Stock-Specific Distribution and Abundance of Immature Chinook Salmon in the Western Bering Sea in Summer and Fall 2002–2004

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Abstract: Seasonal stock-specific distribution and abundance of Chinook salmon (*Oncorhynchus tshawytscha*) were determined using scale pattern analysis of Bering-Aleutian Salmon International Survey (BASIS) samples and catch data collected in the western Bering Sea in summer 2003 and fall 2002–2004. Chinook salmon were sparsely distributed in this region, which greatly limited the number of samples available for stock identification research. Research trawl catches of immature Chinook salmon were highest in northern areas, and catches throughout the region were dominated by fish in their second ocean summer. Estimated percentages of immature Chinook salmon of North American (Alaska) origin (50.2–71.2%) were consistently higher than those of Asian (Russia) origin. The highest estimated abundance of immature Chinook salmon was in summer 2003 (~21 million North American and ~20 million Asian fish). These estimates were extraordinarily high compared to adult returns to Asia and North America in 2004–2006, and we concluded that BASIS stock assessment methods overestimated the abundance of this species. Nevertheless, our results provided the first quantitative evidence of the extensive distribution of immature Chinook salmon of North American origin in the western Bering Sea in summer and fall. We concluded that the western Bering Sea ecosystem is an important summer–fall foraging area for immature Chinook salmon of both Asian and North American origin.

Keywords: abundance, age, biomass, Chinook 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, 2002, 2003, 2004). 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. Chinook salmon (*O. tshawytscha*) are the least abundant species of Pacific salmon (Heard et al. 2007), which increased the difficulty of obtaining adequate BASIS samples for stock identification research. Prior to BASIS research, limited evidence from tagging experiments and stock identification studies using scale pattern analysis indicated that western Alaska was the dominant regional stock of Chinook salmon in the northwestern and central Bering Sea in summer and in the southeastern Bering Sea (west of 170°W) in winter (Major et al. 1978; Myers et al. 1987, 1996, 2004; Myers and Rogers 1988; Healey 1991). Bugaev (2004, 2005) reported preliminary stock-identification results from scale-pattern analyses of Chinook salmon in BASIS samples from the western Bering Sea in 2002–2003. Bugaev's results indicated intermixing of Chinook salmon of Asian (Kamchatka Peninsula) and western Alaska origin in the western Bering Sea portion of the Russian Exclusive Economic Zone (REEZ). In this paper, we briefly review information from BASIS surveys on the distribution, abundance, and biological characteristics of Chinook salmon in the western Bering Sea, and update and extend earlier stock identification results reported by Bugaev (2004, 2005). Our primary objectives were to estimate the proportions and potential abundance of major stocks of Chinook salmon of Asian and North American origin in the western Bering Sea in summer and fall 2002–2004.

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 (2004, 2005) and Bugaev et al. (2004). Briefly, we

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used scale pattern analysis of representative (baseline) samples of Asian and North American Chinook 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 Chinook salmon and associated biological and catch data were collected by the staff of the TINRO-Center from trawl catches of the RV *TINRO* in the western Bering Sea in summer (July–August) 2003 and fall (September–October) 2002–2004 (NPAFC 2003, 2004, 2005). A standard midwater rope trawl (PT/TM 80/396 m) was used to survey the upper epipelagic layer (~upper 40 m).

Shipboard sampling of Chinook 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 (Bugaev et al. 2009). 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. 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. A similar approach has been used for age determination and stock identification of salmon in incidental catches by commercial trawl fisheries in the eastern Bering Sea (Myers and Rogers 1988; Patton et al. 1998; Myers et al. 2004).

Ages of immature Chinook 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 and number of ocean annuli are separated by a dot (Koo 1962). For example, a 1.1 Chinook salmon has one freshwater annulus and one ocean annuli on its scale, and is in its second summer–fall in the ocean. Although juvenile Chinook salmon (x.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 Chinook salmon collected in Districts 8 and 12 (Fig. 1) accounted for approximately 90% of all biostatistical and scale data. Nevertheless, when samples were stratified by district the number of scales was not sufficient to obtain statistically reliable results. Therefore, the mixture samples were pooled over all districts. Samples from a total of 756 Chinook salmon were used for age composition estimates, and only 480 fish were used for stock composition estimates.

Baseline Samples

Baseline scale samples were collected by biologists from KamchatNIRO, Sevvostrybvod (North-East Fishery Protection Service), and the Alaska Department of Fish and Game from the "preferred" body area of adult Chinook salmon in rivers or terminal area fisheries in marine waters in 2004 and 2005. The five baselines used in our analysis included samples from the most abundant stocks of adult Chinook salmon in major watersheds of Kamchatka and western Alaska (Fig. 2). In Kamchatka, these watersheds included the Kamchatka River (eastern Kamchatka) and the Bolshaya River (western Kamchatka). Commercial catches in these two rivers accounted for up to 90% of the total catch of Chinook salmon in Asia, and Kamchatka River catches alone accounted for up to 80% of this total. North American baselines were composed of the three most abundant stocks of Chinook salmon in western Alska (Yukon, Kuskokwim, and Nushagak rivers), which accounted for ~90% of the total catch of Chinook salmon in western Alaska in 2004–2006 (NOAA 2008). The Yukon River baseline is also representative of Chinook salmon of Canadian Yukon origin. The known geographical distribution of Chinook salmon in the Bering Sea also played an important role in the selection of North American baseline samples. Earlier stock identification research using tags, scale patterns, and parasites indicated that the Yukon, Kuskokwim, and Nushagak rivers are the major stocks of Chinook salmon distributed in the eastern and central Bering Sea (Major et al. 1978; Myers at al. 1987; Myers and Rogers

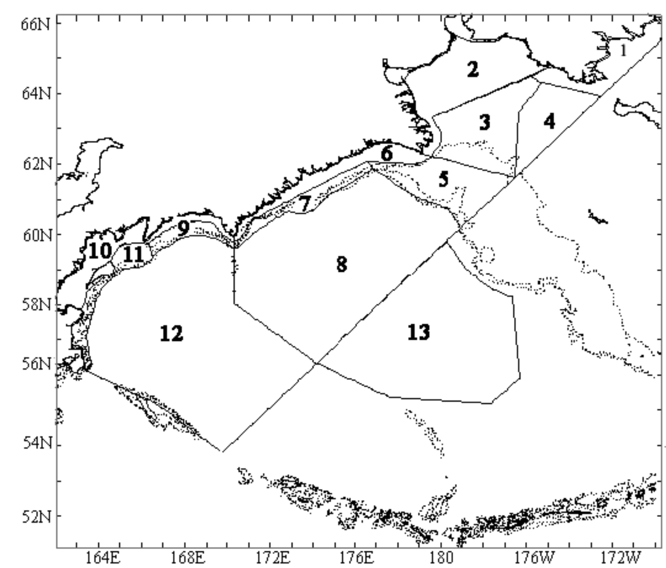

Fig. 1. TINRO-Center biostatistical districts in the western Bering Sea (Shuntov 1986; Volvenko 2003).

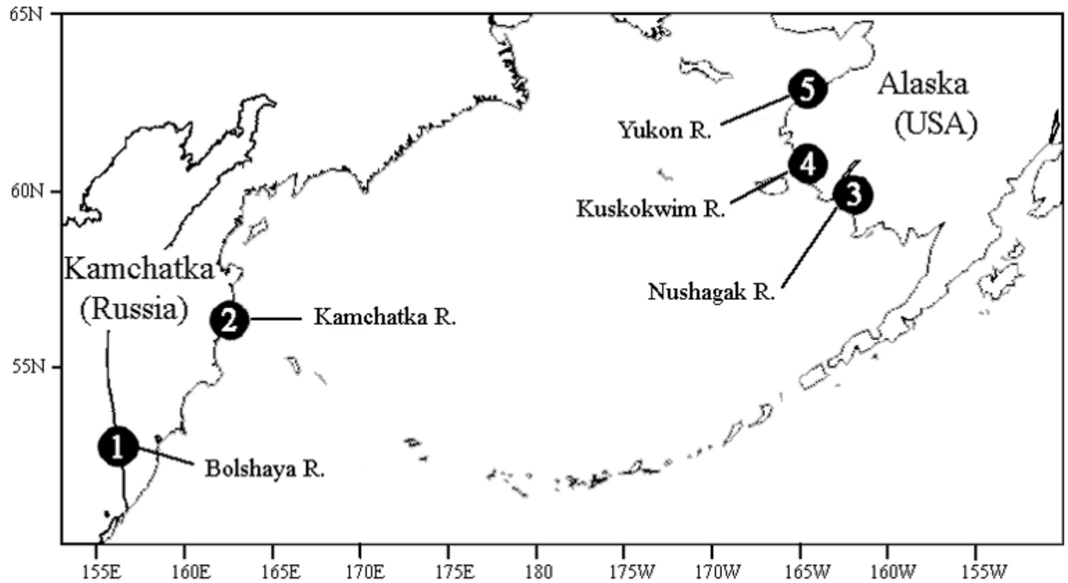

Fig. 2. Locations (numbers in black circles) of major Chinook salmon watersheds in Kamchatka and Alaska represented in the 2004–2005 scale pattern baselines. The Yukon River watershed includes the Canadian Yukon.

1988; Urawa et al. 1998; Klovatch et al. 2002; Myers et al. 2004).

In general the highest accuracies in scale-pattern models are obtained by using baseline samples composed of fish of the same freshwater age group and brood year as fish in the mixture samples (e.g., Myers et al. 1987). This approach minimizes the effects of year-to-year variation in scale growth patterns caused by environmental factors. Because the abundance of Asian Chinook salmon is very low, however, sufficient samples for baselines were obtained only by pooling samples over ocean age group. In the rivers of Kamchatka and western Alaska, the majority (> 90%) of adult Chinook salmon spent from 2–4 winters (ages 1.2, 1.3, and 1.4) in the ocean (Healey 1991). Scale data for these three dominant age groups were pooled into separate baselines for each major stock, which increased the variance of scale pattern variables.

For each baseline stock, we selected a stratified random sample of scales 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. In total, the scale baselines included samples from 1,598 fish.

The average age of fish in the baselines was approximately 1.3. Immature Chinook salmon in the mixed-stock samples were predominantly age 1.1 (up to 80%). Thus, a 2-year lag time was needed to minimize interannual variation between mixed-stock and baseline samples. The 2002 mixed-stock samples were analyzed with baselines samples from adult salmon returns in 2004, and the 2003 mixed-stock samples were analyzed with baselines from 2005 returns. Because baseline samples from 2006 adult salmon returns were not available at the time of this study, the 2004 mixed-stock samples were analyzed with 2005 baseline samples. Differences between the age and brood year of Chinook salmon in the baselines and mixed-stock samples probably reduced the accuracy of the stock composition estimates. Previous studies, however, have indicated that scale patterns are relatively consistent for particular local stocks or complexes of stocks over long periods of time (e.g., Major et al. 1972).

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 in the freshwater and first annual ocean zone along an axis perpendicular to the boundary of the sculptured and unsculptured fields of the scale (Fig. 3). The structure of these two scale growth zones has been used for many years to differentiate local stocks of Pacific salmon in mixed-stock catches in the North Pacific Ocean (e.g., Davis et al. 1990). Scale pattern variables were calculated from inter-circulus measurement. Variables included the total radius of the freshwater zone (FW), total radius of the first ocean zone (O1), total number of circuli in the first ocean zone (C1), five triplets (TR) in the first ocean zone, and five reverse triplets (RTR) in the first ocean zone (Fig. 3).

Estimates of Stock Composition

Differences and similarities in the baseline stocks were evaluated using *t*-tests ($P < 0.05$), hierarchical cluster analysis of Euclidian distances between stock centroids, and canonical discriminant analysis (Bugaev 2007).

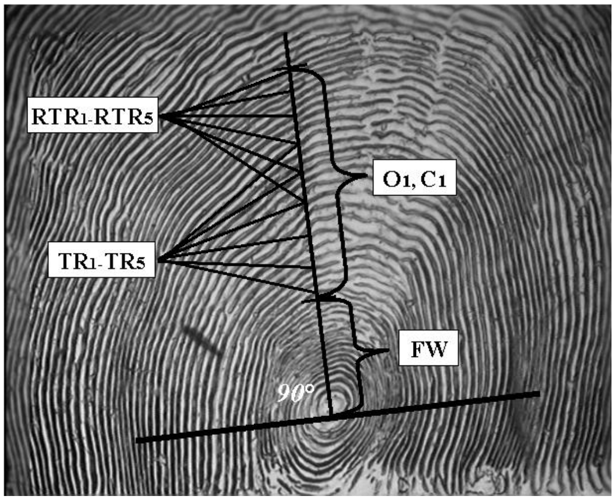

Fig. 3. Image of a Chinook salmon scale showing the scale pattern variables used for stock identification. FW = the total radius of the freshwater zone, O1 = total radius of the first annual ocean growth zone, C1 = number of circuli in the first annual ocean growth zone, TR1-TR5 = radii of groups of three circuli (triplets) in the first ocean zone (five triplets), RTR1-RTR5 = radii of groups of three circuli (reverse-triplets) in the first ocean zone (five reverse-triplets).

Computer simulations were used to evaluate the accuracy of the baseline stock groups 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 Chinook 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 Chinook salmon during BASIS research in the western Bering Sea in summer 2003 and fall 2002–2004 (Glebov 2007). Estimates of the abundance and biomass of Chinook salmon in the Bering Sea portion of the Russian Federation Exclusive Economic Zone (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. 2002). The TINRO-Center estimates were stratified by year, season, maturity group, and biostatistical district (Fig. 1). We apportioned the estimates for immature fish to stock (Asia and North America) using our estimates of stock composition weighted by age group. As a rough measure of the validity of these estimates, we compared them to published information on the abundance of adult Chinook salmon runs in Asia and North America.

RESULTS

Maturity and Age Composition in Mixture Samples

Size-weight characteristics and stage of gonad development indicated that most Chinook salmon in summer–fall BASIS catches in the western Bering Sea were either juvenile (x.0) or immature fish. Mature fish were not observed in the catches. Juvenile Chinook salmon were not included in the analysis because of scale loss during trawl fishing operations.

Age 1.1 fish dominated (75.5–87.9%) mixed-stock samples of immature Chinook salmon in BASIS trawl catches in the western Bering Sea in summer and fall 2002–2004 (Table 1). Percentages of age 1.2 fish were relatively low (8.6–18.8%), and those of other age groups were very low. Ages 1.1 and 1.2 fish accounted for more than 90% of the mixture samples of immature Chinook salmon stratified by year and season.

Table 1. The age composition (% of total sample size) of immature Chinook salmon in BASIS trawl catches by the R/V *TINRO* in the Western Bering Sea in 2002–2004. N = sample size, AAG = percentage of available age groups used for stock identification by scale pattern analysis (only ages 1.1 and 1.2 fish were analyzed). Locations of biostatistical districts are shown in Fig. 1. Juvenile (x.0 fish) Chinook salmon were not included in the analysis because of scale loss during trawl operations.

Year	Season	Biostat. districts	N	Age composition (%)									AAG (%)
				0.1	0.2	0.3	1.1	1.2	1.3	1.4	2.1	2.2	
2002	Autumn	1-12	133	-	0.8	-	76.0	18.8	3.0	-	1.5	-	94.8
2003	Summer	1-12	421	1.7	1.2	0.2	75.5	18.3	2.4	0.2	0.2	0.2	93.8
	Autumn	1-12	144	0.7	0.7	0.7	80.6	11.8	4.9	-	-	0.7	92.4
2004	Autumn	3-12	58	1.7	-	-	87.9	8.6	-	-	1.7	-	96.6

Evaluation of Scale Patterns and Accuracies of Models

Bugaev (2007) reported the detailed results of a statistical evaluation of the scale patterns of local stocks of adult Chinook salmon of Asian and North American origin that were used in the baseline models. In general, the results of cluster and canonical analyses demonstrated a relatively wide range in centroid means of the 2004 and 2005 baselines. Asian and North American stocks of Chinook salmon were clearly distinguishable in the 2004 baselines. In the 2005 baselines, however, the centroids of the Yukon and Kamchatka rivers were similar. In principle, this might result in underestimation or overestimation of the proportions of Chinook salmon of eastern Kamchatka or Alaska origin in the 2003 mixed-stock samples. The results of *t*-tests indicated statistically significant differences ($P < 0.05$) in most pairwise comparisons of baselines. One notable exception was that the 2005 Bolshaya and Nushagak river baselines were not significantly different ($P = 0.36$). However, the most abundant Asian stock (Kamchatka R.) in the 2005 baseline was significantly different ($P < 0.05$) from all North American stocks.

Computer simulations of Chinook salmon baselines (pooled ages 1.2+1.3+1.4) indicated reasonably high mean accuracies (86% for the 2004 and 89% for the 2005 baselines; Tables 2, 3). The accuracy of the 2004 Kuskokwim R. baseline was particularly low (60%), however, errors in the estimates were largely apportioned to geographically adja-

Table 2. Evaluation of the accuracy of a 5-stock maximum likelihood estimate model for ages 1.2 + 1.3 + 1.4 Chinook salmon in 2004, as indicated by computer simulations of 100% representation by one stock group (indicated by grey shading). N = sample size.

Baseline stock	Maximum likelihood estimate/standard deviation					
	N	1	2	3	4	5
1. Bolshaya R.	111	0.9881	0.0787	0.0003	0.0044	0.0013
		0.0216	0.0560	0.0019	0.0080	0.0056
2. Kamchatka R.	241	0.0063	0.8011	0.0000	0.0067	0.0136
		0.0192	0.0914	0.0003	0.0232	0.0240
3. Nushagak R.	150	0.0000	0.0000	0.9677	0.0023	0.1439
		0.0000	0.0000	0.0458	0.0073	0.0657
4. Yukon R.	186	0.0048	0.1190	0.0003	0.9477	0.2382
		0.0107	0.0727	0.0025	0.0509	0.0967
5. Kuskokwim R.	239	0.0008	0.0012	0.0317	0.0389	0.6030
		0.0038	0.0057	0.0459	0.0439	0.1125
Mean accuracy (%)						86.15

Table 3. Evaluation of the accuracy of a 5-stock maximum likelihood estimate model for ages 1.2 + 1.3 + 1.4 Chinook salmon in 2005, as indicated by computer simulations of 100% representation by one stock group (indicated by grey shading). N = sample size.

Baseline stock	Maximum likelihood estimate/standard deviation					
	N	1	2	3	4	5
1. Bolshaya R.	121	0.9781	0.0080	0.0029	0.0090	0.0386
		0.0260	0.0148	0.0068	0.0165	0.0268
2. Kamchatka R.	150	0.0074	0.8462	0.0026	0.0571	0.0069
		0.0196	0.0951	0.0105	0.0768	0.0178
3. Nushagak R.	150	0.0009	0.0012	0.9244	0.0305	0.0606
		0.0039	0.0074	0.0737	0.0315	0.0735
4. Yukon R.	100	0.0126	0.1322	0.0003	0.8481	0.0509
		0.0171	0.0935	0.0029	0.1070	0.0602
5. Kuskokwim R.	150	0.0010	0.0124	0.0698	0.0553	0.8430
		0.0049	0.0281	0.0728	0.0688	0.0973
Mean accuracy (%)						88.80

Table 4. Maximum likelihood estimates (MLE) of stock composition of immature Chinook salmon in trawl catches of the R/V *TINRO* in the western Bering Sea in 2002–2004. N = sample size, SD = standard deviation, CI = confidence interval.

Year	Season	Biostat. dist.	Age	N	Stock/river	MLE	SD	CI (95%)
2002	Autumn	1-12	1.1 + 1.2	87	Bolshaya	-	-	-
					Kamchatka	0.4981	0.0853	0.2941-0.6489
					Nushagak	0.0320	0.0323	0.0000-0.1132
					Yukon	0.0004	0.0020	0.0000-0.2466
					Kuskokwim	0.4695	0.0916	0.2019-0.6266
2003	Summer	1-12	1.1 + 1.2	242	Bolshaya	0.0036	0.0124	0.0000-0.0390
					Kamchatka	0.4756	0.0496	0.3341-0.5980
					Nushagak	0.5208	0.0478	0.3947-0.6539
					Yukon	-	-	-
					Kuskokwim	-	-	-
	Autumn	1-12	1.1 + 1.2	103	Bolshaya	-	-	-
					Kamchatka	0.4148	0.0704	0.2272-0.5812
					Nushagak	0.5852	0.0704	0.4123-0.7507
					Yukon	-	-	-
					Kuskokwim	-	-	-
2004	Autumn	3-12	1.1 + 1.2	48	Bolshaya	-	-	-
					Kamchatka	0.2882	0.0919	0.0998-0.4640
					Nushagak	0.7105	0.0883	0.5077-0.8600
					Yukon	0.0013	0.0439	0.0000-0.1389
					Kuskokwim	-	-	-

cent stocks (Yukon and Kuskokwim rivers). While baseline-dependent simulations might overestimate the true accuracy of the models, we considered these accuracies adequate for identification of stocks at the regional level.

Stock Composition Estimates

Although mixture samples sizes were small, particularly in 2002 and 2004, Alaskan stocks dominated (50.2–71.2%) BASIS catches of immature Chinook salmon in the western Bering Sea in 2002–2004 (Table 4). There were no statistically significant estimates (either not detected or confidence intervals included 0.0) for Chinook salmon of western Kamchatka or Yukon River origin. Although confidence intervals were broad, the dominant stocks of Chinook salmon of western Alaska origin were Kuskokwim River in fall 2002 and Nushagak River in summer–fall 2003 and fall 2004.

Distribution and Assessment of Relative Abundance

Typically, Chinook salmon either did not occur in BASIS catches or were present in low abundance (1–50 fish/km²; Fig. 4). The highest catches of Chinook salmon occurred in the northern districts (1–8). The maximum abundance of Chinook salmon (average of 251–500 fish/km^2) occurred in summer of 2003. This high level of abundance of Chinook salmon was comparable to that of more abundant salmon species, including sockeye salmon (*O. nerka*). In general, however, Chinook salmon were sparsely distributed in the western Bering Sea, which greatly limited the number of samples available for stock identification research.

Estimates of Abundance and Biomass

The maximum estimated abundance/biomass of immature Chinook salmon during the entire study period was in District 8 (3.2–30.1 million fish/4.7–36.4 thousand tons) (Table 5). The estimated abundance/biomass of immature Chinook salmon was also relatively high in District 12 (1.5–2.6 million fish/3.4–4.5 thousand tons). In 2003, the estimated abundance of immature Chinook salmon was nearly three times higher in summer than in fall. In fall, estimated abundance of immature Chinook salmon was relatively high in both 2002 and 2003, and was much lower in 2004.

Estimated abundance and biomass of immature Chinook salmon of Asian origin ranged from 6–20 million fish and 10–25 thousand tons (Table 6). Estimated abundance and biomass of immature Chinook salmon of North American origin ranged from 4–21 million fish and 7–27 thousand tons.

DISCUSSION

Maturity, Age Composition, and Distribution

Glebov (2007) reviewed information on the maturity

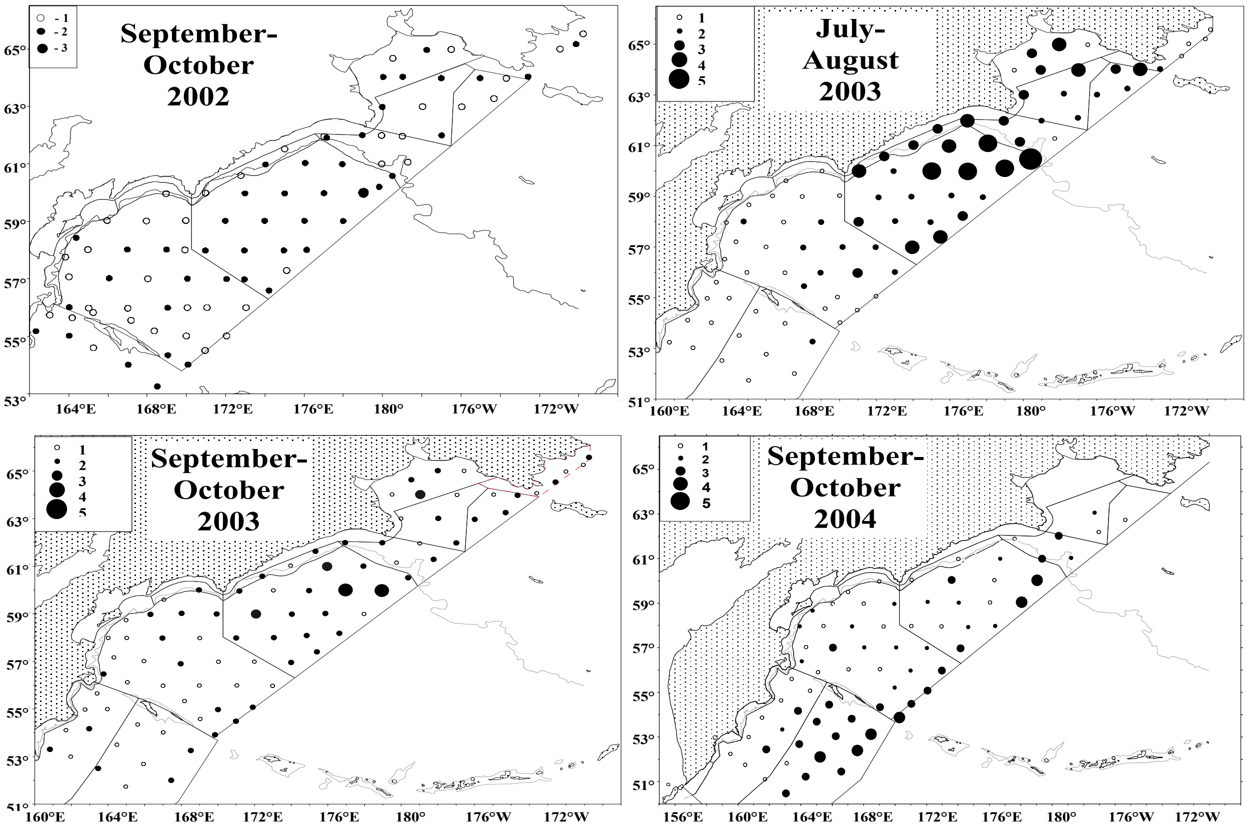

Fig. 4. The spatial distribution and relative abundance of Chinook salmon determined by BASIS research in the western Bering Sea, 2002–2004. Note that scales vary among years. The size of the circles indicates relative abundance (number of fish/km2). Upper left panel (2002): 1 = no catch, 2 = 1–10, 3 = 11–100. Upper right and lower left panels (2003): 1 = no catch, 2 = 1–50, 3 = 51–100, 4 = 101–250, 5 = 251–500. Lower right panel (2004): 1 = no catch; 2 = 1–10; 3 = 11–50; 4 = 51–100; 5 = > 100.

Table 5. The estimated abundance and the biomass of immature Chinook salmon in the epipelagic zone of the western Bering Sea in 2002–2004. Coefficient of trawl catch = 0.3. Data source: TINRO-Centre, Vladivostok. The locations of biostatistical districts are shown in Fig. 1.

Year	Season	Biostatistical districts												Total
		1	2	3	4	5	6	7	8	9	10	11	12	
							Abundance (millions of fish)							
2002	Autumn	0.06	0.47	0.47	0.08	0.26	-	0.05	8.87	-	-	-	1.72	11.98
2003	Summer	0.02	1.63	2.08	1.43	2.18	-	1.20	30.11	-	-	-	2.36	41.01
	Autumn	0.07	0.53	0.23	0.50	0.49	-	0.10	10.83	0.07	-	-	1.54	14.36
2004	Autumn	-	-	0.08	-	0.48	-	-	3.22	-	-	-	2.58	6.36
							Biomass (thousands of tons)							
2002	Autumn	0.38	2.39	0.81	0.05	1.08	-	0.11	9.87	-	-	-	4.54	19.23
2003	Summer	0.13	2.33	2.19	1.27	3.43	-	1.56	36.35	-	-	-	4.01	51.27
	Autumn	0.48	1.59	0.50	1.83	1.13	-	0.10	15.60	0.09	-	-	3.44	24.76
2004	Autumn	-	-	0.10	-	0.80	-	-	4.73	-	-	-	3.96	9.59

Table 6. Estimates of the abundance and biomass of immature Chinook salmon (1.1+1.2 fish) of Asian and North American origin in the western Bering Sea in 2002–2004. Dist. = biostatistical district (Fig. 1), no. = abundance in millions of fish, t = biomass in thousands of metric tons.

Year	Season	Dist.	Total		Asia			North America		
			no.	t	%	no.	t	%	no.	t
2002	Fall	1-12	11.98	16.46	49.8	5.97	8.20	50.2	6.01	8.26
2003	Summer	1-12	41.01	51.27	47.9	19.64	24.56	52.1	21.37	26.71
	Fall	1-12	14.36	24.76	41.5	5.96	10.28	58.5	8.40	14.48
2004	Fall	3-12	6.36	9.59	28.8	1.83	2.76	71.2	.53	6.83

and distribution of Chinook salmon during BASIS surveys in the western Bering Sea in summer and fall 2002–2006. Both juvenile (x.0) and immature Chinook salmon were caught during the surveys. The age structure of immature Chinook salmon in the western Bering Sea during the 2002–2004 BASIS surveys indicated the western Bering Sea is a particularly important rearing area for young (1.1) fish.

We could not use scale pattern analysis to estimate freshwater age composition or stock composition of juvenile salmon because of scale loss during BASIS trawl fishing operations. While it seems reasonable to assume that juvenile Chinook salmon in summer–fall BASIS catches in the western Bering Sea were of Asian origin, similarities in scale patterns of adult salmon of known origin indicated possible intermixing of Kamchatka and western Alaska stocks during their first ocean year. This issue will likely be resolved by future genetic (DNA) stock identification analyses of juvenile Chinook salmon collected in the northern Bering Sea and the Chukchi Sea in summer–fall.

The overall pattern of seasonal migration patterns of immature Chinook salmon in the Bering Sea is a northwestward movement in spring, followed by a southeastward movement in fall (Radchenko and Chigirinsky 1995). During BASIS surveys in summer 2003, immature Chinook salmon were most abundant along the northeastern boundary of the Aleutian Basin (Glebov 2007; Fig. 4). In fall 2002–2004, when immature Chinook salmon began to migrate out of the western Bering Sea, abundance was relatively low except near the eastern border of the REEZ.

Similar distribution patterns of immature Chinook salmon were observed in previous trawl surveys by TINRO-Center in this region (Radchenko and Chigirinsky 1995). These surveys showed that in summer, young (age 1.1) immature Chinook salmon were distributed primarily in the western Aleutian Basin and the shelf and continental slope of the Navarin region. Radchenko and Chigirinsky (1995) speculated that young immature Chinook salmon distributed in this region were of North American origin, as indicated by their small size compared to Kamchatka stocks. By late August and September, older age groups of immature Chinook salmon, likely a mix of Asian and North American stocks, were distributed primarily over the Shirshov Ridge and eastward near the eastern border of the REEZ. In late fall (October–November) older (maturing) Chinook salmon moved into the western Bering Sea, as immature Chinook salmon left the region. Radchenko and Chigirinsky (1995) concluded that distribution of Chinook salmon corresponded well with the distribution of their primary prey, i.e., fish in shelf zones and gonatid squids in the basins.

Comparison of Stock Composition Estimates to Other Studies

Preliminary analyses by Bugaev (2004, 2005) demonstrated the predominance of immature Chinook salmon of eastern Kamchatka and western Alaska origin in BASIS catches in the western Bering Sea in 2002 and 2003. Our reanalysis of these data with brood-year-specific baselines, however, resulted in a substantial increase in estimated percentages of immature Chinook salmon of western Alaskan origin in fall 2002 (~30% increase) and fall 2003 (~20% increase). Preliminary and updated estimates for Chinook salmon of western Alaskan origin in summer 2003 were similar (~50% of total), which was surprising given the high estimated abundance of immature Chinook salmon in the western Bering Sea in summer 2003 (41 million fish; Table 5). Bugaev et al. (2004) estimated that 74% of ages 1.1 and 1.2 immature Chinook salmon in research driftnet catches in the western Bering Sea in July–August 2003 were of North American origin. In each case, the results were clearly influenced by errors in the MLE models, as well as variation in the quality of the scale samples. We suggest that our results should be interpreted as an approximate range of values based on the 95% confidence intervals of our point estimates, e.g., 40–65% of Chinook salmon in summer 2003 samples from the western Bering Sea were of North American origin.

Overall, the results of these scale pattern analyses provided the first quantitative estimaties of the stock compositon of immature Chinook salmon of Asian and North American origin in the western Bering Sea in summer and fall. While researchers had previous assumed that Chinook salmon of western Alaskan origin were the dominant regional stock in the western Bering Sea (e.g., Radchenko and Chigirinsky 1995), this was corroborated by our stock composition estimates (Table 4). The highest percentage of fish of Alaskan origin was in 2004, when there was a significant concentration of Chinook salmon at the eastern boundary of the REEZ. All Asian fish were of East Kamchatka (Kamchatka R.) origin.

Comparison of BASIS Abundance Estimates with Adult Run Sizes

Low catches of immature Chinook salmon during BASIS surveys in the western Bering Sea were expected, as Chinook salmon are the least abundant species of Pacific salmon in Asia and North America (Heard et al. 2007). The upper range of the BASIS estimates of abundance of immature Chinook salmon in the western Bering Sea in 2002–2004, however, was extraordinarily high (41 million fish in summer 2003; Table 5) compared to the production of Chinook salmon in Kamchatka and western Alaska (including the Canadian Yukon).

A conservative estimate of average annual runs (commercial, sport, and subsistence catches + escapement) of Chinook salmon returning to both Kamchatka and western Alaska in 2004–2006 is approximately 1 million fish (TINRO-Center 2005, 2006; Anonymous 2007; NOAA 2008; Jones et al. 2009; D. Molyneaux, Alaska Department of Fish and Game, pers. comm.). Thus, estimates of the abundance of immature Chinook salmon from R/V *TINRO* trawl surveys greatly exceeded (6–40 times) the estimated abundance of annual returns of adult Chinook salmon to rivers in Kamchatka and western Alaska. The estimate of the magnitude of annual adult runs in Kamchatka and western Alaska is conservative because it includes estimates of total runs for only the five major "index" stocks used in our scale pattern analysis.

Trends in the annual abundance of adult returns of Chinook salmon to Kamchatka and western Alaska in the early 2000s varied between regions (Heard et al. 2007). In 2004–2006, estimated average annual returns to western Kamchatka (Bolshaya River) were low and relatively stable (~75,000 fish), while estimated returns to eastern Kamchatka (Kamchatka River) increased substantially after 2003 (~190,000 fish) (TINRO-Center 2005, 2006; Anonymous 2007). In addition, there were exceptionally high annual average runs in the Kuskokwim (~360,000 fish) and Nushagak (~230,000 fish) after 2003, while runs in the Yukon River decreased to a relatively low and stable level (~220,000 fish) in 2004–2006 (NOAA 2008; Jones et al. 2009; D. Molyneaux, Alaska Department of Fish and Game, pers. comm.). These stock-specific trends in abundance are reflected to some degree in our regional stock composition and abundance estimates for immature Chinook salmon in 2002–2004.

Run size estimates for Kamchatka and western Alaska Chinook salmon would be higher than 1 million fish if interceptions by ocean salmon fisheries, bycatch by commercial groundfish fisheries, and removal by poaching (particularly in Kamchatka) were taken into account. In addition, there are numerous small runs of Chinook salmon in Kamchatka and western Alaska for which run size estimates are unavailable. BASIS samples of immature Chinook salmon included fish that would have returned primarily over a period of two to four years. Natural and fishing mortality rates of immature Chinook salmon at sea are not well known, but could be substantial. However, none of these factors alone or in combination are sufficient to explain the high estimated abundance and biomass of Chinook salmon in summer 2003 BASIS catches. In addition, the western Bering Sea includes only a portion of the total area of known ocean distribution of Chinook salmon of Kamchatka and western Alaska origin. There is no evidence that Chinook salmon returning to other regions of Asia or North America are distributed in the western Bering Sea.

We speculate that BASIS stock assessment methods, e.g., the use of a fishing-efficiency coefficient of 0.3, may have resulted in overestimation of the abundance of Chinook salmon. Errors in trawl assessment methods may be exceptionally high for species in low abundance, e.g., only 119 Chinook salmon were caught during the 2002 BASIS trawl fishing operations (Temnykh et al. 2003). Volvenko (2000) discussed other problems with estimation of salmon abundance by trawl sampling. Murphy et al. (2003) compared research trawls and fishing power of vessels used for BASIS research in 2002.

CONCLUSIONS

Our results corroborated previous studies indicating that western Alaska is the dominant regional stock of Chinook salmon in the Bering Sea (e.g., Major et al. 1978; Myers et al. 1987; Myers and Rogers 1988; Healey 1991; Myers et al. 2004). Future genetic studies are needed to validate and refine our estimates. The seasonal stock-specific distribution patterns of Chinook salmon observed in 2002–2004 might have resulted from recent changes in ecosystem conditions in the western Bering Sea that occurred at end of the 20th century and the beginning of the 21st century (Shuntov and Sviridov 2005). On the other hand, the 2002–2004 distributions might represent a long-term, stable balance between abundant stocks of North American origin and scarce stocks of Asian origin. The BASIS estimates of abundance of salmon in western Bering Sea in the early 2000s were extraordinarily high compared to production of Chinook salmon in Kamchatka and western Alaska, including the Canadian Yukon. We concluded that BASIS stock assessment methods for Chinook salmon need to be reevaluated. Nevertheless, our results provided new quantitative evidence of the important role of the western Bering Sea ecosystem as a summer–fall foraging area for immature Chinook salmon of both Asian and North American origin.

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