

Genetic Stock Identification of Chum Salmon Harvested Incidentally in the 1994 and 1995 Bering Sea Trawl Fishery

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In some years, the Bering Sea trawl fishery incidentally harvests (bycatch) large numbers of chum salmon. Because chum salmon were declining in some western Alaska areas, the origins of the chum salmon bycatch were important. Tagging studies have shown that chum salmon originating in Asia and North America migrate through the eastern Bering Sea. Genetic stock identification (GSI), a method of estimating stock composition in mixed-stock fisheries, has helped in evaluating stock contributions to salmon fisheries on the western coast of North America. Through cooperative efforts between state and federal agencies, a comprehensive genetic baseline for Pacific Rim chum salmon stocks has been developed, which enables GSI in fisheries such as the Bering Sea trawl fishery.

In 1994, the National Marine Fisheries Service, Auke Bay Laboratory, initiated a feasibility study of GSI in determining the origins of the chum salmon bycatch in the Bering Sea trawl fishery. Sampling in 1995 was intensified and resulted in samples covering the entire fishing season, representing nearly 11% of the total chum salmon bycatch.

Estimates for our 1994 fishery samples over three period were 39-55% Asian stocks, 20-35% western Alaska stocks, and 21-29% southeastern Alaska, British Columbia, or Washington stocks. One small sample (N = 47) of maturing fish showed a surprisingly large contribution of British Columbia stocks (53%). Estimates for our 1995 samples over seven time periods were 13-51% Asian stocks, 33-53% western Alaska stocks, and 9-46% southeastern Alaska, British Columbia, or Washington stocks. As in 1994, the sample of maturing fish (N = 277) showed a large contribution of British Columbia stocks (49%) and Washington stocks (25%).



INTRODUCTION

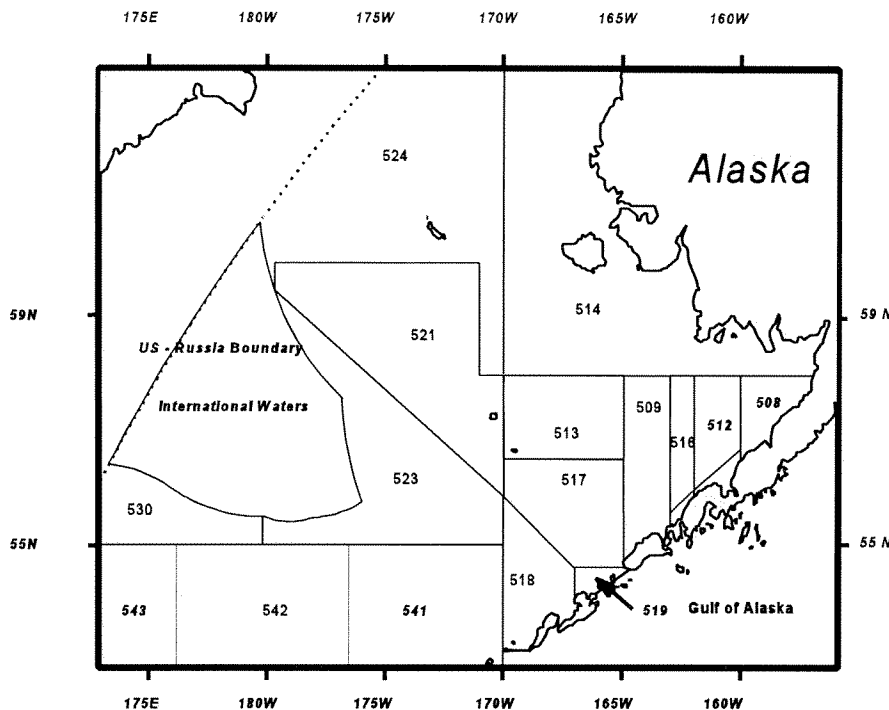
In some years, the Bering Sea trawl fishery for walleye pollock (*Theragra chalcogramma*) incidentally harvests (bycatch) large numbers of chum salmon (*Oncorhynchus keta*). The fishery takes place north of the Alaska Peninsula (Fig. 1) from January to March (the "A" fishery) and from late August to mid-October (the "B" fishery). Most of the chum salmon bycatch is taken in the "B" fishery. The incidental harvest of chum salmon became of concern when spawning escapements of chum salmon to several western Alaska areas declined below historic levels (Eggers 1995), and the stock origins of the bycatch were seen as important to evaluating this fishery's effect on those stocks. The terms stock and population will be used interchangeably and refer to "fish spawning in a particular lake or stream (or portion of) at a particular season, which fish to a substantial degree do not

interbreed with any group spawning in a different place, or in the same place at a different season" (Ricker 1972, p. 28).

Tagging studies have shown that chum salmon originating in Asia and North America migrate through the eastern Bering Sea (Aro 1972; Aro et al. 1971; Brannian 1984; Eggers 1992; Eggers et al. 1991; Meyer 1983). Although tagging studies demonstrated the presence of many stocks in the fishery, estimates of the contributions of these stocks from tagging would be unreliable, given the low level of tagging and the disproportionate tag recovery effort among stocks.

Genetic stock identification (GSI), a method for estimating stock composition in mixed-stock fisheries, was developed in the 1970s and has been used to evaluate stock contributions to salmon fisheries on the western coast of North America (Grant et al. 1980; Milner et al. 1981; Okazaki 1981; Seeb et al. 1986,

Fig. 1 Statistical Reporting Areas of the Bering Sea/Aleutian Islands



1990, 1995; Shaklee et al. 1991; Utter et al. 1974; Wilmot et al. 1992; Winans et al. 1989; Wishard 1980). The method relies on genetic differences among stocks in relative frequencies of protein-coding genes detected by allozyme electrophoresis. The preferred statistical method for computing the stock composition is conditional maximum likelihood (Fournier et al. 1984; Millar 1987; Milner et al. 1981; Pella and Milner 1987; Pella et al. 1996; Smouse et al. 1990). GSI can be used to assess the stock composition of the Bering Sea trawl fishery bycatch of chum salmon.

However, before GSI could be applied, a genetic baseline from potentially contributing chum salmon stocks was needed. Various state and federal agencies cooperated to create this data base (Kondzela et al. 1994; Phelps et al. 1994; Seeb et al. 1995; Wilmot et al. 1994; Winans et al. 1994), which contains information for more than 200 populations of chum salmon throughout the Pacific Rim. Some collections have data on more than 60 loci; however, data for the complete range of chum salmon are currently limited to 20 loci.

Previous studies found geographic differentiation of allozyme frequencies among chum salmon stocks that should provide good estimates of regional contributions to mixed-stock fisheries. Seeb et al. (1995) recently estimated contributions from chum salmon stocks of major regions (Japan; Russia; western Alaska; fall Yukon; Alaska Peninsula,

Kodiak, and Chignik [AP/K/C]; Prince William Sound and southeastern Alaska [PWS/SEA]; British Columbia [BC]; and Washington [WA]) to incidental catches in the South Unimak, Alaska, sockeye salmon fishery.

In 1994, the National Marine Fisheries Service (NMFS) Auke Bay Laboratory (ABL) was assigned the task of determining the feasibility of using GSI to estimate the regional stock contributions to samples from the chum salmon bycatch taken in the 1994 Bering Sea "B" season trawl fishery. The first year, we determined the feasibility of using the existing NMFS Observer Program to collect samples; the second year, the observers took enough samples for statistically valid estimates of stock contributions.

MATERIALS AND METHODS

Baseline Data

The baseline included the 69 populations used by the Alaska Department of Fish and Game (ADF&G) (Seeb et al. 1995) from data provided by various agencies: NMFS (Kondzela et al. 1994; Winans et al. 1994), Washington Department of Fish and Wildlife (Phelps et al. 1995), and the U.S. Fish and Wildlife Service (Wilmot et al. 1994). In addition, eight populations from two new areas in Asia, two from China and six from Russia (Appendix I), were added, for a 77-population baseline. Twenty loci were

available for each population. The rationale behind the construction of the Pacific Rim chum salmon baseline was discussed thoroughly in Seeb et al. (1995).

The baseline samples from China came from the Heilong (Amur) River (fall run) and the Suifen River and were collected by personnel from the Heilongjiang Fisheries Research Institute, Chinese Academy of Fisheries Science, Harbin, People's Republic of China. The Heilong River is the Chinese name for their portion of the river called the Amur River in Russia. The Suifen River flows south from China to the Pacific Ocean just south of Vladivostok, Russia. The baseline samples from Russia were taken by personnel from the Institute of Marine Biology, Far East Branch of the Russian Academy of Science in Vladivostok. Three were from the southern end of Sakhalin Island (Naiba, Udarnitsa, and Kalininka Rivers), and three were from the Premor'ye region near Vladivostok (Avakumovka, Narva, and Ryzanovka Rivers). Tissue samples from Russia and China (eye, heart, liver, and muscle) were taken from each fish, frozen and delivered to ABL for electrophoretic analysis.

Bycatch Sampling

Chum salmon bycatch samples from the Bering Sea "B" fishery were collected by personnel of the NMFS Observer Program. Whole heads were removed so that muscle tissue, heart, and liver remained with the head. The heads were packaged individually with catch information, frozen, and shipped to ABL. Tissue samples were taken from the heads, placed in individual tubes, and frozen at -80°C until electrophoretic analysis.

A total of 457 chum salmon were sampled in 1994 from Aug. 29 to Oct. 8 (Figs. 1, 2) from five statistical areas in the Bering Sea [Areas 509 (N = 8), 513 (N = 24), 517 (N = 316), 521 (N = 91), and 541 (N = 13)]; 410 were immature fish, and 47 were maturing fish that were expected to spawn in the fall of 1994. Maturity was determined by the size of the fish and the condition of the gonads. Four kinds of stock composition comparisons were performed: mature versus immature; east versus west; time periods; and specific areas. Only areas 517 and 521 had sufficient numbers of samples for independent analysis. Areas 521 and 541 were pooled (N = 104) and areas 509, 513, and 517 were pooled (N = 348) for an east-versus west comparison. The samples were stratified by three periods: Aug. 29 to Sept. 5 (N = 319), Sept. 6 to 9 (N = 51), and Sept. 11 to Oct 8 (N = 82).

In 1995, 1,853 chum salmon were sampled from Aug. 14 to Oct. 1 (Fig. 2), and represented nearly 11% of the total chum salmon bycatch (Fig. 3). Due

Fig. 2 Number of chum salmon sampled by the NMFS Observer Program from the 1994 and 1995 Bering Sea trawl "B" season by day.

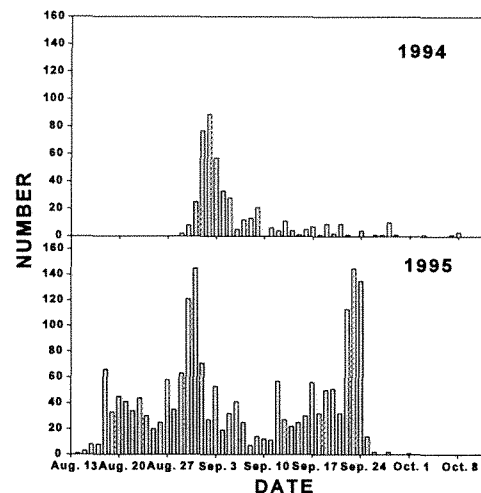
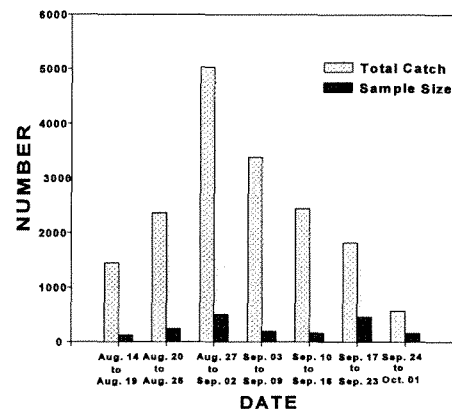


Fig. 3 Total chum bycatch in the 1995 Bering Sea trawl "B" season fishery by week compared with the sample size.



to the reporting procedure in 1995, it was impossible to assign the catch by area. The boats crossed back and forth between areas, and catch records did not indicate which fish were actually caught in which area. All samples appeared to have been harvested in one of four areas: 509, 517, 518, or 519. The stage of maturity was identified by examination of the gonads for 1,650 fish: 1,373 immature and 277 maturing fish. The samples were stratified into seven periods matching the bycatch harvest reporting periods used by the NMFS, Alaska Regional Office: Aug. 14-19 (N = 118), Aug. 20-26 (N = 237), Aug. 27 to Sept. 2 (N = 500), Sept. 3-9 (N = 191), Sept. 10-16 (N = 160), Sept. 17-23 (N = 456), and Sept. 24 to Oct. 1 (N = 153).

Electrophoretic analysis followed procedures described by Aebersold et al. (1987) and Harris and Hopkinson (1976), and results are reported using the genetic nomenclature of the American Fisheries

Society (Shaklee et al., 1990). A total of 62 loci were resolved, of which 20 can be used in the current Pacific Rim baseline. Details for standardizing allele mobility and allele pooling are in Seeb et al. (1995).

Statistical Procedures

The genetic structure of the baseline populations was described by a dendrogram constructed from Cavalli-Sforza and Edwards (1967) chord distances among all 77 populations, using the Unweighted Pair-Group Method with arithmetic averages (UPGMA) (Sneath and Sokal 1973).

Conditional maximum likelihood estimates (MLE) of stock composition of the mixed fishery samples were calculated using the GIRLS program of Masuda et al. (1991). Standard errors of stock composition estimates were determined by 500 bootstrap resamplings of baseline and mixture samples (Efron and Tibshirani 1986).

Simulation studies were conducted to evaluate the reliability of stock composition estimates:

1) Simulated baseline samples of sizes equal to actual baseline samples were generated by resampling. Mixture samples composed of 100% of stocks from a given region in equal proportions were simulated from baseline allele frequencies. Genotypes of individuals in these hypothetical mixtures of known composition were generated from baseline allele frequencies assuming independence of loci and Hardy-Weinberg equilibrium. The GIRLS program calculated the MLE of stock composition for each simulated set of baseline and mixture samples, and the average MLEs of regional composition were compared with the true contribution.

2) We added incremental numbers of simulated fish from a region to a real catch sample to determine how accurately the average composition estimates could track the changing composition of the altered sample. Genotypes of the simulated fish were generated from the baseline in the same manner as described for the simulation studies.

RESULTS

Baseline Data

The addition of the eight new populations from China and Russia to the UPGMA dendrogram (Fig. 4) had little effect on the basic geographic structure displayed in the dendrogram in Seeb et al. (1995). The populations from Sakhalin Island and Premor'ye clustered with the Japanese stocks. A group of outlier observations from Wallace H. Noerenberg (WHN) Hatchery, Prince William Sound; Peterson Lagoon, Alaska Peninsula; and Big Sukhoi Creek and Sturgeon River, Kodiak, Alaska, was shown in Seeb et al.

(1995). Two of the eight additional populations joined these outliers: the Heilong River, China, and the Kalininka River, Sakhalin Island.

Mixture Analysis

Regional stock groups for reporting estimates were the same as ADF&G used for the South Unimak fishery (Seeb et al., 1995): Japan, Russia, western Alaska (summer run), Yukon River (fall run), AP/K/C, PWS/SEA, BC, and WA. In simulation studies where the true regional contributions were 100%, the MLE average estimates were >80% accurate. Estimates for the PWS/SEA region were least accurate (82%), and the estimate for the Yukon River fall run the most accurate (96%) (Table 1).

1994 bycatch

Estimates of the origins of immature and maturing fish were substantially different (Table 2). The Asian component (Japan and Russia) in the immature fish was estimated at 51% versus 32% (no Russian-origin fish) of maturing fish; western Alaska (including western Alaska summer run, fall Yukon, and AP/K/C), 29% versus 12%; and PWS/SEA/BC/WA, 20% versus 56% (BC = 53% of the 56%).

Of the three periods, the first (Aug. 29 to Sept. 5) consisted of approximately 44% Asian, 35% western Alaska, and 21% PWS/SEA/BC/WA fish. The second period (Sept. 6-9) consisted of 39% Asian, 32% western Alaska, and 28% PWS/SEA/BC/WA fish. In the third period (Sept. 11 to Oct. 8), the Asian component increased to 55%, the western Alaska component declined to 20%, and the PWS/SEA/BC/WA component stayed relatively constant at 24%.

Area 517 consisted of 43% Asian, 28% western Alaska, and 30% PWS/SEA/BC/WA fish. Area 521 consisted of 58% Asian, 30% western Alaska, and 12% PWS/SEA/BC/WA fish. Areas 513 and 517 were combined to form an eastern Bering Sea group, close to the Alaska Peninsula and the mouth of Bristol Bay. This group consisted of 42% Asian, 29% western Alaska, and 27% PWS/SEA/BC/WA fish. Areas 521 and 541 were combined to form a western Bering Sea group, which consisted of 66% Asian, 23% western Alaska, and 11% PWS/SEA/BC/WA fish.

The MLEs accurately tracked known additions to an actual mixture sample (Fig. 5). We used the maturing fish mixture sample (Table 2) because the MLE estimates indicated a high percentage of British Columbia fish. Known numbers of simulated British Columbia fish were added to the observed mixture sample (equivalent to altering BC percentages from 53% to 88%), and known numbers of simulated

Fig. 4 UPGMA clustering of Cavalli-Sforza and Edwards (1967) chord distance among 77 populations of Pacific Rim chum salmon.

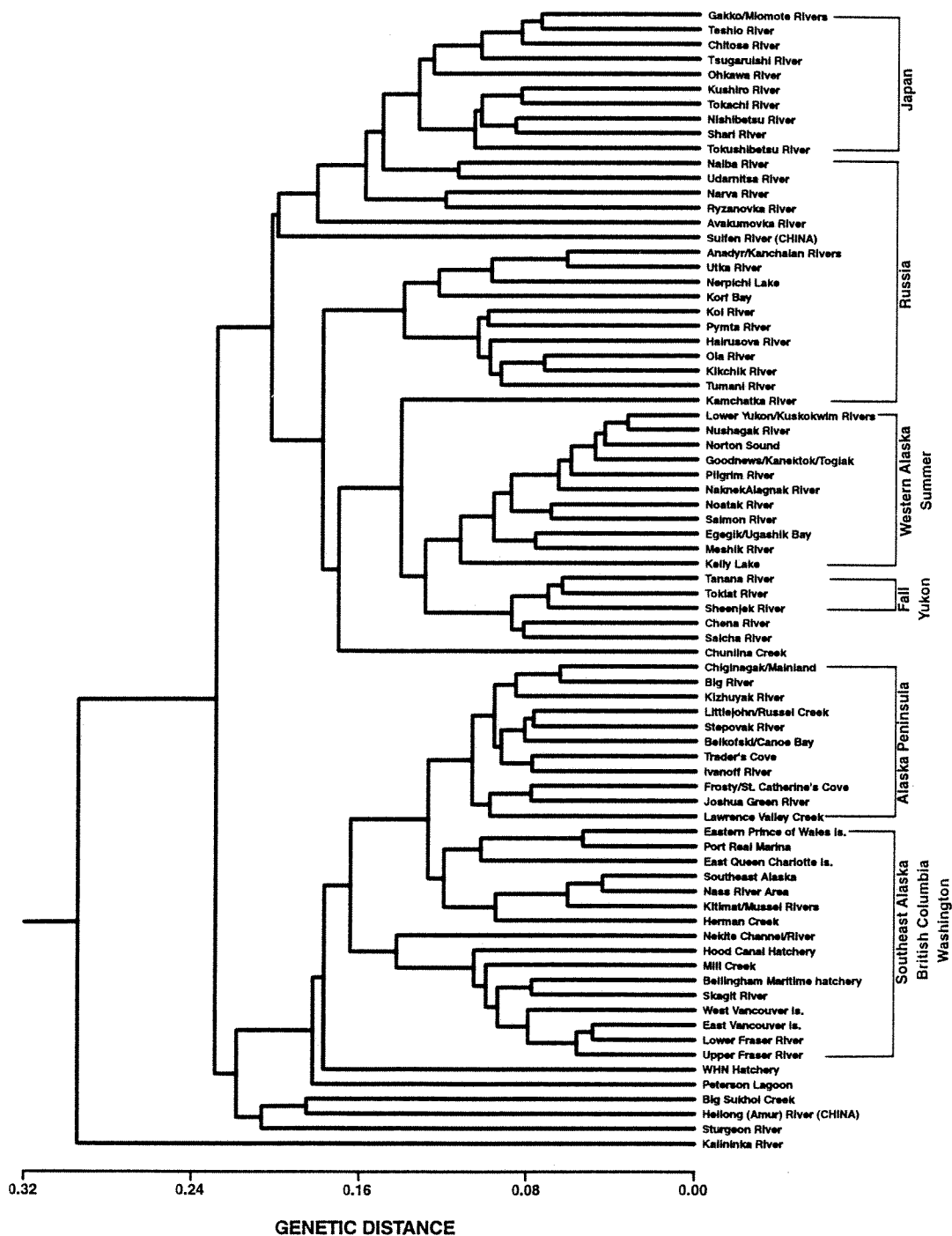


Table 1. Mean estimated proportion for 500 simulations where each region comprises 100% of the mixture (N=300). Cells with asterisks are the correct allocation and should equal 1.000.

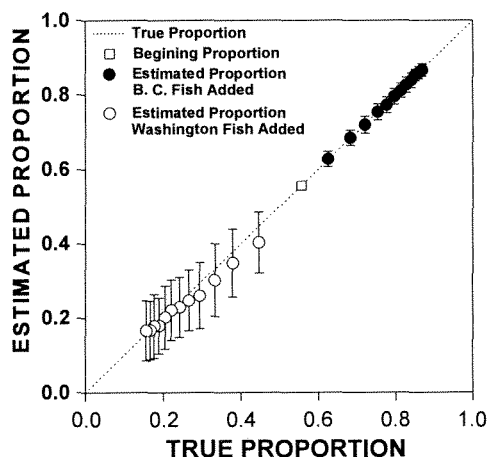
Estimated Region	100% Simulations							
	Japan	Russia	Western Alaska (Summer run)	Fall Yukon	Peninsula/Kodiak/Chignik	SE Alaska/PWS	British Columbia	Washington
Japan	0.9446*	0.0337	0.0082	0.0010	0.0056	0.0032	0.0017	0.0002
Russia	0.0266	0.8921*	0.0265	0.0031	0.0254	0.0237	0.0107	0.0023
Western Alaska (Summer run)	0.0143	0.0376	0.9205*	0.0374	0.0062	0.0052	0.0017	0.0001
Fall Yukon	0.0035	0.9205*	0.0368	0.9573*	0.0013	0.0011	0.0005	0.0000
Peninsula/Kodiak/Chignik	0.0080	0.0242	0.0066	0.0007	0.9348*	0.0233	0.0255	0.0020
SE Alaska/PWS	0.0014	0.0048	0.0006	0.0002	0.0122	0.8211*	0.0575	0.0033
British Columbia	0.0011	0.0043	0.0004	0.0002	0.0123	0.0748	0.8517*	0.0522
Washington	0.0004	0.0009	0.0002	0.0001	0.0022	0.0176	0.0506	0.9399*

Table 2. Estimated regional proportions of Pacific Rim chum salmon in the 1994 Bering Sea trawl fishery. Standard deviations (S.D.) were calculated from 500 bootstraps of the mixture and baseline samples.

Sample	N	Japan		Russia		Western Alaska		Fall Yukon	
		Estimate	S.D.	Estimate	S.D.	Estimate	S.D.	Estimate	S.D.
Immature	410	0.2593	0.0361	0.2485	0.0453	0.2260	0.0502	0.0301	0.0279
Maturing	47	0.3245	0.0932	0.0000	0.0450	0.0630	0.0518	0.0567	0.0546
Aug 29 - Sep 05	319	0.2545	0.0403	0.1806	0.0452	0.2617	0.0526	0.0192	0.0257
Sep 06 - Sep 09	51	0.1511	0.0767	0.2428	0.1082	0.2648	0.1035	0.0251	0.0658
Sep 11 - Oct 08	82	0.3092	0.0754	0.2452	0.0830	0.0929	0.0738	0.1104	0.0522
Area 517	316	0.2421	0.0403	0.1844	0.0491	0.2358	0.0487	0.0146	0.0250
Area 521	91	0.3668	0.0807	0.2101	0.0769	0.2258	0.0862	0.0472	0.0486
Areas 521/541	104	0.4021	0.0710	0.2597	0.0768	0.1686	0.0791	0.0393	0.0412
Areas 509/513/517	348	0.2324	0.0376	0.1882	0.0452	0.2224	0.0521	0.0372	0.0300

Sample	N	Alaska Peninsula, Kodiak and Chignik		Southeast AK/PWS		British Columbia		Washington	
		Estimate	S.D.	Estimate	S.D.	Estimate	S.D.	Estimate	S.D.
Immature	410	0.0322	0.0255	0.0545	0.0320	0.1034	0.0362	0.0462	0.0288
Maturing	47	0.0000	0.0247	0.0000	0.0044	0.5324	0.1369	0.0234	0.1084
Aug 29 - Sep 05	319	0.0717	0.0328	0.0212	0.0317	0.1671	0.0413	0.0240	0.0294
Sep 06 - Sep 09	51	0.0312	0.0695	0.0538	0.0722	0.1179	0.0895	0.1132	0.0700
Sep 11 - Oct 08	82	0.0000	0.0195	0.0000	0.0344	0.1051	0.0579	0.1373	0.0618
Area 517	316	0.0277	0.0288	0.0594	0.0381	0.1601	0.0503	0.0759	0.0446
Area 521	91	0.0265	0.0365	0.0006	0.0245	0.1079	0.0444	0.0151	0.0185
Areas 521/541	104	0.0207	0.0308	0.0012	0.0220	0.0960	0.0387	0.0124	0.0167
Areas 509/513/517	348	0.0268	0.0267	0.0547	0.0364	0.1502	0.0489	0.0880	0.0447

Fig. 5 Results of simulation tests to determine the accuracy of the conditional maximum likelihood estimates (MLEs) to follow additions of known numbers of British Columbia fish to an actual mixture sample. The 45 dotted line represents 100% accuracy; the black circles represent the calculated proportion when British Columbia fish are added, and the open circles represent the calculated portion when Washington fish are added. Error bars are one standard deviation derived from 100 bootstrap resamplings.



Washington fish (equivalent to altering BC percentages from 53% to 16%). Estimated proportions were plotted against the known, altered proportion (Fig. 5). Average MLEs were within 1% of the true proportions when British Columbia fish were added, and within 5% when Washington fish were added.

1995 bycatch

Estimates of the origins of immature and maturing fish in 1995 again differed substantially (Table 3). The Asian component (Japan and Russia) of the immature fish group was estimated at 43% versus 12% of the maturing fish, western Alaska (including western Alaska summer run, fall Yukon, and AP/K/C) at 45% versus 14%, and PWS/SEA/BC/WA at 13% versus 74% (BC = 49% and WA = 25% of the maturing fish).

During the seven periods, the Asian component ranged from 13% to 51% and, in general, increased as the season progressed (Table 3). Russian-origin fish were 2-4 times more abundant than Japanese fish. The western Alaska component (including western Alaska summer run, fall Yukon, and AP/K/C) ranged from 33% to 53%, with the largest proportion showing in late August and early September. Two periods (Sept. 3-9 and Sept. 24 to Oct. 1) showed large proportions of fall Yukon River fish (14% and 16%, respectively). The PWS/SEA/BC/WA

component ranged from 9% to 46% over the fishing season, most occurring early in the season. British Columbia fish made up the largest proportion, followed by Washington fish; PWS/SEA fish did not contribute more than 8%.

We applied the weekly stock composition estimates to the weekly bycatch figures from the NMFS-Alaska Regional Office to arrive at numbers harvested by origin and time period (Table 4). Salmon bycatch figures are reported as chinook salmon or "other" salmon. In the fall fishery, "other" salmon are considered to be almost totally chum salmon. Estimated contributions by regions for all periods were approximately 5,500 Asian; 7,500 western Alaska summer run, fall Yukon, and AP/K/C; and 4,100 PWS/SEA/BC/WA fish.

DISCUSSION

Geographic differentiation among Pacific Rim chum salmon made accurate stock identification at the regional level feasible as a management tool. This genetic differentiation has been amply described by Kondzela et al. (1994), Phelps et al. (1994), Wilmot et al. (1994), and Winans et al. (1994) and summarized in Seeb et al. (1995). Below the regional level, estimates must be viewed cautiously. The fall run of chum salmon into the Yukon River is an exception because of their substantial genetic separation. The addition of eight new populations to the baseline had little effect on the population geographic structure shown in Seeb et al. (1995) for 69 populations. As expected, six of these populations clustered between the Japanese and northern Russian populations: Sakhalin Island and Premor'ye are near Japan, and represented an area where summer-run chum salmon typical of northern Russia overlap with fall-run chum salmon typical of Japan. Two of the eight stocks were outliers: Kalininka River on Sakhalin Island and the Heilong River. According to our Russian source (Dr. Vladimir Efremov, Institute of Marine Biology, Far East Branch Russian Academy of Sciences, Valdivostok), Kalininka chum salmon originated from hatchery operations that started with a small number of fish that probably changed gene frequencies substantially from those of the original wild stock. The samples from those of the original wild stock. The samples from the Heilong River came from a spawning area nearly 1,000 km upstream from the mouth. The genetic differences of these fish may be analogous to the situation in the Yukon River where upriver spawners differ substantially from lower river spawners (Wilmot et al. 1994).

Regional compositions of these Bering Sea chum salmon samples differed substantially from that found by Seeb et al. (1995) for the chum salmon bycatch in the South Unimak sockeye salmon fishery in 1993 and

Table 3. Estimated regional proportions of Pacific Rim chum salmon in the 1995 Bering Sea trawl fishery bycatch. Standard deviations (S.D.) were calculated from 500 bootstraps of the mixture and baseline samples.

Sample	N	Japan		Russia		Western Alaska		Fall Yukon	
		Estimate	S.D.	Estimate	S.D.	Estimate	S.D.	Estimate	S.D.
Immature	1373	0.1051	0.0176	0.3220	0.0272	0.3420	0.0322	0.0818	0.0214
Maturing	277	0.0717	0.0218	0.0521	0.0339	0.0521	0.0231	0.0051	0.0051
Aug 14 - Aug 19	118	0.0367	0.0344	0.0901	0.0512	0.3156	0.0801	0.0463	0.0519
Aug 20 - Aug 26	237	0.1116	0.0389	0.2224	0.0598	0.3022	0.0645	0.0466	0.0256
Aug 27 - Sep 2	500	0.0508	0.0206	0.2440	0.0402	0.3696	0.0525	0.0654	0.0364
Sep 3 - Sep 9	191	0.0706	0.0331	0.2173	0.0581	0.2777	0.0600	0.1431	0.0412
Sep 10 - Sep 16	160	0.0830	0.0422	0.2846	0.0618	0.2702	0.0605	0.0641	0.0309
Sep 17 - Sep 23	456	0.1201	0.0298	0.3850	0.0486	0.2473	0.0509	0.0637	0.0300
Sep 24 - Oct 1	153	0.1651	0.0527	0.2759	0.0654	0.2182	0.0831	0.1567	0.0534

Sample	N	Alaska Peninsula, Kodiak and Chignik		SE Alaska/PWS		British Columbia		Washington	
		Estimate	S.D.	Estimate	S.D.	Estimate	S.D.	Estimate	S.D.
Immature	1373	0.0240	0.0139	0.0615	0.0184	0.0279	0.0144	0.0357	0.0123
Maturing	277	0.0806	0.0388	0.0000	0.0107	0.4928	0.0655	0.2455	0.0704
Aug 14 - Aug 19	118	0.0557	0.0424	0.0482	0.0505	0.3939	0.0690	0.0136	0.0462
Aug 20 - Aug 26	237	0.0340	0.0309	0.0808	0.0438	0.1756	0.0543	0.0269	0.0399
Aug 27 - Sep 2	500	0.0394	0.0226	0.0236	0.0223	0.1245	0.0308	0.0826	0.0271
Sep 3 - Sep 9	191	0.1081	0.0405	0.0408	0.0306	0.0343	0.0405	0.1079	0.0445
Sep 10 - Sep 16	160	0.0000	0.0220	0.0253	0.0231	0.1244	0.0513	0.1485	0.0562
Sep 17 - Sep 23	456	0.0898	0.0321	0.0098	0.0227	0.0368	0.0261	0.0476	0.0228
Sep 24 - Oct 1	153	0.0222	0.0258	0.0392	0.0330	0.1167	0.0430	0.0061	0.0302

Table 4. Estimated number of Pacific Rim chum salmon harvested in the 1995 Bering Sea trawl fishery by area. Standard deviations (S.D.) were calculated from 500 bootstraps of the mixture and baseline samples.

Sample	N	Japan		Russia		Western Alaska		Fall Yukon	
		Estimate	S.D.	Estimate	S.D.	Estimate	S.D.	Estimate	S.D.
Aug 14 - Aug 19	1448	53	50	130	74	457	116	67	75
Aug 20 - Aug 26	2360	263	92	525	141	713	152	110	60
Aug 27 - Sep 2	5029	256	104	1227	202	1859	264	329	183
Sep 3 - Sep 9	3379	239	112	734	196	939	203	484	139
Sep 10 - Sep 16	2439	202	103	694	151	659	148	156	75
Sep 17 - Sep 23	1817	218	54	700	88	449	92	116	55
Sep 24 - Oct 1	565	93	30	156	37	123	47	89	30
Total	17039	1324	545	4166	890	5199	1022	1351	618

Sample	N	Alaska Peninsula Kodiak and Chignik		Southeast AK/PWS		British Columbia		Washington	
		Estimate	S.D.	Estimate	S.D.	Estimate	S.D.	Estimate	S.D.
Aug 14 - Aug 19	1448	81	61	70	73	570	100	20	67
Aug 20 - Aug 26	2360	80	73	191	103	414	128	63	94
Aug 27 - Sep 2	5029	198	114	119	112	626	155	415	136
Sep 3 - Sep 9	3379	365	137	138	103	116	137	365	150
Sep 10 - Sep 16	2439	0	54	62	56	303	125	362	137
Sep 17 - Sep 23	1817	163	58	18	41	67	47	86	41
Sep 24 - Oct 1	565	13	15	22	19	66	24	3	17
Total	17039	900	511	620	508	2162	717	1314	643

1994. They found western Alaska (including fall run Yukon River and AP/K/C) stocks dominated the catch, 59-83%; Asian stocks, 15% to 32%; and PWS/SEA/BC/WA stocks, 2-11%. In contrast, over the total fishing season our samples consisted of 20-35% western Alaska stocks in 1994 and 33-53% in 1995, 39-55% Asian stocks in 1994 and 13-51% in 1995, and 21-29% (excluding the exclusively maturing fish group) PWS/SEA/BC/WA stocks in 1994 and 9-46% in 1995. The large contribution in both 1994 and 1995 (53% [S.E. = 14%] and 49% [S.E. = 7%], respectively) of British Columbia stocks to the maturing fish group was unexpected. Given the small mixture sample in 1994 ($N = 47$), these results should be regarded with caution. However, the 1995 sample was sufficiently large ($N = 277$) for much greater confidence in the stock composition estimates. The simulation studies showed that the contribution of the British Columbia stock group could be estimated reliably when the mixture sample size was increased by the addition of BC fish so that the composition was altered.

Differences in composition between the South Unimak fishery and the Bering Sea trawl fishery could have resulted from both seasonal migratory timing and geography. The South Unimak fishery occurs in June south of the Alaska Peninsula. The Bering Sea trawl fishery occurs from late August to early October north of the Alaska Peninsula, when most western Alaska chum salmon spawners would be in the rivers.

Tagging information supports the presence of British Columbia fish in the Bering Sea trawl fishery area. Four coded-wire tagged chum salmon from British Columbia have been caught in this fishery since 1986 (Dahlberg et al. 1994), and estimated annual return to southern British Columbia over recent years has exceeded five million chum salmon per year (Pacific Salmon Commission 1994). Maturing fish from British Columbia would have to migrate approximately 3,000 km to their spawning rivers. Hartt (1966) estimated ocean migration speeds of chum salmon at about 40 km/day, and this rate increased with proximity to their spawning rivers. Many British Columbia chum salmon spawn in November and December and would have sufficient time to migrate from the Bering Sea in August and September to their spawning rivers in southern British Columbia in November and December (approximately 75 days).

The preliminary study showed that the collection methods used by the NMFS Observer Program could provide high quality samples suitable for allozyme and GSI analysis. Although sampling in the 1994 fishery was minimal and not designed to be representative of the total chum salmon bycatch, the 1995 sampling effort does reflect the total bycatch. Shaklee (1991), in studies of the Columbia River spring chinook

salmon baseline, recommends a mixture sample size of at least 180 individuals. Marlowe and Busack (1995) conducted studies on the chinook salmon baseline from California to southern British Columbia, and mixed fishery samples from the Washington Coast and Strait of Juan de Fuca troll fisheries. Their results showed that for stocks that contribute at least 5-6%, 200 samples are probably sufficient. Stocks or stock groupings that contribute 2% or less to the fishery require 800 samples or more. Sampling in 1995 allowed us to analyze mixed fishery samples of at least 118 fish (first period) and the remainder of our mixed fishery sample groups were greater than 150 fish (153-1,373 fish).

Exploratory studies on the Bering Sea trawl chum salmon bycatch samples used a 190-population baseline. The increase from the 77-population baseline used in the current analysis came from additional populations from SEA/BC/WA. This expanded baseline had little effect on composition estimates for the Asian and western Alaska components of the mixture samples. It did, however, affect the composition distribution among SEA, BC, and WA. In most samples, the MLEs for British Columbia declined, and increased for southeastern Alaska and Washington. However, the change was slight, and accuracy did not improve.

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Appendix

Allelic frequencies at 20 loci for populations of chum salmon from China and Russia. Alleles are designated by their mobility relative to the most common allele (100).

Population	N	sAAT-1,2*				N	mAAT-1*		
		100	120	65	95		-100	-120	-70
CHINA									
Heilong River (Amur)	46	0.962	0.039	0.000	0.000	46	0.924	0.000	0.076
Suifen River	25	0.980	0.020	0.000	0.000	25	1.000	0.000	0.000
RUSSIA - PREMOR'YE									
Avakumovka River	35	0.964	0.007	0.000	0.029	35	1.000	0.000	0.000
Narva River	18	0.958	0.042	0.000	0.000	18	1.000	0.000	0.000
Ryzanovka River	51	0.990	0.010	0.000	0.000	51	1.000	0.000	0.000
RUSSIA - SAKHALIN ISLAND									
Kalininka River	49	0.954	0.046	0.000	0.000	49	1.000	0.000	0.000
Naiba River	61	0.934	0.066	0.000	0.000	61	0.975	0.016	0.008
Udarnitsa River	98	0.944	0.056	0.000	0.000	98	0.985	0.000	0.015
Population	N	mAH-3*			N	ALAT*			
		100	124			100	93	78	
CHINA									
Heilong River (Amur)	43	0.907	0.093	39	0.500	0.500	0.000		
Suifen River	23	0.587	0.413	24	1.000	0.000	0.000		
RUSSIA - PREMOR'YE									
Avakumovka River	23	0.457	0.544	34	0.838	0.162	0.000		
Narva River	17	0.206	0.794	18	0.750	0.250	0.000		
Ryzanovka River	28	0.411	0.589	50	0.750	0.250	0.000		
RUSSIA - SAKHALIN ISLAND									
Kalininka River	35	0.571	0.429	48	0.521	0.479	0.000		
Naiba River	30	0.717	0.283	60	0.750	0.233	0.017		
Udarnitsa River	42	0.595	0.405	96	0.672	0.328	0.000		
Population	N	ESTD*			N	G3PDH-2*			
		100	91	110		100	90		
CHINA									
Heilong River (Amur)	46	0.989	0.011	0.000	44	0.761	0.239		
Suifen River	25	0.860	0.140	0.000	23	0.848	0.152		
RUSSIA - PREMOR'YE									
Avakumovka River	35	0.729	0.271	0.000	34	0.868	0.132		
Narva River	18	0.472	0.528	0.000	18	0.972	0.028		
Ryzanovka River	51	0.657	0.343	0.000	50	0.940	0.060		
RUSSIA - SAKHALIN ISLAND									
Kalininka River	49	0.153	0.847	0.000	49	0.786	0.214		
Naiba River	61	0.762	0.238	0.000	61	0.820	0.180		
Udarnitsa River	98	0.551	0.449	0.000	98	0.903	0.097		

Appendix (continued)

Population	N	GPI-B1,2*			N	GPI-A*			
		100	145	40		100	95	105	
CHINA									
Heilong River (Amur)	40	1.000	0.000	0.000	46	1.000	0.000	0.000	
Suifen River	24	1.000	0.000	0.000	25	1.000	0.000	0.000	
RUSSIA - PREMOR'YE									
Avakumovka River	35	0.993	0.007	0.000	34	1.000	0.000	0.000	
Narva River	18	1.000	0.000	0.000	18	0.972	0.028	0.000	
Ryzanovka River	51	0.995	0.005	0.000	51	0.971	0.029	0.000	
RUSSIA - SAKHALIN ISLAND									
Kalininka River	49	1.000	0.000	0.000	49	1.000	0.000	0.000	
Naiba River	55	1.000	0.000	0.000	61	1.000	0.000	0.000	
Udarnitsa River	98	1.000	0.000	0.000	97	1.000	0.000	0.000	
midHP-1*									
Population	N	100	60	140	20	85			
CHINA									
Heilong River (Amur)	40	0.675	0.325	0.000	0.000	0.000			
Suifen River	24	0.813	0.188	0.000	0.000	0.000			
RUSSIA - PREMOR'YE									
Avakumovka River	35	0.871	0.129	0.000	0.000	0.000			
Narva River	18	0.917	0.083	0.000	0.000	0.000			
Ryzanovka River	51	0.882	0.118	0.000	0.000	0.000			
RUSSIA - SAKHALIN ISLAND									
Kalininka River	48	0.875	0.125	0.000	0.000	0.000			
Naiba River	60	0.875	0.125	0.000	0.000	0.000			
Udarnitsa River	96	0.839	0.162	0.000	0.000	0.000			
siDHP-2*									
Population	N	100	35	85	25	20	110	28	45
CHINA									
Heilong River (Amur)	47	0.457	0.404	0.085	0.053	0.000	0.000	0.000	0.000
Suifen River	24	0.688	0.313	0.000	0.000	0.000	0.000	0.000	0.000
RUSSIA - PREMOR'YE									
Avakumovka River	30	0.583	0.183	0.000	0.000	0.000	0.233	0.000	0.000
Narva River	18	0.528	0.389	0.000	0.056	0.000	0.028	0.000	0.000
Ryzanovka River	47	0.553	0.245	0.000	0.138	0.000	0.064	0.000	0.000
RUSSIA - SAKHALIN ISLAND									
Kalininka River	27	0.593	0.296	0.000	0.037	0.000	0.074	0.000	0.000
Naiba River	20	0.650	0.250	0.075	0.000	0.000	0.025	0.000	0.000
Udarnitsa River	53	0.585	0.255	0.047	0.066	0.000	0.047	0.000	0.000

Appendix (continued)

Population	N	LDH-A1*			N	LDH-B2*			
		100	50	110		100	120	60	
CHINA									
Heilong River (Amur)	38	1.000	0.000	0.000	48	1.000	0.000	0.000	
Suifen River	24	0.917	0.021	0.063	25	1.000	0.000	0.000	
RUSSIA - PREMOR'YE									
Avakumovka River	35	0.871	0.071	0.057	35	1.000	0.000	0.000	
Narva River	18	0.972	0.028	0.000	18	1.000	0.000	0.000	
Ryzanovka River	50	0.930	0.040	0.030	51	1.000	0.000	0.000	
RUSSIA - SAKHALIN ISLAND									
Kalininka River	48	0.969	0.031	0.000	49	1.000	0.000	0.000	
Naiba River	61	0.943	0.057	0.000	61	1.000	0.000	0.000	
Udarnitsa River	98	0.954	0.046	0.000	98	1.000	0.000	0.000	
Population	N	sMDH-A1*			N	sMDH-B1,2*			
		100	200	400		100	72	50	130
CHINA									
Heilong River (Amur)	48	0.906	0.094	0.000	46	1.000	0.000	0.000	0.000
Suifen River	24	0.750	0.250	0.000	25	1.000	0.000	0.000	0.000
RUSSIA - PREMOR'YE									
Avakumovka River	35	0.871	0.129	0.000	35	0.957	0.014	0.000	0.029
Narva River	18	0.889	0.111	0.000	18	0.958	0.028	0.014	0.000
Ryzanovka River	50	0.750	0.250	0.000	51	0.990	0.010	0.000	0.000
RUSSIA - SAKHALIN ISLAND									
Kalininka River	49	1.000	0.000	0.000	49	0.857	0.015	0.122	0.005
Naiba River	35	0.929	0.071	0.000	61	0.967	0.004	0.004	0.025
Udarnitsa River	95	0.916	0.084	0.000	98	0.929	0.010	0.046	0.015
Population	N	mMEP-2*		N	sMEP-1*				
		100	122		100	90			
CHINA									
Heilong River (Amur)	40	0.950	0.050	40.000	1.000	0.000			
Suifen River	24	0.833	0.167	24.000	1.000	0.000			
RUSSIA - PREMOR'YE									
Avakumovka River	35	0.857	0.143	35.000	1.000	0.000			
Narva River	18	0.889	0.111	18.000	1.000	0.000			
Ryzanovka River	51	0.922	0.078	51.000	0.990	0.010			
RUSSIA - SAKHALIN ISLAND									
Kalininka River	48	0.896	0.104	48.000	1.000	0.000			
Naiba River	60	0.825	0.175	60.000	1.000	0.000			
Udarnitsa River	97	0.881	0.119	98.000	1.000	0.000			

Appendix (continued)

Population	N	MPI*				N	PEPA*		
		100	94	110	80		100	90	113
CHINA									
Heilong River (Amur)	44	0.875	0.125	0.000	0.000	44	1.000	0.000	0.000
Suifen River	23	1.000	0.000	0.000	0.000	23	1.000	0.000	0.000
RUSSIA - PREMOR'YE									
Avakumovka River	34	0.941	0.059	0.000	0.000	34	1.000	0.000	0.000
Narva River	18	1.000	0.000	0.000	0.000	18	1.000	0.000	0.000
Ryzanovka River	49	1.000	0.000	0.000	0.000	50	1.000	0.000	0.000
RUSSIA - SAKHALIN ISLAND									
Kalininka River	49	1.000	0.000	0.000	0.000	49	1.000	0.000	0.000
Naiba River	61	0.975	0.025	0.000	0.000	61	1.000	0.000	0.000
Udarnitsa River	98	0.980	0.020	0.000	0.000	98	1.000	0.000	0.000
PEP-B1*									
Population	N	-100	-146	-126	-127	-72			
CHINA									
Heilong River (Amur)	47	0.968	0.032	0.000	0.000	0.000			
Suifen River	24	0.854	0.000	0.146	0.000	0.000			
RUSSIA - PREMOR'YE									
Avakumovka River	34	0.750	0.044	0.206	0.000	0.000			
Narva River	18	0.861	0.000	0.139	0.000	0.000			
Ryzanovka River	51	0.745	0.020	0.235	0.000	0.000			
RUSSIA - SAKHALIN ISLAND									
Kalininka River	49	0.469	0.092	0.439	0.000	0.000			
Naiba River	61	0.795	0.025	0.180	0.000	0.000			
Udarnitsa River	96	0.719	0.057	0.224	0.000	0.000			
PGDH*									
Population	N	100	88	106	95				
CHINA									
Heilong River (Amur)	48	0.969	0.031	0.000	0.000				
Suifen River	25	1.000	0.000	0.000	0.000				
RUSSIA - PREMOR'YE									
Avakumovka River	35	0.986	0.014	0.000	0.000				
Narva River	18	0.972	0.028	0.000	0.000				
Ryzanovka River	51	0.961	0.039	0.000	0.000				
RUSSIA - SAKHALIN ISLAND									
Kalininka River	49	1.000	0.000	0.000	0.000				
Naiba River	61	0.967	0.033	0.000	0.000				
Udarnitsa River	98	0.995	0.005	0.000	0.000				