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Shigehiko Urawa[*1], Yasuhiro Ueno[*2], Yukimasa Ishida[*2], Shogo Takagi[*3],
Gary Winans[*4], and Nancy Davis[*5]

[*1]*Research Division, National Salmon Resources Center, Fisheries Agency of Japan,*
2-2 Nakanoshima, Toyohira-ku, Sapporo 062, Japan
[*2]*National Research Institute of Far Seas Fisheries, Fisheries Agency of Japan,*
2-7-1 Orido, Shizuoka 424, Japan
[*3]*Faculty of Fisheries, Hokkaido University,*
Minato 3-1-1, Hakodate, Hokkaido 041, Japan
[*4]*Northwest Fisheries Science Center, National Marine Fisheries Service,*
2725 Montlake Boulevard East, Seattle, WA 98112, USA
[*5]*University of Washington, Fisheries Research Institute,*
Box 357980, Seattle, WA 98195-7980, USA

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[*1]*National Salmon Resources Center, Fisheries Agency of Japan, 2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan*
[*2]*National Research Institute of Far Seas Fisheries, Fisheries Agency of Japan, 2-7-1 Orido, Shizuoka 424, Japan*
[*3]*Faculty of Fisheries, Hokkaido University, Minato 3-1-1, Hakodate, Hokkaido 041, Japan*
[*4]*Northwest Fisheries Science Center, National Marine Fisheries Service, 2725 Montlake Boulevard East, Seattle, WA 98112, USA*
[*5]*University of Washington, Fisheries Research Institute, Box 357980, Seattle, WA 98195-7980, USA*

Abstract

The geographical origins of young chum salmon (*Oncorhynchus keta*) captured in the Okhotsk Sea, North Pacific Ocean, and Bering Sea were estimated by genetic stock identification techniques. We used a genetic baseline for protein allozyme characters (19 loci) covering 77 North Pacific rims stocks. Among juvenile chum salmon (age 0.0) caught in the Okhotsk Sea, the Japanese regional stock was predominant (71%) in October, but its composition decreased to 36% in November. Juvenile chum salmon migrating to Pacific waters east of the Kuril Islands in November were composed of 57% Japanese and 30% Russian stocks. Young chum salmon (age 0.1) caught in winter in the western North Pacific Ocean consisted of 29% Japanese and 65% Russian stocks in January and 37% Japanese and 45% Russian stocks in February. In summer, young chum salmon (age 0.1) caught in the western and central North Pacific Ocean were predominately of Russian origin (59-69%), but young chum salmon caught in the central Bering Sea (56-57°N, 179°W) were a mixture of Japanese (41%), Russian (38%), and Alaskan (20%) stocks. These results suggest that Japanese chum salmon juveniles remain in the Okhotsk Sea from summer to late autumn, over-winter in the western North Pacific Ocean, and then migrate into the Bering Sea by summer.

Introduction

Previous genetic stock identification (GSI) studies have indicated that in winter Japanese immature and maturing chum salmon (*Oncorhynchus keta*) are distributed in the central and eastern waters of the North Pacific Ocean and in summer they are distributed in the Bering Sea (Urawa et al., 1997; Winans et al., 1998). However, the migration route of young Japanese chum salmon has not been determined. Juvenile chum salmon (age 0.0) are abundant in the Okhotsk Sea during summer and autumn (Ueno, 1997). However, their stock origins have not been determined. The present study was conducted to estimate the stock composition of young chum salmon (age 0.0 and 0.1) caught in the Okhotsk Sea, North Pacific Ocean, and Bering Sea using GSI techniques.

Materials and Methods

Mixture samples

Juvenile chum salmon (age 0.0) were captured in the Okhotsk Sea and western waters of the North Pacific Ocean near the Kuril Islands in October and November 1993 by trawling operations of R/V *Kaiyo-maru* (Table 1). Young chum salmon (age 0.1) were caught in the North Pacific Ocean by trawling operations of R/V *Kaiyo-maru* on January 1996 and February 1998. In the summer of 1996 and 1997, young chum salmon (age 0.1) were caught in research gillnets in the North Pacific Ocean and central Bering Sea during research operations of R/V *Hokko-maru*, *Wakatake-maru*, and *Oshoro-maru*. In addition, juvenile chum salmon were caught in Pacific waters off the west coast of Vancouver Island in October 1996 by trawling operations of a Canadian research vessel. The fork length and weight of each fish were measured and scales were removed for age determination. The muscle, heart, and liver were collected from each fish, these samples were immediately frozen in -40°C or -80°C freezers, and shipped to the Genetics Section of the National Salmon Resources Center for genetic analysis.

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. (1998) 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. (1998) 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 2). 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

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, 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., 1998).

Results

Autumn

In October, the stock composition of juvenile chum salmon caught in the southern Okhotsk Sea (46-48ºN, 145-151ºE) was 71% Japanese and 24% Russian origin (Table 3). In November, the proportion of Japanese-origin juvenile chum salmon decreased to 36% in the southern Okhotsk Sea (46-48ºN, 146-152ºE), and juvenile chum salmon that migrated to the Pacific waters off the Kuril Islands (45ºN, 152ºE) consisted of 57% Japanese and 30% Russian stocks. Juvenile chum salmon caught off the west coast of Vancouver Island in October comprised 53% British Columbia and 21% Alaska Peninsula/Kodiak Island stocks.

Winter

Young chum salmon (age 0.1) captured in the western North Pacific Ocean off the Kamchatka Peninsula were composed of 29% Japanese and 65% Russian stocks in January 1996 (44-46ºN, 160ºE), and 37% Japanese and 45% Russian stocks in February 1997 (42-45ºN, 165ºE).

Summer

In July in western waters of the North Pacific Ocean, Russian-origin young chum salmon (age 0.1) stocks were dominant (Table 3, Figure 1). The estimated stock origins of young chum salmon caught in the central North Pacific Ocean (44-47°N, 179°W) was 59% Russian, 20% Japanese, and 21% Alaskan stocks. In the Gulf of Alaska (52-55°N, 145°W), young chum salmon were estimated to have originated essentially from Alaska (64%; primarily from Southeast and Prince Williams Sound), and British Columbia stocks (19%). In the central Bering Sea (56-57°N, 179°W), approximately 80% of young chum salmon were estimated to be Asian origin and 20% to be Alaskan. The estimated proportion of Asian fish was 41% Japanese and 38% Russian stocks and the estimated proportion of Alaskan fish was primarily from the Alaska Peninsula/Kodiak Island regional stock (16%; Table 3).

Discussion

Numerous chum salmon juveniles are distributed in the Okhotsk Sea from summer to late autumn (Ueno and Ishida, 1996; Ueno, 1997). The distribution of these chum salmon juveniles may be limited to the Okhotsk Sea from August to late October, but in November they migrate into the Pacific waters off the Kuril Islands when the seawater temperature decreases to less than 5ºC (Ogura, 1995). The present GSI study indicates that these chum salmon juveniles include Japanese and Russian stocks. In the Okhotsk Sea, the estimated proportion of Japanese chum salmon was 71% in October, but it reduced to 36% in mid-November. Alternatively, by late November Japanese chum salmon were the predominant stock (57%) in Pacific waters off the Kuril Islands. These results support Ueno and Ishida's (1996) hypothesis that Japanese chum salmon juveniles migrate from Japanese coasts to the Okhotsk Sea where they remain until November. Japanese stocks may migrate from the Okhotsk Sea into Pacific waters earlier than Russian stocks.

Winter high-seas surveys (Ueno et al., 1997; Ishida et al., 1998) showed that young chum salmon (age 0.1) are abundant in the western North Pacific Ocean, however they were rare in the central and eastern North Pacific waters. Overwintering young chum salmon in western waters were estimated to be 29-37% Japanese and 45-65% Russian fish. On the other hand, in summer,

young chum salmon (age 0.1) are more abundant in the central Bering Sea than in the North Pacific Ocean (Figure 1). The present GSI analysis indicated that Japanese chum salmon comprised 41% of young chum salmon in the central Bering Sea and 9-20% in the western and central North Pacific Ocean, where Russian stock is predominant. Therefore young Japanese chum salmon may be distributed in the Bering Sea in summer and mixing with the other age groups of Japanese chum salmon that are distributed in that area in summer (Urawa et al., 1997).

In conclusion, the present GSI results suggest that Japanese chum salmon juveniles remain in the Okhotsk Sea from summer to late autumn, over-winter in the western North Pacific Ocean, and migrate to the Bering Sea by the next summer. We recommend that future GSI samples should be collected in spring and early summer from the western and central North Pacific Ocean and Bering Sea in order to complete the migration model because there is a gap in information about when young Japanese chum salmon move into the Bering Sea.

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Table 1. A list of young chum salmon samples captured in the Okhotsk Sea, North Pacific Ocean (NPO), and Bering Sea for genetic stock identification.

Location of capture	Date of capture	Number of samples	Age	Fork length (mm)	Weight (g)
Okhotsk Sea					
46-48ºN, 145-151ºE	Oct 16-23, 1993	242	0.0	233 (102-302)*	151 (67-337)
46-48ºN, 146-152ºE	Nov 10-16, 1993	180	0.0	221 (166-280)	120 (51-235)
Western NPO					
45ºN, 152ºE	Nov 24, 1993	49	0.0	226 (176-262)	120 (55-168)
44-46ºN, 160ºE	Jan 11, 1996	197	0.1	230 (192-270)	125 (66-207)
42-45ºN, 165ºE	Feb 9-10, 1998	110	0.1	232 (207-273)	122 (79-185)
45-50ºN, 165ºE	July 7-12, 1997	72	0.1	343 (304-398)	444 (340-680)
Central NPO					
44-47ºN, 179ºW	June 22-27, 1996	104	0.1	319 (284-376)	317 (220-550)
Eastern NPO (Gulf of Alaska)					
52-55ºN, 145ºW	July 4-7, 1996	24	0.1	401 (324-496)	750 (460-1440)
Off Vancouver Island					
55ºN, 134ºW	October 10, 1995	98	0.0	211 (190-244)	100 (64-137)
Central Bering Sea					
56-57ºN, 179ºW	July 6-7, 1996	30	0.1	334 (304-374)	402 (260-540)

*Mean (range).

Table 2. 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 3. Regional stock composition estimates (%) of young chum salmon determined by genetic stock analysis.

Location of capture	Date of capture	Japan	Russia	Fall Yukon	Western Alaska	Alaska Pen. /Kodiak	Southeast Alaska/PWS	Alaska Total	British Columbia	Washington
Okhotsk Sea										
46-48N, 145-151E	Oct. 16-23, 1993	70.6±5.8*[1]	24.1±5.1	0	4.3±3.2	0.9±1.9	0.1±0.3	5.3±3.8	0	0
46-48N, 146-152E	Nov. 10-16, 1993	36.0±6.2	50.6±7.1	0	11.5±6.1	1.0±1.8	0	12.6±6.3	0.7±0.9	0.2±0.5
Western NPO										
45N, 152E	Nov. 24, 1993	57.1±13.7	29.6±11.9	0	8.2±8.7	5.1±5.7	0	13.2±10.3	0	0.1±0.1
44-46N, 160E	Jan. 11, 1996	28.6±6.4	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
42-45N, 165E	Feb. 9-10, 1998	37.0±7.5	45.1±8.2	0	7.6±5.8	5.4±3.5	2.0±2.4	15.1±6.7	2.4±2.0	0.5±1.2
45-50N, 165E	July 7-12, 1997	8.9±6.2	69.0±10.2	0	11.1±7.4	11.1±7.1	0	22.2±9.9	0	0
Central NPO										
44-47N, 179W	June 22-27, 1996	19.8±7.9	59.1±9.8	0	12.9±7.1	6.6±5.2	0.9±2.1	20.5±8.8	0.5±1.3	0.2±0.6
Eastern NPO (Gulf of Alaska)										
52-55N, 145W	July 4-7, 1996	5.0±7.3	10.7±10.4	0	14.8±9.4	13.1±14.6	36.3±21.2	64.1±17.8	18.9±14.6	1.4±4.0
Off Vancouver Island										
55N, 134W	Oct. 10, 1995	1.5±2.4	17.4±9.5	0	0.7±1.8	21.4±9.8	2.8±3.5	25.0±10.0	53.4±9.1	2.9±3.7
Central Bering Sea										
56-57N, 179W	July 6-7, 1996	41.3±16.4	38.3±17.5	0	4.3±7.3	15.5±11.1	0.3±1.7	20.1±13.1	0.4±1.5	0

*[1] Estimate ± SD.

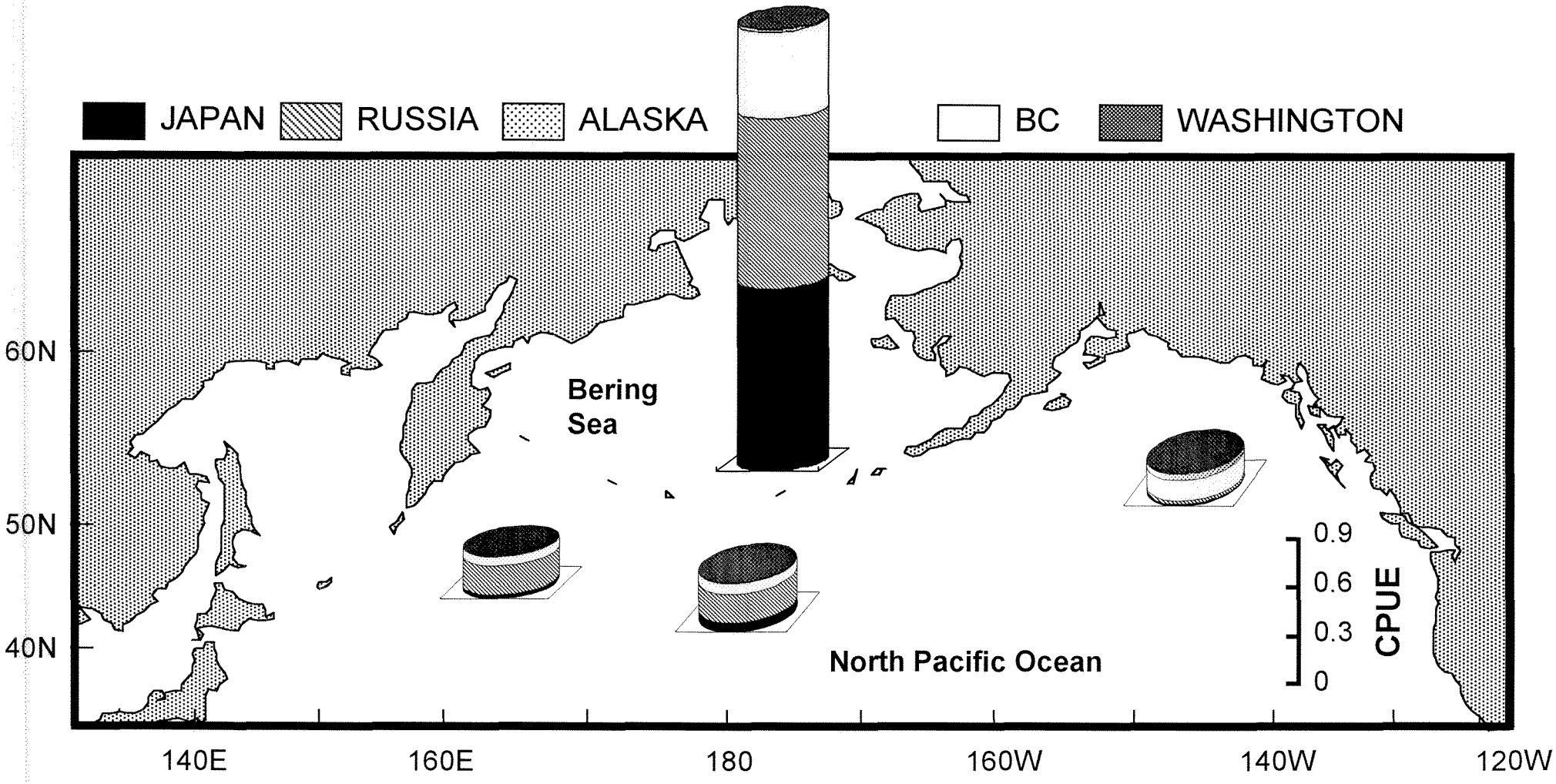

Figure 1. Estimated stock composition (catch per unit effort, CPUE) of young chum salmon (age 0.1) captured in the North Pacific Ocean and Bering Sea in the summer of 1996 and 1997. CPUE = total catch in number/total effort in tans (see Myers et al., 1993).