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Genetic Stock Identification of Chum Salmon in the North Pacific Ocean and Bering Sea during the Winter and Summer of 1996

by

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Genetic stock identification of chum salmon in the North Pacific Ocean and Bering Sea during the winter and summer of 1996

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Abstract

The geographical origins of chum salmon (*Oncorhynchus keta*) captured in the North Pacific Ocean and Bering Sea during the winter and summer of 1996 were determined by genetic stock identification techniques. We used a genetic baseline for protein allozyme characters (19 loci) covering 77 stocks around the North Pacific rim. In January, young chum salmon (ocean age 1) caught in the western North Pacific Ocean (44-45°N, 160°E) consisted of 29% Japanese and 65% Russian stocks, and the estimated stock composition was similar for Japanese stocks of immature chum salmon (ocean age 1-4) caught in the eastern North Pacific Ocean (45-50°N, 162-168°W). However, the Russian stock component declined to 51% and some Alaskan stocks were detected in the mixture (15%). In the Gulf of Alaska (48-54°N, 144-148°W), various regional stocks (19% Japanese, 10% Russian, 35% Alaskan, 19% British Columbia, and 17% Washington stocks) intermingled in the winter, while Alaskan and British Columbia chum salmon were dominant in the summer (49% and 25%, respectively). In June and July, Russian chum stocks were dominant (63-80%) in the western and central North Pacific Ocean, where Japanese stocks were relatively scarce (6-19%). In the central Bering Sea (56-57°N, 179°W), however, the Japanese stock proportion was 25% and 42% among immature and maturing chum salmon, respectively.

Introduction

Chum salmon (*Oncorhynchus keta*) have a wide geographical distribution, with their spawning grounds extending to many rivers and streams in Asia and North America (Neave et al., 1976). Chum salmon migrate to sea after a short freshwater residence, and spend several years at sea before returning to their natal rivers to spawn (Salo, 1991). Thus various regional stocks mix in the North Pacific Ocean and adjacent seas.

The ocean distribution of regional chum salmon stocks has been estimated by tagging (Yonemori, 1975; Neave et al., 1976; Myers et al., 1993, 1996; Ogura, 1994). These results indicated that Japanese chum salmon are widely distributed as far east as 140°W in the North Pacific Ocean and as far north as 64°N in the Bering Sea.

The quantitative estimate of stock composition is important for the stock management of salmon throughout the Pacific rim. Scale pattern analysis attempted to estimate the stock composition of chum salmon in the western and central North Pacific Ocean (Ishida et al., 1983, 1984, 1985, 1988, 1989), but the results appear to be inconsistent with those of high-seas tagging experiments (see Myers et al., 1993).

Genetic stock identification (GSI) techniques using protein variation at protein-coding loci detected with allozyme electrophoresis have been applied to determine specific geographical origin of chum salmon (Winans et al., 1994; Seeb et al., 1995; Wilmot et al., 1995). An extensive genetic baseline for chum salmon stocks has been recently developed cooperatively among various laboratories in Pacific rim countries (Kondzela et al., 1994; Phelps et al., 1994; Winans et al., 1994; Wilmot et al., 1994, 1995; Seeb et al., 1995). The present study was conducted to estimate the stock composition of chum salmon in the North Pacific Ocean and Bering Sea during the winter and summer of 1996 using GSI techniques.

Materials and Methods

High-seas samples

Chum salmon samples were caught by trawl sampling on the high seas of the North Pacific Ocean by R/V *Kaiyo-maru* in January 11-25, 1996 (Table 1). In the summer of 1996, chum salmon were caught by gillnet sampling in the North Pacific Ocean and central Bering Sea by R/V *Hokko-maru*, *Wakatake-maru*, and *Oshoro-maru* (Table 2). The fork length, and body and gonad weights of each fish were measured and scales were removed for age determination. The muscle, heart, and liver were collected from each fish, frozen at -40°C, and shipped to the Genetics Section of the National Salmon Conservation Center for genetic analysis. Maturity of each fish was determined from the gonad weight (Takagi, 1961).

Electrophoresis

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).

Baseline Data

We used the simplified baseline data set formulated in Seeb et al. (1995) for 69 stock groups that was augmented by Wilmot et al. (1995) to a 77 stock group/20 locus data set. Seeb et al. (1995) simplified the entire Pacific rim baseline by selecting representative stocks from southeast Alaska, British Columbia, and Washington and by pooling statistically nonsignificant regional stock pairs or groups for a total of 69 stock groups. Wilmot et al. (1995) added two stocks from China and six stocks from Russia for a total of 77 stock groups. Finally, our analyses are based on a 19-locus baseline (Table 3). We dropped PEPA from our analyses because it was frequently missed in the electrophoretic screening of mixture samples. Because of the low level of PEPA variation, its exclusion from the mixture analyses had minimal to no effect on results reported herein.

Mixed-stock analysis

Point 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 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. (1995). The regional stock groups were Japan, Russia, Western Alaska (summer run), Yukon River (fall run), Alaska Peninsula/Kodiak, Southeast Alaska and Prince William Sound (PWS), British Columbia, and Washington. Simulation studies indicated that average estimates were greater than 80% accurate when true group contributions were 100% (Wilmot et al., 1995).

Results

Winter

Estimates of the origins of high-seas chum salmon were different depending on the region surveyed (Table 4, Figure 1). Young chum salmon (ocean age 1, mean fork length=23.0 cm, n=197) captured in the western North Pacific Ocean (region W-1, 44-45°N, 160°E) off Kamchatka Peninsula included mostly Asian fish (29% Japanese and 65% Russian stocks). Immature chum salmon (ocean age 1-4, n=50) in the eastern North Pacific Ocean (region W-2, 45-50°N, 162-168°W) were composed of 29% Japanese, 51% Russian, and 15% Alaskan, and 5% British Columbian stocks. Chum salmon (ocean age=1-5, n=167) in the Gulf of Alaska (region W-3, 48-54°N, 144-148°W) were mixed with various regional stocks, consisting of 19% Japanese, 10% Russian, 35% Alaskan, 19% British Columbia, and 17% Washington stocks.

Summer

In western waters of the North Pacific Ocean (region S-1, 49-51°N, 165°E), Russian stock composition of immature and maturing chum salmon was predominant (80% and 63%, respectively, Table 5, Figure 2). The estimated proportion of Japanese stocks was low among immature fish (6%), but higher among maturing fish (19%, Table 5). In the central North Pacific Ocean (region S-2, 43-47°N, 179°W), the estimated proportion in immature fish was 69% for Russian stocks, 15% for Japanese stocks, and 16% for North American stocks. In the Gulf of Alaska (region S-3, 51-55°N, 144-145°W), over half (56%) of immature chum salmon were composed of western Alaska and British Columbia stocks, and Alaska Peninsula/Kodiak and British Columbia stocks were predominant (57%) among the maturing fish (Table 5). In the central Bering Sea (region S-4, 56-57°N, 179°W), more than 80% of chum salmon were estimated as Asian origin (Figure 2). The estimated proportion of Japanese stocks was 25% of the immature fish, and 42% of the maturing fish (Table 5).

Discussion

Results of high-seas tagging experiments indicate that Japanese chum salmon are distributed widely in the North Pacific Ocean and Bering Sea in summer (Yonemori, 1975; Ogura, 1994). Our study confirmed that Japanese chum salmon broadly extend east and west in the North Pacific Ocean in winter. The portion of Japanese stocks was almost stable (20-30%) in winter in all three regions (160°E, 162-168°W, and 145-148°W). In summer, however, the Japanese stock proportion was different depending on regions or maturity of fish. Among immature fish, the Japanese proportion was low in the western North Pacific Ocean (6%) and the Gulf of Alaska (5%), and higher in the central North Pacific Ocean (15%) and the central Bering Sea (25%). On the other hand, the estimated portion of Japanese stocks among maturing fish was 19% in the western North Pacific, and 42% in the central Bering Sea. The catch per unit of effort (CPUE) of chum salmon from the research cruises in this survey was highest in the central Bering Sea (Figure 2). The results suggest that Japanese immature chum salmon in the summer tend to be distributed in the Bering Sea rather than in the North Pacific Ocean. Estimates of Japanese maturing chum salmon indicate that they are present in the Bering Sea and western North Pacific waters in June and July.

It is remarkable that in winter various Asian and North American stocks intermingle in the Gulf of Alaska, where chum salmon were relatively abundant during the winter surveys of 1992 and 1996 (Nagasawa et al., 1994; Ueno et al., 1997). Of the regional stock groups, Alaskan stock proportions were the highest (35%) and the proportion of Russian fish was the lowest (10%) in samples from the Gulf of Alaska in winter. Japanese, British Columbia, and Washington chum salmon stocks were present in approximately equal proportion (17-19%, Table 4). Tagging surveys also implied that maturing chum salmon originating from various regions were found in the Gulf of Alaska in spring and summer (Ogura, 1994). Perhaps the Gulf of Alaska is an important area for both Asian and North American chum salmon throughout the.year.

Our study suggests that young chum salmon (ocean age 1) of Japanese origin are distributed in the western waters south of Kamchatka Peninsula during their first winter. Other genetic stock identification studies have indicated that Japanese chum salmon juveniles are mainly distributed in the Okhotsk Sea in autumn (Ueno et al., 1995; Urawa and Ueno, unpublished data). These chum juveniles might migrate into the western North Pacific in winter and move eastward by the following spring, because Japanese immature chum stocks are rare in the western North Pacific waters in summer.

Our summer 1996 chum salmon stock composition estimates for western and central North Pacific waters were similar to estimates calculated by Winans et al. (1997) for summer, 1995 (Figure 2). Their study included samples from the same geographical areas as our study and used the same GSI techniques. However, estimates for the central Bering Sea were different between the two studies. Our estimates indicate that Russian chum salmon was dominant in the Bering Sea in 1996, but Winans et al. (1997) estimated Japanese stocks predominated in 1995. It is unclear if these changes reflect the population dynamics of Japanese and Russian stocks. Further studies are
required in order to confidently apply GSI techniques to estimates of stock population size.

Results from the present study suggest that the stock proportions may be different between immature and maturing fish, but sample sizes in this study are insufficient to calculate individual stock proportions for each maturity group. In an attempt to increase the number of stratified estimates available in future analysis, and reduce the variance of the individual point estimates, steps were taken in the summer field season of 1997 to increase the total number of chum salmon sampled for future electrophoretic studies.

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Table 1. High-seas chum salmon samples collected in the North Pacific Ocean (NPO) in winter for genetic stock identification.

Region	Latitude	Longitude	Date	No. samples	Ocean age
Western NPO	44°31'N	160°00'E	Jan. 11, 96	76	1
(W-1)	45°58'N	160°00'E	Jan. 11, 96	121	1
			(subtotal)	197	1
Eastern NPO	45°58'N	168°06'W	Jan. 18, 96	41	1-2
(W-2)	47°30'N	168°09'W	Jan. 19, 96	3	4
	48°58'N	168°07'W	Jan. 19, 96	1	3
	50°00'N	162°57'W	Jan. 20, 96	5	3-4
			(subtotal)	50	1-4
Gulf of Alaska	54°21'N	148°12'W	Jan. 22, 96	32	2-4
(W-3)	54°36'N	145°11'W	Jan. 23, 96	2	2-3
	53°00'N	145°00'W	Jan. 24, 96	20	3-5
	50°04'N	144°59'W	Jan. 25, 96	67	1-4
	48°29'N	144°48'W	Jan. 25, 96	46	1-4
			(subtotal)	167	1-5

Table 2. High-seas chum salmon samples collected in the North Pacific Ocean (NPO) and Bering Sea (BS) in summer for genetic stock identification.

Region	Latitude	Longitude	Date	Maturity	No. samples	Ocean age
Western NPO	50°00'N	165°00'E	July 4, 96	IM	28	2-3
(S-1)				M	10	2-4
	51°00'N	165°00'E	July 5, 96	IM	31	2-4
				M	16	3-4
	51°00'N	165°00'E	July 6, 96	IM	12	2-6
				M	7	2-4
	50°00'N	165°00'E	July 7, 96	IM	19	2-3
				M	10	2-3
	49°00'N	165°00'E	July 8, 96	IM	5	2-3
				M	9	2-3
			(subtotal)	IM	95	2-6
				M	52	2-4
Central NPO	43°30'N	179°30'W	June 21, 96	IM	4	2-3
(S-2)	44°30'N	179°30'W	June 22, 96	IM	9	1-2
				M	1	2
	45°30'N	179°30'W	June 23, 96	IM	59	1-3
				M	3	1, 3
	46°30'N	179°30'W	June 24, 96	IM	26	1-2
	47°30'N	179°30'W	June 27, 96	IM	86	1-4
				M	4	2-4
			(subtotal)	IM	184	1-4
				M	8	1-4
Gulf of Alaska	55°59'N	144°59'W	July 3, 96	IM	17	2-4
(S-3)				M	17	2-4
	55°00'N	145°00'W	July 4, 96	IM	53	1-4
				M	3	2-3
	54°00'N	144°59'W	July 5, 96	IM	42	1-4
	53°00'N	145°00'W	July 6, 96	IM	19	2
				M	5	1-3
	52°00'N	145°00'W	July 7, 96	IM	63	1-3
				M	4	1-3
	51°00'N	145°00'W	July 8, 96	IM	13	2
				M	2	2
			(subtotal)	IM	207	1-4
				M	31	1-4
Central BS	56°30'N	179°30'W	July 6, 96	IM	75	1-4
(S-4)				M	23	2-5
	57°30'N	179°30'W	July 7, 96	IM	65	1-4
				M	30	2-4
			(subtotal)	IM	140	1-4
				M	53	2-5

Table 3. 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 4. Wintertime regional stock composition of chum salmon in the North Pacific Ocean (NPO) estimated by genetic stock analysis.

Region	N	Japan	Russia	Fall Yukon	Western Alaska	Alaska Peninsula Kodiak	Southeast Alaska/PWS	Alaska Total	British Columbia	Washington
Western NPO (W-1) (44-45°N, 160°E)	197	28.6±6.4*[1]	65.1±7.2	0	2.3±2.9	2.5±3.3	0.7±1.0	5.5±4.7	0.4±0.8	0.4±0.9
Eastern NPO (W-2) (45-50°N, 162-168°W)	50	28.7±10.8	50.6±12.6	0	10.3±8.2	4.8±5.9	0	15.2±10.1	5.1±4.9	0.4±1.5
Gulf of Alaska (W-3) (48-54°N, 144-148°W)	167	18.7±5.6	9.9±6.5	1.1±1.4	11.5±5.3	16.4±6.7	6.2±4.8	35.1±8.0	19.3±8.0	16.9±6.8

*[1] Estimate ± SD.

Table 5. Summertime regional stock composition of chum salmon in the North Pacific Ocean (NPO) and Bering Sea (BS) estimated by genetic stock analysis.

Region	Maturity*[1]	N	Japan	Russia	Fall Yukon	Western Alaska	Alaska Peninsula Kodiak	Southeast Alaska/PWS*[2]	Alaska Total	British Columbia	Washi-ngton
Western NPO (S-1)	IM	95	5.6±5.1*[3]	80.1±8.4	0	8.0±5.3	5.1±4.6	0.8±1.5	14.0±7.2	0.3±0.9	0
(49-51°N, 165°E)	M	52	18.5±8.2	62.5±11.4	4.1±3.3	9.1±7.5	0	1.7±2.5	15.0±8.2	2.7±3.2	1.3±2.6
	(Total)	147	11.2±4.9	76.3±7.0	1.5±1.5	6.3±4.2	1.8±2.1	1.3±1.5	10.9±5.0	0.9±1.2	0.7±1.2
Central NPO (S-2)	IM	184	14.9±5.4	69.4±7.8	0	7.9±4.8	6.5±4.9	0.9±1.7	15.3±7.0	0.3±1.0	0
(43-47°N, 179°W)	M	8	-	-	-	-	-	-	-	-	-
	(Total)	192	15.5±5.4	69.5±7.6	0	8.1±4.7	6.0±4.3	0.6±1.3	14.7±6.9	0.3±0.9	0
Gulf of Alaska (S-3)	IM	207	4.7±2.9	17.6±7.3	0.3±1.0	32.7±5.2	12.4±5.8	5.0±4.0	50.3±7.8	23.4±5.5	4.0±3.6
(51-55°N, 144-145°W)	M	31	5.1±6.2	22.0±11.7	2.4±4.5	6.9±6.9	23.8±13.2	6.3±10.2	39.3±14.0	33.2±11.9	0.3±2.0
	(Total)	238	4.8±2.9	18.4±6.4	0.4±1.0	29.3±5.1	13.5±5.7	5.3±4.3	48.5±7.6	25.3±5.2	2.9±3.1
Central BS (S-4)	IM	140	25.0±6.4	58.0±8.3	1.2±1.4	7.7±5.2	5.7±4.9	0.4±1.2	14.9±6.9	1.2±2.1	0.9±1.4
(56-57°N, 179°W)	M	53	42.0±10.6	40.9±13.3	1.0±1.9	2.3±4.2	5.0±6.2	4.9±5.8	13.2±9.0	3.3±3.5	0.6±1.6
	(Total)	193	31.3±6.2	55.9±8.0	1.0±1.3	4.3±4.0	3.8±3.9	1.1±1.9	10.2±5.7	1.7±1.5	0.9±1.2

*[1]IM, Immature fish; M, maturing fish. *[2] PWS, Prince William Sound. *[3] Estimate ± SD.

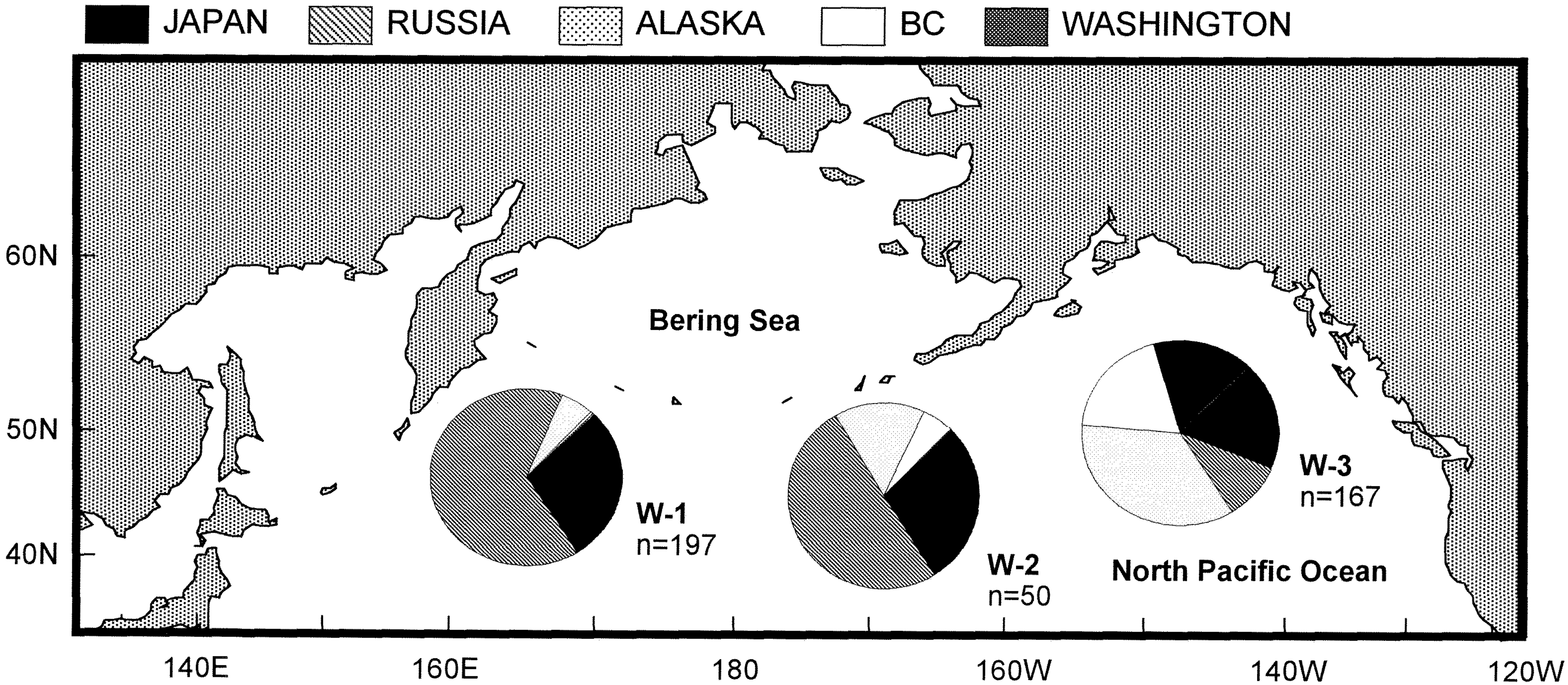

Figure 1. Estimated stock composition (%) of chum salmon captured in sampling areas in the North Pacific Ocean in January, 1996.

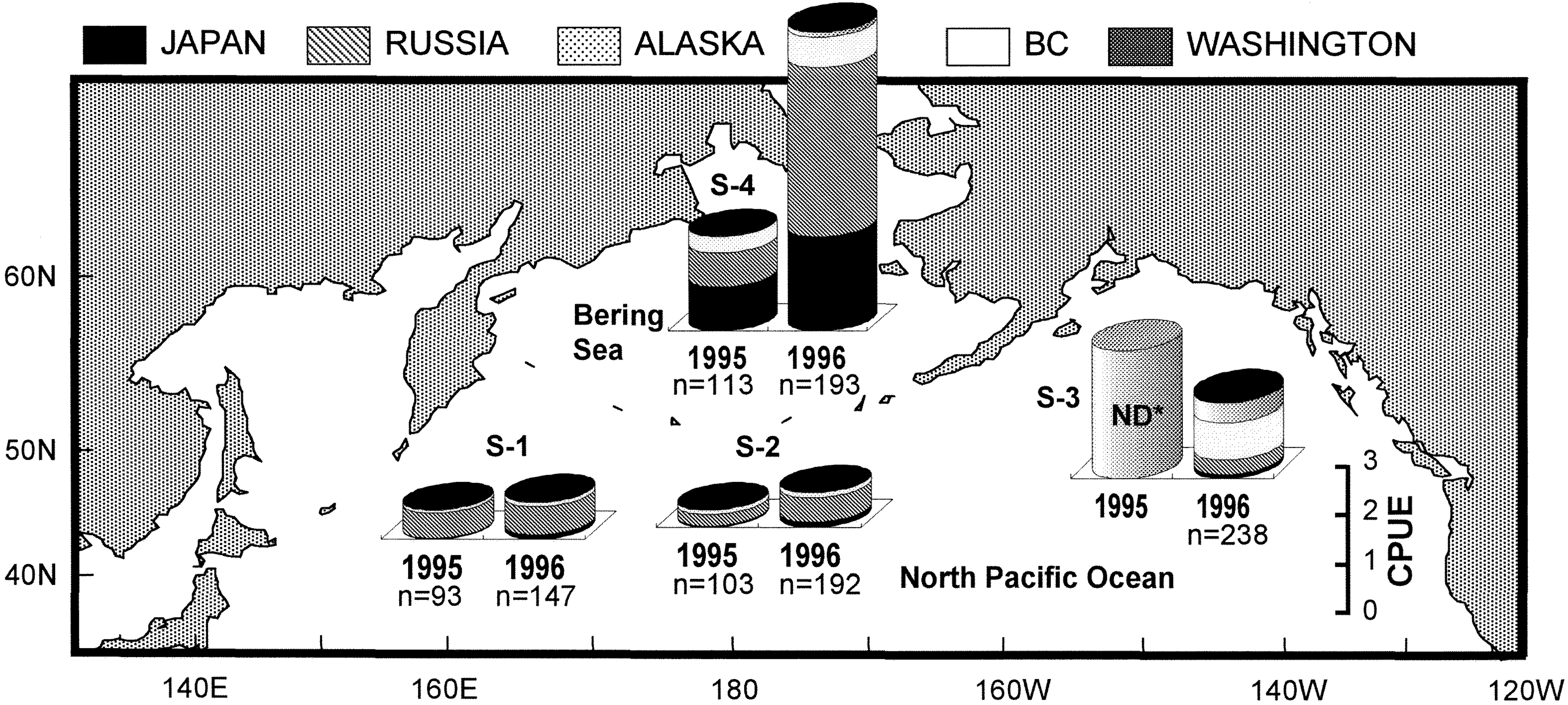

Figure 2. Estimated stock compositions applied to catch per unit of effort (CPUE) values for chum salmon captured in the North Pacific Ocean and Bering Sea in the summers of 1995 and 1996. CPUE = total catch in number/total effort in tans (see Myers et al., 1993). Stock composition estimates for 1995 are from Winans et al. (1997). *ND, stock composition data not available.