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Stock-Specific Distribution and Abundance of Immature Chum Salmon in the Western Bering Sea in Summer and Fall 2002–2003

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Abstract: Seasonal stock-specific distribution and abundance of immature chum salmon (*Oncorhynchus keta*) in the western Bering Sea in summer 2003 and fall 2002–2003 were determined using scale pattern analysis. Results indicated that immature chum salmon were predominantly of Asian (Russian and Japanese) origin. There was considerable spatial and temporal variation in estimated proportions of regional stocks of chum salmon. Russian stocks dominated catches in the southwestern Bering Sea. Japanese and North American stocks were most abundant in the northwestern Bering Sea. Despite low estimated percentages of North American (western Alaska) chum salmon (average ≤ 10%), estimated total abundance of immature chum salmon in the western Bering Sea was very high in the early 2000s. Thus, we concluded that the western Bering Sea ecosystem is an important summer-fall foraging area for immature chum salmon of both Asian and North American origin.

Keywords: abundance, age, biomass, chum salmon, distribution, immature, scale pattern analysis, stock identification, western Bering Sea

INTRODUCTION

The Bering-Aleutian Salmon International Survey (BASIS) was initiated in 2002 to detect and monitor changes in climate-ocean and ecosystem states and Pacific salmon (*Oncorhynchus* spp.) in the Bering Sea (NPAFC 2001). In addition to ichthyological, hydrobiological, and hydrological research, a major focus of BASIS was to estimate seasonal stock-specific distribution and abundance of salmon in the Bering Sea. A number of recent publications have reported the results of stock identification of chum salmon (*O. keta*) in BASIS research vessel catches. Allozyme- and DNA-based genetic characteristics were used to identify chum salmon in BASIS samples collected in the central Bering Sea and adjacent North Pacific waters in summer–fall 2002–2004 (Sato et al. 2004, 2009; Urawa et al. 2004, 2005, 2009; Moriya et al. 2007, 2009). Bugaev et al. (2006) used scale pattern analysis in a preliminary assessment of the distribution of regional stocks of chum salmon in the western Bering Sea, inside the Russian Federation Exclusive Economic Zone (REEZ), in fall 2002 and summer–fall 2003. Collectively, the results of genetic and scale pattern stock-identification studies indicated that the majority of chum salmon in the central and western Bering Sea were of Asian (Russian and Japanese) origin. In this paper, we briefly review information from BASIS surveys in the REEZ on the distribution, abundance, and biological characteristics of chum salmon in the western Bering Sea, and update and extend earlier stock identification results reported by Bugaev et al. (2006). Our primary objectives were to estimate the proportions and potential abundance of regional stocks of chum salmon in the western Bering Sea in fall 2002 and summer–fall 2003.

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MATERIALS AND METHODS

Analysis of scale patterns has been used since the 1950s to estimate the regional stock composition of salmon caught in mixed-stock fisheries on the high seas. Major et al. (1972) outlined the basic principles and procedures of scale pattern analysis. Our methods were similar to those described by Bugaev et al. (2006). Briefly, we used scale pattern analysis of representative (baseline) samples of Asian and North American chum salmon to estimate the proportions of these stock groups in BASIS (mixture) samples and their potential abundance in the western Bering Sea.

Mixture Samples

Mixture samples of chum salmon and associated biological and catch data were collected by the staff of the TINRO-Center from BASIS trawl catches of the RV *TINRO* in the western Bering Sea (REEZ) in summer (July–August) 2003 and fall (September–October) 2002–2003 (NPAFC 2003, 2004). A standard midwater rope trawl (PT/TM 80/396 m) was used to survey the upper epipelagic layer (~upper 40 m).

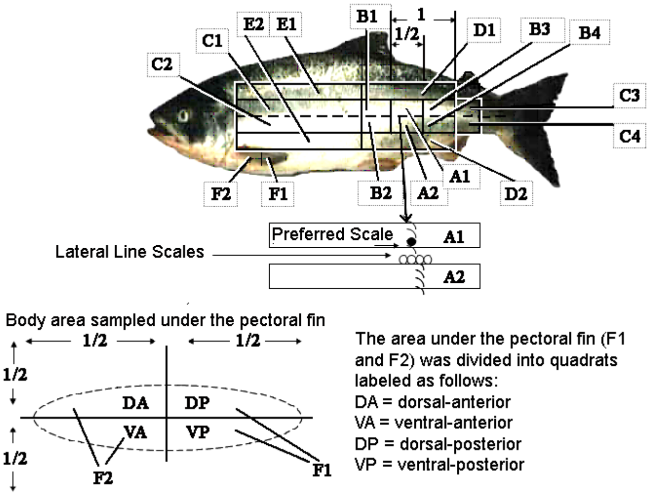
Shipboard sampling of chum salmon included determination of maturity and collection of a scale sample from each fish. Maturity was determined by visual evaluation of the stage of gonad maturation (Pravdin 1966). All fish at stages II and II–III were considered immature (e.g., Mosher 1972; Bugaev 1995; Ito and Ishida 1998). The body area of scale collection was recorded using a classification scheme developed by TINRO-Center (Fig. 1). Collection of preferred scales (Clutter and Whitesel 1956; Knudsen 1985; Davis et al. 1990) was not always possible, as salmon caught in trawls frequently lose many scales. Preferred scales were collected from body areas A or B, but if these scales were missing scales were collected from areas C and D. Both preferred and non-preferred scales were used to estimate age composition. Only preferred scales were used to estimate stock composition, because different rates of scale growth on different parts of the fish's body can influence the results of scale pattern analysis. In all cases, the quality of scales was evaluated visually before inclusion in our analyses.

Ages of immature chum salmon in the mixture samples were determined in the laboratory by counting the number of freshwater and marine annuli on scales, which is the standard method accepted for Pacific salmon (e.g., Ito and Ishida 1998). Age was designated by the European method, whereby the number of freshwater annuli (always zero for chum salmon) and number of ocean annuli are separated by a dot (Koo 1962). For example, an age 0.1 chum salmon has one ocean annulus on its scale and is in its second summer–fall in the ocean. Although juvenile chum salmon (0.0 fish) were present in BASIS trawl catches, samples were insufficient for stock-identification analysis due to scale loss during trawl operations.

Samples of immature chum salmon collected in Districts 8 and 12 (Fig. 2) accounted for approximately 90% of all biostatistical and scale data. Therefore, we pooled samples from individual districts into two geographic regions – a "northern" region that included samples from Districts 1–8 and a "southern" region that included samples from Districts 9–12. The total mixed-stock sample from all districts (4,837 fish) was used for age composition estimates, and a subset of preferred scales from this sample (3,877 fish) was used to estimate stock composition.

Baseline Samples

Baseline scale samples were collected by regional fish-



The area under the pectoral fin (F1 and F2) was divided into quadrats labeled as follows:
DA = dorsal-anterior
VA = ventral-anterior
DP = dorsal-posterior
VP = ventral-posterior

Fig. 1. Classification scheme for coding the body area of scale collection used by TINRO-Center during BASIS trawl surveys.

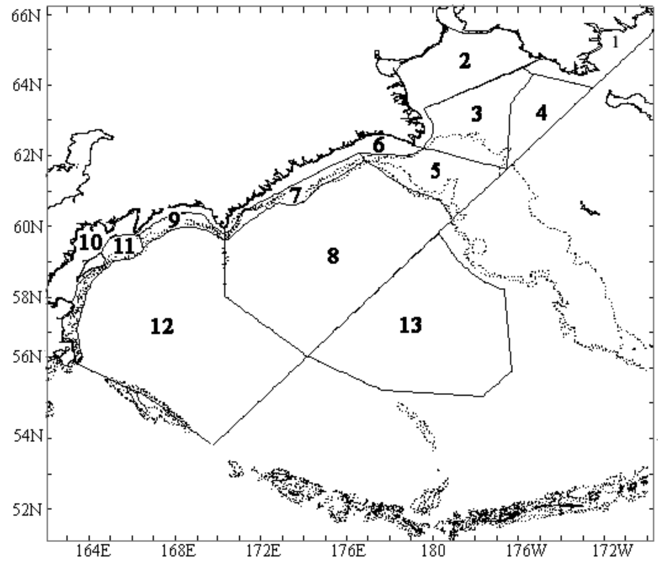


Fig. 2. TINRO-Center biostatistical districts in the western Bering Sea (Shuntov 1986; Volvenko 2003).

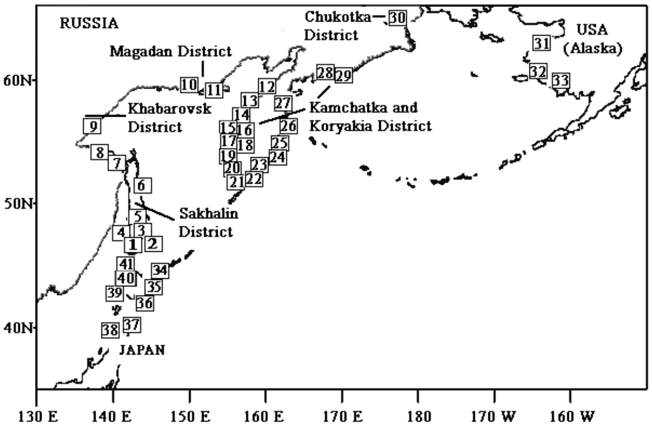


Fig. 3. Locations (indicated by numbers) of 41 chum salmon stocks represented in the 2003 scale pattern baselines. Russia, Sakhalin District: (1) Taranai R., (2) Mordvinov Bay, (3) Belaya R., (4) Kalininka R., (5) Naiba R., (6) Tym' R.; Khabarovsk District: (7) Amur R., (8) Aldoma R., (9) Uda R.; Magadan District: (10) Taui R., (11) Yama R.; Kamchatka and Koryakia District: (12) Palana R., (13) Icha R., (14) Krutogorova R., (15) Vorovskaya R., (16) Kol' R., (17) Pymta R., (18) Kikhchik R., (19) Utka R., (20) Bolshaya R., (21) Opala R., (22) Zhirovaya R., (23) Avacha R., (24) Nalycheva R., (25) Zhupanova R., (26) Kamchatka R., (27) Khailulya R., (28) Impuka R., (29) Apuka R.; Chukotka District: (30) Anadyr' R.; USA (western Alaska): (31) Yukon R., (32) Kuskokwim R., (33) Nushagak R. (Bristol Bay); Japan (Hokkaido and Honshu): (34) Nishibetsu R., (35) Abashiri R., (36) Tokachi R., (37) Tsugaruishi R., (38) Gakko R., (39) Urappu R., (40) Tokushibetsu R., (41) Ishikari R. Scales were collected by personnel from KamchatNIRO, SakhNIRO, MagadanNIRO, TINRO-Center KhBr, ChukotNIRO, Sevvostrybvod, Alaska Department of Fish and Game (Anchorage, Alaska), and the National Salmon Resources Center (Sapporo, Japan).

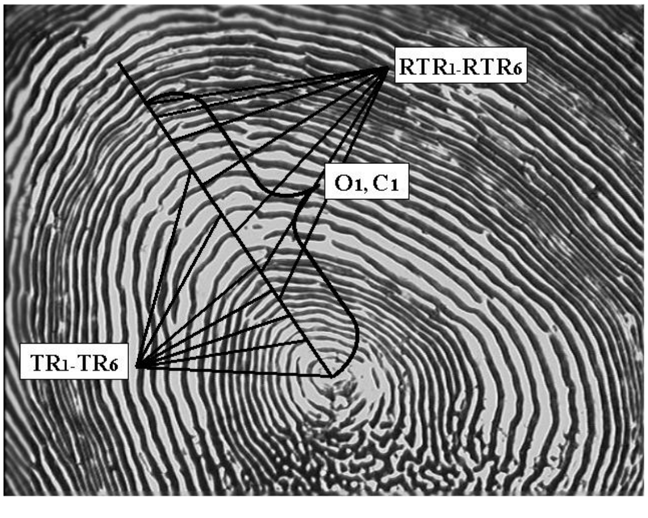


Fig. 4. Image of a chum salmon scale showing the scale pattern variables used for stock identification. O1 = total radius of the first annual ocean growth zone, C1 = number of circuli in the first annual ocean growth zone, TR1-TR6 = radii of groups of three circuli (triplets) in the first ocean zone (six triplets), RTR1-RTR6 = radii of groups of three circuli (reverse-triplets) in the first ocean zone (six reverse-triplets).

ery agency personnel from adult chum salmon returning to principal commercial watersheds in Asia and North America in 2003. Scale samples from 41 stocks of Asian and North American origin were used to form the baselines (Fig. 3). For each stock, we selected a stratified random sample of scales from the two dominant age groups (0.3 and 0.4) that accounted for spatial and temporal population structure (early-, mid-, and late-run timing). This method varied somewhat depending on available sample size. When sample size was small the entire sample was used in the analysis. Scale baselines for 2003 included a total of 5,055 chum salmon specimens, and on average the baseline for each stock consisted of 50–100 scales in every age group.

Scale Measurement

Scales were measured using an optical digitizing system (Biosonics model OPR-513, OPRS, BioSonics Inc., Seattle, WA, USA (Davis et al. 1990)). Measurements were made along the maximum radius of the scale in the first annual zone (Fig. 4). Scale pattern variables were calculated from inter-circulus measurement. Variables included the total radius of the first ocean zone (O1), total number of circuli in the first ocean zone (C1), six triplets (TR) in the first ocean zone, and six reverse triplets (RTR) in the first ocean zone (Fig. 4).

Estimates of Stock Composition

The 41 baseline stocks were combined into a reduced number of regional stocks according to similarity in scale pattern variables, as determined by *t*-tests ($p < 0.05$), hierarchical cluster analysis of Euclidian distances between stock centroids, and canonical discriminant analysis (Bugaev et al. 2007).

Computer simulations were used to evaluate the accuracy of the regional-stock models using a maximum-likelihood estimation (MLE) procedure (Millar 1987, 1990; Patton et al. 1998). The estimation procedure included 500 iterations of randomly sampled scales in the model (with replacement) for 100% representation by one baseline in the simulated mixture.

The baseline data were used to calculate MLEs of stock composition of chum salmon in the mixture samples (Patton et al. 1998). Confidence intervals (95%) of the stock composition estimates were calculated from bootstrap resampling (500) of the baseline and mixture samples (Efron and Tibshirani 1986).

Estimates of Distribution and Abundance

We reviewed information on the distribution and abundance of immature sockeye salmon during BASIS research in the western Bering Sea in summer 2003 and fall 2002–2003 (Zavolokina and Zavolokin 2007). Estimates of the abundance and biomass of chum salmon in the Bering Sea

REEZ were provided by the TINRO-Center. The TINRO-Center estimates were calculated from BASIS trawl catch data using an area-swept formula with a fishing efficiency coefficient of 0.3 for immature salmon (Temnykh et al. 2003). The TINRO-Center estimates were stratified by year, season, maturity group, and biostatistical district. For each year and season, we pooled the TINRO-Center estimates for immature chum salmon into northern (districts 1–8) and southern (districts 9–12) areas (Fig. 1), and apportioned these estimates to three regional stocks (Russia, Japan, and USA) using our estimates of stock composition weighted by age group. Russian-origin chum salmon were further apportioned to three regional stocks: (1) continental coast of the Okhotsk Sea (Magadan) and Kamchatka (Okhotsk-Kamchatka), (2) Sakhalin (Kuril)-Amur, and (3) Chukotka (Fig. 3). As a rough measure of the validity of these estimates, we compared them to published information on the abundance of adult chum salmon runs in Asia and North America.

RESULTS

Age Composition of Immature Chum Salmon

In the western Bering Sea, estimated percentages of immature chum salmon in BASIS catches of immature and maturing chum salmon (not including 0.0 fish) were 98.4% (n = 819) in northern districts and 97.9% (n = 907) in southern districts in fall 2002, 82.6% (n = 1250) in northern districts and 89.4% (n = 652) in southern districts in summer 2003, and 98.8% (n = 640) in northern districts and 96.7% (n = 569) in southern districts in fall 2003.

Three age groups (0.1, 0.2 and 0.3) accounted for 99% of immature chum salmon samples in BASIS trawl catches in the western Bering Sea (Table 1). Age 0.4 fish accounted for less than 1% of samples collected in northern districts in summer 2003 and fall 2003. All districts and time periods were dominated the two age groups (0.1 and 0.2), and northern districts (1–8) consistently had higher percentages of 0.1 fish than southern districts. Percentages of 0.1 chum salmon increased in both the northern and southern areas from summer to fall 2003, while percentages of all older age groups decreased. We referred to 0.1, 0.2, and 0.3 fish as “available age groups” because sample sizes of 0.4 chum salmon were not large enough for scale pattern analysis (AAG; Table 1).

Stock-Specific Differences in Scale Patterns

Bugaev et al. (2007) reported the detailed results of a statistical evaluation of differences in the scale patterns of local stocks of adult chum salmon of Asian and North American origin that were used in the baseline models. The results of hierarchical cluster analysis were used to combine the 41 baseline stocks of chum salmon (Fig. 3) into eight regional stocks for each age group (0.3 and 0.4 fish). The results of *t*-tests ($p < 0.05$) indicated statistically significant differences in 75% (n = 28) of the pairwise comparisons of age 0.3 regional stocks and 79% (n = 28) of age 0.4 comparisons (n = 28).

Unfortunately, the Sakhalin-Amur regional stock did not include baselines from rivers of the southern Kuril Islands. We assumed that the scale patterns of chum salmon of southern Kuril origin (Kunashir and Iturup islands) were similar to those of Sakhalin-Amur origin, because their ocean foraging areas are known to overlap during the first marine year. This issue requires further investigation, however, because age 0.3 chum salmon of Kalininka River (southwest Sakhalin) origin clustered with fish of Japanese origin, rather than with other Sakhalin-Amur origin stocks. This exception has also been observed at the genetic level (Varnavskaya 2001).

The Kamchatka baselines included samples from rivers of both coasts of Kamchatka. While the scale patterns of eastern and western Kamchatka stocks differed, high phenotypic diversity in the mixed-stock sample can increase errors in identification at lower-level hierarchical clusters. Therefore, we used higher-level hierarchical clusters to character-

Table 1. The age composition (% of total sample size) of immature chum salmon samples in the trawl catches of the R/V *TINRO* in the western Bering Sea. Age 0.4 immature chum salmon were not used in subsequent analyses because of low sample sizes. Juvenile (age 0.0 fish) chum salmon were not included in the analysis because of scale loss during trawl operations. N = sample size, AAG = available age groups for identification by scale pattern analysis, North = Districts 1–8, South = Districts 9–12 (Fig. 1).

Year	Season	Biostatistical area	N	Age composition (%)				AAG (%)
				0.1	0.2	0.3	0.4	
2002	Fall	North	806	75.8	21.1	3.1	-	100.0
		South	888	43.2	50.0	6.8	-	100.0
2003	Summer	North	1033	50.6	39.2	9.2	1.0	99.0
		South	583	46.5	37.7	15.8	-	100.0
	Fall	North	632	82.8	12.8	4.3	0.2	99.8
		South	550	75.1	21.6	3.3	-	100.0

ize Kamchatka stocks.

The Okhotsk Coast baselines included samples from rivers tributary to the continental coast of the Okhotsk Sea (Magadan District, Fig. 3). In some cases, baselines from the western and northeastern coasts of Kamchatka also clustered with Okhotsk Coast baselines. A similar trend has been observed at the genetic level for chum salmon of Okhotsk Coast (Taui and Ola rivers) and western Kamchatka origin (Varnavskaya 2001). It is likely that the phenotypic similarity in scale patterns of these stocks depends directly on genotype. For both age groups, the Okhotsk Coast regional cluster included the Tym' River (northeastern Sakhalin) baseline. We cannot explain this phenomenon, however, the probable error in identification of regional stocks would likely be small given the low abundance of Tym' River chum salmon (annual commercial catch of roughly 100–200 tons).

For both age groups, the Chukotka regional stock included only Anadyr River baseline data. The Anadyr River accounts for 80–90% of the commercial harvest of chum salmon in the Chukotka region (Makoedov et al. 2000). Therefore, we considered our assumption that one baseline is representative of the entire region to be reasonable.

The Japanese regional stock included baselines from both Hokkaido and Honshu, and the scale patterns of chum salmon from both areas were relatively homogenous. The only exception was the Tsugaruishi River baseline, which formed a single cluster with the Kalininka River baseline of age 0.3 fish. Moreover, for age 0.3 fish the Avacha River (eastern Kamchatka) baseline clustered with the Japan regional stock group. Again, we assumed that any probable error in our analysis caused by these exceptions would be low because of the high abundance of Japanese chum salmon relative to chum salmon originating in the Kalininka and Avacha rivers.

The Alaska regional stock included chum salmon baselines only from western Alaska (Yukon R., Kuskokwim R., and Nushagak R.), which formed a homogeneous cluster for age 0.3 fish. For age 0.4 fish, Alaska clustered with eastern Kamchatka. At a lower level, however, the stocks formed separate clusters. Until additional data are available, however, an explanation for similarities and differences in scale patterns between chum salmon originating in western Alaska and East Kamchatka is premature.

Accuracies of Stock Identification Models

Computer simulations indicated that the accuracies of the MLE stock identification models were relatively high (means of 91.6% for 0.3 fish and 94.0% for 0.4 fish; Tables 2 and 3). While baseline-dependent simulations might overestimate the true accuracy of the models, we considered these accuracies adequate for identification of chum salmon stocks at the regional level.

Stock Composition Estimates

Regional stocks of Asian origin (Russia and Japan) dominated all time, area, and age strata of immature chum salmon in the 2002 and 2003 BASIS mixture samples from the western Bering Sea REEZ (Table 4). Estimated proportions of Japanese chum salmon were higher in the northern area than in the southern area. Estimated proportions of Alaska chum salmon, which were also higher in the northern area, were either low (< 12% of the total) or were not statistically significant (95% CI included zero). Russian stocks, particularly Sakhalin-Amur and Okhotsk-E. Kamchatka, dominated all strata in fall 2002 and summer 2003. In fall 2003, estimated proportions of Sakhalin-Amur chum salmon were very low (not statistically significant), and chum salmon of Japanese origin dominated most strata. In most fall 2003 strata, the dominant stocks of chum salmon of Russian origin were Okhotsk-eastern Kamchatka or Okhotsk-western Kamchatka, or both. The estimated proportions of Chukotka stocks were very low and not statistically significant except for a few strata in summer 2003 (0.1 and 0.2 fish in the northern area).

Distribution and Assessment of Relative Abundance

In general, the highest catches of immature chum salmon during BASIS trawl-fishing operations were observed in the northern region (District 8; Fig. 5). Catches typically ranged from 2,000–5,000 fish/km^2, and in a few cases were higher. Catches were similar in summer and fall periods. In the southern region (District 12), catches in general did not exceed 200–2,000 fish/km^2. Fall catches of immature chum salmon were slightly higher than summer catches.

Estimates of Abundance and Biomass of Immature Chum Salmon

The abundance and biomass of immature chum salmon were estimated for each statistical district based on catch distribution data (Table 5). In the northern districts (1–8), the highest abundance and biomass of immature chum salmon were observed in summer 2003 (583 million fish and 475 thousand tons), and the lowest—in fall of same year (206 million fish and 136 thousand tons). In the southern districts (9–12) there was less interannual variation in the abundance and biomass of immature chum salmon. The highest abundance and biomass of immature chum salmon were observed there in fall 2002 (151 million fish and 129 thousand tons).

Abundance and Biomass of Asian and North American Stocks

In September–October 2002, stocks of Japanese and Russian origin accounted for most of the estimated abundance and biomass of immature chum salmon (0.1+0.2+0.3

Table 2. Evaluation of the accuracy of an 8-region maximum likelihood estimate model for age 0.3 chum salmon in 2003, as indicated by computer simulations of 100% representation by one regional stock group (indicated by grey shading). N = sample size, Chuk = Chukotka, Sakh = Sakhalin, Kam = Kamchatka, Okh = Okhotsk Coast.

Regional stock	N	Maximum likelihood estimate/standard deviation							
		1	2	3	4	5	6	7	8
1. Chuk.	100	0.9705	0.0061	0.0003	0.0132	0.0053	0.0189	0.0004	0.0000
		0.0402	0.0108	0.0018	0.0187	0.0109	0.0251	0.0021	0.0000
2. Sakh.-Amur R.	353	0.0031	0.8801	0.0208	0.0236	0.0348	0.0040	0.0104	0.0024
		0.0081	0.0762	0.0337	0.0397	0.0518	0.0096	0.0221	0.0083
3. Japan	480	0.0000	0.0239	0.8860	0.0254	0.0144	0.0002	0.0090	0.0023
		0.0000	0.0381	0.0711	0.0388	0.0264	0.0019	0.0217	0.0088
4. West & East Kam.	500	0.0034	0.0197	0.0130	0.8348	0.0482	0.0058	0.0082	0.0000
		0.0123	0.0381	0.0282	0.1031	0.0774	0.0180	0.0203	0.0000
5. Okh. & West Kam.	380	0.0029	0.0302	0.0180	0.0500	0.8494	0.0107	0.0062	0.0000
		0.0093	0.0519	0.0338	0.0779	0.1057	0.0255	0.0146	0.0000
6. Okh. & East Kam.	226	0.0201	0.0065	0.0057	0.0295	0.0275	0.9537	0.0027	0.0045
		0.0363	0.0128	0.0116	0.0402	0.0387	0.0404	0.0064	0.0099
7. Alaska	300	0.0000	0.0207	0.0271	0.0182	0.0085	0.0025	0.9631	0.0000
		0.0000	0.0282	0.0358	0.0253	0.0152	0.0052	0.0377	0.0000
8. Japan & Sakh.	50	0.0000	0.0128	0.0291	0.0053	0.0119	0.0042	0.0000	0.9908
		0.0000	0.0200	0.0371	0.0100	0.0175	0.0079	0.0000	0.0155
Mean accuracy (%)									91.61

Table 3. Evaluation of the accuracy of an 8-region maximum likelihood estimate model for age 0.4 chum salmon in 2003, as indicated by computer simulations of 100% representation by one regional stock group (indicated by grey shading). N = sample size, Chuk = Chukotka, Sakh = Sakhalin, Kam = Kamchatka, Okh = Okhotsk Coast.

Regional stock	N	Maximum likelihood estimate/standard deviation							
		1	2	3	4	5	6	7	8
1. Sakh. & Amur R.	380	0.9317	0.0210	0.0000	0.0196	0.0076	0.0062	0.0092	0.0003
		0.0517	0.0328	0.0000	0.0284	0.0154	0.0120	0.0195	0.0022
2. Japan 1	313	0.0283	0.9278	0.0000	0.0144	0.0153	0.0012	0.0092	0.0028
		0.0431	0.0532	0.0000	0.0253	0.0246	0.0036	0.0188	0.0064
3. Chuk.	16	0.0000	0.0002	0.9958	0.0102	0.0041	0.0250	0.0095	0.0000
		0.0000	0.0021	0.0121	0.0154	0.0085	0.0338	0.0150	0.0000
4. East Kam.	214	0.0071	0.0140	0.0005	0.8713	0.0237	0.0151	0.0061	0.0000
		0.0173	0.0273	0.0038	0.0816	0.0428	0.0300	0.0162	0.0000
5. Alaska	215	0.0141	0.0157	0.0000	0.0413	0.9293	0.0103	0.0006	0.0000
		0.0244	0.0256	0.0000	0.0520	0.0551	0.0174	0.0029	0.0000
6. West Kam.	497	0.0029	0.0034	0.0002	0.0292	0.0089	0.9188	0.0175	0.0000
		0.0072	0.0085	0.0027	0.0409	0.0175	0.0588	0.0304	0.0000
7. Okh.	203	0.0096	0.0115	0.0035	0.0110	0.0111	0.0200	0.9450	0.0000
		0.0166	0.0200	0.0105	0.0187	0.0187	0.0313	0.0450	0.0000
8. Japan 2	100	0.0063	0.0064	0.0000	0.0030	0.0000	0.0034	0.0029	0.9969
		0.0098	0.0105	0.0000	0.0059	0.0000	0.0057	0.0056	0.0067
Mean accuracy (%)									93.96

Table 4. Maximum likelihood estimates (MLE) of regional stock composition of chum salmon in trawl catches of the R/V *TINRO* in the western Bering Sea in 2002–2003. SD = standard deviation, CI = confidence interval, B.S = Bering Sea, W = west, E = East, Kam = Kamchatka.

Year & Season	B.S. Area	Age	N	Regional stock	MLE	SD	CI (95%)
2002 Fall	Northern	0.1	566	Chukotka	0.0023	0.0018	0.0000–0.0083
				Sakhalin-Amur	0.3184	0.0297	0.1885–0.3329
				Japan	0.4088	0.0298	0.3431–0.4871
				W. & E. Kam.	-	-	-
				Okhotsk-W. Kam.	0.0001	0.0002	0.0000–0.0694
				Okhotsk-E. Kam.	0.2632	0.0230	0.2398–0.3503
				Alaska	0.0049	0.0087	0.0000–0.0455
				Japan-Sakhalin	0.0023	0.0018	0.0000–0.0041
		0.2	156	Chukotka	0.0028	0.0036	0.0000–0.0152
				Sakhalin-Amur	0.4429	0.0602	0.2511–0.5225
				Japan	0.4077	0.0580	0.2996–0.5495
				W. & E. Kam.	-	-	-
				Okhotsk-W. Kam.	-	-	-
				Okhotsk-E. Kam.	0.1438	0.0358	0.0699–0.2395
				Alaska	-	-	-
				Japan-Sakhalin	0.0028	0.0036	0.0000–0.0039
		0.3	23	Sakhalin-Amur	0.4810	0.1439	0.1711–0.7325
				Japan 1	0.3652	0.1305	0.1250–0.6273
				Chukotka	-	-	-
				E. Kam.	-	-	-
				Alaska	-	-	-
				W. Kam.	-	-	-
				Okhotsk	0.1379	0.0885	0.0000–0.3261
				Japan 2	0.0159	0.0566	0.0000–0.2584
	Southern	0.1	309	Chukotka	-	-	-
				Sakhalin-Amur	0.5388	0.0420	0.3939–0.5780
				Japan	0.2754	0.0353	0.2090–0.3616
				W. & E. Kam.	-	-	-
				Okhotsk-W. Kam.	-	-	-
				Okhotsk-E. Kam.	0.1858	0.0291	0.1459–0.2759
				Alaska	-	-	-
				Japan-Sakhalin	-	-	-
		0.2	384	Chukotka	-	-	-
				Sakhalin-Amur	0.4251	0.0444	0.2429–0.4416
				Japan	0.1428	0.0264	0.1029–0.2184
				W. & E. Kam.	-	-	-
				Okhotsk-W. Kam.	0.1625	0.0448	0.0755–0.3214
				Okhotsk-E. Kam.	0.2696	0.0327	0.2187–0.3871
				Alaska	-	-	-
				Japan-Sakhalin	-	-	-
		0.3	57	Sakhalin-Amur	0.4806	0.0972	0.2851–0.6797
				Japan 1	0.2174	0.0838	0.0662–0.3846

Table 4 (continued).

Year & Season	B.S. Area	Age	N	Regional stock	MLE	SD	CI (95%)
				Chukotka	-	-	-
				E. Kam.	0.0003	0.0039	0.0000–0.0000
				Alaska	0.0188	0.0211	0.0000–0.0695
				W. Kam.	-	-	-
				Okhotsk	0.2827	0.0721	0.1540–0.4220
				Japan 2	0.0002	0.0039	0.0000–0.0000
2003 Summer	Northern	0.1	436	Chukotka	0.0256	0.0064	0.0299–0.0891
				Sakhalin-Amur	0.2081	0.0348	0.1028–0.2652
				Japan	0.3268	0.0332	0.2522–0.3893
				W. & E. Kam.	0.0615	0.0300	0.0000–0.1177
				Okhotsk-W. Kam.	0.0538	0.0337	0.0143–0.1515
				Okhotsk-E. Kam.	0.2109	0.0273	0.1591–0.2867
				Alaska	0.0879	0.0211	0.0561–0.1437
				Japan-Sakhalin	0.0254	0.0064	0.0000–0.0000
		0.2	342	Chukotka	0.0105	0.0046	0.0036–0.0393
				Sakhalin-Amur	0.2454	0.0370	0.1477–0.3013
				Japan	0.2835	0.0377	0.2031–0.3645
				W. & Kam.	-	-	-
				Okhotsk-W. Kam.	-	-	-
				Okhotsk-E. Kam.	0.3293	0.0314	0.2932–0.4306
				Alaska	0.1209	0.0273	0.0634–0.1704
				Japan-Sakhalin	0.0104	0.0046	0.0000–0.0002
		0.3	69	Chukotka	0.0155	0.0198	0.0000–0.0974
				Sakhalin-Amur	0.3450	0.0973	0.0758–0.5079
				Japan	0.2502	0.0896	0.0528–0.4131
				W. & E. Kam.	0.0392	0.0674	0.0000–0.1687
				Okhotsk-W. Kam.	-	-	-
				Okhotsk-E. Kam.	0.2197	0.0781	0.0898–0.3946
				Alaska	0.1149	0.0678	0.0000–0.2526
				Japan-Sakhalin	0.0155	0.0197	0.0000–0.0215
	Southern	0.1	195	Chukotka	0.0164	0.0105	0.0000–0.1023
				Sakhalin-Amur	0.4342	0.0595	0.2639–0.5016
				Japan	0.0347	0.0228	0.0000–0.0839
				W. & E. Kam.	0.0346	0.0504	0.0000–0.1037
				Okhotsk-W. Kam.	0.0140	0.0648	0.0000–0.1672
				Okhotsk-E. Kam.	0.4059	0.0545	0.3110–0.5549
				Alaska	0.0439	0.0216	0.0081–0.0855
				Japan-Sakhalin	0.0163	0.0105	0.0000–0.0000
		0.2	203	Chukotka	0.0096	0.0062	0.0000–0.0662
				Sakhalin-Amur	0.4222	0.0519	0.2718–0.4893
				Japan	0.1133	0.0360	0.0573–0.2024
				W. & E. Kam.	-	-	-
				Okhotsk-W. Kam.	-	-	-

Table 4 (continued).

Year & Season	B.S. Area	Age	N	Regional stock	MLE	SD	CI (95%)
				Okhotsk-E. Kam.	0.3474	0.0433	0.2605–0.4660
				Alaska	0.0979	0.0307	0.0356–0.1489
				Japan-Sakhalin	0.0096	0.0063	0.0000–0.0000
		0.3	87	Chukotka	0.0231	0.0138	0.0000–0.1087
				Sakhalin-Amur	0.3534	0.0834	0.1742–0.5024
				Japan	0.0843	0.0454	0.0001–0.1632
				W.-E. Kam.	0.0724	0.0779	0.0000–0.2024
				Okhotsk-W. Kam.	0.0286	0.0559	0.0000–0.1682
				Okhotsk-E. Kam.	0.4152	0.0753	0.2761–0.5769
				Alaska	-	-	-
				Japan-Sakhalin	0.0230	0.0138	0.0000–0.0005
2003 Fall	Northern	0.1	436	Chukotka	0.0064	0.0044	0.0000–0.0199
				Sakhalin-Amur	-	-	-
				Japan	0.5433	0.0324	0.4489–0.5797
				W. & E. Kam.	-	-	-
				Okhotsk-W. Kam.	0.2077	0.0319	0.1492–0.2901
				Okhotsk-E. Kam.	0.2048	0.0267	0.1568–0.2720
				Alaska	0.0314	0.0151	0.0138–0.0866
				Japan-Sakhalin	0.0064	0.0039	0.0000–0.0011
		0.2	70	Chukotka	-	-	-
				Sakhalin-Amur	0.0338	0.0693	0.0000–0.1390
				Japan	0.5778	0.0755	0.4249–0.6919
				W. & E. Kam.	-	-	-
				Okhotsk-W. Kam.	0.0234	0.0855	0.0000–0.1908
				Okhotsk-E. Kam.	0.3650	0.0778	0.2121–0.5209
				Alaska	-	-	-
				Japan-Sakhalin	-	-	-
		0.3	35	Chukotka	-	-	-
				Sakhalin-Amur	0.1438	0.1039	0.0000–0.3133
				Japan	0.7766	0.1039	0.5489–0.9280
				W. & E. Kam.	0.0045	0.0459	0.0000–0.1016
				Okhotsk-W. Kam.	-	-	-
				Okhotsk -E. Kam	0.0751	0.0568	0.0000–0.2108
				Alaska	-	-	-
				Japan-Sakhalin	-	-	-
	Southern	0.1	375	Chukotka	0.0051	0.0035	0.0000–0.0188
				Sakhalin-Amur	-	-	-
				Japan	0.4460	0.0364	0.3573–0.4993
				W. & E. Kam.	0.0340	0.0284	0.0000–0.0950
				Okhotsk-W. Kam.	0.3609	0.0443	0.2735–0.4433
				Okhotsk-E. Kam.	0.1091	0.0247	0.0651–0.1690
				Alaska	0.0398	0.0168	0.0204–0.0890
				Japan-Sakhalin	0.0051	0.0035	0.0000–0.0002

Table 4 (continued).

Year & Season	B.S. Area	Age	N	Regional stock	MLE	SD	CI (95%)
		0.2	114	Chukotka	0.0087	0.0074	0.0000–0.0348
				Sakhalin-Amur	0.0040	0.0437	0.0000–0.0893
				Japan	0.5333	0.0672	0.3746–0.6616
				W. & E. Kam.	0.0374	0.0551	0.0000–0.1209
				Okhotsk-W. Kam.	0.1841	0.0916	0.0002–0.3646
				Okhotsk-E. Kam.	0.2139	0.0571	0.1228–0.3704
				Alaska	0.0098	0.0167	0.0000–0.0551
				Japan-Sakhalin	0.0088	0.0074	0.0000–0.0095
		0.3	20	Chukotka	-	-	-
				Sakhalin-Amur	0.1146	0.2104	0.0000–0.5452
				Japan	0.3283	0.1944	0.0000–0.6136
				W. & E. Kam.	0.0419	0.1353	0.0000–0.3112
				Okhotsk-W. Kam.	0.3386	0.2144	0.0000–0.6291
				Okhotsk-E. Kam.	0.1314	0.1070	0.0000–0.3392
				Alaska	0.0452	0.0662	0.0000–0.1885
				Japan-Sakhalin	-	-	-

fish) in the western Bering Sea (99.6% in the northern area; 99.9% in the southern area; Table 6). In the northern area, two regional stocks of Russian origin were dominant: Sakhalin (Kuril)-Amur (34.8% of total abundance and biomass) and Okhotsk-Kamchatka (23.4%). These two regional stocks were also dominant in the southern area (Districts 9–12): Sakhalin-Amur (47.5%) and Okhotsk-Kamchatka (32.1%). The estimated abundance and biomass of chum salmon of Japanese origin were substantially lower in the southern area than in the northern area (Table 6). The estimated abundance and biomass of chum salmon of USA (Alaska) origin and Chukotka origin (0.3% of total abundance and biomass in northern districts; 0.0% in southern districts) were low in comparison to other regional stocks.

In July–August 2003, Russian and Japanese stocks again accounted for most (89.7%) of the estimated abundance and biomass of immature chum salmon in the northern area: Japan (35.4% of total), Sakhalin (Kuril)-Amur (23.5%), Okhotsk-Kamchatka (28.9%), Alaska (10.3%), and Chukotka (1.9%). It is notable that for the entire period of observations in 2002–2003, this was the highest estimate for USA (Alaska) chum salmon. In the southwestern Bering Sea, Japan stocks accounted for a much lower percentage of the total biomass and abundance of immature chum salmon than in the northwestern Bering Sea, and percentages of Sakhalin-Amur (41.6% of total) and Okhotsk-Kamchatka (44.3%) stocks were higher. Estimated abundance and biomass of chum salmon of Alaska origin and Chukotka origin (1.4% of total) were low in comparison to other regional stocks.

In September–October 2003, percentages of Japan stocks increased to 56.7% of the total abundance and biomass of immature chum salmon in the northwestern Bering Sea and 46.8% in the southwestern Bering Sea (Table 6). Percentages of Okhotsk-Kamchatka stocks were also high: 38.8% in the northwestern Bering Sea and 48.7% in the southwestern Bering Sea. Estimated percentages of chum salmon of Chukotka origin (0.6% in both northern and southern districts) and Alaska origin were low throughout the western Bering Sea in comparison to other stocks.

DISCUSSION

Stock-Specific Coherence of Scale-Pattern Baselines

Numerous studies have demonstrated stock-specific coherence in salmon age and scale structure (e.g., Koo 1955; Clutter and Whitesel 1956; Foerster 1968; Anas and Murai 1969; Kulikova 1970, 1975; Mosher 1972; Bugaev 1995; Kaev 1998). Age 0.3 and 0.4 fish typically account for more than 80% of adult chum salmon returns to both continents (Salo 1991). Interannual variation in environmental conditions, however, can affect scale growth. Therefore, the use of mixture and baseline samples from fish of the same brood year is often recommended for scale pattern analysis (Bugaev 2003a,b, 2004). Because of time and labor constraints, however, we used only two baselines composed of ages 0.3 and 0.4 adult chum salmon in 2003 to identify regional stock origins of three age groups (0.1, 0.2, and 0.3) of immature chum salmon in mixed-stock samples from 2002 and 2003.

The hierarchical clustering of chum salmon scale-pattern baselines was similar to that obtained with genetic (allozyme) data (Varnavskaya 2001; Bugaev et al. 2007). The few differences between scale pattern and genetic results are most likely related to the effects of ecological conditions on the early marine growth of chum salmon. Kulikova (1975) found regional stock groups similar to ours using scale data, even though marine ecological conditions changed substantially between the early 1970s and 2000s. In principle, this confirms that the scale patterns of chum salmon are relatively stable over time at the level of regional stock groups. This trend can be explained to some extent by genetic isolation of local stocks. While phenotype strongly depends on an organism's genotype, scale growth is also strongly influenced ecologically. The issue is which factor – genetics or environment – plays a more important role in determining scale growth patterns. The genetic component of phenotypic diversity in scale patterns is most likely evident at the macro-level, i.e., in the highly abundant regional groups of stocks that are geographically isolated during the early marine period. The ecological component is likely more important at the micro-level, i.e., it determines interannual variations in scale structure within specific local stocks. General phenotypic differences in scale structure determined genetically at a regional (macro) level would likely override ecological effects determined at a local (micro) level.

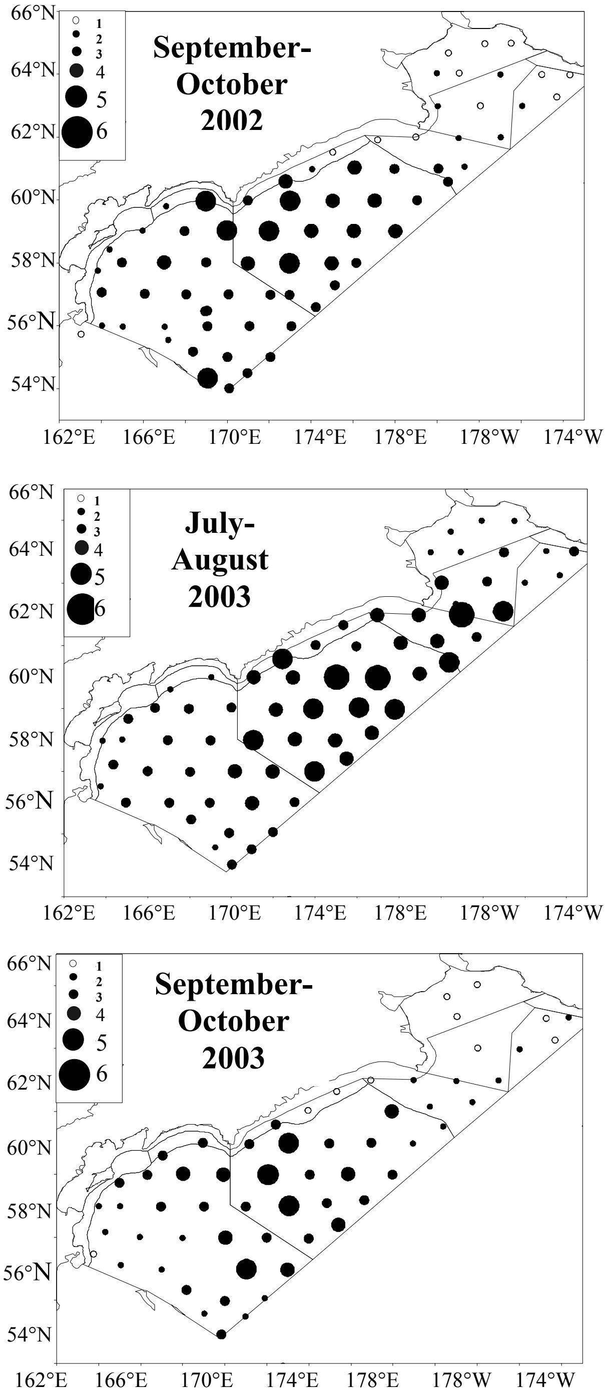


Fig. 5. The spatial distribution and relative abundance of chum salmon determined by BASIS research in the western Bering Sea, 2002-2003. The size of the circles indicates relative abundance (number of fish/km^2): 1 = no catch, 2 = 1–200, 3 = 201–1000, 4 = 1001–2000, 5 = 2001-5000, 6 = >5001.

Thus, in practice the scale-pattern baselines used in our analysis should provide reliable results for geographic region of origin of chum salmon migrating in the western Bering Sea, even though our baselines emphasized the phenotypic diversity of Asian stocks. For identification of chum salmon stocks in the eastern Bering Sea, however, baselines from a much broader spectrum of chum salmon populations of North American origin should be used (e.g., Patton et al. 1998).

Overall, statistical tests indicated that chum salmon stocks originating in Asia and North America could be reliably distinguished in mixed-stock samples from the western Bering Sea using regional stock groups (Bugaev et al. 2007). We caution, however, that the reliability of our results is determined not only by parameters used in the model, but also by the quality of scales in the mixed-stock samples. This is always an important consideration in studies using potentially poor-quality scale samples from fish caught by trawl gear.

Distribution and Abundance of Chum Salmon in the Western Bering Sea

Detailed information on the distribution, abundance, and biological characteristics of chum salmon sampled during BASIS research in the western Bering Sea was reported by Zavolokina and Zavolokin (2007). Immature chum salmon dominated BASIS catches of immature and maturing chum salmon in all areas and time periods. Our age composition estimates indicated that the northwestern Bering Sea is a particularly important foraging area for young (age 0.1) immature chum salmon in fall. As expected, the percentage of mature fish in the survey area was higher in summer than fall, as summer is the period of active prespawning migrations of chum salmon in the sea. In September–October, most prespawning migrations of chum salmon were completed and the percentage of immature individuals increased. Juvenile

Table 5. The estimated abundance and the biomass of immature chum salmon in the epipelagic zone of the western Bering Sea in 2002–2003. Coefficient of trawl catch = 0.3. Data source: TINRO-Center, Vladivostok.

Year	Season	Biostatistical districts												Total
		1	2	3	4	5	6	7	8	9	10	11	12	
							Abundance (millions of fish)							
2002		0.0	0.1	0.5	0.7	3.2	-	1.8	297.8	0.1	-	-	151.1	455.2
2003	Summer	0.1	0.8	54.2	1.8	61.7	-	10.9	453.5	0.4	-	-	121.7	705.1
	Fall	-	-	0.1	0.3	1.1	-	0.6	204.0	1.4	-	-	132.7	340.2
							Biomass (thousands of tons)							
2002	Fall	0.1	0.3	0.7	1.3	5.6	-	1.9	178.4	0.1	-	-	128.5	316.8
2003	Summer	0.2	2.2	100.8	3.2	68.7	-	9.1	290.7	0.6	-	-	118.9	594.4
	Fall	-	-	0.2	0.8	1.0	-	0.8	133.1	1.5	-	-	109.1	246.3

(ocean age .0) chum salmon were more prevalent than maturing fish in BASIS trawl catches in the western Bering Sea. We could not use scale pattern analysis to estimate stock composition of juvenile salmon, however, because of scale loss during BASIS trawl fishing operations. While it seems reasonable to assume that juvenile chum salmon in summer–fall BASIS catches in the western Bering Sea were of Asian origin, similarities in scale patterns (age 0.4 chum salmon in 2003) indicated possible intermixing of eastern Kamchatka and western Alaskan stocks during their first ocean year.

When comparing the results of BASIS surveys from different periods, it is notable that the estimated percentage of the Sakhalin-Amur stock, which was high in fall 2002 and relatively high in the summer 2003, was very low in fall 2003. We hypothesize that in 2003 we observed a summer–fall migration of Sakhalin-Amur chum salmon out of the western Bering Sea. Considering the complicated nature of hydrological and hydrobiological conditions in 2003 (e.g., Basyuk et al. 2007; Shuntov et al. 2007), this scenario is plausible. Nevertheless, we cannot rule out methodical errors due to interannual variations in scale patterns, resulting from differences in the age composition and brood year of chum salmon in baseline and mixture samples.

In all cases, stock composition estimates for western and eastern Kamchatka stocks were low. Hence, we suggest that the majority of mixed samples identified as the Okhotsk-Kamchatka stock consisted of chum salmon originating in the Magadan and Khabarovsk regions. However, we cannot exclude the possibility that northeastern Kamchatka stocks also contributed substantially to estimated percentages of this regional stock, as the western Bering Sea is their traditional foraging area. This and other issues discussed above will likely be clarified through future applications using genetic (DNA) stock identification methods.

The overall pattern of immature chum salmon distribution in the western Bering Sea in summer–fall 2002–2003 was similar to the average summer–fall data from 1982–2004 (Shuntov et al. 2006). However, there was a substantial increase in the estimated biomass of chum salmon in the western Bering Sea in the early 2000s (~146–684 thousand tons, or more than 2–10 times), as compared to the 1990s (~ 40–60 thousand tons), which likely reflects strong interannual variation in freshwater survival at early life stages of chum salmon (Shuntov and Sviridov 2005; Shuntov et al. 2007).

Comparison of Stock Composition Estimates to Other (genetic) Studies

To compare of our scale pattern results with those of genetic analyses of BASIS samples from the central Bering Sea (Sato et al. 2004, 2009; Urawa et al. 2004, 2005, 2009), we summarized our stock composition estimates by major chum salmon-producing nation (Russia, Japan, and USA). These summary estimates showed some stable trends characteristic of the entire observation period: (1) Asian-origin stocks always dominated BASIS catches in the western Bering Sea, (2) percentages of Japanese chum salmon were highest in the northwestern Bering Sea, and (3) percentages of Russian chum salmon were highest in the southwestern Bering Sea. Both scale pattern and genetic results demonstrated the dominance (average 50–70%) of Russian chum salmon stocks at the boundary of the REEZ (near 178°E) in August–September 2002 and 2003, while percentages of Japanese chum salmon in this area averaged 20–40%, and percentages of USA chum salmon were low (average never exceeded 10%). The similarity in results obtained by different stock-identification techniques validates their use to complete BASIS modeling objectives.

The development of seasonal models of the migrations of regional stocks of chum salmon in the western Bering Sea will require additional research. The results of the 2003 surveys, however, indicated that in fall immature Japanese chum salmon migrate from the central Bering Sea to the western Bering Sea. Thus, our results also validate previous observations and models of migration of chum salmon of Asian and American origin in the Western Bering Sea (Neave et al. 1976; Fredin et al. 1977; Urawa 2004).

Comparison of Abundance Estimates of Immature Chum Salmon to Adult Returns

In 2002–2003, the BASIS estimates of abundance of immature chum salmon in the western Bering Sea were very high. The summer survey of 2003 is most illustrative of this point, as our estimates show very high abundances of chum salmon of Japanese (~ 217 million fish) and USA (~ 64 million fish) origin in the western Bering Sea. Again, we emphasize that the abundance of immature chum salmon in western Bering Sea in the early 2000s was very high compared to the 1990s (Shuntov et al. 2007). Compared to average annual (1996–2005) coastal and inshore catches of chum salmon in Asia and North America (Eggers et al. 2003; Karpenko and Rassadnikov 2004, and archival commercial fisheries statistics of KamchatNIRO)—about 300,000 tons by Japan (200,000 tons), Russia (30,000 tons) and the USA (70,000 tons), the estimated abundance of immature chum salmon in the western Bering Sea was notably higher than the potential abundance of coastal runs. The total catch of Pacific salmon, including chum salmon, in the Russian Far East is uncertain, however, due to the extensive poaching. Expert assessments by scientists of KamchatNIRO indicated that recent annual coastal and inshore catches of chum salmon might be as high as 70,000 tons.

If the average weight of an individual chum salmon is 3.0 kg, then potential annual catches in Asia and North America would be approximately 100 million chum salmon. Assuming an average exploitation rate by coastal and inshore fisheries of 70% (average spawning escapement of 30%), then total annual chum salmon runs to Asia and North America would approximate 140–150 million individuals. The estimated abundances of immature chum salmon from BASIS trawl survey data were approximately 2–7 times higher than this approximate estimate of total annual adult returns. The abundance of adult returns is much less than the abundance of immature salmon in the ocean, however, because most chum salmon do not mature until ages 0.3 or 0.4. Nevertheless, the 2002–2003 RV *TINRO* surveys covered only a portion of the entire area of the distribution of chum salmon of Japanese, Russian, and western Alaska origin in the Bering Sea and North Pacific Ocean (e.g., Sato et al. 2009; Urawa et al. 2009). Our results may indicate a very high level of ocean mortality for immature chum salmon. In principle, high mortality could have resulted from increased competition for food or predation due to increased abundance of salmon and mesopelagic fish species, including salmon predators such as North Pacific daggertooth (*Anotopterus*

Table 6. Estimates of the abundance and biomass of Asian and North American (USA) stocks of immature chum salmon in the western Bering Sea in 2003.

Year	Season	Western Bering Sea area	Total abundance and biomass		Regional stock								
					Russia			Japan			USA		
			Millions of fish	Thousands of tons	%	Millions of fish	Thousands of tons	%	Millions of fish	Thousands of tons	%	Millions of fish	Thousands of tons
2002	Fall	Northern	303.94	187.85	58.5	177.80	109.89	41.1	124.92	77.21	0.4	1.22	0.75
		Southern	151.22	128.58	79.6	120.37	102.35	20.3	30.70	26.10	0.1	0.15	0.13
2003	Summer	Northern	582.91	474.97	54.3	316.52	257.91	35.4	206.35	168.14	10.3	60.04	48.92
		Southern	122.17	119.48	87.3	106.65	104.31	9.2	11.24	10.99	3.5	4.28	4.18
2003	Fall	Northern	206.11	135.68	40.9	84.30	55.49	56.7	116.86	76.93	2.4	4.95	3.26
		Southern	134.10	110.60	49.9	66.92	55.19	46.8	62.76	51.76	3.3	4.42	3.65

pharaoh) and longnose lancetfish (*Alepisaurus borealis*), in the western Bering Sea in the early 2000s (Shuntov and Sviridov 2005). Methodical errors in assessing the relative abundance of immature chum salmon in the BASIS trawl survey area are also highly possible to cause the overestimation of chum salmon abundance, as suggested by Bugaev and Myers (2009a, b).

CONCLUSIONS

Our results provided new evidence for the important role of the western Bering Sea ecosystem as a summer–fall foraging area for immature chum salmon of Asian and North American origin. Similar to the results of BASIS genetic stock-identification studies in the central Bering Sea (e.g., Sato et al. 2009; Urawa et al. 2009), Asian stocks dominated BASIS trawl catches of immature chum salmon in the western Bering Sea. In addition, estimated percentages of Japanese stocks were higher in northern areas, and percentages of Russian stocks were higher in southern areas. Estimated percentages of western Alaska stocks in the western Bering Sea were relatively low, but estimated abundance and biomass were high compared to rough estimates of total adult returns in North America. In fall, Japanese stocks apparently migrated into the western Bering Sea from the central Bering Sea, which validated previous observations and models of migration. In contrast, western Alaska stocks apparently migrated out of the western Bering Sea in fall. There was substantial interannual variation in the regional stock composition of chum salmon of Russian origin. Additional BASIS research is needed to further develop seasonal models of the migrations of regional stocks of Asian and North American chum salmon in the western Bering Sea.

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