

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

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Abstract: Seasonal stock-specific distribution and abundance of immature sockeye salmon (*Oncorhynchus nerka*) in the western Bering Sea in summer 2003 and fall 2002–2004 were determined using scale pattern analysis of Bering-Aleutian Salmon International Survey (BASIS) samples. Most (nearly 100%) of the sockeye salmon in BASIS catches were immature. Four age groups, 1.1, 1.2, 2.1 and 2.2, accounted for more than 90% of immature fish. Sockeye salmon of Asian (primarily Kamchatka) origin dominated catches throughout the region. In general, abundance of immature sockeye salmon was highest in the northwestern Bering Sea, where sockeye salmon of North American origin (primarily Bristol Bay stocks) were more abundant than in the southwestern Bering Sea. Estimated abundance of immature sockeye salmon in the western Bering Sea in 2002–2004 was high compared to estimated run sizes of adult returns, particularly in Asia. BASIS stock assessment methods may have overestimated the abundance of salmon or adult run-size statistics may be inaccurate, or both. Nevertheless, our stock-composition estimates were corroborated by other (genetic) studies. We concluded that the western Bering Sea in summer–fall is an important area of intermixing of immature sockeye salmon of Asian and North American origin.

Keywords: abundance, age, biomass, distribution, immature, scale pattern analysis, sockeye salmon, 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, 2003, 2004, 2005). One of the major objectives of BASIS was to estimate seasonal stock-specific distributions of salmon in the Bering Sea. Previous stock identification research indicated that ocean foraging areas of sockeye salmon can be distant from their spawning grounds (e.g., Konovalov 1971; French et al. 1976; Forrester 1987). Prior to BASIS research, very little was known about the stock composition of immature sockeye salmon (*O. nerka*) migrating in the Bering Sea in summer–fall, particularly inside of the Russian Federation’s Exclusive Economic Zone (REEZ). Previous marine stock-identification research in the Russian Far East focused primarily on maturing salmon during their prespawning migrations (e.g., Konovalov 1971; Temnykh et al. 1994, 1997; Temnykh 1996; Varnavskaya 2001; Bugaev 2003a,b,c). Aggregations of maturing sockeye salmon in western Bering Sea waters adjacent Kamchatka and contiguous waters of the western North Pacific Ocean likely include only Asian-origin

stocks (Bugaev 2003b). However, immature sockeye salmon in this oceanic region might include a mixture of Asian and North American stocks. Historical stock-identification research by the International North Pacific Fisheries Commission (INPFC) indicated only that “some portion” of immature sockeye salmon of North American origin (primarily Bristol Bay) were distributed in the central and western Bering Sea in summer–fall (at least to 60°N and west to 166°E; French et al. 1976).

Habicht et al. (2005) used genetic (DNA) methods to identify the origin of sockeye salmon in BASIS samples from 2002–2003. The results of Habicht et al. indicated that sockeye salmon of Bristol Bay origin were the dominant stock in all regions of the Bering Sea in summer–fall, except in the southwestern REEZ where Russian (Kamchatka) stocks dominated. Bugaev (2004, 2005, 2006) used scale pattern analysis to estimate the stock composition of immature sockeye salmon in 2002–2004 BASIS samples from the REEZ. In general, Bugaev’s preliminary results were similar to those of Habicht et al. (2005). In this paper, we update the results of (Bugaev et al. 2004, 2005, 2006), briefly review BASIS data on distribution and abundance of immature sockeye salmon, and provide provisional estimates of

the abundance and biomass of Asian and North American sockeye salmon in the western Bering Sea.

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 (2003a, 2004, 2005, 2006). Briefly, we used scale pattern analysis of representative (baseline) samples of Asian and North American sockeye 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 sockeye salmon and associated biological and catch data were collected by the staff of the TINRO-Center in 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 sockeye 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.

Ages of immature sockeye 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 1.2 fish has one freshwater annulus and two ocean annuli on its scale, and is in its third summer–fall in the ocean. Although juvenile sockeye salmon (.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 sockeye salmon collected in Dis-

tricts 8 and 12 (Fig. 1) 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 mixture sample from all districts (3,691 fish) was used to estimate age composition by year, season, and region, and a subset of preferred scales from this sample (2,678 fish) was used to estimate stock composition.

Baseline Samples

Baseline scale samples were collected by regional fishery agency personnel (KamchatNIRO, ChukotNIRO, Sevostroybvd (North-East Fishery Protection Service), and the Alaska Department of Fish and Game) from adult sockeye salmon returning to principal commercial watersheds in Asia and North America in 2003–2005. Scale samples and associated age data from 36 stocks of sockeye salmon of Asian (Kamchatka and Chukotka) and North American (Alaska) origin were used to form the baselines (Fig. 2).

Two different baselines were formed for each stock and adult return year (2003–2005) by pooling samples of the four most common age groups of adult sockeye salmon by freshwater age: (1) ages 1.2 + 1.3 and (2) ages 2.2 + 2.3. These baselines were used to estimate stock composition of fish of the same freshwater age group in the previous year's (2002–2004) mixture sample of immature ocean ages .1 and .2 sockeye salmon. This approach was taken to reduce the effects of year-to-year variation in scale growth patterns caused by environmental factors. However, pooling by ocean age (.2 + .3 fish) was necessary to obtain a sufficient number of scales for each stock in the two baselines.

For each baseline stock, we selected a stratified random

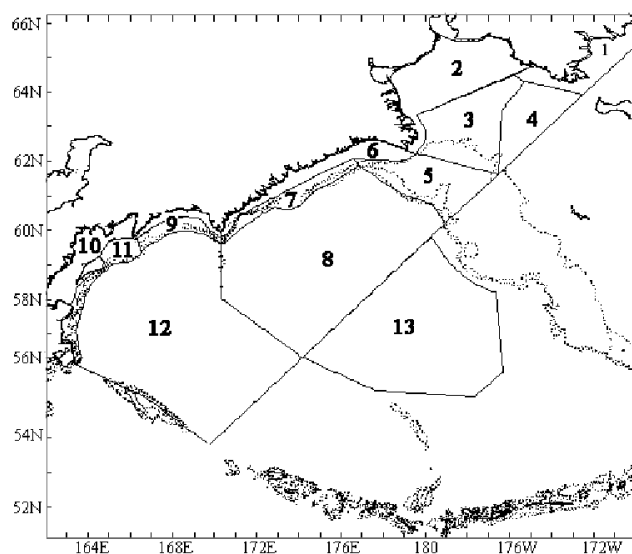


Fig. 1. TINRO-Center biostatistical districts in the western Bering Sea (Shuntov 1986; Volvenko 2003).

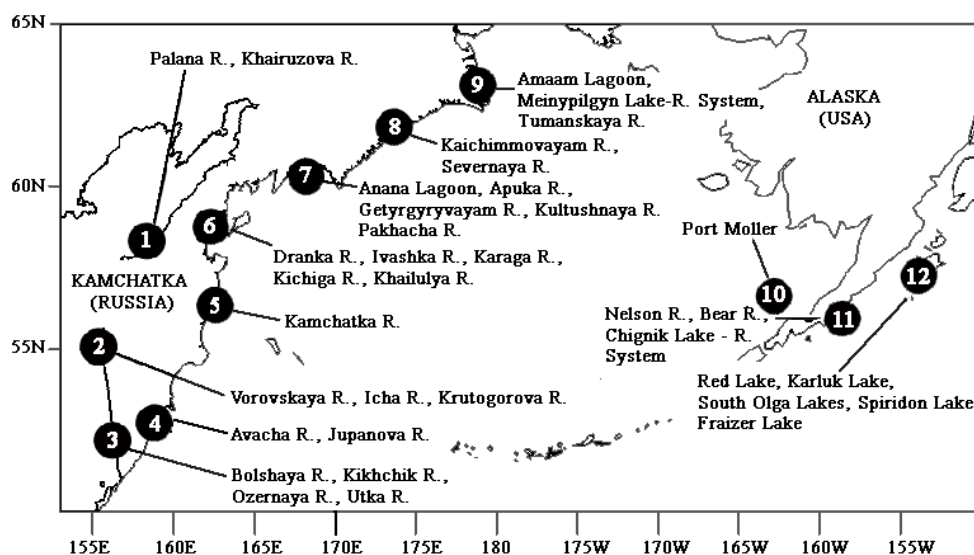


Fig. 2. Locations (numbered black circles) of 12 sockeye salmon stock groups represented in the 2003–2005 scale pattern baselines. The baseline scale samples and associated data were collected by scientists of KamchatNIRO, ChukotNIRO, Sevvostrybvod, and the Alaska Department of Fish and Game. 1 = northwestern Kamchatka, 2 = western Kamchatka, 3 = southwestern Kamchatka, 4 = southeastern Kamchatka, 5 = eastern Kamchatka, 6–8 = northeastern Kamchatka, 9 = Chukotka, 10 = central Alaska (Bristol Bay), 11 = southwestern Alaska (Alaska Peninsula), 12 = Kodiak Island.

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.

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). Scale pattern variables were calculated from inter-circulus measurements. 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), six triplets (TR) in the first ocean zone, and six reverse triplets (RTR) in the first ocean zone (Fig. 3).

Estimates of Stock Composition

The 36 baseline stocks were combined into a reduced number of stock groups 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 2007).

Computer simulations were used to evaluate the accuracy of the baseline stock groups using a maximum-likelihood estimation procedure (Millar 1987, 1990; Patton et al. 1998). The estimation procedure included 500 iterations of random-

ly sampled scales in the model (with replacement) for 100% representation by one baseline in the simulated mixture.

The baseline data were used to calculate maximum likelihood estimates of stock composition of sockeye 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).

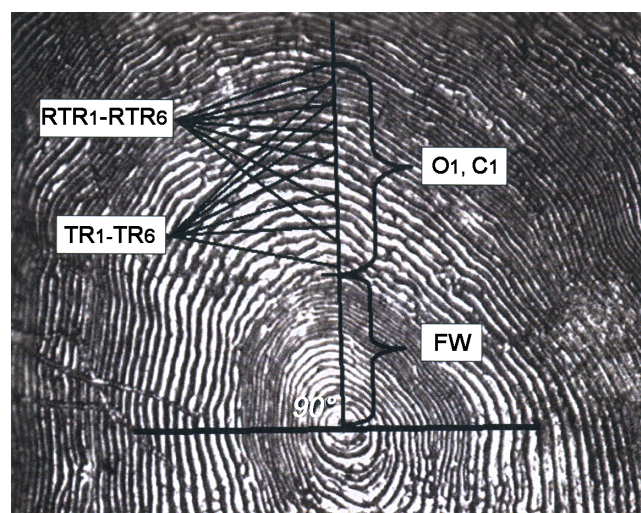


Fig. 3. Image of a sockeye salmon scale showing the scale pattern variables used for stock identification. FW = the total radius of freshwater zone, O1 = total radius of the first annual ocean growth zone, C1 = number of circuli in the first annual ocean growth zone, TR1–TR6 = radii of groups of three 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).

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 2002–2004 (Glebov 2007). Estimates of the abundance and biomass of sockeye 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 sockeye salmon into northern (districts 2–8) and southern (districts 9–12) areas (Fig. 1), and apportioned these estimates 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 sockeye salmon runs in Asia and North America.

RESULTS

Age Composition of Immature Sockeye Salmon

The 2002–2004 catches of immature sockeye salmon in the western Bering Sea were dominated (84.8 to 94.6%) by four age groups (1.1, 1.2, 2.1, and 2.2), which we referred to as “available age groups” because sample sizes of the other age groups were not large enough for scale pattern analysis (AAG; Table 1). Over the entire survey period, percentages of young immature sockeye salmon in their second ocean summer (primarily 1.1 and 2.1 fish) were higher

(~50–80% of total) than those of older ocean age groups of immature sockeye salmon. In fall 2002–2004, percentages of 1.1 sockeye salmon were higher than percentages of 2.1 sockeye salmon in the northern districts, while percentages of the two age groups were relatively similar in the southern districts. From summer to fall 2003, percentages of 1.1 sockeye salmon increased and percentages of 2.1 sockeye salmon decreased in northern districts. Immature sockeye salmon in their third ocean summer (primarily 1.2 and 2.2 fish) ranged from approximately 20–40% of the total sample. In fall 2002, percentages of 1.2 and 2.2 fish were higher than percentages of 1.1 and 2.1 fish in the northern districts. Samples sizes of other age groups of sockeye salmon were usually < 10% of the total sample in each year, season, and area stratum.

Stock-Specific Differences in Scale Patterns

Bugaev (2007) reported the detailed results of a statistical evaluation of differences in the scale patterns of local stocks of adult sockeye salmon of Asian and North American origin that were used in the baseline models. In general, the results of cluster and canonical analyses indicated that sockeye salmon of Ozernaya River (western Kamchatka) origin, which is the main stock in Asia, were well differentiated from other stocks. In contrast, stocks of eastern Kamchatka origin (Kamchatka River and a group of minor stocks of northeast Kamchatka origin) were often similar in scale structure to sockeye salmon of Alaskan origin (primarily Bristol Bay stocks). The scale patterns of adult 2.2 + 2.3 sockeye salmon of Asian and North American origin were significantly different (t -tests, $P < 0.05$). This result was important to our objective to estimate abundance and biomass of Asian and North American sockeye salmon in the western Bering Sea,

Table 1. The age composition (% of total sample size) of immature sockeye salmon in BASIS trawl catches by the R/V *TINRO* in the western Bering Sea. N = sample size, AAG = available age groups for identification by scale pattern analysis. North = Districts 1–8 and South = Districts 9–12 (Fig. 1). Juvenile (age x.0) sockeye salmon were not included in the analysis because of scale loss during trawl operations.

Year-Season	N	Age composition (%)													AAG %
Area		0.1	0.2	0.3	1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	4.1	
2002-Fall															
North	438	1.4	2.1	-	23.1	30.4	3.2	-	14.2	19.6	1.8	1.0	3.2	-	87.3
South	642	2.8	2.9	0.1	22.6	20.6	2.2	-	22.6	19.0	2.9	3.3	0.9	-	84.8
2003-Summer															
North	527	2.6	1.0	0.4	36.8	11.4	0.2	-	38.9	5.5	0.4	2.1	0.6	0.2	92.6
South	447	5.1	1.6	0.7	29.5	16.1	1.8	-	26.8	14.3	0.4	2.2	1.3	-	86.8
2003-Fall															
North	310	2.9	1.6	-	51.6	11.0	1.6	-	21.0	7.4	0.6	1.9	0.3	-	91.0
South	566	5.5	0.9	-	32.0	14.0	1.1	0.2	29.2	12.0	0.9	3.4	1.1	-	87.1
2004-Fall															
North	295	1.7	0.7	-	42.7	16.3	-	-	29.8	5.8	-	2.7	-	0.3	94.6
South	466	6.4	1.3	0.4	36.9	10.5	-	-	39.5	3.2	-	1.3	0.4	-	90.1

because 2.2 and 2.3 are the dominant age groups of the two major Asian stocks of sockeye salmon—Lake Kuril (Ozer-naya River) and Lake Azabache (Kamchatka River). For 1.2 + 1.3 sockeye salmon, there were fewer statistically significant differences between Asian and North American stocks, as well as between Asian stocks, than were found for 2.2 + 2.3 fish (t -tests, $p < 0.05$). In general, this was due to similarity in scale patterns of 1.2 + 1.3 sockeye salmon of eastern Kamchatka and Alaska origin, and to the wide diversity in scale phenotypes of minor stocks of western Kamchatka and eastern Kamchatka origin. In addition, there was considerable annual variation in differences in scale growth patterns between 1.2 + 1.3 stocks, which was likely due to annual changes in freshwater and early ocean foraging conditions. Nevertheless, similar trends were observed in all age 1.2 + 1.3 baselines, and errors due to annual variation in scale patterns were considered to be standard throughout the entire period of observations.

Accuracies of Stock Identification Models

Computer simulations indicated that the accuracies of the maximum-likelihood stock identification models were relatively high (mean 84.5–91.2%; Tables 2–7). 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. Three models (1.2 + 1.3 fish in 2003 and 2004, 2.2 + 2.3 fish in 2003) included a multi-regional stock, i.e., a stock composed of stocks originating in both Asia and North America (Table 2, no. 2; Table 3, no. 5; Table 4, no. 4). Four models included a multi-regional stock composed of local stocks originating in both eastern and western Kamchatka (age 2.2 + 2.3 in 2002 and 2003; 1.2 + 1.3 in 2004, 2.2 + 2.3 in 2005) (Table 3, no. 5; Table 4, no. 5; Table 7, no. 4). To estimate biomass

and abundance of sockeye salmon by region, the estimated proportions of multi-regional stocks in the mixture sample were later apportioned to the component regional stock with the highest abundance of adult returns.

Stock Composition Estimates

Regional stocks of Asian origin dominated all time-area strata of 2.1+2.2 immature sockeye salmon, while proportions of stocks of North American origin (primarily Bristol Bay) were relatively high in time-area strata of 1.1+1.2 immature sockeye salmon (Table 8).

In fall 2002, estimated percentages of the 1.1+1.2 multi-regional stock (primarily sockeye salmon of Bristol Bay origin) were relatively high in both northern (51.7%) and southern areas (44.1%), and estimated percentages of 2.1+2.2 Bristol Bay sockeye salmon were relatively low in both the northern (23.6%) and southern areas (2.6%).

In summer 2003, estimated percentages of all age groups of Bristol Bay sockeye salmon were lower in northern (34.4% of 1.1+1.2 fish and 18.3% of 2.1+2.2 fish) and southern (11.3% of 1.1+1.2 fish and 0.9% of 2.1+2.2 fish) areas than in fall 2002.

In fall 2003, estimated percentages of 1.1+1.2 Bristol Bay sockeye salmon were slightly higher in the northern area (53.6%) and considerably lower in the southern area (17.7%) than in fall 2002, and estimated percentages of 2.1+2.2 Bristol Bay sockeye salmon were relatively low in both the northern (10.9%) and southern areas (6.3%).

In fall 2004, estimated percentages of 1.1+1.2 Bristol Bay fish were lower in the northern area (27.2%) than in 2002 and 2003, and were similar to fall 2003 in the southern area (20.4%). For 2.1+2.2 fish, no sockeye salmon of Bristol Bay origin were detected in either the northern or southern areas in fall 2004.

Table 2. Evaluation of the accuracy of a 5-region maximum likelihood estimate model for ages 1.2 and 1.3 sockeye salmon in 2003, as indicated by computer simulations of 100% representation by one regional stock group (indicated by grey shading). N = sample size.

Regional stock	N	Maximum likelihood estimate/standard deviation				
		1	2	3	4	5
1. Northeastern Kamchatka + Chukotka	303	0.8889	0.0642	0.0028	0.0381	0.0035
		0.0694	0.0474	0.0072	0.0391	0.0087
2. Central (Bristol Bay) and Southwestern Alaska + Northeastern and Southeastern Kamchatka	477	0.0673	0.8239	0.0003	0.0730	0.0078
		0.0686	0.0831	0.0024	0.0779	0.0146
3. Kodiak I.	150	0.0177	0.0069	0.9869	0.0030	0.0001
		0.0204	0.0139	0.0215	0.0089	0.0010
4. Eastern (Kamchatka R.) and Northeastern Kamchatka	231	0.0254	0.0924	0.0095	0.8770	0.0034
		0.0336	0.0762	0.0201	0.0832	0.0084
5. Western and Southwestern Kamchatka	301	0.0007	0.0126	0.0005	0.0089	0.9852
		0.0023	0.0180	0.0029	0.0125	0.0171
Mean accuracy (%)						91.24

Table 3. Evaluation of the accuracy of a 6-region maximum likelihood estimate model for ages 2.2 and 2.3 sockeye salmon in 2003, as indicated by computer simulations of 100% representation by one regional stock group (indicated by grey shading). N = sample size.

Regional stock	N	Maximum likelihood estimate/standard deviation					
		1	2	3	4	5	6
1. Northeastern Kamchatka + Chukotka	337	<u>0.8144</u>	<u>0.0234</u>	<u>0.0096</u>	<u>0.0047</u>	<u>0.0830</u>	<u>0.0002</u>
		0.0827	0.0256	0.0157	0.0103	0.0521	0.0024
2. Central Alaska (Bristol Bay)	150	<u>0.0092</u>	<u>0.9321</u>	<u>0.0180</u>	<u>0.0043</u>	<u>0.0959</u>	<u>0.0003</u>
		0.0237	0.0569	0.0312	0.0156	0.0722	0.0023
3. Eastern (Kamchatka R.), Southeastern, and Northwestern Kamchatka	220	<u>0.0803</u>	<u>0.0176</u>	<u>0.9170</u>	<u>0.0001</u>	<u>0.0365</u>	<u>0.0000</u>
		0.0527	0.0310	0.0463	0.0009	0.0370	0.0000
4. Kodiak I.	200	<u>0.0079</u>	<u>0.0079</u>	<u>0.0012</u>	<u>0.8599</u>	<u>0.0459</u>	<u>0.0000</u>
		0.0126	0.0194	0.0040	0.0817	0.0506	0.0000
5. Southwestern Alaska + Northeastern Kamchatka	384	<u>0.0864</u>	<u>0.0186</u>	<u>0.0030</u>	<u>0.1310</u>	<u>0.7360</u>	<u>0.0000</u>
		0.0726	0.0374	0.0114	0.0829	0.0971	0.0000
6. Southwestern Kamchatka (Ozernaya R.)	100	<u>0.0018</u>	<u>0.0004</u>	<u>0.0512</u>	<u>0.0000</u>	<u>0.0027</u>	<u>0.9995</u>
		0.0054	0.0028	0.0316	0.0004	0.0079	0.0033
Mean accuracy (%)							87.65

Table 4. Evaluation of the accuracy of a 6-region maximum likelihood estimate model for ages 1.2 and 1.3 sockeye salmon in 2004, as indicated by computer simulations of 100% representation by one regional stock group (indicated by grey shading). N = sample size.

Regional stock	N	Maximum likelihood estimate/standard deviation					
		1	2	3	4	5	6
1. Kodiak I.	279	<u>0.9586</u>	<u>0.0037</u>	<u>0.0109</u>	<u>0.0043</u>	<u>0.0017</u>	<u>0.0031</u>
		0.0343	0.0074	0.0156	0.0104	0.0046	0.0061
2. Central Alaska (Bristol Bay)	195	<u>0.0302</u>	<u>0.8038</u>	<u>0.0374</u>	<u>0.0873</u>	<u>0.0396</u>	<u>0.0053</u>
		0.0323	0.1092	0.0519	0.0829	0.0420	0.0175
3. Eastern Kamchatka (Kamchatka R.) + Chukotka	295	<u>0.0006</u>	<u>0.0618</u>	<u>0.8421</u>	<u>0.0860</u>	<u>0.0611</u>	<u>0.0384</u>
		0.0040	0.0580	0.0974	0.0785	0.0503	0.0357
4. Southwestern Alaska + Northeastern Kamchatka	333	<u>0.0001</u>	<u>0.0935</u>	<u>0.0917</u>	<u>0.8029</u>	<u>0.0409</u>	<u>0.0038</u>
		0.0017	0.1012	0.0910	0.1102	0.0522	0.0150
5. Northeastern and Northwestern Kamchatka	200	<u>0.0064</u>	<u>0.0249</u>	<u>0.0171</u>	<u>0.0163</u>	<u>0.8192</u>	<u>0.0595</u>
		0.0112	0.0343	0.0268	0.0315	0.0793	0.0644
6. Western and Southwestern Kamchatka	349	<u>0.0041</u>	<u>0.0123</u>	<u>0.0008</u>	<u>0.0032</u>	<u>0.0375</u>	<u>0.8899</u>
		0.0094	0.0232	0.0057	0.0098	0.0520	0.0734
Mean accuracy (%)							85.28

Distribution and Assessment of Relative Abundance

Catches of immature sockeye salmon were highest in Districts 8 and 12 (Fig. 4). Average catches were approximately 100–500 fish/km². In 2002 and 2003, catches of sockeye salmon at some stations were very high (≥ 1000 fish/km²). In District 8, sockeye salmon were distributed throughout the entire area in fall 2002–2003 or concentrated in the northern part of the district in summer 2003 and fall 2004. In District 12, catches were highest west of 167–168°E, and substantially lower near the border of the

REEZ. Seasonal variation in 2003 might reflect southward migration of some immature sockeye salmon from northern districts in fall (Glebov 2007).

Estimates of Abundance and Biomass of Immature Sockeye Salmon

The estimated maximum abundance/biomass of immature sockeye salmon occurred in fall 2002 (77 million fish/92 thousand t in Districts 5–8; 75 million fish/86 thousand t in southern District 12; Table 9). Estimated abundance and

Table 5. Evaluation of the accuracy of a 5-region maximum likelihood estimate model for ages 2.2 and 2.3 sockeye salmon in 2004, as indicated by computer simulations of 100% representation by one regional stock group (indicated by grey shading). N = sample size.

Regional stock	N	Maximum likelihood estimate/standard deviation				
		1	2	3	4	5
1. Eastern Kamchatka (Kamchatka R.) + Chukotka	325	<u>0.9233</u>	<u>0.0892</u>	<u>0.0645</u>	<u>0.0038</u>	<u>0.0464</u>
		0.0602	0.0593	0.0542	0.0089	0.0585
2. Central (Bristol Bay) and Southwestern Alaska	423	<u>0.0155</u>	<u>0.7835</u>	<u>0.0345</u>	<u>0.0098</u>	<u>0.0090</u>
		0.0319	0.1006	0.0607	0.0260	0.0245
3. Kodiak I.	293	<u>0.0369</u>	<u>0.0923</u>	<u>0.8870</u>	<u>0.0030</u>	<u>0.0034</u>
		0.0472	0.0726	0.0773	0.0093	0.0125
4. Southwestern Kamchatka (Ozernaya R.)	202	<u>0.0044</u>	<u>0.0205</u>	<u>0.0126</u>	<u>0.9825</u>	<u>0.0001</u>
		0.0103	0.0318	0.0217	0.0280	0.0012
5. Southeastern Kamchatka	32	<u>0.0199</u>	<u>0.0145</u>	<u>0.0014</u>	<u>0.0009</u>	<u>0.9411</u>
		0.0319	0.0255	0.0067	0.0046	0.0635
Mean accuracy (%)						90.35

Table 6. Evaluation of the accuracy of a 5-region maximum likelihood estimate model for ages 1.2 and 1.3 sockeye salmon in 2005, as indicated by computer simulations of 100% representation by one regional stock group (indicated by grey shading). N = sample size.

Regional stock	N	Maximum likelihood estimate/standard deviation				
		1	2	3	4	5
1. Central Alaska (Bristol Bay)	150	<u>0.9121</u>	<u>0.1155</u>	<u>0.0077</u>	<u>0.0134</u>	<u>0.0384</u>
		0.0852	0.0875	0.0175	0.0275	0.0501
2. Eastern (Kamchatka R.) and Northeastern Kamchatka	411	<u>0.0585</u>	<u>0.7520</u>	<u>0.0583</u>	<u>0.0053</u>	<u>0.0466</u>
		0.0836	0.1150	0.0501	0.0155	0.0658
3. Southwestern Alaska + Kodiak I.	401	<u>0.0000</u>	<u>0.0392</u>	<u>0.9259</u>	<u>0.0058</u>	<u>0.0085</u>
		0.0002	0.0371	0.0501	0.0097	0.0137
4. Northwestern, West, and Southwestern Kamchatka	453	<u>0.0199</u>	<u>0.0201</u>	<u>0.0049</u>	<u>0.8930</u>	<u>0.0203</u>
		0.0267	0.0242	0.0095	0.0677	0.0301
5. Northeastern and Southeastern Kamchatka	220	<u>0.0095</u>	<u>0.0732</u>	<u>0.0032</u>	<u>0.0825</u>	<u>0.8862</u>
		0.0218	0.0658	0.0080	0.0638	0.0805
Mean accuracy (%)						87.38

biomass of immature sockeye salmon were very high in two biostatistical districts (8 and 12). In the northern area (District 8) estimated abundance and biomass in fall 2003 were substantially lower in fall 2003 than in fall 2002 and 2004. In the southern area (District 8) in fall, there was a declining trend in estimated abundance and biomass over the three-year period. In 2003, estimated abundance/biomass decreased from summer to fall in the northern area and increased from summer to fall in the southern area.

Abundance and Biomass of Asian and North American Stocks

In all time and area strata, estimates of abundance and biomass of immature sockeye salmon (1.1+1.2+2.1+2.2 fish)

were consistently higher for Asian stocks than for North American stocks (Table 10). Estimates of abundance and biomass of North American stocks were highest in the northern area in fall 2002 and summer 2003. Although estimated percentages of North American stocks in the northern area were similar in fall 2002 and 2003, the estimated total abundance and biomass of immature sockeye salmon was substantially lower in fall 2003 than in fall 2002. In the southern area in fall, the estimated abundance and biomass of North American stocks decreased over the period from 2002 to 2004.

For Asian stocks, estimates of abundance and biomass of immature sockeye salmon (1.1+1.2+2.1+2.2 fish) were further apportioned to two groups: (1) eastern Kamchatka+Chukotka stocks and (2) western Kamchatka stocks. In the northern

Table 7. Evaluation of the accuracy of a 6-region maximum likelihood estimate model for ages 2.2 and 2.3 sockeye salmon in 2005, as indicated by computer simulations of 100% representation by one regional stock group (indicated by grey shading). N = sample size.

Regional stock	N	Maximum likelihood estimate/standard deviation					
		1	2	3	4	5	6
1. Chukotka	76	0.8430	0.0106	0.0294	0.0068	0.0009	0.0168
		0.0641	0.0157	0.0253	0.0182	0.0041	0.0188
2. Central Alaska (Bristol Bay) + Kodiak I.	450	0.0048	0.6571	0.0295	0.0004	0.1229	0.0278
		0.0165	0.1505	0.0485	0.0030	0.1186	0.0399
3. Eastern Kamchatka (Kamchatka R.)	150	0.0460	0.1349	0.9344	0.0417	0.0148	0.0000
		0.0392	0.0773	0.0554	0.0359	0.0248	0.0000
4. Northeastern Kamchatka + Northwestern Kamchatka	142	0.0702	0.0051	0.0002	0.9045	0.0004	0.0185
		0.0522	0.0110	0.0014	0.0517	0.0031	0.0267
5. Southwestern Alaska	195	0.0164	0.1595	0.0065	0.0018	0.8059	0.0106
		0.0296	0.1252	0.0190	0.0064	0.1288	0.0329
6. Southwestern Kamchatka (Ozernaya R.)	150	0.0196	0.0328	0.0000	0.0448	0.0551	0.9263
		0.0324	0.0408	0.0000	0.0375	0.0620	0.0576
Mean accuracy (%)							84.52

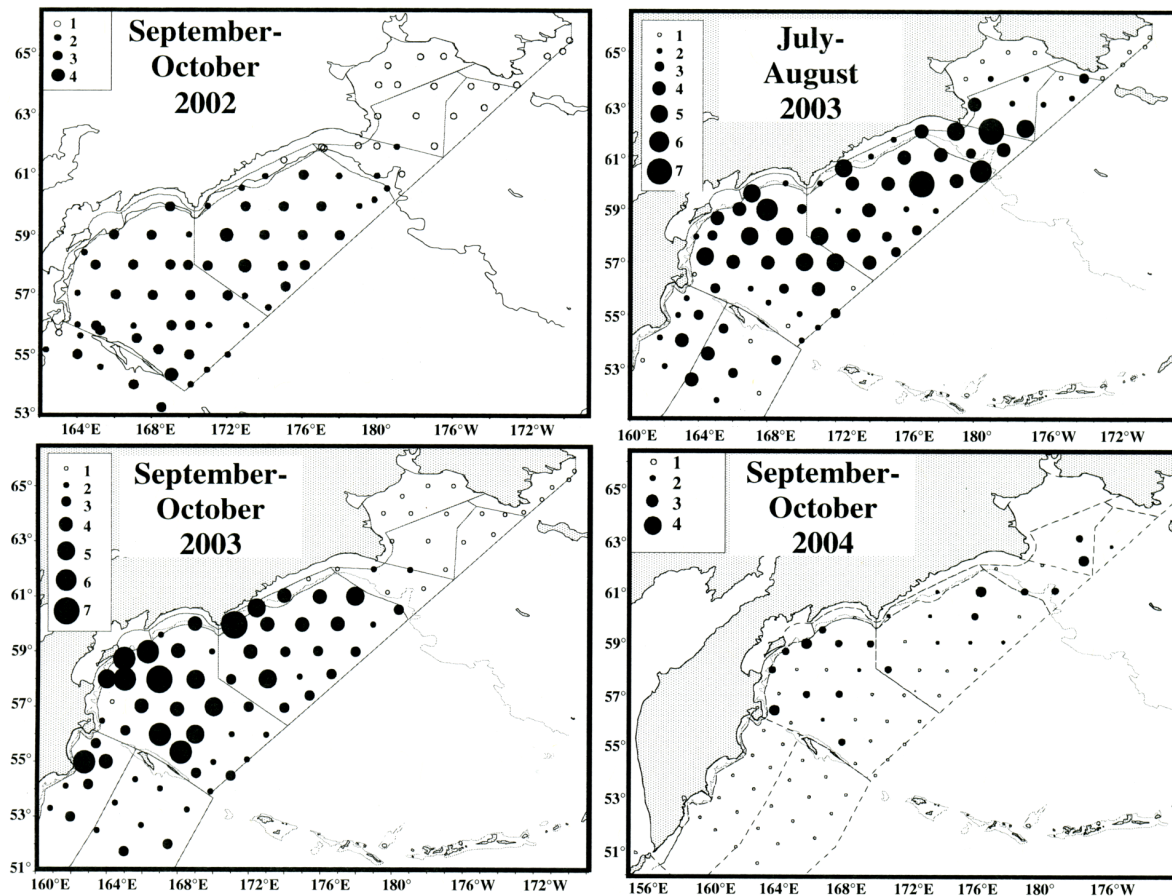
**Fig. 4.** The spatial distribution and relative abundance of sockeye salmon determined by BASIS research in the western Bering Sea, 2002-2004. Note that scales vary among years. The size of the circles indicates relative abundance (number of fish/km²). Upper left panel (2002): 1 = no catch, 2 = 1–10, 3 = 11–100, 4 = 101–1000. Upper right and lower left panels (2003): 1 = no catch, 2 = < 50, 3 = 51–100, 4 = 101–250, 5 = 251–500, 6 = 501–1000, 7 = > 1001. Lower right panel (2004): 1 = no catch; 2 = 1–10; 3 = 11–100; 4 = 101–500.

Table 8. Evaluation of the accuracy of a 6-region maximum likelihood (MLE) estimate model for ages 2.2 and 2.3 sockeye salmon in 2005, as indicated by computer simulations of 100% representation by one regional stock group (indicated by grey shading). CI (95%) = 95% confidence interval, N = sample size, SD = standard deviation. Geographic locations of regional stocks are shown in Fig. 2. CAK = Central Alaska (Port Moller, Bristol Bay), Chuk = Chukotka, EKam = Eastern Kamchatka, Kodiak I. = Kodiak Island, NEKAM = Northeastern Kamchatka, NWKAM = Northwestern Kamchatka, SEKAM = Southeastern Kamchatka, SWAK = Southwestern Alaska, SWKAM = Southwestern Kamchatka, WKAM = Western Kamchatka.

Year & Season	Bering Sea Area	Age	N	Regional stock	MLE	SD	CI (95%)
2002 Fall	Northern	1.1-1.2	193	NEKam-Chuk	0.2696	0.0503	0.1656-0.3707
				CAK-SWAK-NEKam-SEKam	0.5167	0.0576	0.4003-0.6386
				Kodiak I.	0.0162	0.0140	0.0000-0.0467
				EKam-NEKam	-	-	-
				WKam-SWKam	0.1975	0.0336	0.1283-0.2692
		2.1-2.2	135	NEKam-Chuk	0.1641	0.0504	0.0458-0.2278
				CAK	0.2355	0.0690	0.1003-0.3943
				EKam-SEKam-NWKam	0.4408	0.0721	0.2919-0.5902
				Kodiak I.	-	-	-
				SWAK+ NEKam	-	-	-
	Southern	1.1-1.2	214	SWKam	0.1596	0.0378	0.0983-0.2476
				NE Kam.-Chuk	0.2466	0.0455	0.1473-0.3384
				CAK- SWAK-NEKam-SEKam	0.4537	0.0614	0.3198-0.5910
				Kodiak I.	-	-	-
				EKam- NEKam	0.0581	0.0397	0.0000-0.1445
		2.1-2.2	232	WKam-SWKam	0.2416	0.0356	0.1733-0.3218
				NE Kam.-Chuk	0.1104	0.0316	0.0372-0.1441
				CAK	0.0264	0.0359	0.0000-0.1201
				EKam-SEKam-NWKam	0.6137	0.0548	0.4729-0.7077
				Kodiak I.	-	-	-
2003 Summer	Northern	1.1-1.2		SWAK-NEKam	-	-	-
				SWKam	0.2495	0.0361	0.1908-0.3667
				Kodiak I.	0.0132	0.0114	0.0000-0.0419
				CAK	0.3437	0.0793	0.1607-0.5288
				EKam-Chuk	0.2858	0.0659	0.1531-0.4354
		2.1-2.2	180	SWAK-NEKam	0.3017	0.0798	0.1187-0.4675
				NEKam-NWKam	-	-	-
				WKam-SWKam	0.0556	0.0354	0.0000-0.1358
				EKam-Chuk	0.4444	0.0617	0.3205-0.5913
				CAK-SWAK	0.1829	0.0609	0.0000-0.2246
	Southern	1.1-1.2	120	Kodiak I.	-	-	-
				SWKam	0.3727	0.0567	0.3095-0.5796
				SEKam	-	-	-
				Kodiak I.	0.0085	0.0099	0.0000-0.0344
				CAK	0.1138	0.0699	0.0000-0.2583
		2.1-2.2	127	EKam-Chuk	0.1225	0.0708	0.0000-0.3013
				SWAK-NEKam	0.5800	0.0994	0.3445-0.7744
				NEKam-NWKam	0.0370	0.0442	0.0000-0.1369
				WKam-SWKam	0.1382	0.0569	0.0227-0.2725
				EKam-Chuk	0.5471	0.0647	0.4179-0.6864
		2.1-2.2	127	CAK-SWAK	0.0088	0.0422	0.0000-0.0831
				Kodiak I.	-	-	-
				SWKam	0.4441	0.0654	0.2893-0.5709
		2.1-2.2	127	SEKam	-	-	-

Table 8 (continued).

Year & Season	B.S. Area	Age	N	Regional stock	MLE	SD	CI (95%)
Fall	Northern	1.1-1.2	178	Kodiak I.	-	-	-
				CAK	0.5358	0.0650	0.3849-0.6654
				EKam-Chuk	0.3852	0.0600	0.2599-0.5126
				SWAK-NEKam	-	-	-
				NEKam-NWKam	-	-	-
				WKam-SWKam	0.0790	0.0397	0.0000-0.1761
		2.1-2.2	86	EKam-Chuk	0.4370	0.0756	0.2876-0.5833
				CAK-SWAK	0.1094	0.0644	0.0000-0.2285
				Kodiak I.	-	-	-
				SWKam	0.4536	0.0745	0.3266-0.6241
				SEKam	-	-	-
	Southern	1.1-1.2	225	Kodiak I.	-	-	-
				CAK	0.1766	0.0555	0.0509-0.2708
				EKam-Chuk	0.4085	0.0607	0.2616-0.5242
				SWAK-NEKam	0.0499	0.0564	0.0000-0.1865
				NEKam-NWKam	-	-	-
				WKam-SWKam	0.3650	0.0485	0.2533-0.4716
		2.1-2.2	200	EKam-Chuk	0.2327	0.0477	0.1354-0.3478
				CAK-SWAK	0.0626	0.0442	0.0000-0.1385
				Kodiak I.	-	-	-
				SWKam	0.7047	0.0509	0.6030-0.8324
				SEKam	-	-	-
2004 Fall	Northern	1.1-1.2	163	CAK	0.2725	0.0764	0.0693-0.4306
				EKam-NEKam	0.6508	0.0883	0.4355-0.8604
				SWAK-Kodiak I.	0.0767	0.0410	0.0114-0.1830
				NWKam-WKam-SWKam	-	-	-
				NEKam-SEKam	-	-	-
		2.1-2.2	115	Chuk	0.1239	0.0448	0.0211-0.2214
				CAK-Kodiak I.	-	-	-
				EKam	0.5773	0.0726	0.4120-0.7185
				NEKam-NWKam	0.1114	0.0548	0.0000-0.2133
				SWAK	0.0567	0.0579	0.0000-0.1532
				SWKam	0.1307	0.0619	0.0255-0.2689
	Southern	1.1-1.2	155	CAK	0.2039	0.0706	0.0378-0.3372
				EKam-NEKam	0.4822	0.1028	0.2603-0.6995
				SWAK-Kodiak I.	0.1239	0.0409	0.0484-0.2201
				NWKam-WKam-SWKam	-	-	-
				NEKam-SEKam	0.1900	0.0706	0.0286-0.3498
		2.1-2.2	163	Chuk	0.0552	0.0253	0.0000-0.0929
				CAK-Kodiak I.	-	-	-
				EKam	0.2057	0.0460	0.1150-0.3130
				NEKam-NWKam	0.2744	0.0548	0.1709-0.3960
				SWAK	-	-	-
				SWKam	0.4647	0.0584	0.3526-0.5856

Table 9. The estimated abundance and biomass of immature sockeye 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-Fall	-	-	-	-	0.5	-	0.1	76.6	-	-	-	75.3	152.5
2003-Summer	-	0.3	5.8	0.6	13.1	-	0.9	50.1	1.1	-	-	40.0	111.7
2003-Fall	-	-	-	-	0.2	-	2.5	30.1	0.2	-	-	68.2	101.3
2004-Fall	-	-	0.1	-	0.7	-	0.1	72.9	-	-	-	48.2	122.0
Biomass (thousands of tons)													
2002-Fall	-	-	-	-	0.6	-	0.2	91.6	-	-	-	86.1	178.4
2003-Summer	-	0.2	3.8	0.4	8.8	-	0.7	39.1	0.6	-	-	30.0	83.8
2003-Fall	-	-	-	-	0.1	-	2.3	26.3	0.2	-	-	61.7	90.6
2004-Fall	-	-	0.1	-	0.5	-	0.1	63.9	-	-	-	44.3	108.9

Table 10. Estimates of the number (no., millions of fish) and biomass (thousands of metric tons) of immature sockeye salmon (1.1+1.2+2.1+2.2 fish) of Asian and North American origin in the western Bering Sea in 2002–2004. The northern area includes Districts 1–8 and the southern area includes Districts 9–12 (Fig. 1).

Year-Season B.S. Region	Total abundance and biomass		Regional stock					
			Asia			North America		
	no.	tons	%	no.	tons	%	no.	tons
2002-Fall								
Northern	77.18	92.36	58.9	45.46	54.40	41.1	31.72	37.96
Southern	75.30	86.06	76.9	57.91	66.18	23.1	17.39	19.88
2003-summer								
Northern	70.68	53.07	57.0	40.29	30.25	43.0	30.39	22.82
Southern	41.04	30.78	65.2	26.76	20.07	34.8	14.28	10.71
2003-Fall								
Northern	32.82	28.72	60.6	19.89	17.40	39.4	12.93	11.32
Southern	68.46	61.90	84.9	58.12	52.55	15.1	10.34	9.35
2004-Fall								
Northern	73.80	64.60	77.0	56.83	49.74	23.0	16.97	14.86
Southern	48.15	44.30	83.9	40.40	37.17	16.1	7.75	7.13

area, percentages of the total estimated abundance/biomass were consistently higher for eastern Kamchatka+Chukotka stocks (40.9% in fall 2002, 36.3% in summer 2003, 40.5% in fall 2004, and 71.6% in fall 2004) than for western Kamchatka stocks (18.0% in fall 2002, 20.7% in summer 2003, 20.1% in fall 2004, and 5.4% in fall 2004). In the southern area, percentages of the total estimated abundance/biomass were higher for eastern Kamchatka+Chukotka stocks in fall 2002 (52.2%), summer 2003 (35.6%), and fall 2004 (60.0%) than for western Kamchatka stocks in fall 2002 (24.7%), summer 2003 (29.6%), and fall 2004 (23.9%). In fall 2003,

percentages of the total estimated abundance/biomass of immature sockeye salmon were substantially higher for western Kamchatka (52.4%) than for eastern Kamchatka+Chukotka (32.5%).

DISCUSSION

Maturity, Age Composition, and Distribution

Glebov (2007) reviewed information on the distribution and migrations of sockeye salmon during BASIS surveys in

the western Bering Sea in summer and fall 2002–2006. Most (nearly 100%) of the sockeye salmon in trawl catches by the RV *TINRO* in summer and fall 2002–2004 were immature. A single maturing sockeye salmon was caught during the summer 2003 survey. The near absence of maturing sockeye salmon in trawl catches in the western Bering Sea was expected, because prespawning aggregations of maturing sockeye salmon in the western Bering Sea (primarily of eastern Kamchatka origin) are usually completed by the second half of July (Bugaev 2003a,d). Juvenile (ocean age .0) sockeye salmon were more prevalent than maturing fish in BASIS trawl catches in the western Bering Sea. However, we could not use scale pattern analysis to estimate stock composition of juvenile salmon because of scale loss during BASIS trawl fishing operations. While it seems reasonable to assume that juvenile sockeye salmon in summer–fall BASIS catches in the western Bering Sea were of Asian origin, similarities in scale patterns indicated possible intermixing of eastern Kamchatka, Chukotka, and Alaskan stocks during their first ocean year. This issue will likely be resolved by future genetic (DNA) stock identification analyses.

The age structure of immature sockeye salmon in the western Bering Sea during the 2002–2004 BASIS surveys was typical for this period of ocean life (French et al. 1976; Burgner 1991). For our stock-identification analysis, we used baselines composed of the four dominant age groups of sockeye salmon (1.2, 1.3, 2.2 and 2.3). These age groups account for about 90% of all adult returns of sockeye salmon in Asia and North America (Burgner 1991; Bugaev 1995).

Comparison of Stock Composition Estimates to Other Studies

The results of preliminary scale pattern analyses indicated that the western Bering Sea in summer and fall is an area of intermingling of immature sockeye salmon of Asian and North American origin, and that there is considerable spatial, seasonal, and annual variation in the proportions of Asian and North American origin stocks distributed in this region (Bugaev 2004, 2005, 2006). In general our results were similar to these preliminary analyses. Nevertheless, there were some notable differences. For example, in fall 2002 catches our estimated percentages of Alaskan stocks were 10–20% higher than those of Bugaev (2004), while our estimated percentages of western Kamchatka stocks were correspondingly lower. In summer 2003 catches, our estimated percentage of Alaskan stocks in the southwestern Bering Sea (Districts 9–12) was 34.8%, which was 25.9% lower than the preliminary estimate (Bugaev 2005). Brood-year specific baselines were not available for use in preliminary analyses, and likely resulted in errors in the models when there was significant interannual variation in freshwater and early marine scale growth patterns.

In general, the results of genetic stock identification studies corroborate our scale pattern analysis results. A direct

comparison of our stock composition estimates with those of genetic analyses of 2002–2004 BASIS mixture samples (Habicht et al. 2005; Gritsenko et al. 2007) is not possible because of differences in experimental design among studies. For example, investigations differed in the number and geographic range of stocks included in the baseline models, the number of mixture samples analyzed, and the biological (age), spatial, and temporal stratification of results. Nevertheless, a broad comparison of the results of these studies with respect to estimated proportions of immature sockeye salmon of Asian and North American origin is possible.

Habicht et al. (2005) used a DNA baseline (13 micro-satellite and two single nucleotide polymorphism (SNP) markers) to estimate stock proportions of immature sockeye salmon in summer–fall 2002–2003 BASIS samples. Their mixture samples were pooled over years. Similar to our results, Habicht et al. estimated that immature sockeye salmon of Asian origin were the dominant (~80%) stock in the southwestern Bering Sea. In contrast to our results, Habicht et al. estimated that Asian stocks accounted for < 50% of immature sockeye salmon in the northwestern Bering Sea. However, their Asian baseline was not comprehensive, including only Kamchatka River and Lake Kuril populations. Updated estimates using a more comprehensive (SNP) baseline indicated that Asian populations dominated BASIS catches in both southern (~94%) and northern (~62%) areas of Bering Sea (Districts 8 and 12, Fig. 4) in fall 2002–2004 (C. Habicht, chris.habicht@alaska.gov, pers. comm.).

Gritsenko et al. (2007) analyzed fall 2004 BASIS samples of immature sockeye salmon from the Bering Sea REEZ using genetic (SNP) analysis. Their estimated percentage of Asian stocks in the northwestern Bering Sea (72%) was similar to that of C. Habicht (chris.habicht@alaska.gov, pers. comm.). Our results also indicated that Asian stocks dominated BASIS samples from this region in fall 2004, although the total percentage of Asian stocks was substantially higher among age 2.1+2.2 fish (94%) than age 1.1+1.2 fish (65%; Table 8).

Our results and those of other (genetic) studies corroborate conceptual models of ocean migrations of sockeye salmon of Asian and North American origin in the western Bering Sea (French et al. 1976; Burgner 1991; Myers et al. 2007). The results of BASIS stock identification studies provide quantitative evidence that immature sockeye salmon of Asian (Kamchatka) origin are the dominant regional stock of this species in the western Bering Sea in fall. In addition, percentages of sockeye salmon of North American origin were higher in the northwestern Bering Sea (Districts 1–8) than in the southwestern Bering Sea (Districts 9–12). These results conform to known patterns of distribution of sockeye salmon originating from both continents, and are reasonable considering the geographic proximity of the northwestern Bering Sea to Alaska.

Distribution and Abundance of Sockeye Salmon Stocks in the Western Bering Sea

Abundance of sockeye salmon in Asia and North America was relatively high during the early 2000s (Eggers and Irvine 2007). However, BASIS estimates of abundance of immature sockeye salmon in the western Bering Sea (Table 9) were very high compared to estimated annual runs (catch + escapement) of sockeye salmon in Asia and North America. For example, the estimated total annual Pacific-Rim run of sockeye salmon averaged 79 million sockeye salmon in 2003–2005 (G. Ruggerone, Natural Resources Consultants, Seattle, pers. comm.). High estimates of abundance of immature sockeye salmon in the western Bering Sea might be explained, in part, by the presence of multiple brood years and age-classes of immature sockeye salmon that would have returned to their natal streams over a period of several years. The western Bering Sea, however, includes only a portion of the total area of known ocean distribution of Asian and North American sockeye salmon (Myers et al. 2007). We speculate that BASIS stock assessment methods, in particular the use of a fishing-efficiency coefficient of 0.3, may have resulted in overestimation of the abundance of immature salmon in the western Bering Sea.

In addition, official run-size statistics for adult salmon may be inaccurate. For example, official statistics indicated that total annual runs of adult sockeye salmon in Russia averaged 10.8 million fish in 2004–2006 (Anonymous 2005, 2006, 2007). Our estimates of abundance of immature sockeye salmon of Asian origin in the western Bering Sea in fall were 103 million fish in 2002, 78 million fish in 2004, and 97 million fish in 2005 (Table 10). Historically high catches (~15–18 thousand t) of sockeye salmon on the west coast of Kamchatka (the Ozernaya River), which exceeded the maximum recorded for the past one hundred years, have occurred since 2002 (Bugaev and Bugaev 2003). This likely contributed to the high abundance of immature sockeye salmon of Asian origin in the western Bering Sea in 2002–2004. The abundance of sockeye salmon of northeastern Kamchatka origin has also increased, although official statistics on catches and escapement in this area are not accurate because of extensive poaching. In recent years a similar poaching problem has occurred in the Kamchatka River Basin, as a result of its proximity to a number of human settlements.

Ecological conditions apparently also played an important role in the distribution and abundance of immature sockeye salmon in the western Bering Sea in summer–fall 2002–2004 (Shuntov et al. 2007). In principle, summer–fall foraging and migratory strategies of sockeye salmon in the western Bering Sea are relatively stable. Western Kamchatka (Ozernaya River) sockeye salmon are the most abundant regional stock of sockeye salmon in Asia. Our estimates indicated a relatively stable and high abundance of immature sockeye salmon of western Kamchatka origin in the western Bering Sea in 2002–2004. Estimated percentages of sockeye

salmon of eastern Kamchatka, northeastern Kamchatka, and Chukotka origin, which are indigenous to the western Bering Sea, were also relatively stable and high. Our results, as well as those of other stock identification studies (Habicht et al. 2005; Gritsenko 2007), indicated significant foraging migrations of immature sockeye salmon of Alaskan origin in the western Bering Sea. Alaskan stocks dominate total Pacific Rim runs of sockeye salmon (Eggers and Irvine 2007), and Bristol Bay stocks accounted for an average of 50% (37 million fish) of total annual Pacific Rim runs in 2003–2005 (G. Ruggerone, Natural Resources Consultants, Seattle, pers. comm.). In general, BASIS estimates of total abundance of immature sockeye salmon were highest in the northern districts (2–8) of the western Bering Sea, except in fall 2003 (Table 9). The estimated abundance of North American stocks, primarily Bristol Bay, was higher in the northwestern Bering Sea than in the southwestern Bering Sea (Table 10). This may reflect northwestward shifts in distribution immature sockeye salmon of North American origin that resulted from large-scale ecosystem changes and favorable ecological conditions for foraging salmon in the western Bering Sea in the early 2000s (Shuntov and Sviridov 2005). These changes included weaker winter monsoons, stronger summer monsoons, below normal ice cover, increased sea surface temperature, and increased inflow of Pacific waters into the Bering Sea (Glebova 2007; Basyuk et al. 2007; Shuntov et al. 2007). These changes may have also influenced the distribution and abundance of salmon predators. Differences between estimated abundances of immature and adult salmon might be explained in part by high ocean mortality due to increased abundance of predators. For example, Sviridov et al. (2004) and Bugaev and Shevlyakov (2007) observed high numbers of wounded and scarred salmon during research vessel surveys in the REEZ. Further research, however, is needed to clarify the dynamics of distribution and abundance of sockeye salmon of Asian and North American origin in the western Bering Sea against the background of ecosystem changes at the beginning of the 21st century.

Stock-specific ocean assessments of distribution and abundance of immature sockeye salmon can serve as pre-season indicators of adult returns, providing a useful decision-making tool for fishery managers. In the REEZ, this issue has usually been addressed by analysis of data on the distribution of salmon during feeding migrations in waters adjacent to the area of reproduction of certain regional stock groups (e.g., Shuntov et al. 1989a,b; Yerokhin 2002). Nevertheless, this method seems to lead to frequent errors in run forecasting. Ocean stock assessment methods for salmon, e.g., trawl fishing efficiency coefficients, need further evaluation and refinement. Stock assessments performed at multiple life stages of salmon can result in more complete and accurate management recommendations. New genetic tools have the potential to provide a rapid and precise procedure for real-time ocean stock assessment of immature salmon. The use of this approach in the western Bering Sea

might improve assessments of the potential abundance of sockeye salmon returning to all regions in Asia and some regions of North America. In addition, trawl survey research would benefit from activities that provide practical tools that can be used by managers to forecast the runs of major species and stocks.

CONCLUSIONS

We conclude that the western Bering Sea is an important area of intermixing of immature sockeye salmon of Asian and North American origin. In principle, this phenomenon has been known for a long time (e.g., Kononov 1971), however, the results of scale pattern and genetic stock identification analyses (Habicht et al. 2005; C. Habicht, chris.habicht@alaska.gov, pers. comm.) have provided new quantitative evidence of the extent of intermixing of sockeye salmon of Asian and North American origin in the western Bering Sea. We speculated that there might have been a substantial increase in “visitors” to the western Bering Sea from stocks originating in Alaska and western Kamchatka in the early 2000s. Stock-specific changes in abundance and distribution might have resulted from complex interactions between density-dependent and ecosystem factors. However, the temporal span of observations from BASIS research is not yet sufficient to understand the dynamics of stock-specific distribution and abundance of sockeye salmon or to provide accurate run forecasting tools for fishery management.

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