NOAA Technical Memorandum NMFS-AFSC-422

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August 2021

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
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This document should be cited as follows:

C. M. Kondzela, J. A. Whittle, P. D. Barry, Hv. T. Nguyen, E. M. Yasumiishi, D. W. Nicolls, J. T. Watson, and W. A. Larson. 2021. Genetic stock composition analysis of chum salmon from the prohibited species catch of the 2019 Bering Sea walleye pollock trawl fishery. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-422, 69 p.

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ABSTRACT

Chum salmon (*Oncorhynchus keta*) that are caught in Alaska's federally managed groundfish trawl fisheries are designated as prohibited species catch (PSC). We analyzed genetic stock compositions of chum salmon PSC samples collected from the 2019 walleye pollock (*Gadus chalcogrammus*) fishery in the Bering Sea. Samples were genotyped for 11 microsatellite markers from which stock contributions were estimated using a range-wide chum salmon microsatellite baseline. In 2019, one genetic sample was collected from approximately every 34 chum salmon caught in the Bering Sea midwater pollock trawl fishery. The evaluation of sampling in the Bering Sea based on time, location, and vessel indicated that the number of genetic samples was representative of the total chum salmon PSC in the Bering Sea, with the exception that several high chum salmon catches were under-sampled due to a lack of sampling materials. Most of the chum salmon PSC was caught throughout the B-season in contrast to the high and early catches in the B-season in years 2017 and 2018. Based on the analysis of 1,848 chum salmon, the largest stock group was Northeast Asia (39%), followed by Eastern Gulf of Alaska/Pacific Northwest (23%), Southeast Asia (18%), Western Alaska (16%), Southwest Alaska (4%), and Upper/Middle Yukon (< 1%) stocks. The majority of chum salmon were age-3 and age-4, 42% and 46%, respectively. The stock composition varied by age with age-3 and age-4 chum salmon approximately equally from Asian and North American stocks, and most age-5 chum salmon from NE Asia stocks. The three fishing sectors -- catcher-processor, shoreside, and mothership -- had variable stock proportions and numbers of chum salmon caught, with the catcher-processor and shoreside sectors encountering predominantly NE Asia chum salmon.

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INTRODUCTION

Pacific salmon (*Oncorhynchus* spp.) are prohibited species in the federally managed Bering Sea and Gulf of Alaska (GOA) groundfish fisheries, which are subject to complex management rules (NPFMC 2020a, b) that are in part designed to reduce prohibited species catch (PSC). It is important to understand the stock composition of Pacific salmon caught in these fisheries, which take place in areas that are known feeding habitat for multiple brood years of chum salmon (*O. keta*) from many different localities in North America and Asia (Myers et al. 2007, Davis et al. 2009, Urawa et al. 2009). Determining the geographic origin of salmon caught in federally managed fisheries is essential for understanding the effects that fishing has on chum salmon stocks, especially those with conservation concerns (NPFMC 2012).

We present the genetic stock composition estimates for the samples of chum salmon PSC collected during 2019 from the U.S. Bering Sea walleye pollock (*Gadus chalcogrammus*) trawl fishery. In 2019, the pollock fishery accounted for 97% of the total chum salmon taken in the Bering Sea groundfish fisheries (NMFS 2021a). The samples collected from the 2019 GOA groundfish fisheries were not analyzed due to restricted access to the laboratory during the COVID-19 pandemic.

The National Marine Fisheries Service (NMFS) reporting areas associated with the groundfish fisheries are shown in Figure 1 and are presented later to describe the spatial distribution of the chum salmon catch and genetic samples. The data reporting tool, Alaska Fisheries Information Network (AKFIN[1]), developed by the Pacific States Marine Fisheries Commission (PSMFC), simplifies access to fishery information associated with the genetic samples of salmon PSC and is useful for organizing sample datasets at the finer resolution of

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[1] AKFIN website (http://dev.akfin.org/home/)

ADF&G groundfish statistical areas (Fig. 1). The AKFIN reports were used to construct spatial-temporal sets of genetic samples from the 2019 chum salmon PSC caught along the outer continental shelf.

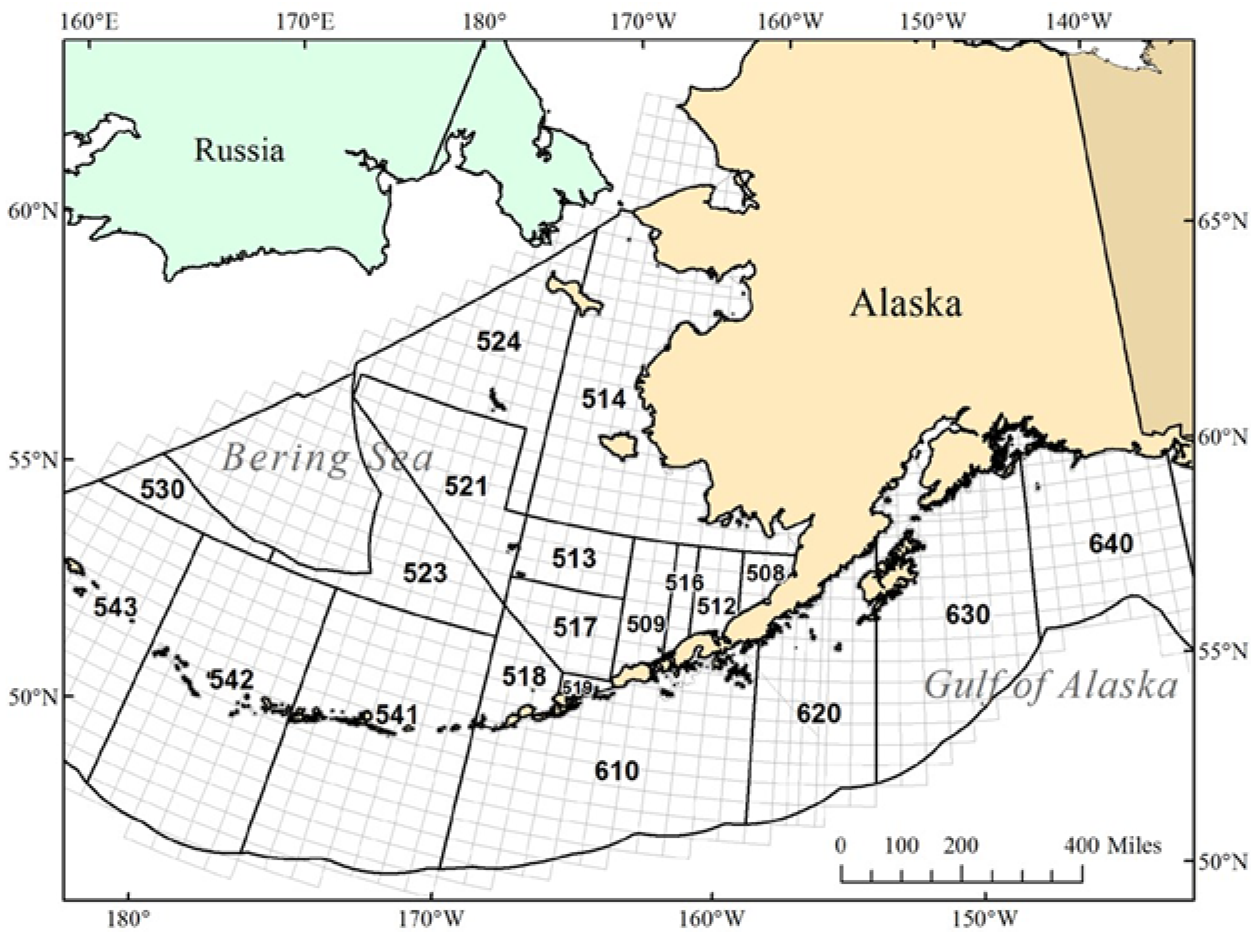

Figure 1. -- NMFS reporting areas associated with the Bering Sea-Aleutian Island and Gulf of Alaska groundfish fisheries are numbered and outlined in black. The ADF&G groundfish statistical areas are outlined in light gray.

For additional background and methods, this report is intended to be supplemented with the chum salmon reports prepared previously for the 2005-2018 Bering Sea trawl fisheries (Guyon et al. 2010; Marvin et al. 2011; Gray et al. 2010, 2011a, b; Kondzela et al. 2012, 2013, 2016, 2017; Vulstek et al. 2014; Whittle et al. 2015, 2018, 2021a, b). The chum salmon PSC is designated as non-Chinook (*O. tshawytscha*) in the NMFS database and comprises over 95% of the non-Chinook category in the Bering Sea (NPFMC 2007).

SAMPLE DISTRIBUTION

Genetic samples were collected from the chum salmon caught in the Bering Sea pollock fishery by the Alaska Fisheries Science Center's (AFSC) North Pacific Groundfish and Halibut Observer Program (Observer Program) in 2019 for analysis at the AFSC's Auke Bay Laboratories (ABL). Sampling was changed in 2011 from previous years (Faunce 2015, Cahalan et al. 2014) to implement a systematic sampling protocol recommended by Pella and Geiger (2009) with a goal to sample axillary processes (for genetic analysis) and scales (for ageing) from every 30th chum salmon throughout the season.

In 2019, an estimated 347,882 chum salmon (99.4% of the non-Chinook salmon caught in 2019) were caught in the pollock-directed trawl fisheries and represent the fourth largest catch of chum salmon in the pollock fisheries since 1994 (NMFS 2021a). This catch is twice the 1994-2018 average of 171,540 chum salmon and more than four times the median of 81,507 (Fig. 2). As in previous years, nearly all (99.9%) of the chum salmon were caught during the pollock B-season (approximately 10 June to November 1; Fig. 3) in NMFS reporting areas 509-524 (Fig. 1). Unlike the high chum salmon PSC that occurred very early in the 2017 and 2018 B-seasons, the chum salmon catch in 2019 was distributed throughout the B-season with the highest catch occurring later (Fig. 4). Genetic samples were collected from 10,056 fish (NMFS 2021b), which represented a sampling rate of 1 of every 34.4 chum salmon caught (or 2.91% of the chum salmon PSC).

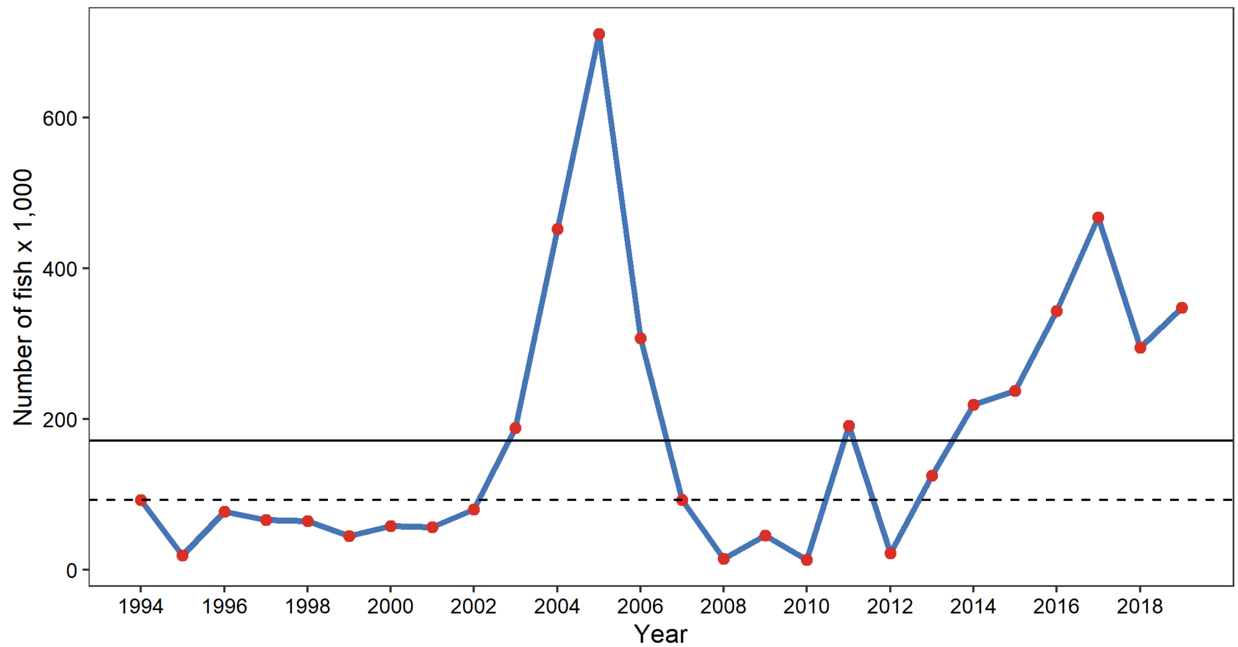

Figure 2. -- Chum salmon prohibited species catch (PSC) per year from the Bering Sea pollock-directed trawl fisheries (listed as non-Chinook salmon in NMFS 2021a). Estimates for years prior to 2011; censuses for years from 2011 to present. The solid horizontal line represents the mean PSC and the dashed line represents the median PSC, 1994-2018.

Biases and errors associated with past collections of genetic samples from the salmon PSC have the potential to affect stock composition estimates (NMFS 2009, Pella and Geiger 2009). The systematic sampling protocols recommended by Pella and Geiger (2009) were implemented in the Bering Sea pollock fisheries in 2011 to reduce sampling error and bias, the efficacy of which was evaluated by comparing the genetic sample distributions and the overall PSC estimates by using Chi-square tests. Low sample sizes in some time/area strata were pooled prior to testing. For the entire year, weeks 4-16 and 43-45 were pooled. For the B-season, weeks 23-27 and 40-45, and two areas of aggregated NMFS reporting areas (509-519), and (521, 523, 524) were pooled. Temporal bias by statistical weeks (ending on Saturday) appeared to be minimal (Fig. 3) when samples were pooled across management areas, although the Chi-square test was highly significant (χ^2 = 402.8, 21 d.f., P << 0.001), due primarily to under-sampling during weeks 25-26 and 35-36. During the B-season, temporal biases also appeared minimal at finer spatial scales (Fig. 5), but the Chi-square test was highly significant; (χ^2= 390.4, 13 d.f., P << 0.001) due primarily to under-sampling in aggregated NMFS reporting areas (509-519) during weeks 23-27 and 35-36, and NMFS reporting areas (521, 523, 524) during week 35. The NMFS and ADF&G reporting area was known for samples collected at the haul-level from at-sea processors (hauls), but due to the uncertainty of catch location for samples collected at the trip-level from shore-side processors (offloads) in which deliveries may have contained mixed hauls from multiple reporting areas, the reporting area of the chum salmon catch from offloads was identified as the area where most of the pollock were caught during a fishing trip.

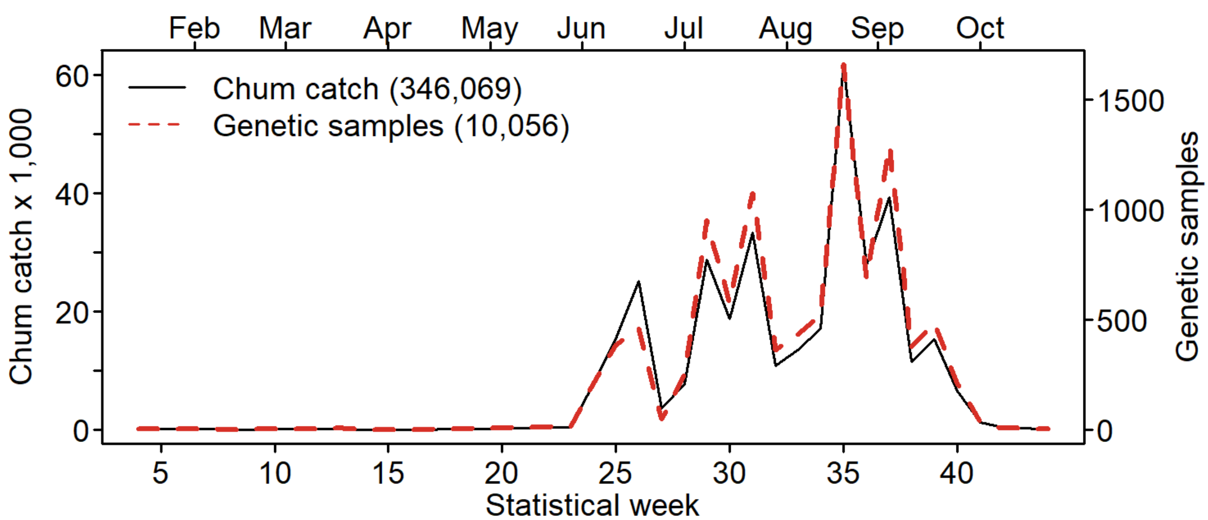

Figure 3. -- Number of chum salmon caught (black, solid line) and genetic samples collected (red, dashed line) from the 2019 Bering Sea pollock fishery by statistical week. Weeks 1-23 correspond to the A-season, whereas weeks 24-43 correspond to the B-season.

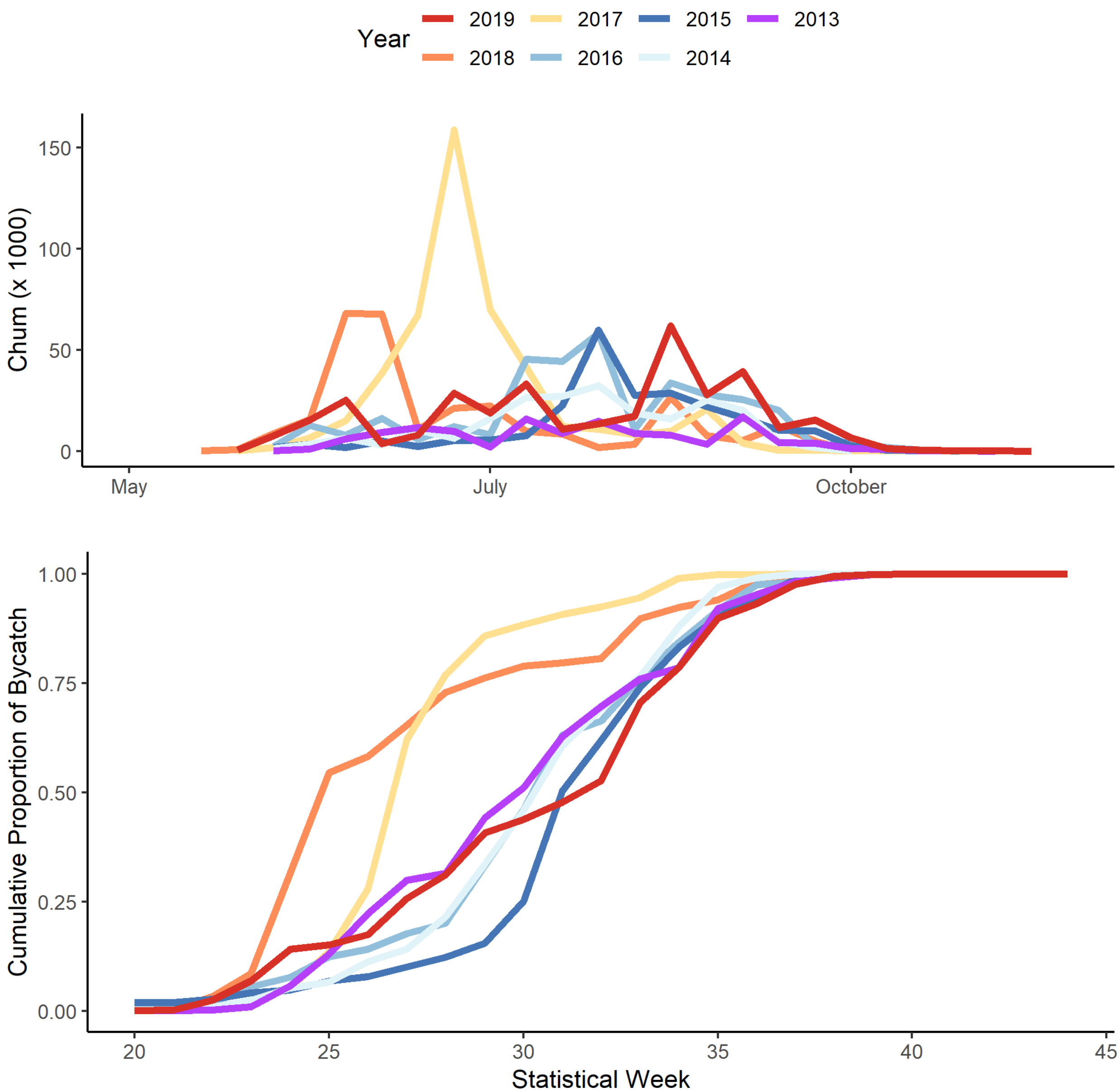

Figure 4. -- Number of chum salmon caught during the B-season (top) and cumulative proportion of chum salmon catch (bottom) from the Bering Sea pollock trawl fishery by statistical week for years 2013 to 2019.

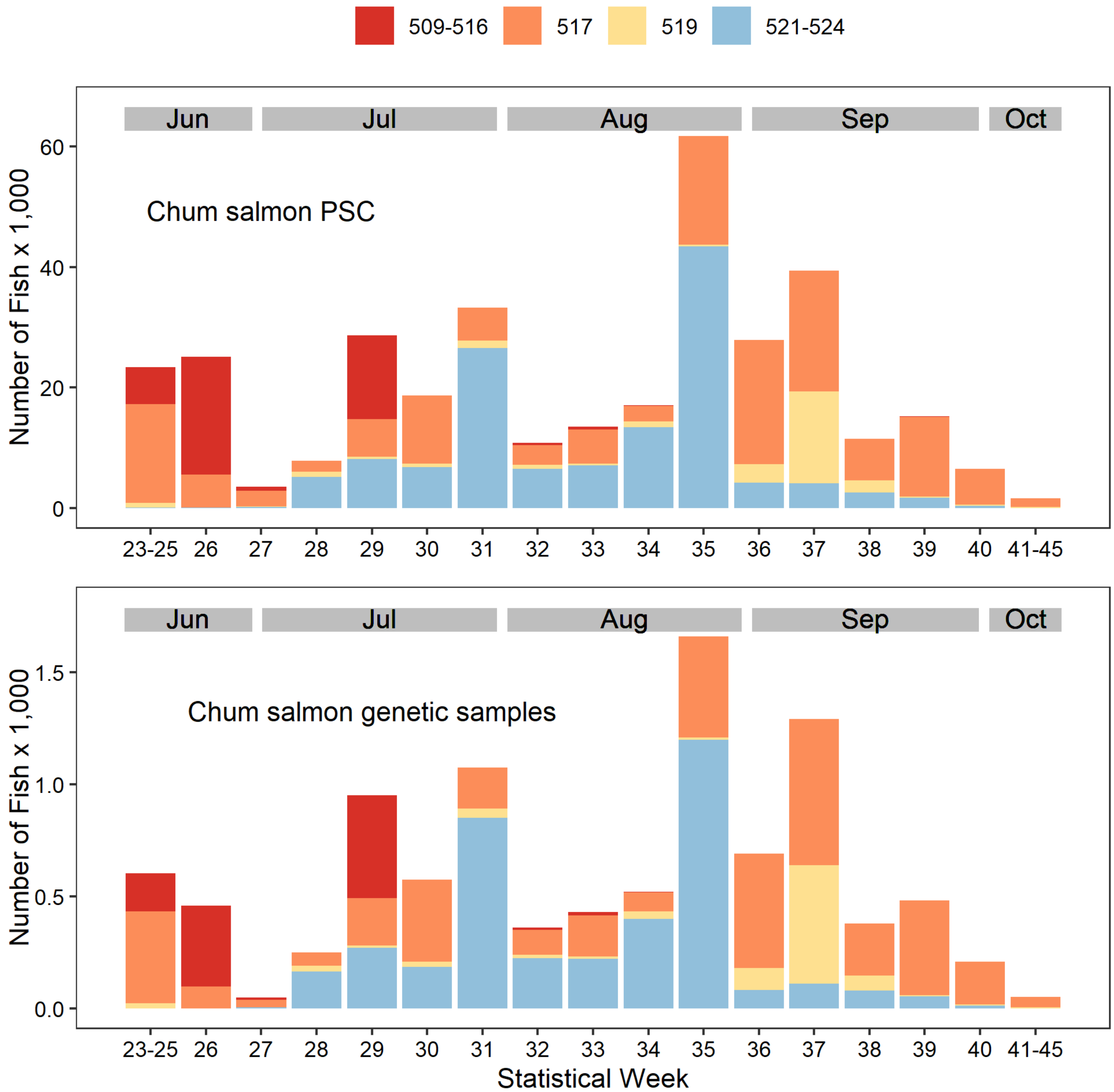

Figure 5. -- Number of chum salmon caught (top) and genetic samples collected (bottom) from the 2019 Bering Sea, B-season pollock fishery by statistical week and NMFS reporting area (designated in the legend).

The systematic collecting protocol was also evaluated by comparing the total number of chum salmon caught on each vessel to the number of genetic samples collected from each vessel during 2019. Of the 95 vessels that participated in the midwater trawl fishery during the A- and

B-seasons, 89 vessels caught chum salmon. The chum salmon catch was subsampled by observers for genetic samples across a large range (up to 15,000 fish) of chum salmon catch per vessel (Fig. 6). Per vessel, the ratio of numbers of genetic samples to numbers of chum salmon caught was 1 in 38.2 ± 25.2 fish (mean ± S.D.; unweighted by proportion of bycatch each vessel caught), which was lower than the protocol sampling goal of one genetic sample from every 30th chum salmon caught. The high standard deviation was due to one vessel with a low sampling ratio (1 sample per 241 chum caught); when this vessel is excluded, the ratio of numbers of genetic samples to numbers of chum salmon caught was 1 in 35.8 ± 11.8 fish (mean ± S.D.). In 2019, 50% of the chum salmon PSC was counted from at-sea hauls and 50% from shoreside offloads. By vessel, the sampling ratio was 1 in 38.3 fish and 1 in 38.0 fish for at-sea and shoreside offloads, respectively, a non-significant difference (t-test; P = 0.47). More than one-quarter of the vessels had PSC catches that were undersampled for genetic samples by 10% or more, which explains most of the sampling bias observed across temporal and spatial strata described above (Figs. 3 and 5). Most of the under-sampling occurred during and immediately after high PSC catches, presumably because of insufficient sampling materials.

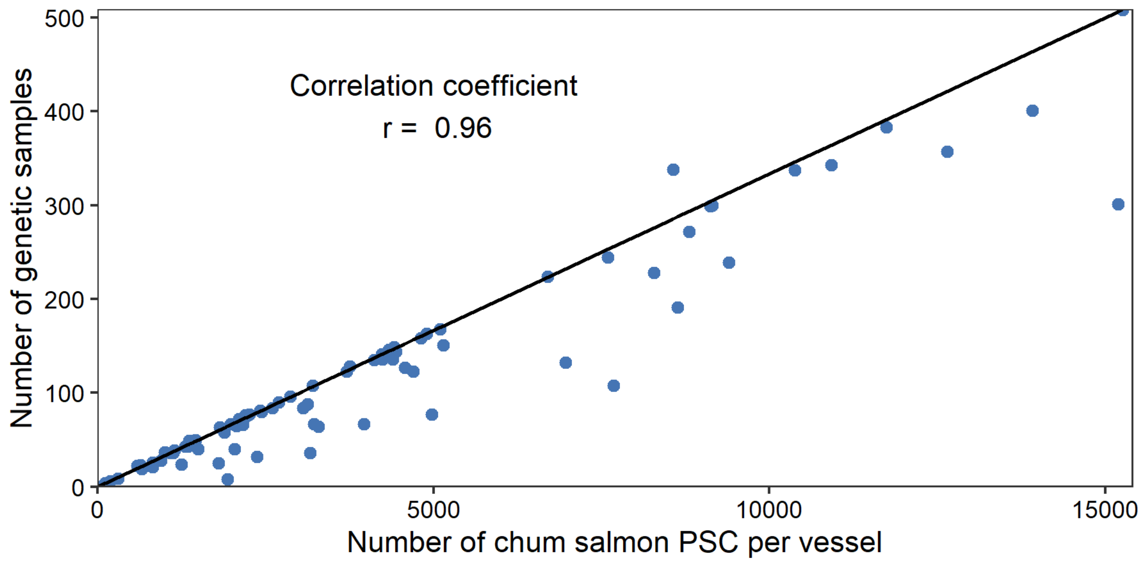

Figure 6. -- Chum salmon catch and genetic samples from each of 89 vessels in the 2019 Bering Sea, A- and B- seasons of the pollock fishery. Black diagonal line represents the expected sampling rate.

LABORATORY ANALYSES

Chum salmon samples from the Bering Sea, B-season pollock fishery were subsampled in order to minimize laboratory costs while limiting potential bias of mixed-stock estimates. To minimize bias in subsampling (see Whittle et al. 2015 for subsampling effects), the full collection of 9,935 chum salmon received at ABL was first sorted by cruise, haul or offload, and specimen number, and then every 5th sample was selected for analysis. DNA was extracted from the axillary processes of 1,977 chum salmon and an additional 421 samples that were selected for the 4-cluster spatial-temporal analyses to increase the sample sizes to approximately 200 samples in each time-area stratum. Too few samples were collected from the Bering Sea A-season to analyze (PSC = 498; samples collected = 16).

DNA was extracted and microsatellite genotyping was performed (Guyon et al. 2010) for 11 microsatellite loci: *Oki100* (Beacham et al. 2009a), *Omm1070* (Rexroad et al. 2001), *Omy1011* (Spies et al. 2005), *One101*, *One102*, *One104*, *One114* (Olsen et al. 2000), *Ots103*

(Beacham et al. 1998), *Ots3* (Greig and Banks 1999), *Otsg68* (Williamson et al. 2002), and *Ssa419* (Cairney et al. 2000). Thermal cycling for the amplification of DNA fragments with polymerase chain reaction (PCR) was performed on a dual 384-well GeneAmp PCR System 9700 (Applied Biosystems, Inc.). Samples from the PCR reactions were diluted into 96-well plates with the GeneScan™ 600 LIZ™ Size Standard for analysis with a 48-capillary, 36 cm array on the ABI 3730*xl* Genetic Analyzer (Applied Biosystems, Inc.). Genotypes were double-scored with GeneMapper 5.0 software (Applied Biosystems, Inc.).

Of the 2,398 chum salmon PSC samples from the Bering Sea, 93% were successfully genotyped for 8 or more of the 11 loci for an average of 10.8 loci (Table 1). No duplicate genotypes were detected with GenAlEx 6.5 (Peakall and Smouse 2006, 2012).

Table 1. -- Number of chum salmon genetic samples from the 2019 Bering Sea, B-season pollock fishery that were genotyped per number of loci.

Number loci	**Genetic samples**
11	2,024
10	132
9	28
8	53
<8	161

Quality control of sample handling and genotyping was examined by reanalyzing 8.6% of the samples: DNA was plated from the 8 samples in the left-most column of each elution plate for a total of 207 samples that were then processed for genotyping as described above. Genotypes from the quality control dataset were then compared to the genotypes of the original dataset (Table 2). Across 11 loci there were a total of 68 differences in 4,166 alleles between the original and quality control datasets, which represented an overall discrepancy rate of 1.63%.

Table 2. -- Number of allele differences by locus between the original and quality control datasets for samples with non-questionable genotypes of chum salmon from the 2019 Bering Sea, B-season pollock fishery.

Locus	**Number alleles compared**	**Number allele differences**	**Percent difference**
Oki100	382	14	3.66
Omm1070	364	16	4.40
Omy1011	372	0	0
One101	372	6	1.61
One102	366	2	0.55
One104	388	2	0.52
One114	394	2	0.51
Ots103	392	2	0.51
Ots3	384	20	5.21
OtsG68	386	0	0
Ssa419	366	4	1.09

GENETIC STOCK COMPOSITION

For the mixture genotypes, allele designations were standardized to match those in the Fisheries and Oceans Canada (DFO) chum salmon microsatellite baseline (Beacham et al. 2009b, c). Standardized genotypes were saved as text files and the data were formatted into mixture files compatible with software used for stock composition estimation. Stock compositions were determined with mixed-stock analysis (MSA) by comparing mixture genotypes with allele frequencies from reference baseline populations. As described previously (Gray et al. 2010), with minor changes to regional group names, baseline populations were grouped into six regions: Southeast Asia (SE Asia), Northeast Asia (NE Asia), Western Alaska (W Alaska), Upper/Middle Yukon (Up/Mid Yukon), Southwest Alaska (SW Alaska), and the Eastern GOA/Pacific Northwest (EGOA/PNW) (Fig. 7). The regional groups were selected based on principal coordinate and simulation analyses as described in Guyon et al. (2010). A listing of the individual populations grouped by region is provided in Appendix I.

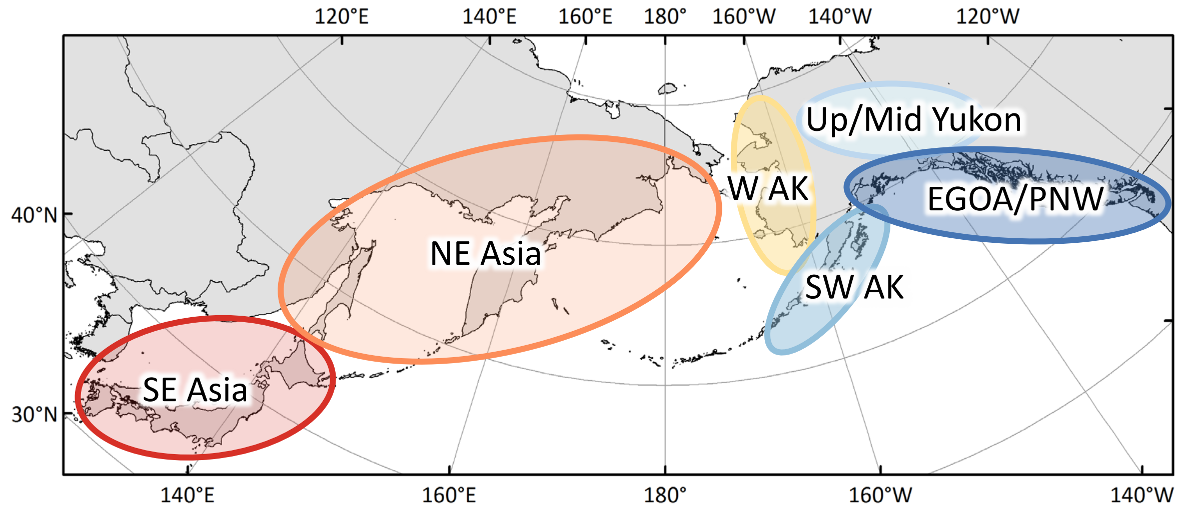

Figure 7. -- Six regional groups of baseline chum salmon populations used in this report.

The stock composition analyses for the 2019 chum salmon samples were performed with the Bayesian conditional MSA approach with bootstrapping over reporting groups implemented in the R package *rubias* (Moran and Anderson 2019). Stock composition estimates based on data from all 11 loci were derived for the six regional groups (Table 3; Appendix II). For all estimates, the Dirichlet prior parameters for the stock proportions were defined by region to be $1/(GC_g)$, where C_g is the number of baseline populations in region g, and G is the number of regions[2]. For each analysis, six MCMC chains of 100,000 iterations (burn-in of 50,000) were run starting at disparate values of stock proportions configured such that 95% of the stocks came from one designated region with weights equally distributed among the stocks of that region. The remaining 5% was equally distributed among remaining stocks from all other regions.

[2] In analyses prior to the 2013 chum salmon PSC analysis, a flat prior (1/381) was assigned to each baseline population. Priors defined by region may reduce bias due to differences in how densely regions are represented by baseline populations.

Convergence was assessed with Gelman-Rubin shrink factors estimated with the gelman.diag function in the coda R library (Plummer et al. 2006), which were 1.00-1.01 (Table 3; Appendix II) across all datasets, conveying convergence to a single posterior distribution for each analysis (Gelman and Rubin 1992, Pella and Masuda 2001). A basic overview of the Bayesian method used for mixed-stock analysis in our report is presented in Appendix III.

The stock composition estimates were summarized by the mean, standard deviation, median, 95% credible interval (2.5th and 97.5th percentile of the MCMC iterates in the posterior output), and P = 0, which is the probability that a stock composition estimate is effectively zero (Munro et al. 2012). The P = 0 statistic is the frequency of the last half of the MCMC iterates of each chain for which the individual regional contribution to the mixture was less than a threshold of $0.5E^{-6}$. This statistic may be more useful than the credible interval for assessing the presence or absence of minor stocks. For example, the P = 0 value associated with the Up/Mid Yukon stock estimate for the B-season sample set (Table 3) indicates that there is a 2% probability that essentially zero chum salmon from this stock were caught in this season.

Table 3. -- Regional stock composition estimates of chum salmon from the 2019 Bering Sea, B-season pollock fishery. Mean proportion estimates are provided with standard deviations (SD), 95% credible intervals, median estimate, P = 0 statistic (values > 0.5 are shaded), and the Gelman-Rubin shrink factor. PSC is the census of chum salmon caught and n is the number of samples genetically analyzed.

Bering Sea pollock trawl fishery, B-season (PSC = 345,571; n = 1,848)

Region	**Est. num.**	**Mean**	**SD**	**2.5%**	**Median**	**97.5%**	**P = 0**	**Shrink**
SE Asia	62,194	0.180	0.009	0.162	0.180	0.199	0	1.00
NE Asia	135,614	0.392	0.014	0.366	0.392	0.419	0	1.00
W Alaska	55,084	0.159	0.010	0.139	0.159	0.180	0	1.00
Up/Mid Yukon	935	0.003	0.002	0.000	0.002	0.007	0.02	1.00
SW Alaska	12,568	0.036	0.006	0.026	0.036	0.048	0	1.01
E GOA/PNW	79,174	0.229	0.011	0.208	0.229	0.251	0	1.00

COMPARISON WITH PREVIOUS ESTIMATES

The stock composition estimates from the analysis of the 2019 chum salmon samples collected during the B-season were similar to the estimates from past years for four of the six regions (SE Asia, NE Asia, W Alaska, and EGOA/PNW), after systematic sampling was in effect (Fig. 8, upper panel). In 2019, the NE Asia stocks dominated the regional contributions as in 2017 and 2018; however, the Up/Mid Yukon stocks were nearly absent, and the SW Alaska stocks were approximately double that of the average from previous years. The extent to which year-to-year differences in regional stock contributions are attributable to differences in fishing locations and times or migration patterns of chum salmon is beyond the scope of this report. However, with systematic sampling of the Bering Sea chum salmon PSC in place, the role of these factors on the year-to-year variation of stock estimates will be easier to determine.

The 1994-1995 chum salmon stock composition estimates were produced with allozyme data (Wilmot et al. 1998), whereas the 2005-2019 estimates were derived from DNA-based microsatellite loci (Guyon et al. 2010; Marvin et al. 2011; Gray et al. 2010, 2011a, b; Kondzela et al. 2012, 2013, 2016, 2017; Vulstek et al. 2014; Whittle et al. 2015, 2018, 2021a, b). Although the same set of bycatch samples have not been analyzed with allozyme and microsatellite DNA markers, other studies have shown concordant stock estimates with allozyme and microsatellite markers on a smaller geographic scale (e.g., Scribner et al. 1998) and we assume that these two marker sets produce similar stock estimates on a wider geographic scale because the allozyme (77 populations) and microsatellite DNA (381 populations) baselines have data from many of the same populations and have similar regional groups (Beacham et al. 2009b, c; Wilmot et al. 1998).

The large variation in total chum salmon caught across the years (Fig. 2) was reflected in the high standard errors of the mean number of chum salmon caught by region (unweighted by year) when stock composition estimates are extrapolated to the total chum salmon PSC from the Bering Sea pollock fishery (Fig. 8, lower panel). Since 2011, the genetic samples have been collected systematically, resulting in the extrapolations being relatively free of sampling bias. The location and timing of collections prior to 2011 was not always representative of the entire chum salmon PSC within a given year. In 2019, the numbers of chum salmon from SE Asia, NE Asia, W Alaska, and SW Alaska stocks were higher than in previous years (2011-2018) under systematic sampling. The above average bycatch in 2019 and the high proportion of NE Asia fish is reflected in high numbers of chum salmon intercepted from this region.

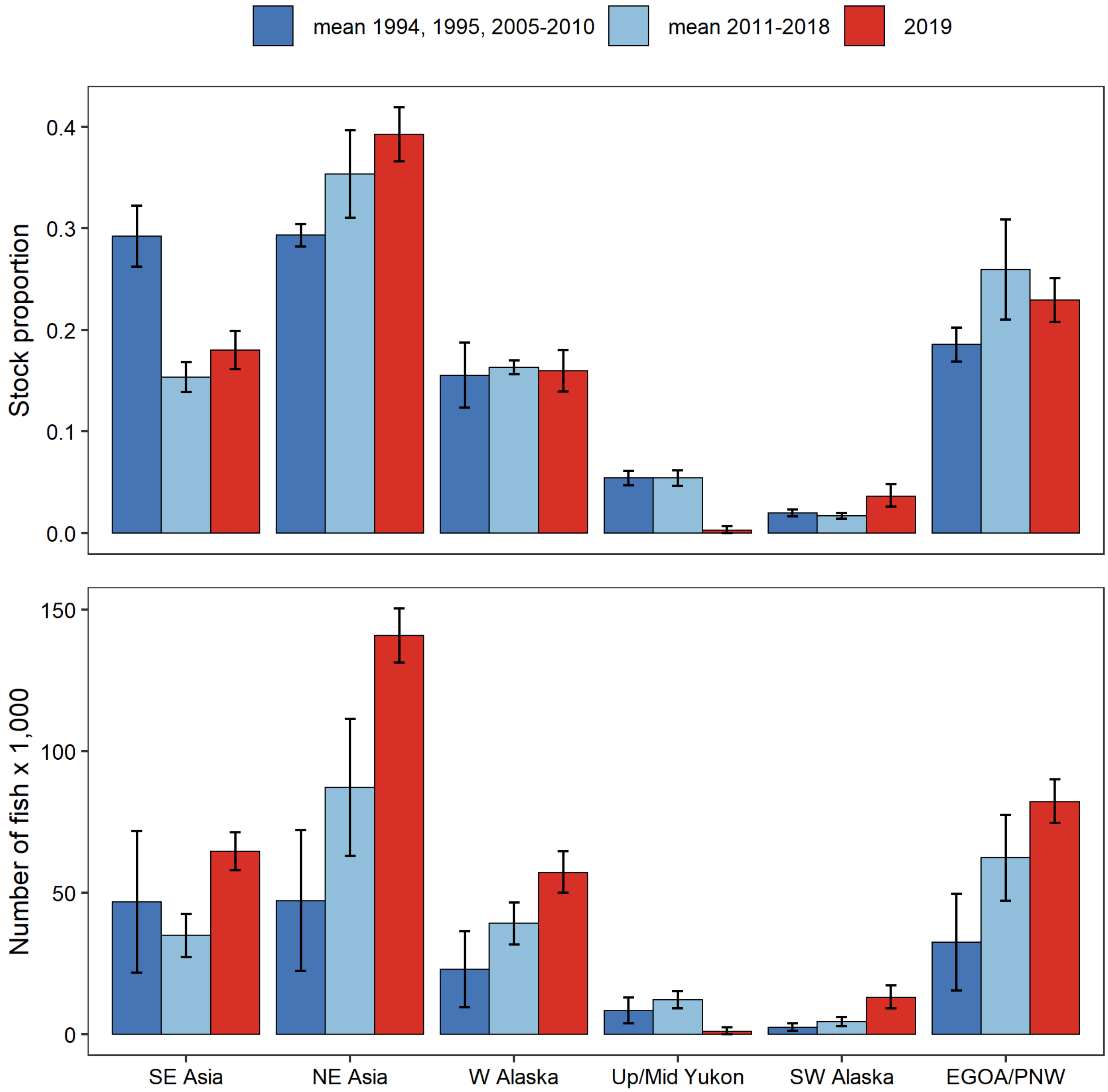

Figure 8. -- Comparison of the stock composition estimates of chum salmon from the 2019 Bering Sea, B-season pollock fishery with the estimates from 2011 to 2018 (systematic sampling) and the unweighted mean estimates from 1994, 1995, and 2005-2010 (non-systematic sampling). Proportions in top panel; numbers of fish in bottom panel, where 1994-2010 are estimates and 2011-2019 are censuses (NMFS 2021a). Standard errors of the mean estimates are shown for the combined years; 95% credible intervals are shown for the 2019 analysis. Error bars are based on only the mixed-stock analyses and do not include errors associated with the overall annual PSC estimation or potential biases in sample distribution.

TEMPORAL STRATIFICATION

Resolving the temporal distribution of the chum salmon PSC is important for better understanding the seasonal impacts of the pollock trawl fishery on salmon stocks. If the chum salmon stock distribution changes consistently over time, it may be possible to manage the pollock fishery in a manner that minimizes effects on critical salmon stocks.

As with the 2005-2018 analyses, the 2019 Bering Sea sample set from the B-season was split into three time periods: Early, Middle, and Late (Table 4). Stock composition estimates were made as described previously for each of the three temporal strata (Appendix II). Some of the stock contributions changed during the course of the season (Fig. 9; Appendix II). The contributions were nearly identical in all three time periods for each of the SE Asia and NE Asia regions, with the NE Asia contribution the highest of all reporting groups in all three time periods. The W Alaska contribution was higher in the Early time period, 28%, and lower in the Middle and Late time periods, 14% and 11%, respectively. The Up/Mid Yukon contribution was very low in the Early and Middle time periods (< 1%) and absent in the Late time period. The EGOA/PNW contributions increased over three-fold (9% to 29%) across the three time periods. The SW Alaska stock contributions have not exceeded 5.6% in any year and therefore data for this regional group are not included.

Table 4. -- Temporal groups from the genetic sample sets of chum salmon from the 2019 Bering Sea, B-season pollock fishery.

Time period	Weeks	Dates	Number of samples
Early	23-29	June 2 - July 20	424
Middle	30-34	July 21 - August 24	543
Late	35-43	August 25 – October 26	881

The 2011-2018 stock compositions for similar temporal strata are included for comparison purposes (Fig. 9). Across the years, with the exception of 2019, the SE Asia contribution was higher in the Early time period than the Middle and Late time periods. The NE Asia contributions varied across years within each time period in a manner that was consistent across all three time periods, especially in the Middle and Late time periods. The W Alaska contributions were similar across years within each time period and slightly higher across years in the Early and Middle time periods than in the Late time period. The Up/Mid Yukon contributions were consistently low across years at all three time periods. The EGOA/PNW contributions varied across years within each time period with nearly identical patterns of variation in the Middle and Late time periods. The inverse relationship of stock proportions across years between the NE Asia and EGOA/PNW regions during the Middle and Late time periods persisted in 2019. Results from the temporal analysis should be used cautiously because spatial differences exist in the time-stratified sample sets and these differences are known to affect the stock composition estimates.

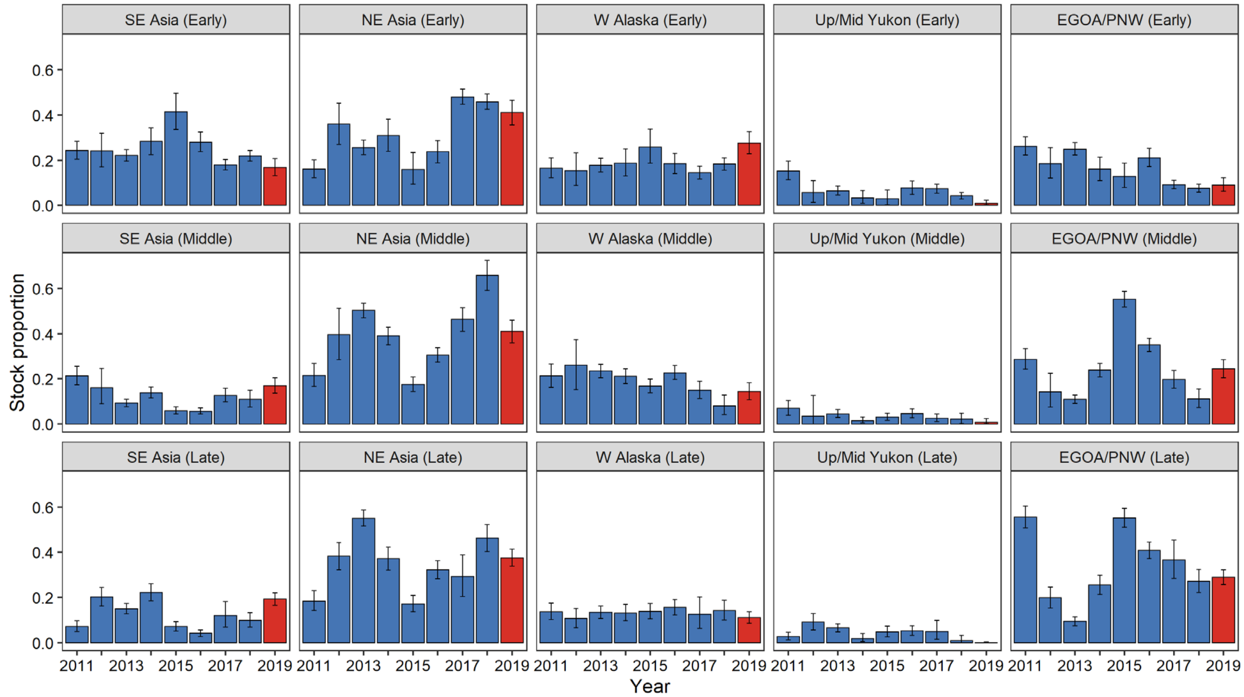

Figure 9. -- Stock composition estimates (mean ± 95% credible intervals) for the 2011-2019 chum salmon from the Early, Middle, and Late periods of the Bering Sea, B-season pollock fishery (defined in Table 4). Not shown is the SW Alaska region for which estimates never exceeded 5.6%. The current sampling year (2019) is denoted in red.

SPATIAL STRATIFICATION

Resolution of the spatial distribution of the chum salmon PSC is important for better understanding the impacts of the pollock trawl fishery on salmon stocks. In 2019, for the ninth year, the Observer Program undertook a complete census of chum salmon caught in the Bering Sea pollock trawl fisheries. Approximately 50% of the chum salmon catch was counted and sampled at shoreside processing facilities; the remaining 50% was counted and sampled at sea. Of the shoreside offloads, 36% of the chum salmon catch was from vessels that fished in one ADF&G statistical area during a trip. For the 64% of chum salmon catch offloaded from vessels that fished in multiple ADF&G statistical areas during a trip (32% of total chum salmon catch), the area assigned to an offload was the area where the highest weight of pollock was caught.

The 2019 Bering Sea genetic samples from the B-season were split into two areas (see Fig. 1): the U.S. waters of the Bering Sea west of 170°W (areas 521, 523, and 524), and the southeastern Bering Sea east of 170°W (areas 509, 513, 516, 517, and 519). Stock compositions for the two spatial strata were estimated as described previously (Fig. 10; Appendix II). Approximately three-quarters of the chum salmon caught to the west of 170°W in the Bering Sea were from Asian stocks, whereas the fish caught to the east of 170°W were nearly equally from Asian and North American stocks. NE Asia stocks were the largest contributor to the chum salmon catch in both areas, with a slightly higher contribution (43%) in the area west of 170°W than in the east (37%). SE Asia stocks contributed more to waters west of 170°W than to the southeastern Bering Sea (31% vs. 10%), whereas the W Alaska (21% vs. 7%) and EGOA/PNW (27% vs. 15%) stock contributions were higher in the east. The low contributions from the Up/Mid Yukon and SW Alaska stocks were similar between the spatial strata.

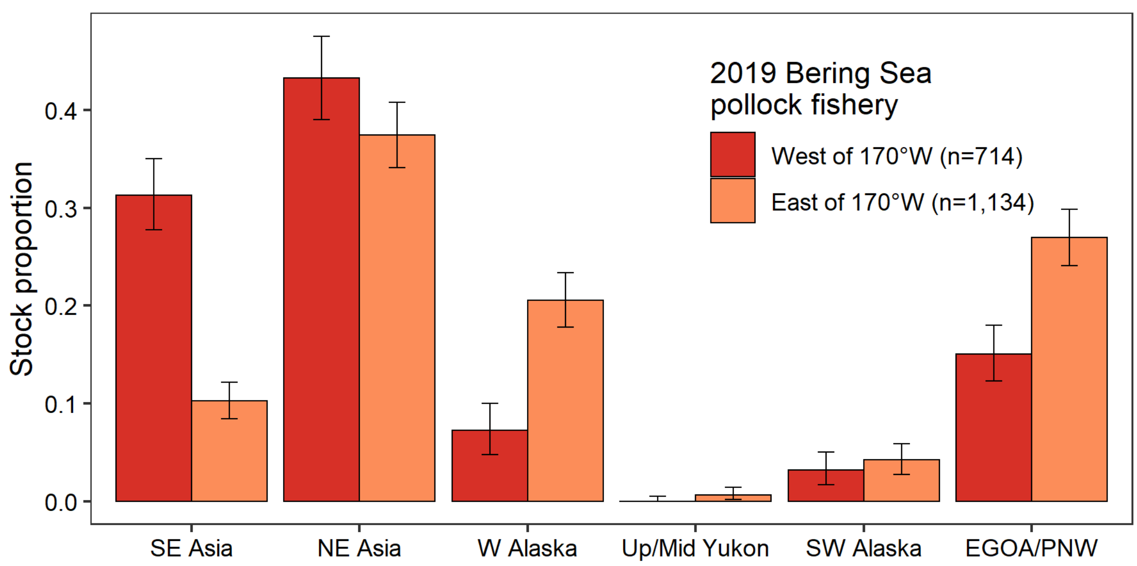

Figure 10. -- Stock composition estimates and 95% credible intervals for the chum salmon from the 2019 Bering Sea, B-season pollock fishery from the U.S. waters of the Bering Sea west of 170°W (aggregate area 521/523/524) and the southeastern Bering Sea east of 170°W (aggregate area 509/513/516/517/519).

To better understand the distribution of chum salmon stocks across time and space in the Bering Sea PSC from the pollock fishery, the 2019 stock composition estimates were compared from four spatial clusters and two time periods. Samples from the B-season were aggregated into Early (statistical weeks 23-32) and Late (statistical weeks 33-43) time periods at four spatial clusters that were based on ADF&G statistical areas along the continental shelf edge (Table 5; Fig. 11; Appendix IV). Excluded from this analysis are 121 samples (5%) from offloads of vessels that fished in multiple ADF&G statistical areas that encompass more than one cluster. The NE Asia stocks dominated the chum salmon catch at many of the four clusters and two time periods, with the EGOA/PNW stock contribution in Cluster 2 during the Late time period being the notable exception (Fig. 12; Appendix II). Several stocks exhibited a gradient of contributions along the continental shelf. The SE Asia stocks were most prevalent in the northwest portion (Cluster 4) of the shelf in both time periods, whereas the W Alaska stocks had higher contributions toward the southeast (Cluster 1) in both time periods. The EGOA/PNW stock contributions were highest in Clusters 1-3, particularly in the Late time period. Contributions from the Up/Mid Yukon and SW Alaska stocks were low in all four clusters and both time periods.

Table 5. -- Collection information for the four spatial clusters of chum salmon caught in two time periods, Early (weeks 23-32) and Late (weeks 33-43), during the 2019 Bering Sea, B-season pollock fishery and analyzed for genetic stock composition.

Spatial cluster	**Time period**	**Samples received**	**Samples analyzed**
1	Early	1,762	325
1	Late	2,692	499
2	Early	345	187
2	Late	696	186
3	Early	1,521	291
3	Late	169	151
4	Early	113	105
4	Late	2,070	372

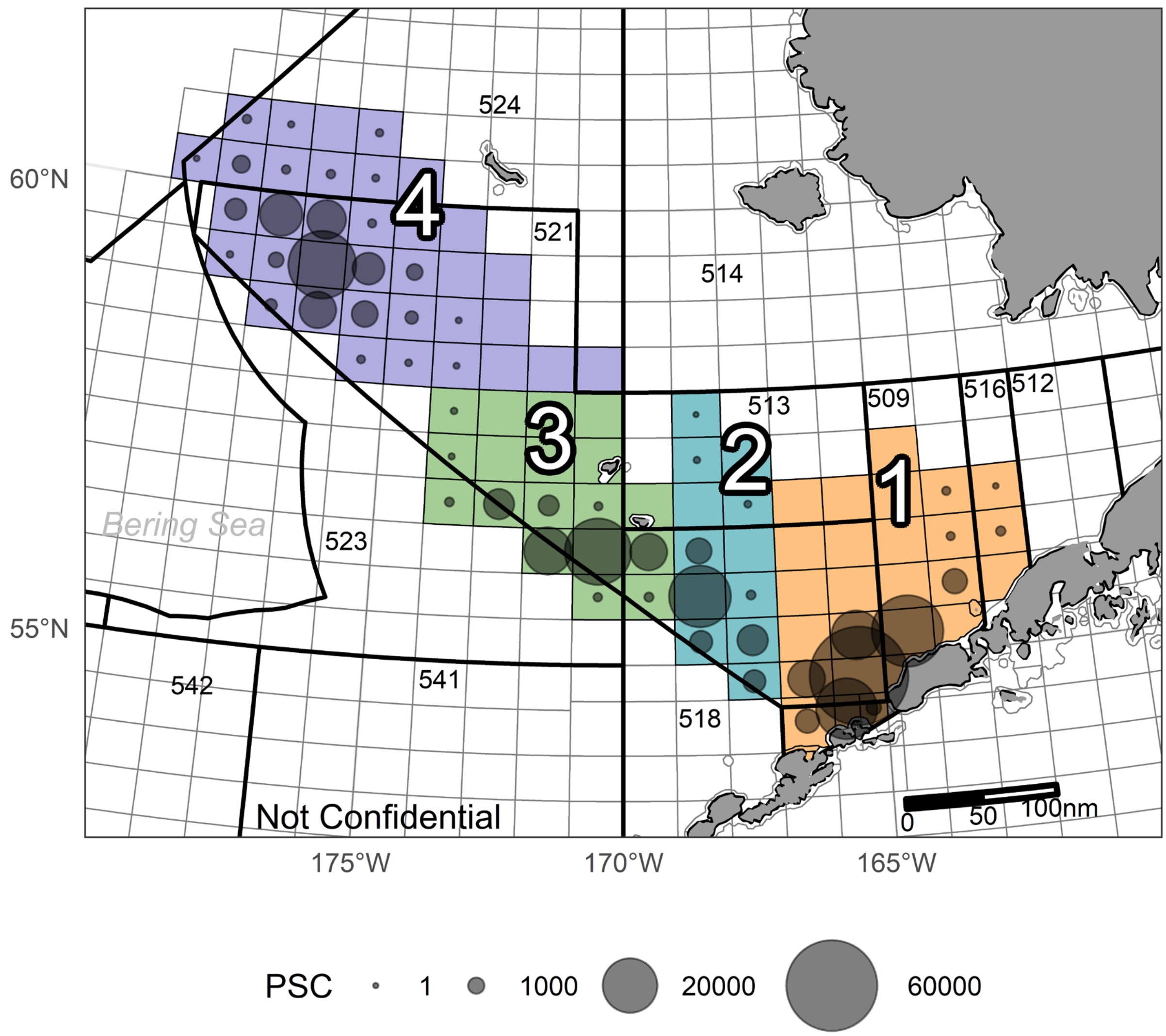

Figure 11. -- Four spatial clusters of ADF&G statistical areas in which chum salmon were collected from the Bering Sea, B-season pollock fishery in at least one year from 2013 to 2019 (highlighted); ADF&G areas in which samples were collected in 2019 from at least three vessels are indicated with circles sized relative to the number of chum salmon caught. NMFS reporting areas associated with the Bering Sea-Aleutian Island groundfish fisheries are numbered in black.

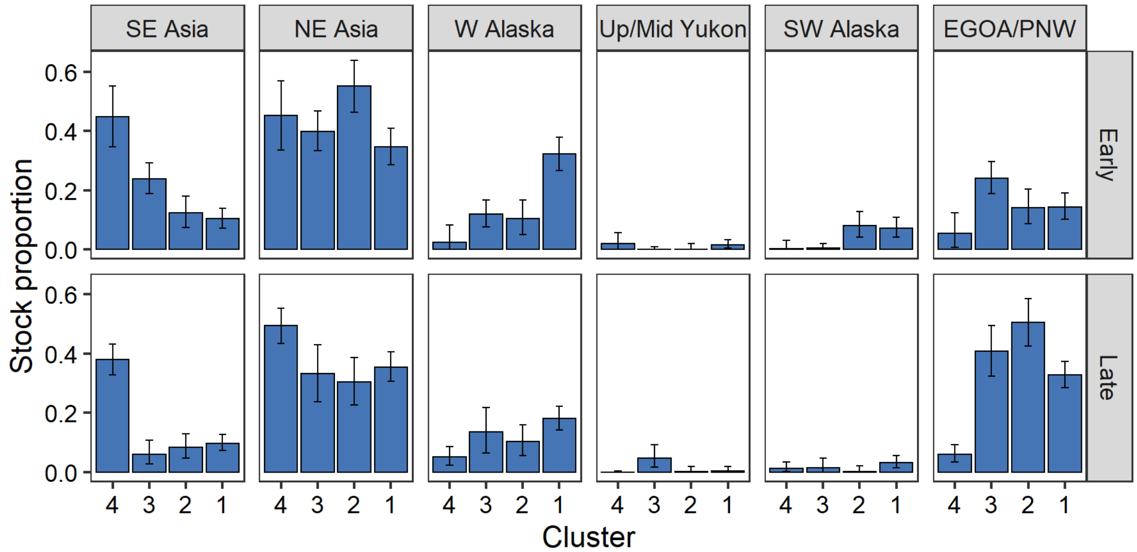

Figure 12. -- Stock composition estimates and 95% credible intervals for the chum salmon collected from four spatial clusters along the continental shelf edge (Fig. 11) during Early (Weeks 24-32) and Late (Weeks 33-43) time periods of the 2019 Bering Sea, B-season pollock fishery.

AGE STRATIFICATION

Scale ageing of the genetic samples permitted the evaluation of age-specific stock contributions of each region to the chum salmon PSC. Total age of individual fish was estimated as the number of freshwater and saltwater annuli formed on the scale plus one to account for the winter spent rearing in fresh water. Approximately 80% of the successfully genotyped chum salmon caught in the 2019 Bering Sea, B-season pollock fishery could be aged; the remaining samples could not be aged for a variety of reasons, such as the scales were missing, collected from a non-preferred location on the fish, or regenerated. The total age composition was 2% age-2, 42% age-3, 46% age-4, 10% age-5, and < 1% age-6. The proportions of age-3 and age-4 fish were higher and lower, respectively, in 2019 than in 2017 and 2018. Stock composition was estimated for chum salmon, ages 3-5 (Fig. 13; Appendix II). Stock composition varied by age with approximately half of the age-3 and age-4 fish each from Asian and North American stocks.

The component of age-3 fish from Asia was equally from SE Asia and NE Asia stocks, and most of the North American contribution was primarily from EGOA/PNW stocks. The component of age-4 fish from Asia was primarily from NE Asia, and the highest North American contribution was from W Alaska stocks. Most of the age-5 fish were from NE Asia stocks.

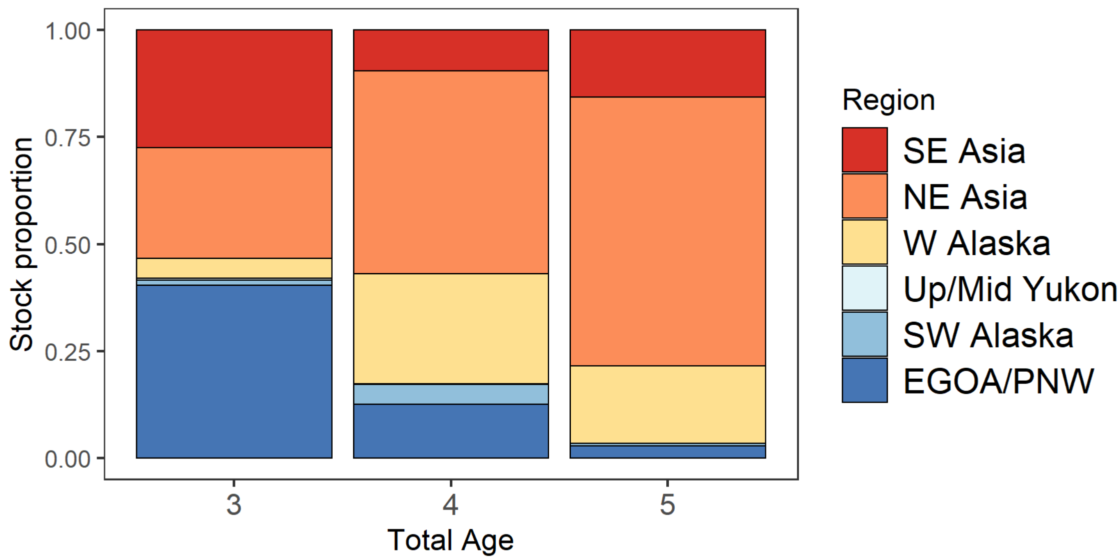

Figure 13. -- Stock composition estimates for the three predominate ages of chum salmon from the 2019 Bering Sea, B-season pollock fishery. Sample sizes were 610, 679, and 155 chum salmon for age-3, age-4, and age-5, respectively.

Stock estimates for many combinations of age, time, and spatial strata are available in Appendix II. The datasets with spatial strata (Clusters 1-4) include the extra samples added to increase the dataset sizes and are not necessarily representative of the entire bycatch. Full exploration of the stock estimates from the many multi-strata datasets are beyond the scope of this report, although several results are noted here (Fig. 14). One of the most striking differences in stock estimates are between age-3 and age-4 chum salmon regardless of time period or spatial strata. Roughly half of the age-3 fish from Clusters 1-3 were from EGOA/PNW stocks, whereas half or more of the age-4 fish from Clusters 2-4 were from Asian stocks. The Asian stocks dominated both ages from fish collected in Cluster 4, with most of the age-3 fish from SE Asia and age-4 fish from NE Asia.

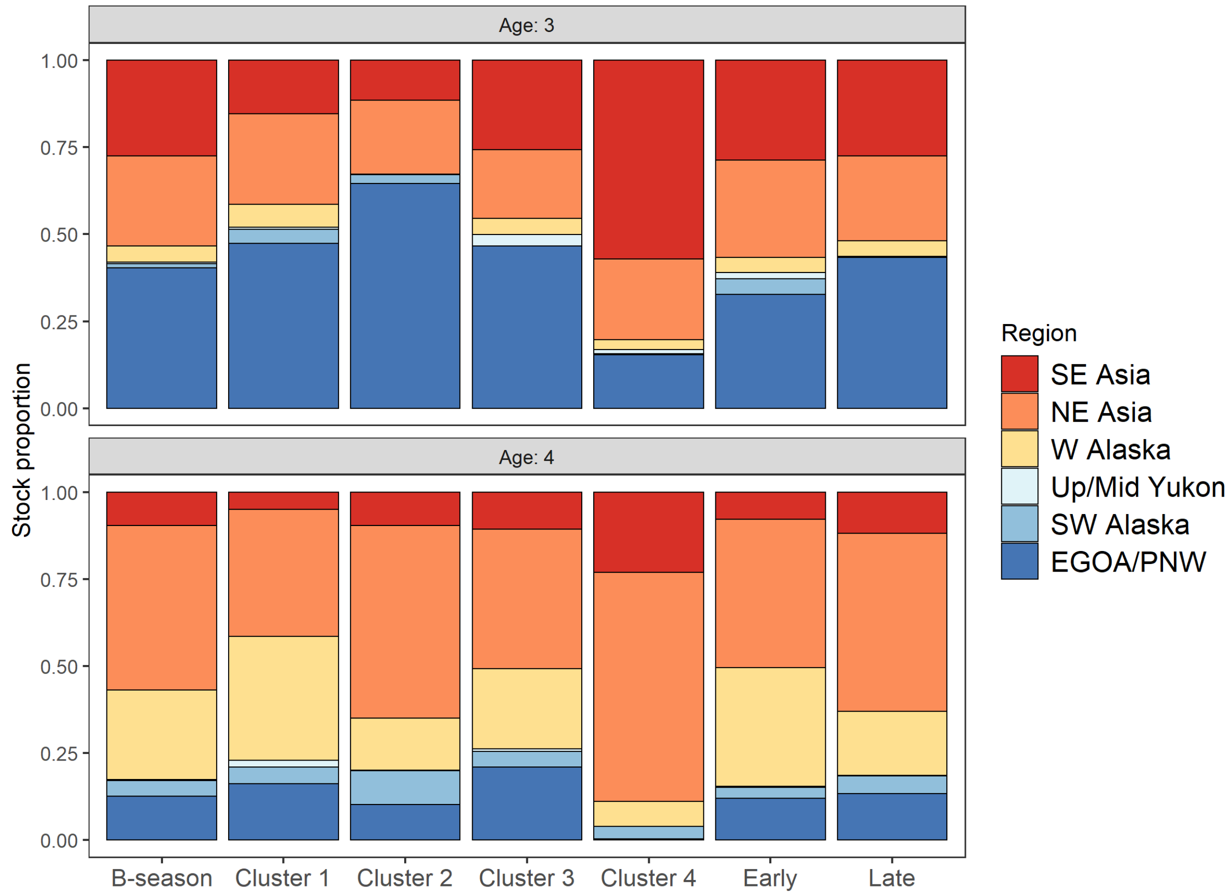

Figure 14. -- Stock composition estimates for the age-3 and age-4 chum salmon from the 2019 Bering Sea, B-season pollock fishery for the entire season, in four areas along the continental shelf (Clusters 1-4; Fig. 11), and in two time periods, Early (weeks 24-32) and Late (weeks 33-43).

FISHING SECTOR

In 2019, sample sizes were sufficient to estimate stock compositions for all three fishing sectors: catcher-processor, shoreside (catcher-vessel), and mothership (Fig. 15; Appendix II)[3].

[3] The terms "shoreside" or "catcher-vessel" in this report are synonymous with the use of "inshore" in the Federal Register.

Consistent with greater pollock quotas and fishing effort, more chum salmon were collected from each of the catcher-processor (129,082) and shoreside (171,993) sectors than the mothership sector (44,496). The majority of fish caught in all three sectors were from NE Asia stocks; the proportion of stocks from other regional groups varied by fishing sector (Fig. 15, upper panel). For example, a higher proportion of chum salmon from SE Asia stocks were caught by catcher-processors and motherships; however, a higher proportion of chum salmon from W Alaska stocks were caught by the mothership and shoreside sectors. The catcher-processor sector had higher proportions of Asian fish than the shoreside sector, which can be explained at least in part by catcher-processor dominance in the northwestern area of the fishery (Haynie and Pfeiffer 2013) where Asian fish are most prevalent (Fig. 12). Similarly, the W Alaska component was higher in the shoreside sector because this fishing sector is primarily concentrated in the southeastern area of the Bering Sea, where W Alaska stocks are most abundant (Fig. 12).

When the estimates from the six regional groups were pooled into two reporting groups, Asia and North America, the estimated number of chum salmon from Asia that the catcher-processor and shoreside sectors caught was similar (93,226 and 87,744, respectively); however, the estimated number of fish from North America caught in the shoreside sector was substantially larger (84,249) than from the catcher-processor sector (35,856; Fig. 15, lower panel). The mothership sector had approximately equal numbers of fish from the Asia and North America reporting groups (23,686 and 20,810, respectively).

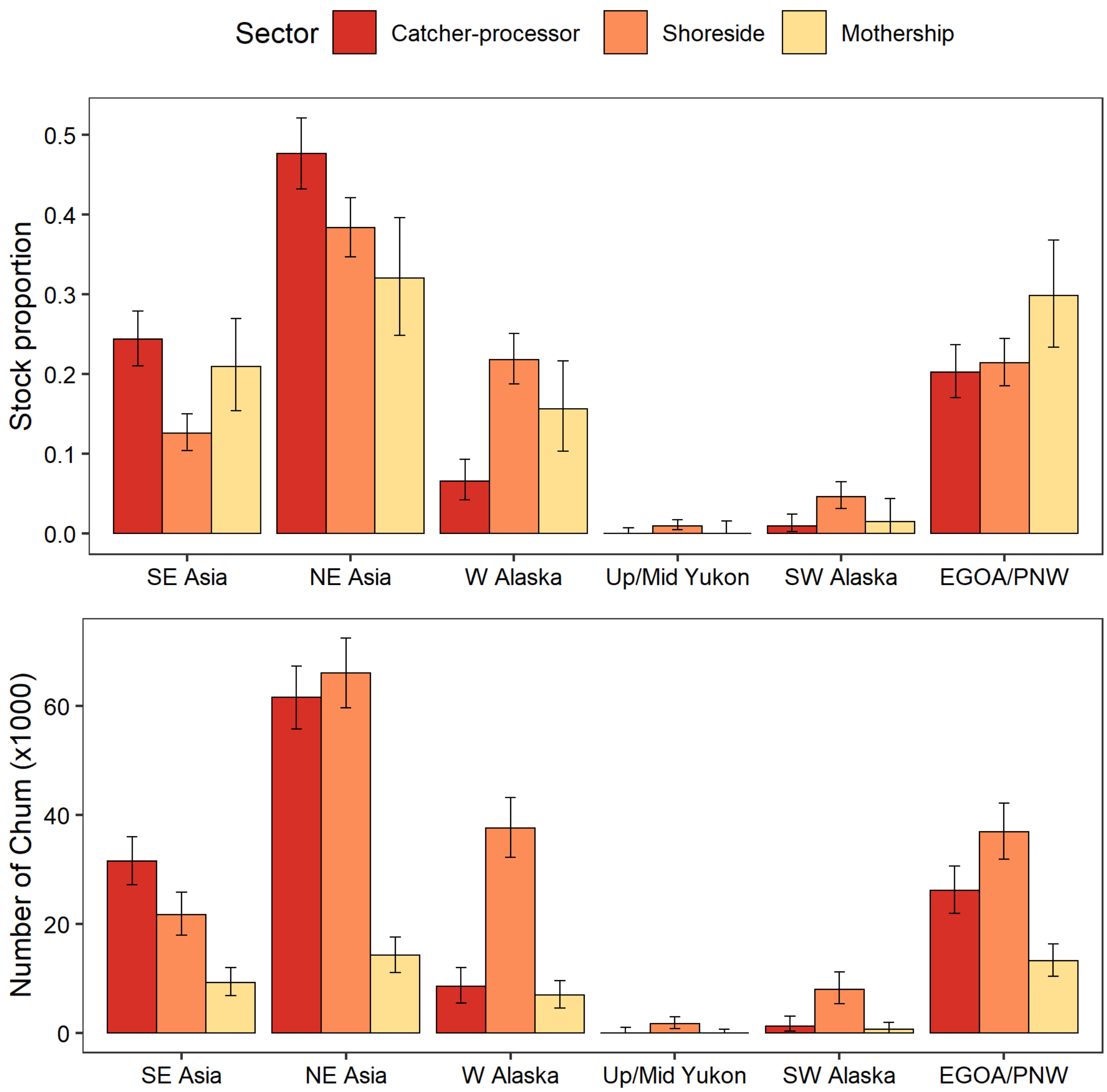

Figure 15. -- Stock composition estimates and 95% credible intervals for chum salmon from the 2019 Bering Sea, B-season pollock fishery from the catcher-processor, shoreside, and mothership fishing sectors. Proportions in top panel; numbers of fish in bottom panel.

SUMMARY

Stock composition estimates of the salmon caught in the Bering Sea groundfish fisheries are needed for fishery managers to understand the impact of these fisheries on salmon populations, particularly those in western Alaska. This report provides the genetic stock composition analyses of chum salmon PSC from the 2019 Bering Sea pollock fishery based on 2,237 samples genotyped: 1,848 representative, plus 389 extra samples added to increase sample size for spatial-temporal datasets. The limitations and results of this analysis are summarized below and in Appendix II.

Sampling Issues

We highlight the reduced spatial and temporal biases in the Bering Sea 2019 sample set (Figs. 3 and 5) relative to sample biases that were inherent before 2011. Amendment 91 to the North Pacific Fishery Management Council fishery management plan for groundfish of the Bering Sea and Aleutian Islands Management Area[4] requires that all salmon caught in the Bering Sea pollock fishery be sorted by species and counted to ensure compliance with the salmon PSC limits for the pollock fishery. This regulation led to a more representative sampling protocol, which in 2019, was met for 87% of chum salmon PSC (Fig. 6). As in 2017 and 2018, several vessels with high chum salmon PSC in the 2019 B-season were under-sampled due to limited sampling materials. Nevertheless, most of the chum salmon PSC was representatively sampled in 2019 and improved the capability to characterize the origin of salmon caught in the Bering Sea pollock fishery.

Stock Composition Estimates

More than half of the genetic samples collected from chum salmon caught in the 2019 Bering Sea, B-season pollock fishery were from Asia, with the majority from NE Asia (39%) stocks (Table 3; Fig. 8). The contribution from North America was predominantly from EGOA/PNW (23%) and W Alaska (16%) stocks. For the fourth consecutive year, the high chum salmon PSC in 2019 resulted in a large number of chum salmon caught from NE Asia stocks

[4] 75 FR 53026, August 30, 2010. https://www.federalregister.gov/documents/2010/08/30/2010-20618/fisheries-of-the-exclusive-economic-zone-off-alaska-chinook-salmon-bycatch-management-in-the-bering

(approximately 135,000 fish); the other stock groups also had higher numbers of chum salmon than in prior years, with the exception of the Up/Mid Yukon stocks, which were nearly absent in 2019. Although chum salmon sample collection in 2019 was largely representative for the pollock fishery, with the exception of lower than expected sample sizes from several under-sampled vessels, there were interannual differences in sampling (space and time) relative to previous years, so that caution must be used in making year-to-year comparisons.

Temporal and Spatial Effects

As in previous years, stock composition estimates of chum salmon from the 2019 Bering Sea, B-season pollock fishery changed across the three time periods for some reporting groups, suggesting a shift in the timing of chum salmon stocks in the Bering Sea, changes in fishing or sampling locations, or both (Fig. 9). We observed a higher contribution of W Alaska stocks during the Early time period and EGOA/PNW stocks during the Middle and Late time periods, and similar contributions across the three time periods from SE Asia and NE Asia stocks. An inverse relationship of contribution across years between NE Asia and EGOA/PNW stocks was most evident during the Middle and Late time periods.

Spatial analysis indicated that the majority of the chum salmon from U.S. waters of the Bering Sea west of 170°W originated from Asian stocks, whereas, the fish caught east of 170°W were approximately equally from Asia and North American stocks (Fig. 10). The SE Asia stock contribution was three times higher west of 170°W, and the W Alaska and EGOA/PNW stock contributions were approximately two times higher east of 170°W. The contributions of the other stocks were similar east and west of 170°W.

An examination of chum salmon stock estimates on both spatial and temporal strata indicates that stocks are not uniformly distributed (Figs. 11 and 12). The proportion of stocks from SE Asia was higher in the most northwestern area of the fishery (e.g., Cluster 4) and earlier in the season. The NE Asia stocks dominated both time periods at most spatial strata. Of the North American stocks, the W Alaska stock contribution was higher toward the southeastern portion of the fishery (e.g., Cluster 1) in the Early time period, the Up/Mid Yukon and SW Alaska contributions were low in both time periods and all spatial strata, and the EGOA/PNW contribution was higher in the Late time period and from Clusters 1-3 in both time periods.

Age Stratification

Knowledge about the age structure of salmon can be used to develop adult-equivalency (AEQ) models, which estimates impacts of PSC on individual salmon stocks (Ianelli and Stram 2015, Murphy et al. 2016). AEQ model development will benefit from more accurate age information such as that obtained from ageing fish scales.

The majority of the genetic samples collected from chum salmon caught in the Bering Sea, B-season pollock fishery were age-3 (42%) and age-4 (46%), with most of the remainder age-5 (10%). The age-3 chum salmon were about equally from Asian and North American stocks, primarily from SE Asia (28%), NE Asia (26%), and EGOA/PNW (40%) stocks. The age-4 chum salmon were about equally from Asian and North American stocks, primarily from NE Asia (47%) and W Alaska (26%) stocks (Fig. 13). The majority of age-5 chum salmon were from Asia (78%), primarily from NE Asia (63%) stocks. In general, this pattern was consistent at finer temporal and spatial scales (Fig. 14). Although a full exploration of the stock estimates from the many multi-strata datasets was not developed in this report, stock estimates for 2019 are available for many age-time-spatial strata in Appendix II.

Fishing Sector

In all three sectors, but most notably from the catcher-processor and shoreside sectors, the highest contribution by both proportions and numbers of fish was from NE Asia stocks (Fig. 15). Most of the chum salmon were caught in the catcher-processor and shoreside sectors, with the highest number of W Alaska fish from the shoreside sector. The number of chum salmon in the mothership sector was low for every reporting group.

Application of Estimates

The extent to which any salmon stock is impacted by the Bering Sea trawl fisheries is dependent on many factors including 1) the overall abundance of the PSC, 2) the age of the salmon caught, 3) the age composition of the salmon stocks at return, and 4) the total escapement of the affected stocks, taking into account lag time for maturity and returning to the river. As such, a higher stock composition estimate one year does not necessarily imply greater impact than a smaller estimate in another year.

ACKNOWLEDGMENTS

The collection of salmon tissue samples was an enormous endeavor by observers deployed through the AFSC's Fisheries Monitoring and Analysis Division (FMA). Katie D'Amelio and Kirby Karpan of ABL provided substantial support processing samples in the laboratory. Fishery information was provided by the FMA, Pacific States Marine Fisheries Commission (PSMFC), and NMFS Alaska Regional Office. Particular thanks go to Rob Ames, Bob Ryznar, and Camille Kohler (affiliate) of PSMFC who created and updated the AKFIN reports that facilitate access to salmon bycatch data in tabular and graphical form, and provide a mechanism to archive the genetic data. The baseline used for these analyses was obtained through a web portal sponsored by Fisheries and Oceans Canada and developed in their Molecular Genetics Laboratory with genetic loci identified in a number of laboratories. This document was reviewed by the ADF&G and AFSC, with special thanks to Jim Lee (AFSC Comms.).

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APPENDICES

Appendix I

Table of individual chum salmon populations in the Fisheries and Oceans Canada (DFO) microsatellite baseline (Beacham et al. 2009b, c), grouped by the six regions in this report that were used for stock identification of chum salmon caught in the Bering Sea pollock trawl fishery.

Appendix Table I. -- Chum salmon populations in the Fisheries and Oceans Canada (DFO) microsatellite baseline grouped by six regions used in the analyses of this report.

DFO num.	Population name	Reg num.	Region
41	Abashiri	1	SE Asia
215	Avakumovka	1	SE Asia
40	Chitose	1	SE Asia
315	Gakko_River	1	SE Asia
292	Hayatsuki	1	SE Asia
44	Horonai	1	SE Asia
252	Kawabukuro	1	SE Asia
313	Koizumi_River	1	SE Asia
300	Kushiro	1	SE Asia
37	Miomote	1	SE Asia
391	Namdae_R	1	SE Asia
231	Narva	1	SE Asia
298	Nishibetsu	1	SE Asia
293	Ohkawa	1	SE Asia
297	Orikasa	1	SE Asia
214	Ryazanovka	1	SE Asia
312	Sakari_River	1	SE Asia
311	Shari_River	1	SE Asia
36	Shibetsu	1	SE Asia
299	Shikiu	1	SE Asia
253	Shiriuchi	1	SE Asia
310	Shizunai	1	SE Asia
217	Suifen	1	SE Asia
35	Teshio	1	SE Asia
39	Tokachi	1	SE Asia
38	Tokoro	1	SE Asia
314	Tokushibetsu	1	SE Asia
291	Toshibetsu	1	SE Asia
296	Tsugaruishi	1	SE Asia
316	Uono_River	1	SE Asia
309	Yurappu	1	SE Asia
218	Amur	2	NE Asia
207	Anadyr	2	NE Asia
384	Apuka_River	2	NE Asia
382	Bolshaya	2	NE Asia
380	Dranka	2	NE Asia

DFO num.	Population name	Reg num.	Region
223	Hairusova	2	NE Asia
378	Ivashka	2	NE Asia
213	Kalininka	2	NE Asia
225	Kamchatka	2	NE Asia
219	Kanchalan	2	NE Asia
379	Karaga	2	NE Asia
294	Kikchik	2	NE Asia
209	Kol	2	NE Asia
233	Magadan	2	NE Asia
211	Naiba	2	NE Asia
295	Nerpichi	2	NE Asia
381	Okhota	2	NE Asia
212	Oklan	2	NE Asia
222	Ola	2	NE Asia
386	Olutorsky_Bay	2	NE Asia
228	Ossora	2	NE Asia
224	Penzhina	2	NE Asia
385	Plotnikova_R	2	NE Asia
221	Pymta	2	NE Asia
220	Tauy	2	NE Asia
383	Tugur_River	2	NE Asia
226	Tym_	2	NE Asia
230	Udarnitsa	2	NE Asia
290	Utka_River	2	NE Asia
208	Vorovskaya	2	NE Asia
387	Zhypanova	2	NE Asia
348	Agiapuk	3	W Alaska
376	Alagnak	3	W Alaska
3	Andreafsky	3	W Alaska
357	Aniak	3	W Alaska
301	Anvik	3	W Alaska
80	Chulinak	3	W Alaska
347	Eldorado	3	W Alaska
358	George	3	W Alaska
307	Gisasa	3	W Alaska
371	Goodnews	3	W Alaska

Appendix Table I. Continued.

DFO num.	Population name	Reg num.	Region
288	Henshaw_Creek	3	W Alaska
339	Imnachuk	3	W Alaska
361	Kanektok	3	W Alaska
362	Kasigluk	3	W Alaska
328	Kelly_Lake	3	W Alaska
340	Kobuk	3	W Alaska
343	Koyuk	3	W Alaska
363	Kwethluk	3	W Alaska
336	Kwiniuk_River	3	W Alaska
303	Melozitna	3	W Alaska
373	Mulchatna	3	W Alaska
372	Naknek	3	W Alaska
330	Niukluk	3	W Alaska
329	Noatak	3	W Alaska
345	Nome	3	W Alaska
302	Nulato	3	W Alaska
374	Nunsatuk	3	W Alaska
13	Peel_River	3	W Alaska
322	Pikmiktalik	3	W Alaska
331	Pilgrim_River	3	W Alaska
346	Shaktoolik	3	W Alaska
341	Snake	3	W Alaska
368	Stuyahok_River	3	W Alaska
375	Togiak	3	W Alaska
154	Tozitna	3	W Alaska
342	Unalakleet	3	W Alaska
344	Ungalik	3	W Alaska
8	Big_Creek	4	U/M Yukon
89	Big_Salt	4	U/M Yukon
86	Black_River	4	U/M Yukon
87	Chandalar	4	U/M Yukon
28	Chandindu	4	U/M Yukon
82	Cheena	4	U/M Yukon
81	Delta	4	U/M Yukon
7	Donjek	4	U/M Yukon
5	Fishing_Br	4	U/M Yukon
88	Jim_River	4	U/M Yukon

DFO num.	Population name	Reg num.	Region
85	Kantishna	4	U/M Yukon
2	Kluane	4	U/M Yukon
59	Kluane_Lake	4	U/M Yukon
181	Koyukuk_late	4	U/M Yukon
90	Koyukuk_south	4	U/M Yukon
10	Minto	4	U/M Yukon
6	Pelly	4	U/M Yukon
439	Porcupine	4	U/M Yukon
83	Salcha	4	U/M Yukon
4	Sheenjek	4	U/M Yukon
1	Tatchun	4	U/M Yukon
9	Teslin	4	U/M Yukon
84	Toklat	4	U/M Yukon
360	Alagoshak	5	SW Alaska
333	American_River	5	SW Alaska
366	Big_River	5	SW Alaska
354	Coleman_Creek	5	SW Alaska
355	Delta_Creek	5	SW Alaska
359	Egegik	5	SW Alaska
332	Frosty_Creek	5	SW Alaska
365	Gertrude_Creek	5	SW Alaska
370	Joshua_Green	5	SW Alaska
364	Meshik	5	SW Alaska
283	Moller_Bay	5	SW Alaska
369	Pumice_Creek	5	SW Alaska
367	Stepovak_Bay	5	SW Alaska
335	Sturgeon	5	SW Alaska
350	Uganik	5	SW Alaska
334	Volcano_Bay	5	SW Alaska
356	Westward_Creek	5	SW Alaska
239	Ahnuhati	6	E GOA/PNW
69	Ahta	6	E GOA/PNW
155	Ain	6	E GOA/PNW
183	Algard	6	E GOA/PNW
58	Alouette	6	E GOA/PNW
325	Alouette_North	6	E GOA/PNW
270	Andesite_Cr	6	E GOA/PNW

Appendix Table I. Continued.

DFO num.	Population name	Reg num.	Region
428	Arnoup	6	E GOA/PNW
153	Ashlulm	6	E GOA/PNW
156	Awun	6	E GOA/PNW
133	Bag_Harbour	6	E GOA/PNW
164	Barnard	6	E GOA/PNW
16	Bella_Bell	6	E GOA/PNW
79	Bella_Coola	6	E GOA/PNW
49	Big_Qual	6	E GOA/PNW
201	Big_Quilcene	6	E GOA/PNW
281	Bish_Cr	6	E GOA/PNW
198	Bitter_Creek	6	E GOA/PNW
103	Blackrock_Creek	6	E GOA/PNW
390	Blaney_Creek	6	E GOA/PNW
138	Botany_Creek	6	E GOA/PNW
264	Buck_Channel	6	E GOA/PNW
169	Bullock_Chann	6	E GOA/PNW
61	Campbell_River	6	E GOA/PNW
323	Carroll	6	E GOA/PNW
78	Cascade	6	E GOA/PNW
76	Cayeghle	6	E GOA/PNW
42	Cheakamus	6	E GOA/PNW
398	Cheenis_Lake	6	E GOA/PNW
51	Chehalis	6	E GOA/PNW
19	Chemainus	6	E GOA/PNW
47	Chilliwack	6	E GOA/PNW
392	Chilqua_Creek	6	E GOA/PNW
117	Chuckwalla	6	E GOA/PNW
139	Clapp_Basin	6	E GOA/PNW
107	Clatse_Creek	6	E GOA/PNW
118	Clyak	6	E GOA/PNW
62	Cold_Creek	6	E GOA/PNW
77	Colonial	6	E GOA/PNW
353	Constantine	6	E GOA/PNW
168	Cooper_Inlet	6	E GOA/PNW
197	County_Line	6	E GOA/PNW
12	Cowichan	6	E GOA/PNW
414	Crag_Cr	6	E GOA/PNW

DFO num.	Population name	Reg num.	Region
161	Dak_	6	E GOA/PNW
259	Dana_Creek	6	E GOA/PNW
123	Date_Creek	6	E GOA/PNW
250	Dawson_Inlet	6	E GOA/PNW
91	Dean_River	6	E GOA/PNW
261	Deena	6	E GOA/PNW
170	Deer_Pass	6	E GOA/PNW
46	Demamiel	6	E GOA/PNW
210	Dipac_Hatchery	6	E GOA/PNW
319	Disappearance	6	E GOA/PNW
269	Dog-tag	6	E GOA/PNW
177	Draney	6	E GOA/PNW
114	Duthie_Creek	6	E GOA/PNW
427	East_Arm	6	E GOA/PNW
266	Ecstall_River	6	E GOA/PNW
94	Elcho_Creek	6	E GOA/PNW
193	Ellsworth_Cr	6	E GOA/PNW
203	Elwha	6	E GOA/PNW
276	Ensheshese	6	E GOA/PNW
263	Fairfax_Inlet	6	E GOA/PNW
32	Fish_Creek	6	E GOA/PNW
429	Flux_Cr	6	E GOA/PNW
102	Foch_Creek	6	E GOA/PNW
179	Frenchman	6	E GOA/PNW
227	Gambier	6	E GOA/PNW
96	Gill_Creek	6	E GOA/PNW
166	Gilttoyee	6	E GOA/PNW
145	Glendale	6	E GOA/PNW
135	Gold_Harbour	6	E GOA/PNW
11	Goldstream	6	E GOA/PNW
66	Goodspeed_River	6	E GOA/PNW
136	Government	6	E GOA/PNW
205	Grant_Creek	6	E GOA/PNW
100	Green_River	6	E GOA/PNW
450	GreenRrHatchery	6	E GOA/PNW
237	Greens	6	E GOA/PNW
141	Harrison	6	E GOA/PNW

Appendix Table I. Continued.

DFO num.	Population name	Reg num.	Region
438	Harrison_late	6	E GOA/PNW
64	Hathaway_Creek	6	E GOA/PNW
234	Herman_Creek	6	E GOA/PNW
17	Heydon_Cre	6	E GOA/PNW
407	Hicks_Cr	6	E GOA/PNW
400	Homathko	6	E GOA/PNW
411	Honna	6	E GOA/PNW
204	Hoodsport	6	E GOA/PNW
185	Hooknose	6	E GOA/PNW
406	Hopedale_Cr	6	E GOA/PNW
412	Hutton_Head	6	E GOA/PNW
278	Illiance	6	E GOA/PNW
152	Inch_Creek	6	E GOA/PNW
146	Indian_River	6	E GOA/PNW
92	Jenny_Bay	6	E GOA/PNW
115	Kainet_River	6	E GOA/PNW
144	Kakweiken	6	E GOA/PNW
268	Kalum	6	E GOA/PNW
395	Kanaka_Cr	6	E GOA/PNW
402	Kano_Inlet_Cr	6	E GOA/PNW
162	Kateen	6	E GOA/PNW
389	Kawkawa	6	E GOA/PNW
95	Kemano	6	E GOA/PNW
192	Kennedy_Creek	6	E GOA/PNW
238	Kennell	6	E GOA/PNW
351	Keta_Creek	6	E GOA/PNW
101	Khutze_River	6	E GOA/PNW
126	Khutzeymateen	6	E GOA/PNW
282	Kiltuish	6	E GOA/PNW
93	Kimsquit	6	E GOA/PNW
187	Kimsquit_Bay	6	E GOA/PNW
419	Kincolith	6	E GOA/PNW
273	Kispiox	6	E GOA/PNW
106	Kitasoo	6	E GOA/PNW
99	Kitimat_River	6	E GOA/PNW
275	Kitsault_Riv	6	E GOA/PNW
163	Kitwanga	6	E GOA/PNW

DFO num.	Population name	Reg num.	Region
271	Kleanza_Cr	6	E GOA/PNW
437	Klewnuggit_Cr	6	E GOA/PNW
21	Klinaklini	6	E GOA/PNW
418	Ksedin	6	E GOA/PNW
125	Kshwan	6	E GOA/PNW
423	Kumealon	6	E GOA/PNW
112	Kwakusdis_River	6	E GOA/PNW
436	Kxngeal_Cr	6	E GOA/PNW
127	Lachmach	6	E GOA/PNW
262	Lagins	6	E GOA/PNW
131	Lagoon_Inlet	6	E GOA/PNW
448	LagoonCr	6	E GOA/PNW
167	Lard	6	E GOA/PNW
160	Little_Goose	6	E GOA/PNW
50	Little_Qua	6	E GOA/PNW
413	Lizard_Cr	6	E GOA/PNW
119	Lockhart-Gordon	6	E GOA/PNW
176	Lower_Lillooet	6	E GOA/PNW
137	Mace_Creek	6	E GOA/PNW
242	Mackenzie_Sound	6	E GOA/PNW
116	MacNair_Creek	6	E GOA/PNW
55	Mamquam	6	E GOA/PNW
121	Markle_Inlet_Cr	6	E GOA/PNW
27	Martin_Riv	6	E GOA/PNW
338	Mashiter_Creek	6	E GOA/PNW
109	McLoughin_Cr	6	E GOA/PNW
178	Milton	6	E GOA/PNW
194	Minter_Cr	6	E GOA/PNW
254	Mountain_Cr	6	E GOA/PNW
111	Mussel_River	6	E GOA/PNW
157	Naden	6	E GOA/PNW
337	Nahmint_River	6	E GOA/PNW
444	Nakut_Su	6	E GOA/PNW
14	Nanaimo	6	E GOA/PNW
122	Nangeese	6	E GOA/PNW
422	Nass_River	6	E GOA/PNW
399	Necleetsconnay	6	E GOA/PNW

Appendix Table I. Continued.

DFO num.	Population name	Reg num.	Region
113	Neekas_Creek	6	E GOA/PNW
321	Neets_Bay_early	6	E GOA/PNW
320	Neets_Bay_late	6	E GOA/PNW
173	Nekite	6	E GOA/PNW
104	Nias_Creek	6	E GOA/PNW
143	Nimpkish	6	E GOA/PNW
53	Nitinat	6	E GOA/PNW
191	Nooksack	6	E GOA/PNW
186	Nooseseck	6	E GOA/PNW
318	NorrishWorth	6	E GOA/PNW
159	North_Arm	6	E GOA/PNW
377	Olsen_Creek	6	E GOA/PNW
184	Orford	6	E GOA/PNW
287	Pa-aat_River	6	E GOA/PNW
260	Pacofi	6	E GOA/PNW
56	Pallant	6	E GOA/PNW
65	Pegattum_Creek	6	E GOA/PNW
48	Puntledge	6	E GOA/PNW
98	Quaal_River	6	E GOA/PNW
147	Quap	6	E GOA/PNW
108	Quartcha_Creek	6	E GOA/PNW
199	Quinault	6	E GOA/PNW
110	Roscoe_Creek	6	E GOA/PNW
397	Salmon_Bay	6	E GOA/PNW
195	Salmon_Cr	6	E GOA/PNW
134	Salmon_River	6	E GOA/PNW
200	Satsop	6	E GOA/PNW
236	Sawmill	6	E GOA/PNW
410	Seal_Inlet_Cr	6	E GOA/PNW
158	Security	6	E GOA/PNW
130	Sedgewick	6	E GOA/PNW
393	Serpentine_R	6	E GOA/PNW
317	Shovelnose_Cr	6	E GOA/PNW
249	Shustnini	6	E GOA/PNW
206	Siberia_Creek	6	E GOA/PNW
25	Silverdale	6	E GOA/PNW
196	Skagit	6	E GOA/PNW
274	Skeena	6	E GOA/PNW
171	Skowquiltz	6	E GOA/PNW
447	SkykomishRiv	6	E GOA/PNW
132	Slatechuck_Cre	6	E GOA/PNW
43	Sliammon	6	E GOA/PNW
15	Smith_Cree	6	E GOA/PNW
54	Snootli	6	E GOA/PNW
180	Southgate	6	E GOA/PNW
26	Squakum	6	E GOA/PNW
142	Squamish	6	E GOA/PNW
128	Stagoo	6	E GOA/PNW
265	Stanley	6	E GOA/PNW
52	Stave	6	E GOA/PNW
396	Stawamus	6	E GOA/PNW
409	Steel_Cr	6	E GOA/PNW
424	Stewart_Cr	6	E GOA/PNW
416	Stumaun_Cr	6	E GOA/PNW
327	Sugsaw	6	E GOA/PNW
324	Surprise	6	E GOA/PNW
75	Taaltz	6	E GOA/PNW
30	Taku	6	E GOA/PNW
18	Takwahoni	6	E GOA/PNW
251	Tarundl_Creek	6	E GOA/PNW
149	Theodosia	6	E GOA/PNW
22	Thorsen	6	E GOA/PNW
129	Toon	6	E GOA/PNW
279	Tseax	6	E GOA/PNW
202	Tulalip	6	E GOA/PNW
97	Turn_Creek	6	E GOA/PNW
430	Turtle_Cr	6	E GOA/PNW
247	Tuskwa	6	E GOA/PNW
165	Tyler	6	E GOA/PNW
33	Tzoonie	6	E GOA/PNW
124	Upper_Kitsumkal	6	E GOA/PNW
140	Vedder	6	E GOA/PNW
70	Viner_Sound	6	E GOA/PNW
45	Wahleach	6	E GOA/PNW

Appendix Table I. Continued.

DFO num.	Population name	Reg num.	Region
172	Walkum	6	E GOA/PNW
73	Waump	6	E GOA/PNW
232	Wells_Bridge	6	E GOA/PNW
352	Wells_River	6	E GOA/PNW
105	West_Arm_Creek	6	E GOA/PNW
267	Whitebottom_Cr	6	E GOA/PNW
326	Widgeon_Slough	6	E GOA/PNW
277	Wilauks_Cr	6	E GOA/PNW
120	Wilson_Creek	6	E GOA/PNW
401	Worth_Creek	6	E GOA/PNW
60	Wortley_Creek	6	E GOA/PNW
248	Yellow_Bluff	6	E GOA/PNW
434	Zymagotitz	6	E GOA/PNW

Appendix II

Regional stock composition estimates of chum salmon samples from the 2019 Bering Sea, B-season pollock trawl fishery. Estimated number of prohibited species catch (PSC), mean estimates, standard deviations (SD), 95% credible intervals, median estimate, the probability that the stock estimate is equal to zero (P = 0; values > 0.5 are shaded; Munro et al. 2012), and the Gelman-Rubin shrink factor (SF) are reported. For each stratum, PSC is the number of chum salmon reported as caught and n is the number of genetic samples used in the analysis. Early time period is Weeks 23-29, Middle time period is Weeks 30-34, and Late time period is Weeks 35-43. For the analyses of four spatial clusters, the Early time period is Weeks 23-32 and the Late time period is Weeks 33-43. Sample sets with spatial strata by cluster have extra samples added to increase sample size, and may produce stock estimates that differ from sample sets that are representative of the bycatch.

Appendix II. -- Regional stock composition estimates of chum salmon samples from the 2019 Bering Sea, B-season pollock trawl fishery.

B-season (PSC = 345,571; n = 1,848)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	62,195	0.180	0.009	0.162	0.180	0.199	0	1.00
NE Asia	135,615	0.392	0.014	0.366	0.392	0.419	0	1.00
W Alaska	55,085	0.159	0.010	0.139	0.159	0.180	0	1.00
Up/Mid Yukon	935	0.003	0.002	0.000	0.002	0.007	0.02	1.00
SW Alaska	12,568	0.036	0.006	0.026	0.036	0.048	0	1.01
E GOA/PNW	79,174	0.229	0.011	0.208	0.229	0.251	0	1.00

Early (PSC = 88,467; n = 424)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	14,875	0.168	0.019	0.133	0.168	0.207	0	1.00
NE Asia	36,354	0.411	0.028	0.356	0.411	0.466	0	1.00
W Alaska	24,457	0.276	0.025	0.229	0.276	0.326	0	1.00
Up/Mid Yukon	837	0.009	0.005	0.002	0.009	0.022	0	1.00
SW Alaska	3,978	0.045	0.012	0.025	0.044	0.070	0	1.00
E GOA/PNW	7,966	0.090	0.016	0.062	0.089	0.123	0	1.00

Middle (PSC = 93,221; n = 543)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	15,866	0.170	0.017	0.138	0.170	0.205	0	1.00
NE Asia	38,201	0.410	0.025	0.360	0.410	0.460	0	1.00
W Alaska	13,405	0.144	0.019	0.107	0.143	0.183	0	1.00
Up/Mid Yukon	674	0.007	0.007	0.001	0.004	0.024	0	1.00
SW Alaska	2,354	0.025	0.009	0.011	0.024	0.046	0	1.01
E GOA/PNW	22,722	0.244	0.020	0.205	0.243	0.285	0	1.00

Late (PSC = 163,883; n = 881)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	31,581	0.193	0.014	0.166	0.192	0.221	0	1.00
NE Asia	61,540	0.376	0.019	0.338	0.375	0.413	0	1.00
W Alaska	18,077	0.110	0.013	0.086	0.110	0.137	0	1.00
Up/Mid Yukon	0	0.000	0.001	0.000	0.000	0.004	0.77	1.00
SW Alaska	5,334	0.033	0.007	0.020	0.032	0.048	0	1.00
E GOA/PNW	47,351	0.289	0.017	0.257	0.289	0.322	0	1.00

Appendix II. -- Continued.

East of 170°W (PSC = 215,131; n = 1,134)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	22,040	0.102	0.009	0.085	0.102	0.122	0	1.00
NE Asia	80,474	0.374	0.017	0.341	0.374	0.408	0	1.00
W Alaska	44,176	0.205	0.014	0.178	0.205	0.233	0	1.00
Up/Mid Yukon	1,373	0.006	0.003	0.002	0.006	0.014	0	1.00
SW Alaska	9,092	0.042	0.008	0.027	0.042	0.059	0	1.00
E GOA/PNW	57,977	0.269	0.015	0.241	0.269	0.298	0	1.00

West of 170°W (PSC = 130,440; n = 714)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	40,837	0.313	0.019	0.277	0.313	0.350	0	1.00
NE Asia	56,451	0.433	0.022	0.390	0.433	0.475	0	1.00
W Alaska	9,431	0.072	0.013	0.048	0.072	0.100	0	1.00
Up/Mid Yukon	0	0.000	0.001	0.000	0.000	0.005	0.79	1.00
SW Alaska	4,130	0.032	0.008	0.017	0.031	0.050	0	1.00
E GOA/PNW	19,591	0.150	0.015	0.123	0.150	0.180	0	1.00

Cluster 1 Early (PSC = 68,443; n = 325)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	7,043	0.103	0.017	0.072	0.102	0.139	0	1.00
NE Asia	23,716	0.347	0.032	0.286	0.346	0.409	0	1.00
W Alaska	21,994	0.321	0.029	0.265	0.321	0.380	0	1.00
Up/Mid Yukon	1,053	0.015	0.007	0.005	0.014	0.032	0	1.00
SW Alaska	4,842	0.071	0.017	0.040	0.070	0.107	0	1.00
E GOA/PNW	9,796	0.143	0.023	0.101	0.142	0.190	0	1.00

Cluster 1 Late (PSC = 86,530; n = 499)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	8,496	0.098	0.014	0.072	0.098	0.127	0	1.00
NE Asia	30,729	0.355	0.025	0.306	0.355	0.406	0	1.00
W Alaska	15,616	0.180	0.020	0.142	0.180	0.222	0	1.00
Up/Mid Yukon	406	0.005	0.005	0.000	0.003	0.018	0	1.00
SW Alaska	2,862	0.033	0.010	0.016	0.032	0.056	0	1.00
E GOA/PNW	28,421	0.328	0.023	0.284	0.328	0.374	0	1.00

Appendix II. -- Continued.

Cluster 2 Early (PSC = 10,539; n = 187)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	1,290	0.122	0.027	0.075	0.121	0.179	0	1.00
NE Asia	5,814	0.552	0.045	0.463	0.552	0.639	0	1.00
W Alaska	1,093	0.104	0.030	0.051	0.102	0.167	0	1.00
Up/Mid Yukon	13	0.001	0.005	0.000	0.000	0.019	0.67	1.00
SW Alaska	844	0.080	0.022	0.042	0.078	0.129	0	1.00
E GOA/PNW	1,486	0.141	0.030	0.087	0.139	0.203	0	1.00

Cluster 2 Late (PSC = 25,394; n = 186)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	2,125	0.084	0.021	0.047	0.082	0.129	0	1.00
NE Asia	7,745	0.305	0.040	0.227	0.304	0.386	0	1.00
W Alaska	2,632	0.104	0.026	0.057	0.102	0.160	0	1.00
Up/Mid Yukon	46	0.002	0.005	0.000	0.000	0.019	0.63	1.00
SW Alaska	28	0.001	0.006	0.000	0.000	0.022	0.69	1.00
E GOA/PNW	12,817	0.505	0.041	0.426	0.505	0.585	0	1.00

Cluster 3 Early (PSC = 48,046; n = 291)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	11,431	0.238	0.026	0.188	0.237	0.291	0	1.00
NE Asia	19,161	0.399	0.034	0.332	0.399	0.467	0	1.00
W Alaska	5,703	0.119	0.023	0.076	0.118	0.167	0	1.00
Up/Mid Yukon	0	0.000	0.002	0.000	0.000	0.008	0.78	1.00
SW Alaska	190	0.004	0.006	0.000	0.001	0.021	0	1.00
E GOA/PNW	11,561	0.241	0.027	0.189	0.240	0.296	0	1.00

Cluster 3 Late (PSC = 5,552; n = 151)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	337	0.061	0.021	0.027	0.058	0.108	0	1.00
NE Asia	1,842	0.332	0.049	0.238	0.331	0.431	0	1.00
W Alaska	758	0.137	0.039	0.065	0.134	0.218	0	1.00
Up/Mid Yukon	267	0.048	0.020	0.017	0.046	0.093	0	1.00
SW Alaska	80	0.014	0.013	0.000	0.011	0.048	0	1.00
E GOA/PNW	2,267	0.408	0.043	0.325	0.408	0.495	0	1.00

Appendix II. -- Continued.

Cluster 4 Early (PSC = 3,337; n = 105)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	1,494	0.448	0.053	0.346	0.447	0.551	0	1.00
NE Asia	1,506	0.451	0.060	0.335	0.452	0.569	0	1.00
W Alaska	82	0.025	0.023	0.000	0.020	0.081	0.14	1.00
Up/Mid Yukon	68	0.020	0.015	0.001	0.017	0.057	0	1.00
SW Alaska	7	0.002	0.009	0.000	0.000	0.030	0.67	1.00
E GOA/PNW	179	0.054	0.031	0.006	0.050	0.124	0.01	1.00

Cluster 4 Late (PSC = 74,157; n = 372)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	28,171	0.380	0.027	0.329	0.380	0.433	0	1.00
NE Asia	36,680	0.495	0.030	0.435	0.495	0.554	0	1.00
W Alaska	3,853	0.052	0.016	0.023	0.051	0.086	0	1.00
Up/Mid Yukon	2	0.000	0.001	0.000	0.000	0.005	0.77	1.00
SW Alaska	914	0.012	0.009	0.002	0.011	0.035	0	1.00
E GOA/PNW	4,538	0.061	0.015	0.035	0.060	0.092	0	1.00

Age-3 Fish (PSC = 143,890; n = 610)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	39,506	0.275	0.019	0.238	0.274	0.312	0	1.00
NE Asia	37,231	0.259	0.021	0.219	0.259	0.300	0	1.00
W Alaska	6,716	0.047	0.011	0.026	0.046	0.070	0	1.00
Up/Mid Yukon	731	0.005	0.003	0.001	0.004	0.013	0	1.00
SW Alaska	1,710	0.012	0.006	0.004	0.011	0.026	0	1.00
E GOA/PNW	57,996	0.403	0.021	0.361	0.403	0.445	0	1.00

Age-4 Fish (PSC = 160,166; n = 679)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	15,444	0.096	0.012	0.073	0.096	0.122	0	1.00
NE Asia	75,709	0.473	0.023	0.427	0.473	0.518	0	1.00
W Alaska	41,234	0.257	0.020	0.219	0.257	0.298	0	1.00
Up/Mid Yukon	294	0.002	0.003	0.000	0.001	0.012	0.40	1.00
SW Alaska	7,309	0.046	0.011	0.027	0.045	0.069	0	1.00
E GOA/PNW	20,176	0.126	0.015	0.098	0.126	0.156	0	1.00

Appendix II. -- Continued.

Age-5 Fish (PSC = 33,967; n = 144)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	5,313	0.156	0.033	0.098	0.155	0.225	0	1.00
NE Asia	21,338	0.628	0.049	0.530	0.629	0.722	0	1.00
W Alaska	6,121	0.180	0.039	0.108	0.179	0.261	0	1.00
Up/Mid Yukon	0	0.000	0.004	0.000	0.000	0.015	0.77	1.00
SW Alaska	229	0.007	0.011	0.000	0.001	0.040	0	1.00
E GOA/PNW	966	0.028	0.017	0.002	0.026	0.068	0.01	1.00

Age-3 Early (PSC = 46,941; n = 199)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	13,483	0.287	0.034	0.224	0.286	0.355	0	1.00
NE Asia	13,117	0.279	0.038	0.208	0.279	0.356	0	1.00
W Alaska	2,029	0.043	0.021	0.008	0.041	0.090	0	1.00
Up/Mid Yukon	823	0.018	0.011	0.003	0.016	0.043	0	1.00
SW Alaska	2,145	0.046	0.014	0.024	0.044	0.078	0	1.00
E GOA/PNW	15,345	0.327	0.036	0.259	0.326	0.398	0	1.00

Age-3 Late (PSC = 96,949; n = 411)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	26,643	0.275	0.023	0.231	0.274	0.321	0	1.00
NE Asia	23,701	0.244	0.025	0.197	0.244	0.295	0	1.00
W Alaska	4,323	0.045	0.013	0.022	0.044	0.073	0	1.00
Up/Mid Yukon	2	0.000	0.001	0.000	0.000	0.004	0.78	1.00
SW Alaska	221	0.002	0.004	0.000	0.000	0.015	0.50	1.00
E GOA/PNW	42,060	0.434	0.026	0.383	0.434	0.486	0	1.00

Age-4 Early (PSC = 75,955; n = 322)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	5,948	0.078	0.016	0.050	0.077	0.113	0	1.00
NE Asia	32,405	0.427	0.033	0.362	0.426	0.493	0	1.00
W Alaska	25,889	0.341	0.031	0.281	0.341	0.403	0	1.00
Up/Mid Yukon	217	0.003	0.005	0.000	0.001	0.016	0.35	1.00
SW Alaska	2,378	0.031	0.013	0.010	0.030	0.060	0	1.00
E GOA/PNW	9,118	0.120	0.021	0.081	0.119	0.164	0	1.00

Appendix II. -- Continued.

Age-4 Late (PSC = 84,211; n = 357)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	9,983	0.119	0.019	0.085	0.118	0.157	0	1.00
NE Asia	43,046	0.511	0.032	0.448	0.511	0.574	0	1.00
W Alaska	15,583	0.185	0.026	0.137	0.184	0.237	0	1.00
Up/Mid Yukon	105	0.001	0.005	0.000	0.000	0.019	0.61	1.00
SW Alaska	4,297	0.051	0.015	0.027	0.050	0.083	0	1.00
E GOA/PNW	11,197	0.133	0.021	0.093	0.132	0.177	0	1.00

Age-3 Cluster 1 (PSC = 64,528; n = 232)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	9,949	0.154	0.024	0.110	0.153	0.205	0	1.00
NE Asia	16,723	0.259	0.034	0.195	0.258	0.327	0	1.00
W Alaska	4,314	0.067	0.020	0.032	0.065	0.109	0	1.00
Up/Mid Yukon	380	0.006	0.005	0.000	0.004	0.020	0	1.00
SW Alaska	2,615	0.041	0.014	0.019	0.038	0.074	0	1.00
E GOA/PNW	30,548	0.473	0.035	0.404	0.473	0.543	0	1.00

Age-3 Cluster 1 Late (PSC = 36,030; n = 207)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	5,076	0.141	0.025	0.096	0.140	0.193	0	1.00
NE Asia	9,755	0.271	0.036	0.202	0.270	0.344	0	1.00
W Alaska	3,042	0.084	0.022	0.045	0.083	0.132	0	1.00
Up/Mid Yukon	0	0.000	0.002	0.000	0.000	0.008	0.78	1.00
SW Alaska	386	0.011	0.011	0.001	0.007	0.039	0	1.00
E GOA/PNW	17,770	0.493	0.038	0.421	0.493	0.567	0	1.00

Age-3 Cluster 2 (PSC = 14,962; n = 134)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	1,724	0.115	0.029	0.064	0.113	0.178	0	1.00
NE Asia	3,167	0.212	0.044	0.132	0.210	0.302	0	1.00
W Alaska	0	0.000	0.008	0.000	0.000	0.028	0.71	1.00
Up/Mid Yukon	16	0.001	0.004	0.000	0.000	0.014	0.68	1.00
SW Alaska	392	0.026	0.022	0.005	0.021	0.078	0	1.00
E GOA/PNW	9,662	0.646	0.047	0.552	0.647	0.735	0	1.00

Appendix II. -- Continued.

Age-3 Cluster 3 (PSC = 22,317; n = 169)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	5,720	0.256	0.035	0.191	0.255	0.328	0	1.00
NE Asia	4,410	0.198	0.038	0.126	0.196	0.276	0	1.00
W Alaska	1,052	0.047	0.023	0.010	0.045	0.098	0	1.00
Up/Mid Yukon	730	0.033	0.015	0.009	0.031	0.067	0	1.00
SW Alaska	0	0.000	0.004	0.000	0.000	0.015	0.77	1.00
E GOA/PNW	10,405	0.466	0.041	0.386	0.466	0.548	0	1.00

Age-3 Cluster 3 Early (PSC = 20,006; n = 121)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	6,624	0.331	0.045	0.246	0.330	0.422	0	1.00
NE Asia	5,194	0.260	0.048	0.169	0.258	0.358	0	1.00
W Alaska	1,300	0.065	0.031	0.014	0.062	0.134	0	1.00
Up/Mid Yukon	371	0.019	0.015	0.003	0.015	0.058	0	1.00
SW Alaska	4	0.000	0.005	0.000	0.000	0.016	0.76	1.00
E GOA/PNW	6,513	0.326	0.044	0.242	0.324	0.416	0	1.00

Age-3 Cluster 4 (PSC = 32,263; n = 176)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	18,424	0.571	0.039	0.492	0.571	0.647	0	1.00
NE Asia	7,494	0.232	0.038	0.162	0.231	0.309	0	1.00
W Alaska	891	0.028	0.017	0.001	0.025	0.067	0.02	1.00
Up/Mid Yukon	391	0.012	0.008	0.002	0.010	0.033	0	1.00
SW Alaska	82	0.003	0.007	0.000	0.000	0.023	0.60	1.00
E GOA/PNW	4,980	0.154	0.030	0.101	0.153	0.217	0	1.00

Age-3 Cluster 4 Late (PSC = 30,878; n = 134)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	18,336	0.594	0.045	0.504	0.594	0.680	0	1.00
NE Asia	6,376	0.206	0.044	0.126	0.205	0.298	0	1.00
W Alaska	982	0.032	0.021	0.000	0.029	0.081	0.02	1.00
Up/Mid Yukon	0	0.000	0.003	0.000	0.000	0.009	0.78	1.00
SW Alaska	228	0.007	0.011	0.001	0.002	0.038	0	1.00
E GOA/PNW	4,956	0.161	0.035	0.098	0.159	0.234	0	1.00

Appendix II. -- Continued.

Age-4 Cluster 1 (PSC = 71,827; n = 311)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	3,579	0.050	0.013	0.028	0.049	0.078	0	1.00
NE Asia	26,185	0.365	0.032	0.302	0.364	0.428	0	1.00
W Alaska	25,593	0.356	0.032	0.294	0.356	0.420	0	1.00
Up/Mid Yukon	1,422	0.020	0.012	0.003	0.017	0.049	0	1.00
SW Alaska	3,397	0.047	0.015	0.022	0.046	0.081	0	1.00
E GOA/PNW	11,652	0.162	0.023	0.119	0.161	0.210	0	1.00

Age-4 Cluster 1 Early (PSC = 31,722; n = 154)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	1,682	0.053	0.019	0.022	0.051	0.095	0	1.00
NE Asia	11,136	0.351	0.045	0.265	0.350	0.441	0	1.00
W Alaska	13,655	0.430	0.044	0.345	0.430	0.517	0	1.00
Up/Mid Yukon	371	0.012	0.011	0.001	0.009	0.040	0	1.00
SW Alaska	1,729	0.054	0.021	0.019	0.052	0.102	0	1.00
E GOA/PNW	3,148	0.099	0.029	0.049	0.097	0.161	0	1.00

Age-4 Cluster 1 Late (PSC = 40,105; n = 157)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	2,418	0.060	0.020	0.027	0.058	0.104	0	1.00
NE Asia	14,572	0.363	0.046	0.275	0.363	0.455	0	1.00
W Alaska	11,943	0.298	0.043	0.215	0.297	0.385	0	1.00
Up/Mid Yukon	387	0.010	0.013	0.000	0.006	0.047	0.31	1.00
SW Alaska	2,576	0.064	0.023	0.028	0.062	0.117	0	1.00
E GOA/PNW	8,209	0.205	0.035	0.141	0.203	0.276	0	1.00

Age-4 Cluster 2 (PSC = 16,654; n = 168)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	1,608	0.097	0.026	0.052	0.095	0.152	0	1.00
NE Asia	9,209	0.553	0.048	0.458	0.553	0.646	0	1.00
W Alaska	2,482	0.149	0.037	0.082	0.147	0.225	0	1.00
Up/Mid Yukon	33	0.002	0.006	0.000	0.000	0.022	0.64	1.00
SW Alaska	1,627	0.098	0.027	0.050	0.096	0.156	0	1.00
E GOA/PNW	1,694	0.102	0.028	0.052	0.100	0.162	0	1.00

Appendix II. -- Continued.

Age-4 Cluster 2 Early (PSC = 4,885; n = 104)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	486	0.099	0.034	0.043	0.096	0.173	0	1.00
NE Asia	3,019	0.618	0.063	0.493	0.619	0.738	0	1.00
W Alaska	640	0.131	0.050	0.044	0.128	0.239	0	1.00
Up/Mid Yukon	0	0.000	0.008	0.000	0.000	0.027	0.74	1.00
SW Alaska	557	0.114	0.039	0.042	0.111	0.198	0	1.00
E GOA/PNW	183	0.037	0.024	0.000	0.034	0.095	0.02	1.00

Age-4 Cluster 3 (PSC = 24,842; n = 162)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	2,639	0.106	0.026	0.060	0.104	0.163	0	1.00
NE Asia	9,966	0.401	0.051	0.302	0.401	0.502	0	1.00
W Alaska	5,733	0.231	0.041	0.154	0.229	0.314	0	1.00
Up/Mid Yukon	183	0.007	0.009	0.000	0.005	0.032	0.18	1.00
SW Alaska	1,092	0.044	0.021	0.010	0.042	0.092	0	1.00
E GOA/PNW	5,229	0.210	0.037	0.143	0.209	0.286	0	1.00

Age-4 Cluster 3 Early (PSC = 22,268; n = 98)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	2,875	0.129	0.035	0.069	0.126	0.206	0	1.00
NE Asia	8,075	0.363	0.061	0.248	0.361	0.486	0	1.00
W Alaska	5,794	0.260	0.053	0.162	0.259	0.367	0	1.00
Up/Mid Yukon	0	0.000	0.004	0.000	0.000	0.014	0.78	1.00
SW Alaska	840	0.038	0.024	0.006	0.034	0.094	0	1.00
E GOA/PNW	4,684	0.210	0.046	0.126	0.208	0.307	0	1.00

Age-4 Cluster 4 (PSC = 35,912; n = 155)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	8,294	0.231	0.036	0.164	0.230	0.304	0	1.00
NE Asia	23,634	0.658	0.045	0.569	0.659	0.743	0	1.00
W Alaska	2,551	0.071	0.029	0.021	0.069	0.134	0	1.00
Up/Mid Yukon	0	0.000	0.004	0.000	0.000	0.013	0.76	1.00
SW Alaska	1,303	0.036	0.019	0.009	0.034	0.079	0	1.00
E GOA/PNW	130	0.004	0.010	0.000	0.000	0.034	0.48	1.00

Appendix II. -- Continued.

Age-4 Cluster 4 Late (PSC = 34,370; n = 134)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	7,665	0.223	0.038	0.153	0.222	0.301	0	1.00
NE Asia	22,530	0.656	0.048	0.559	0.657	0.747	0	1.00
W Alaska	2,711	0.079	0.033	0.022	0.077	0.150	0	1.00
Up/Mid Yukon	33	0.001	0.005	0.000	0.000	0.017	0.70	1.00
SW Alaska	1,089	0.032	0.019	0.007	0.028	0.077	0	1.00
E GOA/PNW	342	0.010	0.013	0.000	0.006	0.046	0.25	1.00

Catcher-processor (PSC = 129,082; n = 681)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	31,511	0.244	0.017	0.210	0.244	0.279	0	1.00
NE Asia	61,533	0.477	0.023	0.432	0.477	0.521	0	1.00
W Alaska	8,556	0.066	0.013	0.042	0.066	0.093	0	1.00
Up/Mid Yukon	0	0.000	0.002	0.000	0.000	0.008	0.78	1.01
SW Alaska	1,289	0.010	0.006	0.002	0.009	0.024	0	1.00
E GOA/PNW	26,192	0.203	0.017	0.170	0.203	0.237	0	1.00

Mothership (PSC = 44,496; n = 211)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	9,319	0.209	0.030	0.154	0.209	0.270	0	1.00
NE Asia	14,252	0.320	0.038	0.249	0.319	0.396	0	1.00
W Alaska	6,967	0.157	0.029	0.103	0.155	0.217	0	1.00
Up/Mid Yukon	0	0.000	0.005	0.000	0.000	0.016	0.77	1.00
SW Alaska	673	0.015	0.012	0.001	0.013	0.044	0	1.00
E GOA/PNW	13,284	0.299	0.034	0.234	0.298	0.368	0	1.00

Shoreside (PSC = 171,993; n = 930)

Region	Est. num.	Mean	SD	2.5%	Median	97.5%	P = 0	SF
SE Asia	21,705	0.126	0.012	0.104	0.126	0.150	0	1.00
NE Asia	66,003	0.384	0.019	0.347	0.384	0.421	0	1.00
W Alaska	37,595	0.219	0.016	0.188	0.218	0.251	0	1.00
Up/Mid Yukon	1,710	0.010	0.003	0.005	0.009	0.018	0	1.00
SW Alaska	8,057	0.047	0.009	0.031	0.046	0.065	0	1.00
E GOA/PNW	36,922	0.215	0.015	0.186	0.214	0.245	0	1.00

Appendix III

Basic overview of Bayesian mixed-stock analysis pertinent to the chum salmon prohibited species catch (PSC) in the Bering Sea pollock trawl fishery.

Mixed stock analysis (MSA) requires three components:

1. A mixture containing genotypes of samples of unknown origin (e.g., chum salmon PSC samples).

2. A baseline of allele frequencies of potentially contributing stocks in the mixture (same genetic markers as the mixture). The baseline is typically comprised of stock groups[5], populations that are grouped due to genetic similarity, geographic proximity, or political boundaries. For the chum salmon PSC we used the 381-population, 11-locus microsatellite baseline from Fisheries and Oceans Canada (DFO), with populations grouped into six regions.

3. A method to compare the mixture to the baseline to estimate the proportions of baseline populations, or more commonly stock groups, in the mixture. Two methods have been used in our MSA studies:

   a. **Maximum-likelihood** method in program SPAM (Debevec et al. 2000, ADF&G 2003) has been used in analyses in previous years. For the chum salmon PSC samples, the likelihood method typically estimates stock proportions similar to those produced by the Bayesian method. A comparison of the stock proportions produced by the two methods provides a quality control check on the MSA.

   b. **Bayesian** method in program BAYES (Pella and Masuda 2001) and *rubias* (Moran and Anderson 2019), described below.

MSA using the BAYES and *rubias* programs requires several steps:

1. Assign parameters of the prior distribution for the unknown stock proportions. Typically an uninformative prior with parameters equal to 1/number of stocks is used unless independent information is available for setting an informative prior. If stock-group estimates are made, then an uninformative prior for the stock-group proportions is set (parameters equal to $1/GC_g$ where G is the number of groups and C_g is the number of baseline populations in group g).

2. Choose the number of Markov chain Monte Carlo (MCMC) samples to simulate from the posterior distribution of stock proportions (depends on the data, but 50,000 to 100,000 is commonly used in our salmon mixed-stock applications).

3. Run several sets of MCMC samples (at least 3 "chains") with disparate values of initial mixture stock proportions such that most of the contribution comes from one stock or stock group. In the chum salmon PSC analyses, six chains were used, the first of which was started with 95% of the contribution coming from the first baseline region and 5% from all other regions. The other chains were similarly started.

[5] Depending upon the context, stock groups are sometimes referred to as reporting groups or regional groups.

4. Evaluate convergence of stock proportion estimates to the posterior distribution. Two diagnostics help gauge convergence. Increase the number of MCMC samples until the stock estimates converge.

    a. **Within chains:** the Raftery and Lewis (1996) diagnostic is useful for determining the number of MCMC samples required to estimate quantiles of the posterior distribution with a specified accuracy and probability.

    b. **Across chains:** the Gelman and Rubin (1992) diagnostic compares the variation within a single chain for a given parameter (e.g., unknown stock proportion) to the total variation among chains and summarizes the two measures by a univariate statistic called the shrink factor. A shrink factor near 1 is consistent with convergence of the samples to the posterior distribution. A shrink factor >1.2 may indicate lack of convergence.

5. Once convergence is determined, the MCMC samples of stock composition estimates are combined from all chains and summarized (e.g., mean, median, standard deviation, 2.5% and 97.5% quantiles), typically from the last half of the chains to remove the influence of the initial values.

Appendix IV

Four spatial clusters of ADF&G groundfish statistical areas[6] of chum salmon prohibited species catch sampled from 2013 to 2019 during the B-season of the Bering Sea pollock trawl fishery and analyzed for genetic stock composition. The areas sampled in 2019 in which at least three fishing vessels are represented are in bold (Fig. 11).

[6] http://www.adfg.alaska.gov/index.cfm?adfg=fishingCommercialByFishery.statmaps

Cluster 1: 625504, 625531, 625600, 625630, 625700, 625730, 635501, **635504**, **635530**, 635600, 635630, 635700, 635730, 645434, **645501**, 645502, 645530, 645600, 645630, 645700, 645730, 655407, **655409**, **655410**, **655430**, **655500**, 655530, **655600**, 655630, 655700, 655730, 665335, 665336, **665401**, 665403, 665404, **665430**, 665500, 665530, 665600, 665630, 665700, 665730

Cluster 2: **675430**, **675500**, 675530, 675600, 675630, 675700, 675730, **685500**, **685530**, **685600**, 685630, 685700, 685730

Cluster 3: 695530, **695600**, 695631, 695632, **705530**, **705600**, **705630**, 705701, 705730, **715600**, **715630**, 715700, 715730, **725630**, 725700, 725730, **735630**, **735700**, 735730, 745730

Cluster 4: 705800, 705830, 715800, 715830, 725800, 725830, 725900, 735800, 735830, 735900, 735930, **745800**, **745830**, **745900**, 745930, 746000, 755800, **755830**, **755900**, **755930**, **756000**, **765830**, **765900**, **765930**, **766000**, 766030, **775830**, **775900**, **775930**, **776000**, 776030, **785900**, **785930**, **786000**, **786030**

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August 2021

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