Agenda Item G.8.a
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2023 Chinook Bycatch - Preliminary in-season assessment of ESU-specific impacts in Pacific hake trawl fisheries

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Abstract

Unusually high levels of Chinook salmon bycatch were observed in spring 2023 among multiple mid-water trawl fleets in US West Coast groundfish fisheries. Chinook bycatch accounting and management in groundfish fisheries is based on the total number of Chinook, not stock-specific impacts. However, recognizing heightened interest in understanding impacts to certain Evolutionarily Significant Units (ESUs) at this time, Northwest Fisheries Science Center staff analyzed expedited the processing and analysis of data for spring bycatch sampled by the At-Sea Hake Observer Program (A-SHOP) and shoreside IFQ Catch Monitor Program (CMP). This report describes results from compositional forecasts used to project likely ESU-specific impacts from spring bycatch in at-sea and shoreside Pacific hake sectors, including a large bycatch event (LBE) that occurred at a high latitude, far to the north of most bycatch in this fishery. Of 2076 Chinook sampled by both programs (1154 and 922, respectively), 331 or 16% are projected to have come from listed ESUs. Those estimated percentages were similar for A-SHOP samples and most CMP samples (9-10%). However, because the predictive model is strongly driven by latitude, the LBE reported by the CMP is likely to have a very different ESU composition with a much higher percentage of listed fish (44%). For the LBE, we predicted significant numbers of Puget Sound and Lower Columbia River fish (108 and 60), but many fewer from California Coast (2). By contrast the at-sea sectors are projected to have very low numbers of Puget Sound and Lower Columbia River (5 each) but high numbers for California Coast (72). A similar pattern was seen for other sensitive ESUs such as Klamath/Trinity. The southern footprint of the at-sea fleet is expected to take >500 Klamath/Trinity fish, which are abundant at southern latitudes and are historically major contributors to bycatch. The predictions reported here for at-sea bycatch are being tested against genetic mixture analysis of actual tissue samples. Preliminary results are expected for presentation at the September Council meeting.

Introduction

High salmon bycatch May and early June of 2023 in Pacific hake fisheries led to calls from the management community for in-season analysis of ESU-specific impacts on Chinook salmon. Rapid-response and real-time genetic mixture analyses are generally avoided because of the inherent inefficiency of these dedicated efforts. However, it was determined that elevated concerns were such that some expedited evaluation was warranted, despite the fact that there is no mechanism for in-season management response to specific ESU impacts. Although real-time analysis (daily or weekly) of these fisheries is essentially intractable, this in-season analysis is an attempted compromise. The NWFSC does not currently have the resources to support regular in-season genetic mixture analysis of chinook bycatch in groundfish fisheries.

History of US West Coast compositional forecasting of Chinook ESU impacts

The NWFSC's Fishery Resource Analysis and Monitoring (FRAM) and Conservation Biology (CB) divisions implemented the genetic research, monitoring and evaluation (RM&E) program in 2008. In the early years, only limited resources were available and it took time for data to accrue and patterns to emerge. Eventually, all collection and biodata were evaluated with an 8-year time series for predictive ability in estimating ESU-specific impacts. It became clear that simple mean latitude of all samples collected in a given year was by far the strongest predictor of stock composition (Figures 1-3). Moreover, it was an accessible quantity that could be developed for different fishery management scenarios (Matson and Hooper 2021).

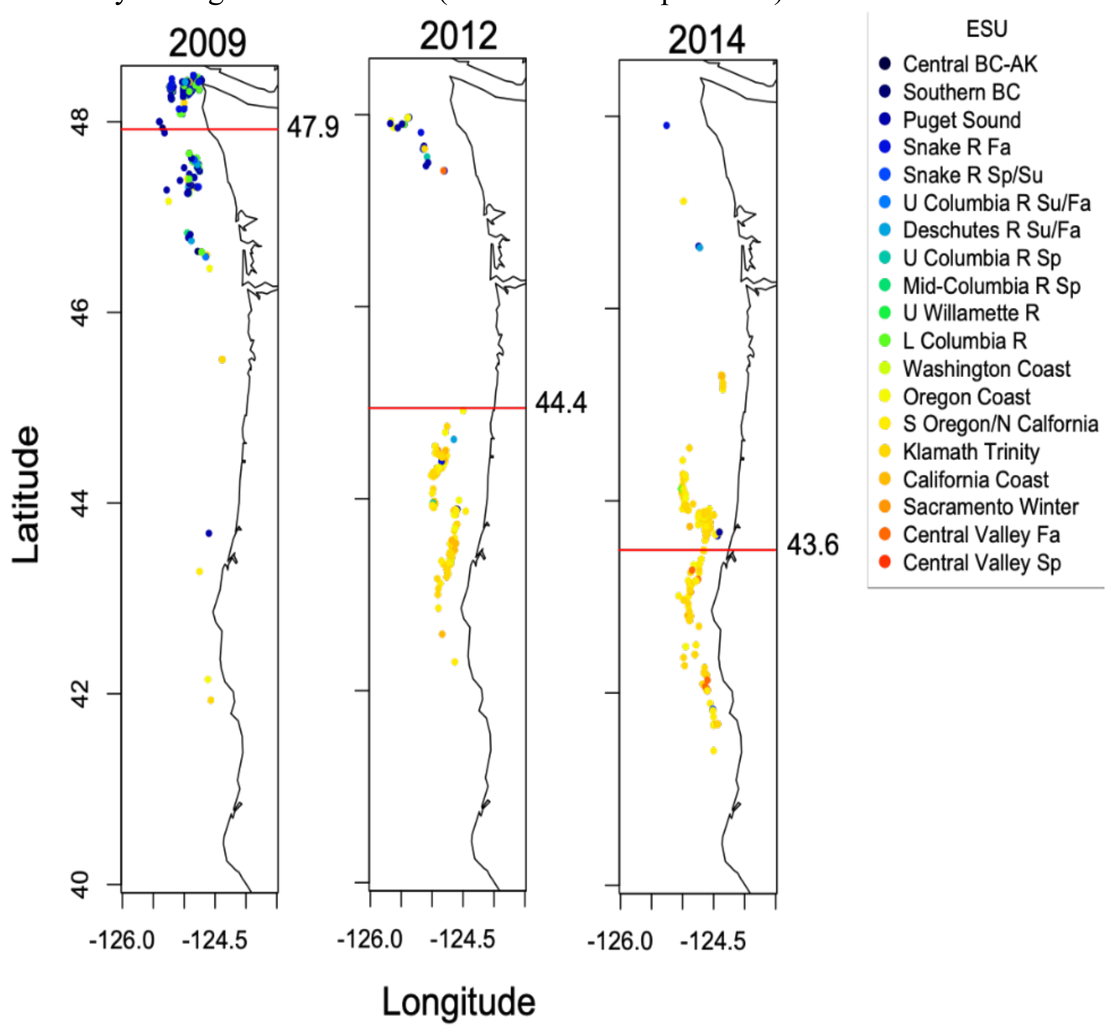

Figure 1. Shifts in mean latitude of annual bycatch produced significant changes in stock proportions.

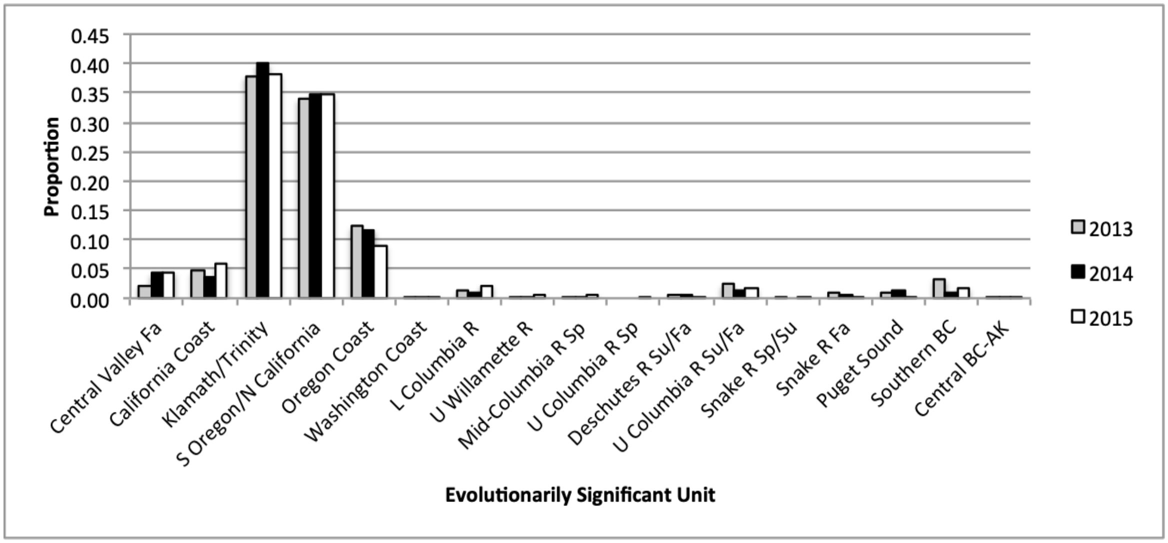

Figure 2. Bycatch samples in 2013, 2014, and 2015 had similar latitudinal distribution and also similar stock compositions.

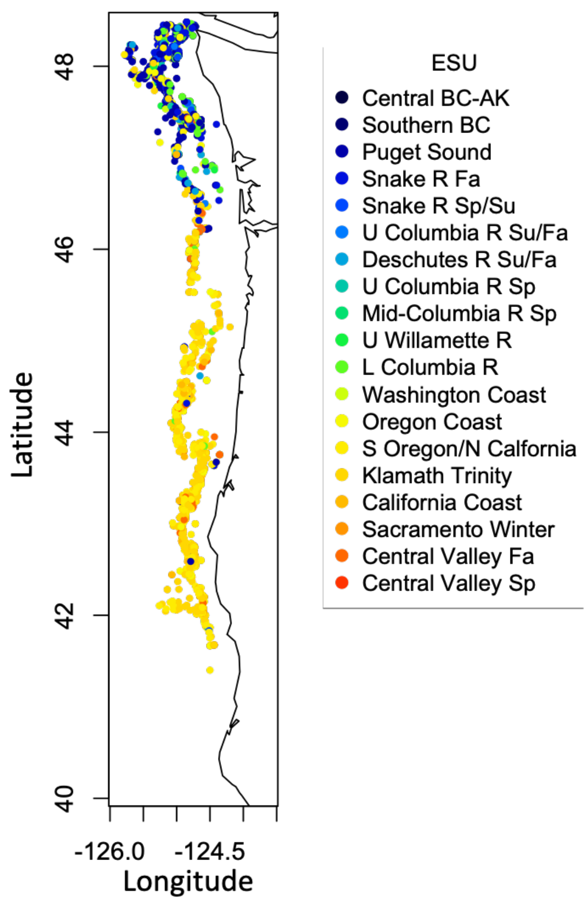

Figure 3. Chinook salmon taken in the at-sea sectors of the US West Coast Pacific hake fishery 2008 – 2015 (N = 3042) showed a clear latitudinal cline in stock composition.

Between 2015 and 2016, NWFSC began developing predictive compositional forecasting models to evaluate fishery contingencies and develop take tables for the 2017 groundfish BiOp (NMFS 2017). These were simply regression models that accommodated the multinomial logistic distributions of Chinook salmon ESUs (bounded by zero and one). Initial attempts were crude, but the method showed promise and was refined, cross validated, and extensively reviewed by NWFSC staff and anonymous reviewers. A paper describing the model is currently invited for publication in Evolutionary Applications, and the manuscript is available in preprint (Moran et al. 2021).

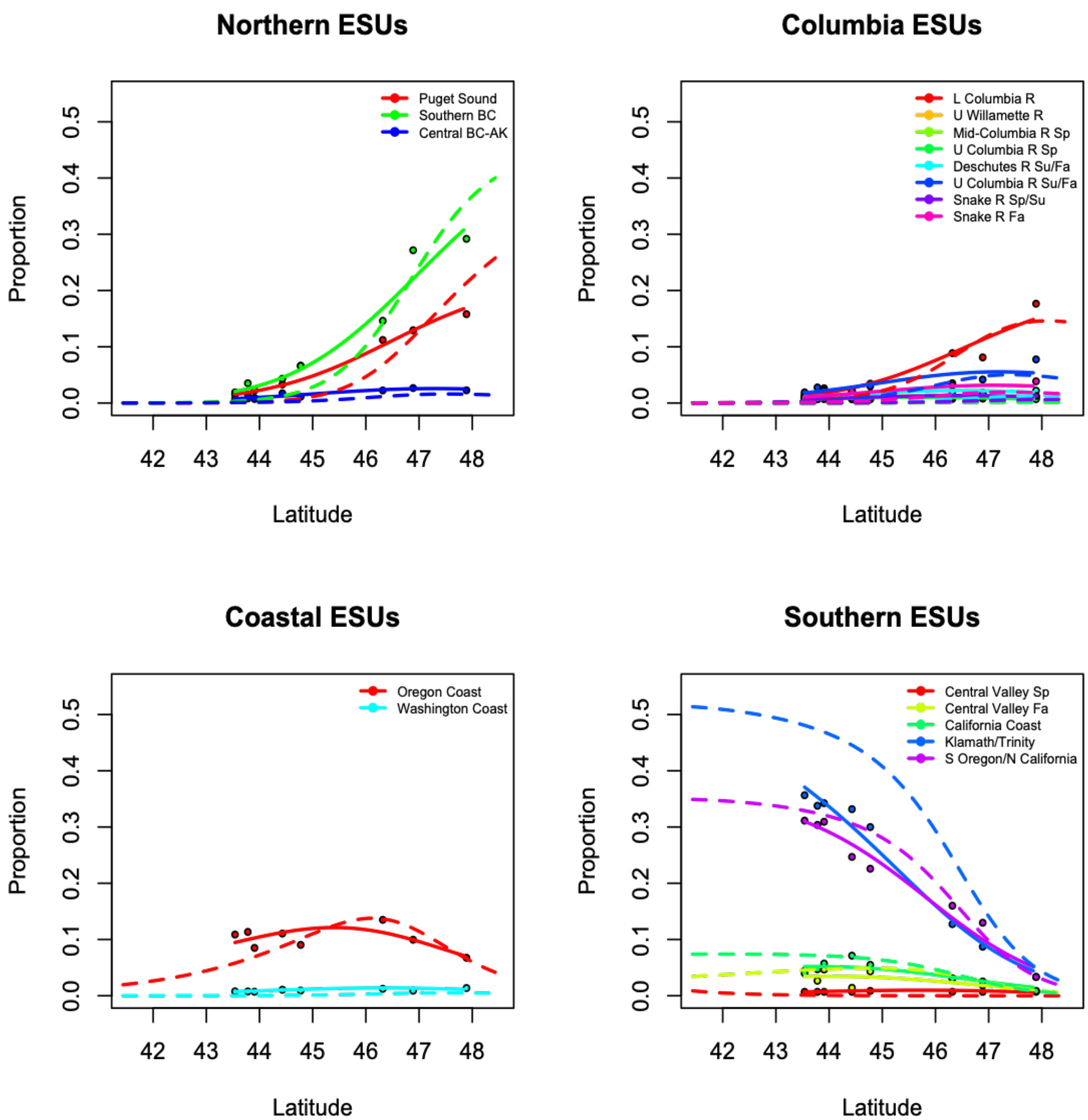

Figure 4. Stock proportion versus latitude inferred by using Dirichlet regression (dashed) and multinomial logistic regression (solid). Points represent observed proportions used to train the Dirichlet model. All four plots sum to one but are separated by region for clarity.

Recent compositional forecasting in support of fishery management and conservation

In the subsequent years, NWFSC collaborated with NOAA's West Coast Region on a variety of management applications involving genetic mixture analysis and compositional forecasting based on these regression models:

- 2017 groundfish BiOp and Incidental Take Statement (NMFS 2017)
- 2018 inferred ESU composition of an under-sampled LBE (10 fish sampled of 173 taken in a single haul)
- 2018 evaluation of the new base period implementation in the Chinook FRAM (Moran et al. 2018)
- Extensive cross validation of the at-sea forecasting model used in the BiOp (Moran et al. 2021)
- 2022 start date rule change to facilitate attainment, 15 May to 1 May (Final rule)
- Stock-specific growth curves and geographic availability for the SRKW consultation and BiOp (Matson et al. 2022)
- Temperature effects on diel migration and exacerbation of Chinook bycatch (Sabal et al. 2023)
- 2023 evaluation of Exempted Fishery Permits and impacts south of latitude 42 (in progress)

Again, these latitudinal models were developed for the highly mobile at-sea sectors that have widely different geographic footprints in different years and in different seasons. The shoreside Pacific hake fishery shows much more limited latitudinal variability. For that reason and because at the time less information was available for the shoreside fleet, the determination was made for the 2017 BiOp to use a static model of stock composition based on previous observation, irrespective of latitude (NMFS 2017). Although new training data have been added to the shoreside model (PMFC 2022), it is not cross validated against independent sample sets, as was done for the at-sea, latitude-dependent model (Moran et al. 2021).

Prediction of bycatch impacts for spring 2023

The goal of the current study is to provide a preliminary snapshot of Chinook salmon ESU-specific impacts (numbers of fish taken) across multiple Pacific hake fisheries by using, 1) Compositional forecasts informed by latitude and derived from predictive modeling (Dirichlet and multinomial logistic regression) and 2) Static predictions, irrespective of latitude, based on composition previously observed in the shoreside hake sector. These predictions are for ESU composition of tissue samples already collected.

Ultimately, these stock composition projections for A-SHOP samples will be validated by genotyping of 366 tissue samples (of 1154) and conditional maximum likelihood mixture modeling (aka genetic stock identification, GSI). The laboratory work and mixture analyses were also expedited and are currently in progress. Preliminary mixture results are expected to be available for presentation to the Council and interested parties at the 2023 September meeting.

The A-SHOP also read 164 Chinook coded-wire tags associated with 2023 spring bycatch and query results from RMIS are now available. However, considerable work remains to generate ESU proportions from CWT recoveries. The tag release groups can easily be parsed into ESUs, but more effort is required to obtain all the tag rates for relevant years and programs and apply expansions to generate comparable results to genetic mixture analysis.

This report was a collaboration of NOAA's NWFSC and WCR. The primary audience is intended to be the Pacific Fishery Management Council, including the Salmon Advisory Subpanel, the Groundfish Advisory Subpanel and the Groundfish Management Team, and all other parties interested in Chinook salmon ESU-specific bycatch impacts. We welcome comments and critique as well as suggestions for further analyses.

Materials and Methods

At-Sea Hake Observer Program (A-SHOP)

Haul and biodata were collected by the At-Sea Hake Observer Program (A-SHOP) and provided by NWFSC's FRAM Division. These preliminary records were obtained on 30 June 2023 (sample range roughly corresponding with spring season in salmon bycatch reporting) in advance of the fin-clip tissue samples, which would come later. The data were summarized in a series of tables and figures. Details of tissue collection protocol are available in the A-SHOP Training Manual (NWFSC 2022).

The collection data from the A-SHOP were used to determine the latitudinal distribution of samples, which was then used to infer likely ESU composition based on predictive models (NMFS 2017, Moran et al 2021). This was carried out independently for at-sea and shoreside bycatch, and for the large bycatch event (LBE) for reasons described above.

Shoreside IFQ Catch Monitor Program (CMP)

For the IFQ shoreside deliveries we conducted an analysis of bycatch through June 30 using numbers from PSMFC (Kelsey Lawson, pers. comm. 7 Jul 2023). Most of the numbers observed in that period were applied to a static model (irrespective of latitude). However, the LBE at an extreme northern latitude required special consideration.

Nearly 45% of shoreside Chinook bycatch (413 of 922) in spring of 2023 was offloaded in a single delivery. Because the delivery came from an electronically monitored vessel, we were able to obtain the exact location of the haul in question (suppressed here for confidentiality). The LBE occurred at the northern end of the distribution of previous bycatch. The latitude was slightly beyond the limit of our multinomial logistic regression model (based on individuals) but substantially beyond our Dirichlet model (based on annual mean latitudes).

Those predicted numbers for at-sea and shoreside bycatch were combined to give a preliminary approximation of Chinook salmon ESU-specific impacts for Pacific hake fisheries. Errors associated with these forecast estimates are problematical. We have previously used simulations and multinomial variance to capture some classes of variation, but we have failed to calculate truly defensible credible intervals that capture experiment-wise error. Experience shows that summary metrics such as mean square error and mean arctangent absolute percentage error are more meaningful than individual error bars for evaluating forecast performance (Moran et al. 2021). The variance structure of genetic bycatch data presents a variety of special statistical challenges.

Results

Although not directly relevant to the immediate task of estimating 2023 spring season ESU stock composition in Pacific hake fisheries, we provide a brief description of collection and biodata from the CP, MS, and tribal at-sea sectors, however, the tribal sector did not contribute to the bycatch records analyzed for this report. We offer this summary to give context for interpretation of our compositional forecasts.

Chinook salmon bycatch in trawl fisheries shows a highly skewed distribution. Most hauls catch zero Chinook (data not shown) or very few (Fig. 5). Occasionally, there are large bycatch events that might disproportionately impact certain ESUs relative to expectation.

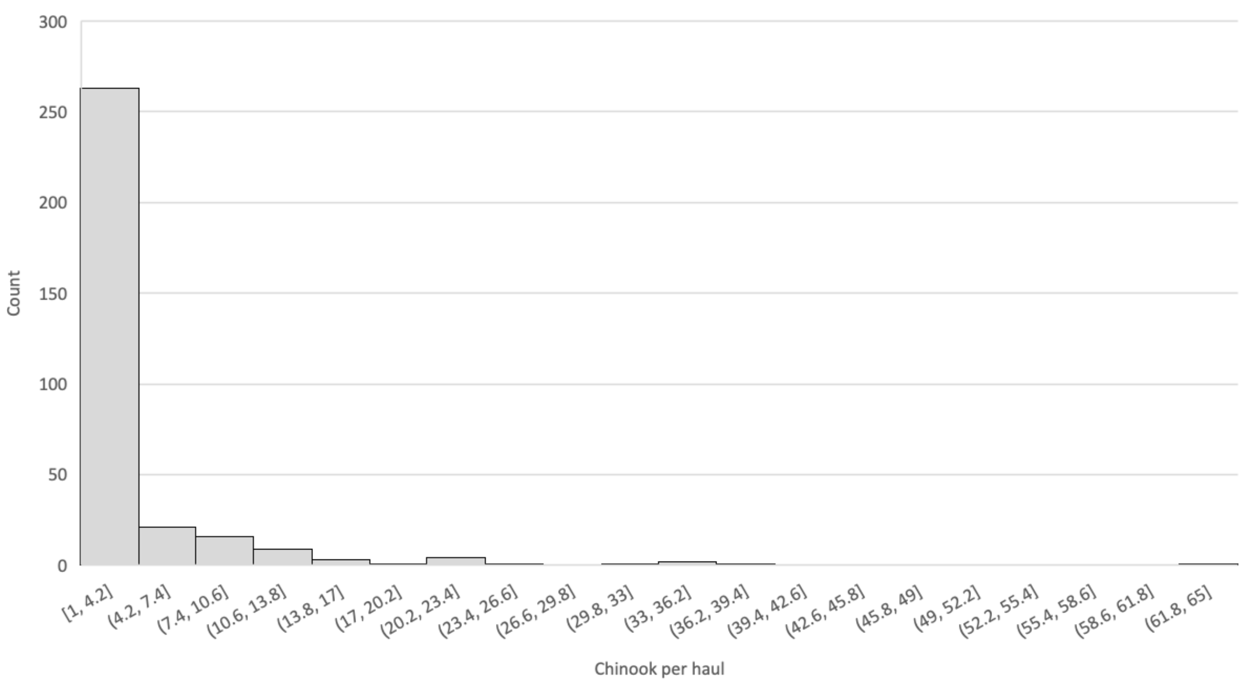

Figure 5. Frequency histogram of Chinook salmon per at-sea haul for spring 2023 (CP and MS combined) illustrates the highly skewed distribution of bycatch.

Records of fork length in at-sea bycatch demonstrated a wide range of sizes and different size classes for both female and male Chinook salmon (figs. 6 – 7). This size diversity is important for interpreting potential effects of migration timing on stock composition in specific temporal windows and for LBEs (see below).

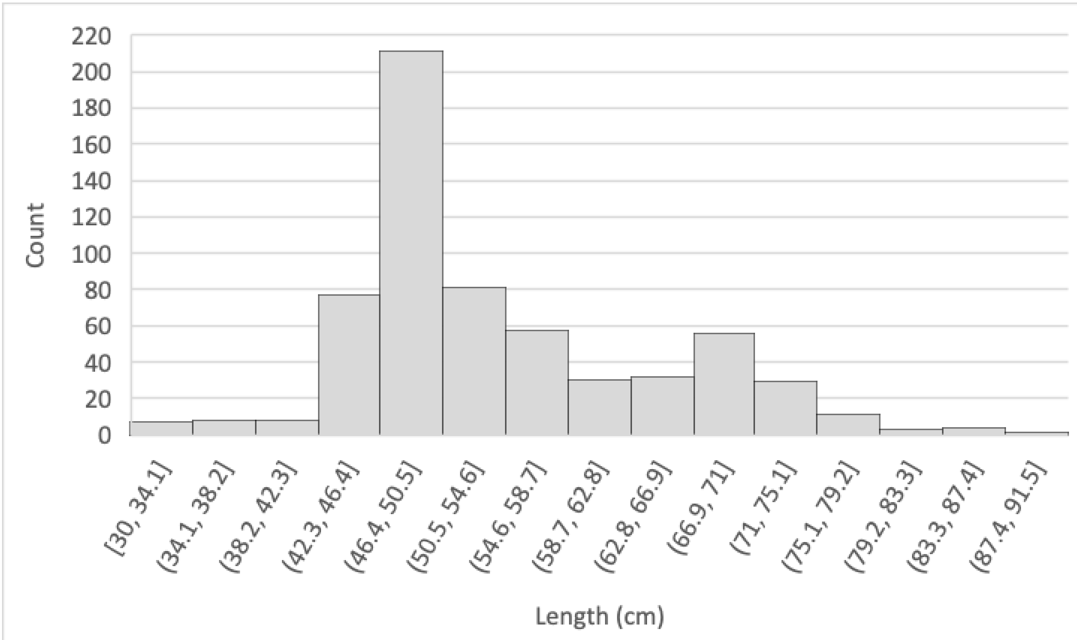

Figure 6. Length distribution for **female** Chinook salmon observed in bycatch associated with at-sea Pacific hake fishery sectors, spring 2023.

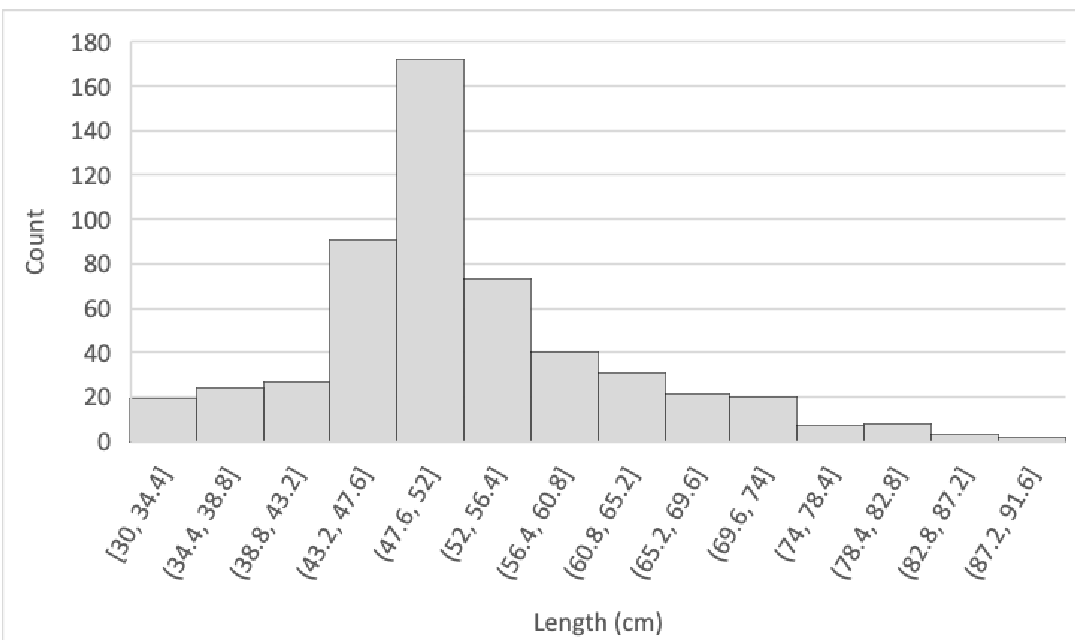

Figure 7. Length distribution for **male** Chinook salmon observed in bycatch associated with at-sea Pacific hake fishery sectors, spring 2023.

Latitudinal distribution of bycatch is central to the analysis of the at-sea Pacific hake sectors. Prior chinook bycatch analysis for the Pacific Fishery Management Council noted that bycatch and bycatch rates are anticipated to be higher and more variable when the whiting fleet fishes under a southern distribution (PFMC 2019, 2022). The samples collected in spring of 2023 included more fish from southern latitudes than have typically been observed in the at-sea fisheries (Fig. 8). The mean latitude of at-sea bycatch was 42.854, whereas the lower limit of the Dirichlet regression training data set was 43.539. The multinomial logistic regression (MLR) model was on more solid footing with a lower limit of 41.433. A similar problem was observed for the LBE at high latitude (exact value suppressed). The northern limit of the DR model was only 47.891, also more than half a degree out of range. Despite these statistical violations, and with no other options to obtain the desired information, we proceeded with the analysis as usual by averaging the proportions obtained from DR and MLR and applying those intermediate values to the numbers of Chinook recorded.

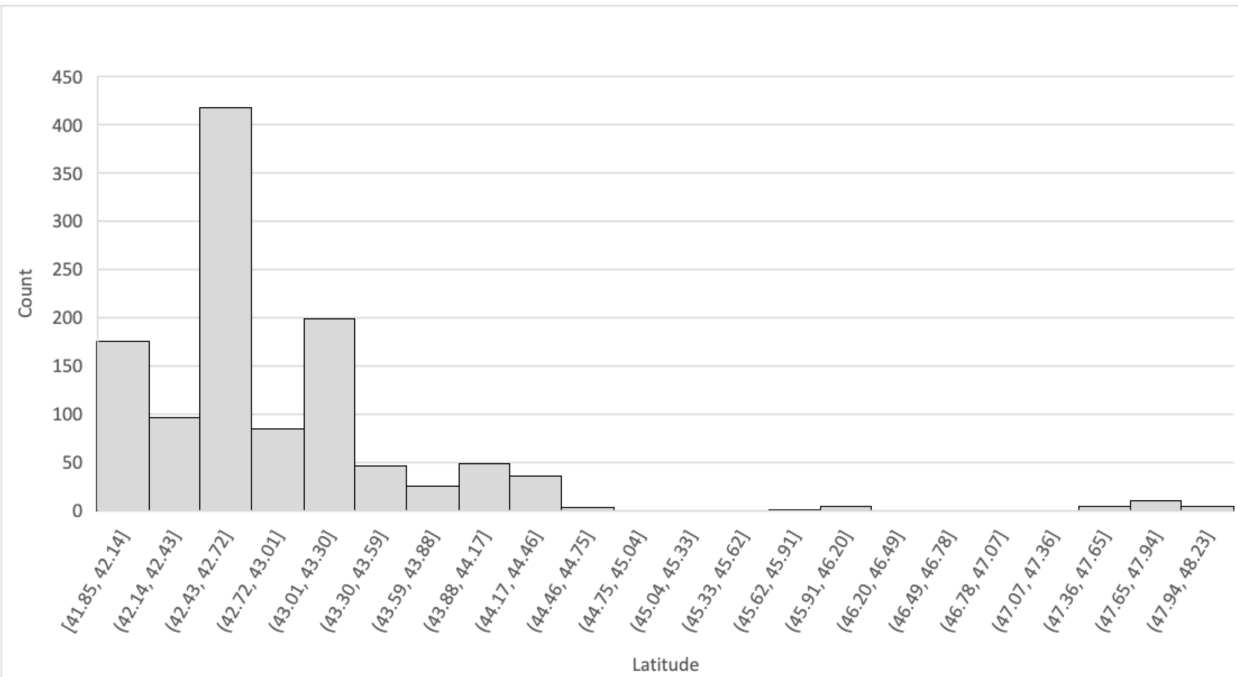

Figure 8. A frequency histogram of latitudes observed in the at-sea sectors in 2023 shows a more southerly distribution than in previous years (data not shown).

Compositional forecasts for spring 2023

Figures 9 – 11 depict the ESU stock compositions that were used to parse the numbers of Chinook salmon bycatch. A-SHOP and CMP-LBE samples were analyzed with the latitudinal at-sea model (figs. 9 and 11), whereas the balance of the CMP samples were parsed with the static, latitude independent shoreside model (Fig. 10).

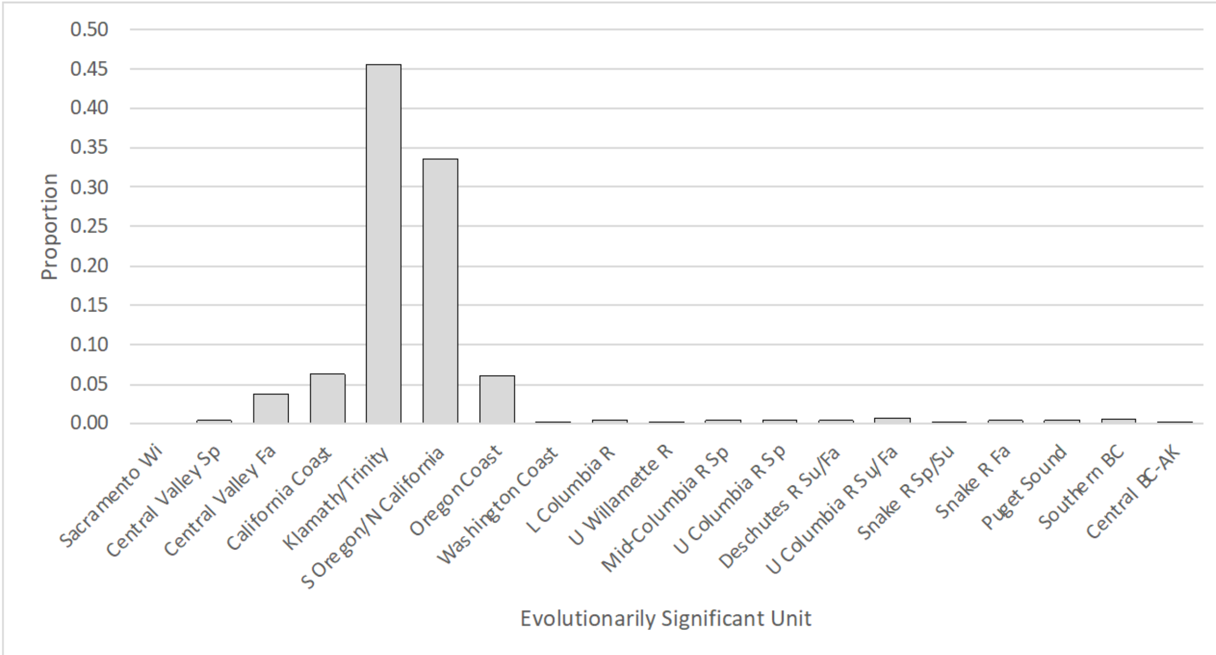

Figure 9. Projected Chinook salmon ESU-level impacts for all at-sea Pacific hake sectors combined in spring of 2023. These predictions are based on mean latitudinal distribution alone for samples already collected by NOAA observers (42.854).

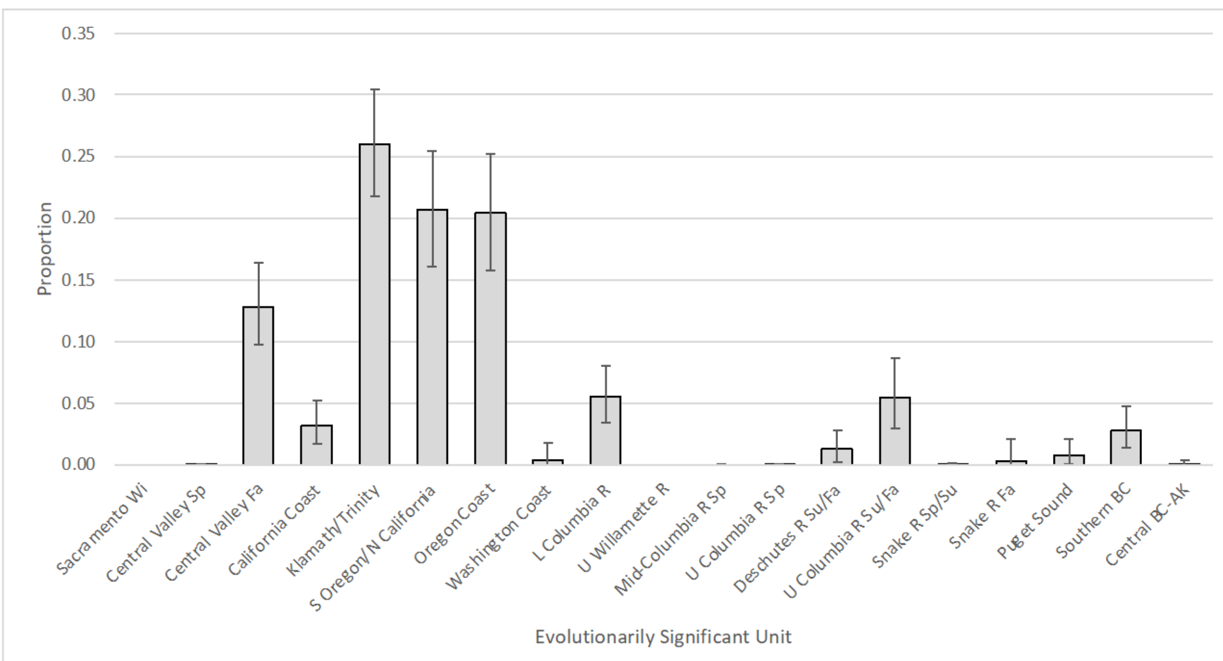

Figure 10. Projected ESU composition for 509 of 922 Chinook salmon already taken by 7/6/23 in the shoreside Pacific hake fishery (no modeling for latitude in this geographically static fishery, relative to as-sea sectors). The remaining 413 samples CMP-LBE were estimated separately (Fig. 11). Errors depict 95% credible intervals of the mixture proportions from observed genotypes, just one component of the variance in compositional forecasting.

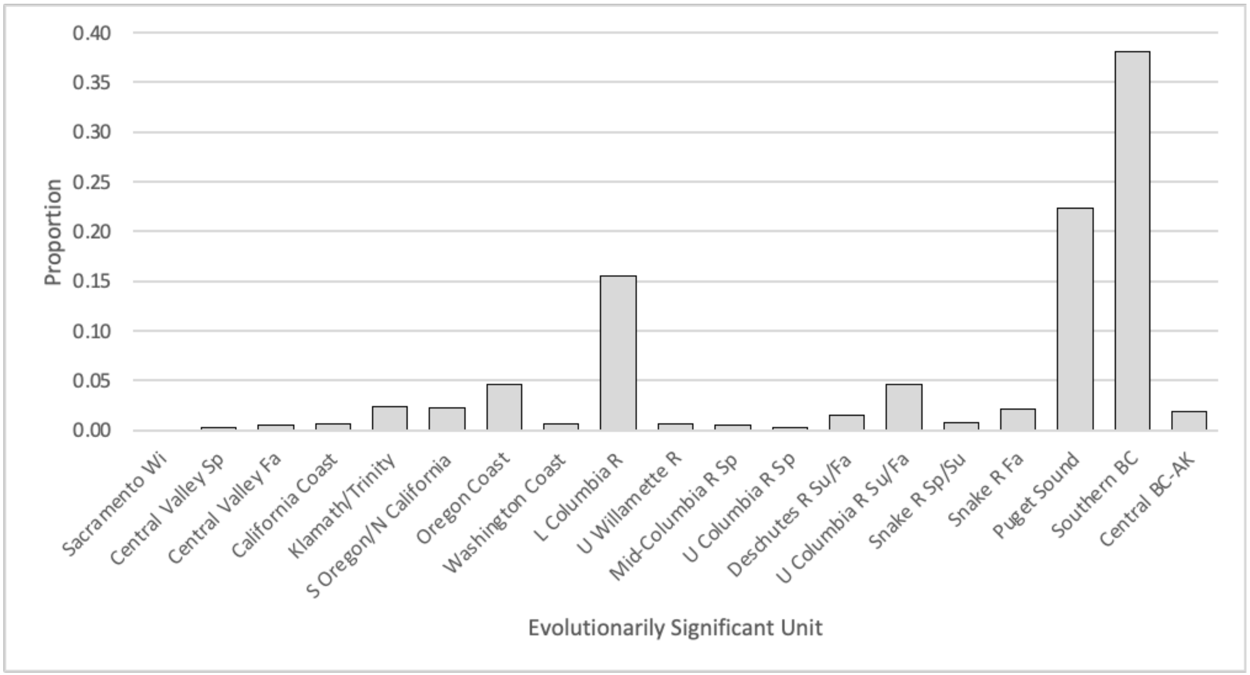

Figure 11. Modeled proportions given the latitude of a single LBE of 413 Chinook salmon observed in the CMP north of latitude 48 (exact latitude suppressed for confidentiality).

Numbers of Chinook salmon taken in 2023 spring bycatch for Pacific hake fisheries

Proportions in figures 9 - 11 were applied to the numbers of Chinook salmon recorded by observers and catch monitors to produce the final estimates of incidental take in combined Pacific hake fisheries for spring of 2023 (Table 1).

Table 1. Total estimated numbers of Chinook salmon for listed (bold) and unlisted ESUs (A-SHOP&CMP) using combined bycatch associated with at-sea Pacific hake sectors (A-SHOP) and IFQ shoreside deliveries (CMP and CMP-LBE), spring 2023

ESU	A-SHOP	CMP	CMP-LBE	Total A-SHOP&CMP
Sacramento Wi	**0**	**0**	**0**	**0**
Central Valley Sp	**4**	**0**	**1**	**6***
Central Valley Fa	43	65	2	111
California Coast	**72**	**16**	**3**	**91**
Klamath/Trinity	527	132	10	669
S Oregon/N California	386	105	10	501
Oregon Coast	69	104	19	193
Washington Coast	3	2	3	8
L Columbia R	**5**	**28**	**64**	**97**
U Willamette R	**3**	**0**	**3**	**6**
Mid-Columbia R Sp	3	0	2	6
U Columbia R Sp	**3**	**0**	**1**	**5**
Deschutes R Su/Fa	5	7	6	17
U Columbia R Su/Fa	8	28	19	55
Snake R Sp/Su	**3**	**0**	**3**	**6**
Snake R Fa	**5**	**2**	**9**	**15**
Puget Sound	**5**	**4**	**92**	**101**
Southern BC	7	14	157	178
Central BC-AK	3	0	8	11
Total listed	**100**	**51**	**180**	**331**
Total	1154	509	413	2076
Percent listed	**9%**	**10%**	**44%**	**16%**

* Apparent arithmetic errors due to rounding of modeled values

Discussion

Understanding typical spring season ESU-specific bycatch impacts is not a simple matter of looking at previous years and inferring similar proportions. In different years, the at-sea Pacific hake fleet fishes at different latitudes. Those effects of latitude generally overwhelm the effects of migration timing for particular stocks. For that reason, we need some estimate of the latitudinal distribution of bycatch for the highly mobile at-sea sectors before we can make inferences about likely ESU stock-specific impacts. In response to concerns from the Council over high spring bycatch and interest in understanding ESU-specific impacts, the A-SHOP and CMP expedited delivery of preliminary bio and haul data (as well as tissue samples and CWT data) that would not normally have been reported until September of 2024. These are the data, specifically the mean latitudes and numbers of Chinook salmon, on which our current analysis and report are based.

Specific impacts on listed and sensitive Chinook salmon ESUs

Given the large number of listed ESUs and their strong association with latitude, avoiding listed and sensitive ESUs in the north generally means higher impacts in the south and vice versa. Puget Sound, Lower Columbia, California Coast, and Klamath/Trinity all made significant contributions to spring bycatch in 2023, but those impacts were quite different among sample sets. These differences were consistent with the latitudinal distributions of those sets, e.g., at-sea bycatch is highly variable but often clustered in the south. That variability was documented in the BiOp and incorporated into incidental take projections (NMFS 2017).

A-SHOP and CMP together sampled 2076 Chinook salmon in this early period (1154 and 922, respectively). Of that total, 331 or 16% are likely to have come from listed ESUs. Those estimated percentages were similar for A-SHOP samples and around half of the CMP samples (9-10%). However, the LBE reported by the CMP from north of latitude 48 is likely to have a very different ESU composition with a much higher percentage of listed fish (44%). Using a latitudinally explicit model for the LBE, we estimated large numbers of Puget Sound and Lower Columbia River fish were likely taken (108 and 60), but very few fish from California Coast (2). By contrast, the at-sea sectors with their more southerly distribution are projected to have very low numbers of Puget Sound and Lower Columbia River fish (5 each) but high numbers from California Coast ESU (72).

Other non-listed but sensitive ESUs such as Klamath/Trinity also exhibit these north-south clines in frequency of bycatch. The southern footprint of the at-sea fleet is expected result in more than 500 Klamath/Trinity fish in bycatch. Klamath/Trinity are abundant in bycatch at southern latitudes, and historically they are major contributors to incidental take in groundfish fisheries.

The largest single stock group contributing to the LBE is predicted to have been Southern BC (likely lower Fraser fish, but this remains to be determined).

Central Valley fall is not a major contributor to bycatch, especially in the at-sea sectors, where it is generally below 3%. For spring 2023 we estimated Central Valley fall at only 3.7% of at-sea bycatch. It remains a bit of mystery why this stock is so abundant in directed harvest but relatively rare in at-sea bycatch (Satterthwaite et al. 2015). We presume it is related to depth or distance off shore, more subtle than latitude but potentially relevant here.

Caveats and limitations of the current analysis

The forecasting models are intended to predict annual impacts. That means they assume intra-annual variation is subsumed. The broad size distribution is important for stock composition because it suggests that pulses of migratory fish will be buffered by fish of different ages at different points in migration. This is a unique attribute of bycatch relative to harvest where take is focused on larger adult and sub-adult fish. Harvest fisheries are more likely to be affected by pulses of fish from specific populations (Moran et al 2021).

We have special concerns this year, beyond normal caution regarding compositional forecasting. First, spring bycatch showed a strongly southern distribution, actually beyond the data range for the Dirichlet regression model (though not the multinomial logistic regression model, which is based on individual fish, rather than annual averages). Mean latitude for at-sea spring bycatch is more than half a degree south of the limit of the Dirichlet model. Second, unusually high bycatch in early 2023 might reflect new biological and/or environmental conditions that are not captured in the training period of our model (2008 – 2015). Clearly something is different this year, but whether it materially affects our multinomial models we don't yet know. Third, an exceptionally large bycatch event was observed by the CMP at a higher latitude than represented in either regression model. This obviously represents a fundamental violation of statistical principles in attempting to draw inference outside the range of the original values. Only the unusually high interest in stock-specific impacts this spring justifies such a transgression from normal statistical rigor.

The LBE prediction should therefore be taken with extreme caution, especially because we don't know the size distribution of those fish. Until we receive details from CMP, it's possible that a pulse of fish from particular ESUs might have been present in that haul. Over 400 fish from a single haul at this high latitude will undoubtedly diverge from expectation for typical stock composition in shoreside bycatch.

Further evaluation of 2023 impacts and model improvement

Preliminary genetic mixture analyses of a subset of the A-SHOP-provided tissue samples will be available soon. Once we have completed processing fin-clip samples and conducting mixture analyses, we can parse assignment/allocation among populations within ESU reporting groups. This will help identify which specific populations are contributing to bycatch. With complete genetic analysis to come in 2024, we can also map individual ESU encounters and compare to previous years, e.g., Fig. 3. Similarly, we can stratify all the collection and biodata by ESU, e.g., stock-specific length-weight curves, or time-depth-temperature relationships (e.g., Sabal et al. 2023).

A great deal of new training data are currently available for genetic mixture model improvement and further testing of forecasting models on recent bycatch. These include years since 2017 for A-SHOP and CMP samples as well as representatives of West Coast Groundfish Observer Program (WCGOP) samples nearly every year since 2008. We look forward to implementing similar compositional forecasting models applied to bottom trawl and perhaps midwater rockfish trawl.

This fall, NWFSC staff will also work on basic support for genetic mixture analysis in Chinook. We are developing a hierarchical genetic mixture modeling approach that would use disparate baseline reference data sets more efficiently and potentially obtain more precise and accurate estimates of individual assignment and mixture proportions. The hierarchical method seeks to address the lack of convergence among West Coast salmon genetic laboratories on a common set of genetic markers. It uses multiple reference data sets with mismatched sets of markers to infer both individual stock of origin and modeled mixture proportions.

Finally, we are interested in theoretical consideration of individual assignment and modeled proportions in different applications, including trait inference and ESU-specific catch per unit effort. There is much interest in individual assignment, however, there can be substantial bias in some applications. Moreover, it is statistically inefficient to estimate the origin for each of many hundreds or thousands of fish if the information can be obtained by simply estimating the specific parameters of interest. Nevertheless, individual assignment can be effective depending on the application and the structure of the data (Moran et al. 2014).

We hope this report was useful to the Council, and we welcome suggestions for improvement. As time and resources permit, that could include additional/alternative analyses of existing data, as well as more general considerations for NWFSC's bycatch RM&E work and applications of genetic and genomic technologies to fishery management and conservation in general.

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- Sustainable Fisheries Division
  - Anadromous Harvest Management Branch
  - Groundfish Branch
- Protected Resources Division

Pacific Fishery Management Council

- Groundfish Management Team

Pacific States Marine Fishery Commission

- IFQ Catch Monitor Program

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