between species, ocean conditions (salinity, depth, currents, e.g.), and timing and location of spawning as well as winter habitat. Further long-term studies are required to clarify factors affecting the migration and distribution of salmon in the ocean.

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