Update on Chinook salmon mortality due to bycatch in the EBS pollock fishery

Summary

This paper updates past analysis from the North Pacific Fishery Management Council (NMFS/NPFMC 2015, Ianelli and Stram 2015) using recent Chinook salmon prohibited species catch (PSC) and length composition data collected by observers from the pollock fishery along with genetics as summarized in annual Technical Memoranda (e.g., Iii et al. 2018). The length data were converted to age composition estimates using the same strata configurations and available age data from the previous analyses. These estimates were then applied to the same model to arrive at adult equivalency (AEQ) estmates (and estimated uncertainty). These were applied to the latest available genetics data (by A and B seasons) to estimate AEQ to regional origins. Finally, these estimates are compared with the recent run-size estimates provided by ADFG. Results indicate that the ratio of AEQ relative to regional run strengths for coastal west Alaska and Yukon river stocks remains low since Amendments 91 and 110 went into effect.

Methods

A method was developed to estimate how salmon bycatch numbers would propagate to adult equivalent spawning salmon. That is, how many and in what year *would* the salmon have returned had they not been taken as bycatch. A stochastic "adult equivalence" (AEQ) model was developed, which accounts for sources of uncertainty and allows for estimating the impact on run strengths from selected regions (Ianelli and Stram 2015). The steps in this process are briefly outlined as:

1. Compile statistics on Chinook salmon bycatch by region and season in the pollock fishery including
    a. Total bycatch by season and main sector (Table 1)
    b. Length and sex composition of the bycatch (sample sizes are shown in Table 2)
    c. Date and location
2. Compile available age composition data organized by strata (here historical age-length keys were used for A and B seasons between two main fishing areas of the Bering Sea; Fig. 1).
3. Convert the seasonal and regional length compositions (shown by absolute measurements in Fig. 2 and by proportion in Fig. 3) into age estimates for each year, area, season using the age-length keys from step 2 (Fig. 4 and Fig. 5; Tables 3 and 4).
4. Provide demographic characteristics of Chinook salmon for use in the AEQ model (these include the oceanic survival-at-age and maturity-at-age and were the same values as used in Ianelli and Stram 2015).
5. Update the season-specific genetics information (the "Bayes" estimates were used from Iii et al. (2013, 2015, 2018), Guthrie et al. (2013, 2014, 2016) for the period 2011-2016 (Table 5).
6. Run the AEQ model with these inputs (extending the estimates back to 1994-2017) and compile/summarize results.
7. Compare a subset (where data are available) of the AEQ results against corresponding run-strength estimates.

The model on the reduction in Chinook salmon returns in year t, AEQ_t, can thus be expressed (without stock specificity) as:

$$AEQ_t = \sum_{a=3}^{7} c_{t,a}\gamma_a + \sum_{j=3}^{6}\sum_{a=j+1}^{7}\left[\gamma_a c_{t-(a-j),j}\prod_{i=j}^{a-1}\left(1-\gamma_i\right)s_i\right] \qquad (1)$$

where $c_{t,a}$ is the bycatch of age *a* salmon in year *t*, s_a is the proportion of salmon surviving from age *a* to *a+1*, and γ_a is the proportion of salmon at sea that would have returned to spawn at age *a*. In words, the first term to the right of the equals sign is simply the number of mature Chinook salmon in the bycatch in the current year whereas the second term accounts for the Chinook salmon caught in previous years that would have been mature in the current year. All age 7 Chinook salmon in the bycatch were assumed to be returning to spawn in the year they were caught (i.e. $\gamma_7 = 1$) and they represent the oldest fish in the model. We assume that 7 year-old Chinook salmon taken in the fall were returning to spawn that year. In fact, these fish would have been more likely to return the following year. This assumption simplified the model and data preparation. Also, relatively few fish this age were caught late in the season.

Given estimates of AEQ, the model partitions these into regional stock groups (RSG) groups. This was done by assigning the stratum-specific AEQ estimates to each of the nine identified RSGs (e.g., Table 5; Guthrie *et al.*, 2013 for RSG and genetic stock identification, or GSI, determinations). We assumed that given the number of samples used for GSI within each year (*t*) and stratum (*i*) that the numbers assigned to RSG *k* can be assumed to follow a multinomial distribution with parameters

$$p_{t,i,1},\ldots,p_{t,i,9} \qquad \sum_k p_{t,i,k} = 1\,. \qquad (2)$$

For the years where GSI information is missing (data from 1994-2006 and 2017 which are absent from Table 6), the estimated proportions by RSGs were based on mean stratum-specific values from the years when GSI data were available. These additional parameters were constrained based on the estimated within-stratum inter-annual variability. That is, if the proportions assigned to RSGs varied as estimated from the genetics data, then that variability was propagated to the years when genetic data were unavailable. This was a compromise which acknowledges sampling uncertainty for those years and correctly weights the information (due to sample size) between years when GSI information was available. For example, the new observer data collection system for genetic samples has resulted in more precise estimates of GSI in recent years hence those years have greater influence on stratum-specific GSI results. Adjusting the AEQ for RSG requires estimation over a range of years when GSI results are available. This was accomplished here by applying the appropriate GSI results (i.e. estimates of proportions within RSGs) for the years as lagged by AEQ. This step is needed to apportion the AEQ results to stock of origin based on genetic samples which consist of mature and immature fish. By splitting the AEQ estimates to relative contributions of bycatch from previous years, and applying GSI data from those years, they can then be realigned and renormalized to get proportions from systems by year. For years in which GSI information was unavailable, mean GSI data (with an error term which accounted for year-effect variability) were used.

Since Chinook salmon bycatch occurs in both the A and B season of the pollock fishery, data from these seasons were modeled separately. For each separate run, Monte-Carlo Markov Chain (MCMC) samples from the posterior distribution were obtained based on chain lengths of 1 million (after burn in) and selecting every 200th parameter draw. Output resulted in 5,000 samples from each season (summed over strata) and then summed to get annual AEQ totals by RSG. The model was implemented using ADMB (Fournier *et al.,* 2012) software.

Separate estimates of run-strengths (from 1994-2017) were used assuming uncertainties in run size:

$$\dot{S}_{t,k} = S_{t,k} e^{\varepsilon_t} \qquad \varepsilon_t \sim N\left(0, \sigma_S^2\right) \tag{3}$$

where σ_S^2 was a pre-specified level of run-size variance (assumed to correspond to a conservative coefficient of variation of 10% for this study). The measure that relates the historical bycatch levels to the subsequent returning salmon run *k* in year *t*, the "impact", is thus:

$$u_{t,k} = \frac{AEQ_{t,k}}{AEQ_{t,k} + \dot{S}_{t,k}} \tag{4}$$

where $AEQ_{t,k}$ and $\dot{S}_{t,k}$ are the adult-equivalent bycatch and stock size (run return) estimates. The calculation of $AEQ_{t,k}$ includes the bycatch of salmon returning to spawn in year *t* and the bycatch from previous years for the same brood year (i.e., at younger, immature ages). Note that the allocation of the AEQ to RSGs is necessarily independent of the age composition of the bycatch.

Results and conclusions

Results of the AEQ overall were similar to past analyses which evaluated data through 2012 (Fig. 6). Adding in the stock identification data shows the AEQs broken out by regional stock groups are quite similar over time (Fig. 7 and 8).

This analysis was a relatively straightforward update from the work used for Amendment 110 (NMFS/NPFMC 2015). This work was done without testing alternative stratifications of data nor incorporating any new age data that may be available from the bycatch. The key new pieces were the stock identification results (by season) and the total bycatch numbers, and corresponding length frequencies. The updated bycatch numbers remain low relative to the 2005–2007 period (Fig 6). However, there appears to be a slight increasing trend since 2013 (Fig. 6), similar to the trend seen in updated run strengths (Fig. 7). The run strengths were quite similar to previous estimates and combined with the AEQ estimates, results suggest that the impact rate has remained low but there appears to be a slight upturn for the 2017 bycatch levels.

The extent that sampling levels could be improved might be worth re-examining (Faunce 2015). For example, increasing the length composition sample size might provide added insights on biological patterns in the bycatch (present practice of only measuring fish from which genetics samples are taken has greatly reduced these data collections). However, given that observer efforts are fully prescribed, some tradeoff analyses might be warranted. This analysis could also be improved by obtaining more contemporary length-at-age data for the age-length keys as there is some evidence of changes in growth over time (Ohlberger et al. 2018).

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Tables

Table 1. Chinook salmon bycatch in the pollock fishery by season (A and B), area (NW=west of 170°W; SE=east of 170°W), and sector (CV=shorebased catcher vessels, At sea means mothership operations, catcher-processors, and CDQ). *Source: NMFS Alaska Region, Juneau.*

	A Season			B Season			
Sector	CV	At sea	A sub-total	CV	At sea	B sub-total	Total
1991	10,192	26,646	36,838	1,667	548	2,215	39,053
1992	6,725	16,688	23,413	1,604	8,654	10,258	33,671
1993	3,017	12,398	15,415	2,614	18,590	21,204	36,619
1994	8,346	18,939	27,285	1,206	3,399	4,605	31,890
1995	2,040	6,942	8,982	781	3,640	4,421	13,403
1996	15,228	20,757	35,985	9,944	9,544	19,488	55,473
1997	4,954	5,393	10,347	22,551	11,423	33,974	44,321
1998	4,334	10,784	15,118	27,218	8,909	36,127	51,245
1999	3,103	3,248	6,351	2,662	2,964	5,626	11,977
2000	878	2,544	3,422	718	821	1,539	4,961
2001	8,555	9,928	18,483	3,779	11,182	14,961	33,444
2002	10,336	11,457	21,793	9,560	3,141	12,701	34,494
2003	15,367	17,242	32,609	6,998	5,979	12,977	45,586
2004	11,576	11,529	23,105	22,231	6,364	28,595	51,700
2005	13,797	13,491	27,288	34,826	5,204	40,030	67,318
2006	35,638	22,653	58,291	22,648	1,731	24,379	82,670
2007	36,463	33,770	70,233	41,338	10,680	52,018	122,251
2008	10,692	5,823	16,515	4,245	588	4,833	21,348
2009	6,241	3,643	9,884	2,207	485	2,692	12,576
2010	3,735	3,894	7,629	1,932	135	2,067	9,696
2011	4,442	2,695	7,137	13,950	4,412	18,362	25,499
2012	7,988	3,148	11,136	9,955	146	10,101	21,237
2013	6,592	4,595	11,187	4,105	542	4,647	15,834
2014	6,420	5,116	11,536	2,712	783	3,495	15,031
2015	7,789	4,522	12,311	2,492	3,180	5,672	17,983
2016	8,040	8,776	16,816	1,984	3,117	5,101	21,917
2017	9,057	12,538	21,595	5,991	2,339	8,330	29,925
2018	2,682	3,825	6,507	0	0	0	6,507

Table 2. The number of Chinook salmon measured for lengths in the pollock fishery by season (A and B), and area ((NW=west of 170°W; SE=east of 170°W). *Source: NMFS Alaska Fisheries Science Center observer data.*

Season	A	B		
Area	All	NW	SE	Total
1991	5,098	112	278	5,488
1992	3,927	20	2,008	5,955
1993	2,648	184	1,230	4,062
1994	6,150	372	1,259	7,781
1995	2,324	39	1,009	3,372
1996	13,221	178	7,872	21,271
1997	4,831	1154	12,625	18,610
1998	4,904	229	12,000	17,133
1999	3,127	628	2,067	5,822
2000	2,013	223	687	2,923
2001	8,211	1841	3,555	13,607
2002	9,448	137	6,367	15,952
2003	15,707	1838	5,235	22,780
2004	11,355	3062	9,627	24,044
2005	13,929	5935	10,460	30,324
2006	25,165	1231	12,842	39,238
2007	26,822	3457	22,528	52,807
2008	7,294	344	2,193	9,831
2009	4,969	249	1,159	6,377
2010	3,485	137	828	4,450
2011	751	163	1,720	2,634
2012	820	17	359	1,196
2013	850	57	458	1,365
2014	1,193	68	292	1,553
2015	1,333	288	341	1,962
2016	1,877	83	448	2,408
2017	2,337	57	701	3,095

Table 3. Age specific Chinook salmon mean bycatch estimates by season and calendar age based on the mean of 1000 bootstrap samples of available length and age data, 1991–2006. Note that totals may differ from official totals due to random variability of the bootstrap sampling procedure.

Year/season	Age 3	Age 4	Age 5	Age 6	Age 7	Total
1991	**5,624**	**15,901**	**13,486**	**3,445**	**347**	**38,802**
A	5,406	14,764	12,841	3,270	313	36,593
B	218	1,137	646	174	34	2,209
1992	**5,136**	**9,528**	**14,538**	**3,972**	**421**	**33,596**
A	1,017	4,633	13,498	3,798	408	23,355
B	4,119	4,895	1,040	174	13	10,241
1993	**2,815**	**16,565**	**12,992**	**3,673**	**401**	**36,446**
A	1,248	3,654	7,397	2,778	290	15,368
B	1,567	12,910	5,595	895	111	21,078
1994	**849**	**5,300**	**20,533**	**4,744**	**392**	**31,817**
A	436	3,519	18,726	4,211	326	27,218
B	413	1,781	1,807	533	66	4,599
1995	**498**	**3,895**	**4,827**	**3,796**	**367**	**13,382**
A	262	1,009	3,838	3,534	327	8,969
B	236	2,885	989	263	40	4,413
1996	**5,091**	**18,590**	**26,202**	**5,062**	**421**	**55,366**
A	863	7,187	23,118	4,431	349	35,947
B	4,228	11,403	3,085	632	71	19,418
1997	**5,855**	**23,972**	**7,233**	**5,710**	**397**	**43,167**
A	456	2,013	3,595	3,899	271	10,234
B	5,399	21,958	3,638	1,811	126	32,933
1998	**19,168**	**16,169**	**11,751**	**2,514**	**615**	**50,216**
A	1,466	2,254	8,639	2,079	512	14,950
B	17,703	13,915	3,112	435	103	35,266
1999	**870**	**5,343**	**4,424**	**1,098**	**21**	**11,757**
A	511	1,639	3,151	898	18	6,217
B	360	3,704	1,272	200	3	5,540
2000	**662**	**1,923**	**1,800**	**518**	**34**	**4,939**
A	365	1,167	1,406	453	26	3,416
B	298	757	395	66	8	1,522
2001	**6,512**	**12,365**	**11,948**	**1,994**	**190**	**33,009**
A	2,840	3,458	9,831	1,798	171	18,098
B	3,672	8,907	2,117	196	19	14,910
2002	**3,843**	**13,893**	**10,655**	**5,469**	**489**	**34,349**
A	1,580	5,063	9,234	5,328	478	21,683
B	2,263	8,830	1,421	141	11	12,666
2003	**5,703**	**16,723**	**20,124**	**3,791**	**298**	**46,639**
A	2,941	9,408	17,411	3,437	267	33,464
B	2,763	7,315	2,713	354	31	13,175
2004	**6,935**	**23,740**	**18,371**	**4,406**	**405**	**53,858**
A	1,111	5,520	13,090	3,763	354	23,838
B	5,824	18,220	5,282	643	51	30,020
2005	**10,466**	**30,717**	**21,886**	**4,339**	**304**	**67,711**
A	1,407	6,993	15,563	3,361	226	27,550
B	9,059	23,724	6,323	978	78	40,161
2006	**11,835**	**31,455**	**32,452**	**6,636**	**490**	**82,869**
A	3,604	17,574	30,447	6,404	465	58,494
B	8,231	13,881	2,005	232	25	24,374

Table 4. Age specific Chinook salmon mean bycatch estimates by season and calendar age based on the mean of 1000 bootstrap samples of available length and age data, 2007–2017. Note that totals may differ from official totals due to random variability of the bootstrap sampling procedure.

Year/season	Age 3	Age 4	Age 5	Age 6	Age 7	Total
2007	**16,174**	**66,024**	**33,286**	**5,579**	**357**	**121,419**
A	5,791	29,269	28,648	5,059	317	69,084
B	10,384	36,755	4,638	520	40	52,336
2008	**670**	**4,691**	**11,098**	**1,943**	**156**	**18,558**
A	159	2,936	10,647	1,913	154	15,808
B	511	1,755	451	30	2	2,749
2009	**328**	**3,706**	**5,654**	**1,392**	**111**	**11,190**
A	94	2,768	5,453	1,377	110	9,802
B	234	938	200	14	2	1,389
2010	**388**	**2,115**	**4,852**	**1,217**	**94**	**8,666**
A	160	1,417	4,733	1,209	93	7,612
B	227	698	119	8	1	1,054
2011	**3,271**	**7,697**	**4,405**	**946**	**82**	**16,401**
A	141	2,242	3,888	927	80	7,277
B	3,130	5,455	518	19	1	9,124
2012	**857**	**3,075**	**4,604**	**949**	**86**	**9,570**
A	87	2,166	4,502	946	85	7,785
B	770	908	102	3	1	1,785
2013	**1,226**	**5,124**	**3,499**	**668**	**58**	**10,575**
A	465	3,605	3,327	662	58	8,116
B	761	1,519	172	6	0	2,459
2014	**1,289**	**5,359**	**5,882**	**698**	**58**	**13,285**
A	941	4,157	5,699	689	57	11,543
B	347	1,202	183	9	0	1,742
2015	**1,850**	**7,859**	**4,697**	**925**	**61**	**15,391**
A	1,241	5,811	4,423	917	60	12,453
B	608	2,048	273	8	0	2,938
2016	**1,538**	**9,063**	**7,821**	**1,010**	**77**	**19,508**
A	884	7,446	7,679	1,005	76	17,091
B	654	1,617	142	5	0	2,418
2017	**2,406**	**10,135**	**11,787**	**1,917**	**148**	**26,393**
A	872	8,144	11,638	1,909	147	22,710
B	1,534	1,991	149	8	1	3,683

Table 5. The stock composition estimates (using the "Bayes" estimates) as presented in Auke Bay Lab publications on Chinook salmon bycatch by season (Iii et al. 2013, 2015, 2018, Guthrie et al. 2013, 2014, 2016), 2011–2016.

	Russia	Coast W AK	Mid-Yukon	Up Yukon	N AK Penn	NW GOA	Copper	NE GOA	Coast SE AK	BC	WA/OR/CA	% in A season
A season												% in A season
2011	0.2%	53.9%	1.8%	7.4%	21.8%	0.6%	0.0%	0.0%	3.1%	7.2%	4.0%	28%
2012	0.5%	67.8%	1.2%	3.1%	16.2%	0.2%	0.0%	0.1%	1.7%	7.3%	1.9%	68%
2013	0.9%	50.2%	1.1%	7.2%	19.1%	0.5%	0.1%	0.0%	1.9%	17.0%	2.0%	63%
2014	0.6%	54.7%	3.3%	4.1%	22.7%	0.1%	0.0%	0.0%	0.6%	10.2%	3.7%	77%
2015	0.6%	45.9%	1.0%	3.6%	14.5%	2.8%	0.2%	0.0%	3.9%	19.1%	8.4%	67%
2016	0.6%	39.0%	1.7%	2.2%	16.9%	0.6%	0.0%	0.0%	3.9%	26.1%	8.9%	77%
B season												% in B season
2011	1.0%	73.7%	1.3%	0.7%	3.4%	3.6%	0.6%	0.1%	1.4%	7.8%	6.4%	72%
2012	2.4%	51.9%	0.2%	1.0%	0.1%	3.8%	0.1%	0.1%	8.2%	15.3%	16.9%	32%
2013	0.9%	51.9%	1.9%	1.4%	5.9%	6.9%	0.1%	0.0%	1.9%	14.3%	14.8%	37%
2014	0.4%	31.7%	1.7%	1.6%	0.1%	18.4%	0.1%	0.1%	3.6%	24.5%	17.9%	23%
2015	0.5%	39.6%	1.7%	2.7%	10.6%	4.0%	0.1%	0.0%	4.5%	21.8%	14.5%	33%
2016	0.2%	16.5%	0.4%	0.7%	1.1%	5.8%	1.8%	0.0%	6.5%	37.0%	29.9%	23%
Total												
2011	0.8%	68.2%	1.4%	2.6%	8.5%	2.8%	0.4%	0.1%	1.9%	7.6%	5.7%	
2012	1.1%	62.8%	0.9%	2.4%	11.1%	1.3%	0.0%	0.1%	3.7%	9.8%	6.7%	
2013	0.9%	50.8%	1.4%	5.1%	14.2%	2.9%	0.1%	0.0%	1.9%	16.0%	6.7%	
2014	0.6%	49.3%	2.9%	3.5%	17.5%	4.4%	0.0%	0.0%	1.3%	13.5%	7.0%	
2015	0.6%	43.8%	1.2%	3.3%	13.2%	3.2%	0.2%	0.0%	4.1%	20.0%	10.4%	
2016	0.5%	33.8%	1.4%	1.8%	13.2%	1.8%	0.4%	0.0%	4.5%	28.7%	13.8%	

Table 6. Mean values of stochastic simulation results of AEQ Chinook mortality attributed to the pollock fishery by region, 1994–2017. These simulations include stochasticity in natural mortality (CV=0.1), bycatch age composition (via bootstrap samples), maturation rate (CV=0.1), and stock composition (as detailed above). **NOTE**: these results are based on the assumption that the genetics findings from the 2005-2016 data represent the historical pattern of bycatch stock composition (by strata). Italicized column is the sum of the western Alaska stocks AEQ estimate.

	BC-WA-OR	Coast W AK	Middle Yukon	Upper Yukon	*Combined West. AK*	N AK Penin	NW GOA	Russia	SEAK	Other	Total
1994	8,211	16,681	510	1,067	*18,258*	4,507	835	219	972	14	33,016
1995	4,983	10,367	320	687	*11,374*	2,916	475	133	596	8	20,485
1996	7,151	15,406	483	1,075	*16,964*	4,585	612	191	869	9	30,381
1997	8,499	15,998	472	893	*17,363*	3,707	1,032	227	973	20	31,821
1998	8,946	15,634	443	740	*16,817*	2,993	1,246	238	994	25	31,259
1999	6,884	11,643	324	505	*12,472*	2,011	1,010	183	754	21	23,335
2000	4,176	6,969	192	291	*7,452*	1,149	625	111	455	13	13,981
2001	4,382	8,636	260	525	*9,421*	2,204	481	117	512	8	17,125
2002	6,173	12,764	393	839	*13,996*	3,555	599	165	737	10	25,235
2003	8,027	16,466	505	1,069	*18,040*	4,524	796	214	955	13	32,569
2004	9,479	18,839	570	1,162	*20,571*	4,885	1,020	253	1,112	19	37,339
2005	11,794	22,156	652	1,232	*24,040*	5,109	1,439	314	1,350	28	44,074
2006	15,090	30,213	917	1,886	*33,016*	7,941	1,595	403	1,775	29	59,849
2007	18,092	36,543	1,114	2,315	*39,972*	9,766	1,870	482	2,137	33	72,352
2008	15,078	29,362	879	1,748	*31,989*	7,311	1,704	402	1,752	32	58,268
2009	7,706	14,873	443	871	*16,187*	3,638	888	205	892	16	29,532
2010	2,909	6,061	187	403	*6,651*	1,710	276	78	348	5	11,977
2011	2,276	5,798	160	337	*6,295*	1,387	275	72	306	5	10,616
2012	2,642	7,460	189	354	*8,003*	1,417	377	92	370	8	12,909
2013	2,570	6,396	171	337	*6,904*	1,324	340	83	336	7	11,564
2014	2,743	5,941	189	397	*6,527*	1,718	297	78	335	5	11,703
2015	3,135	6,187	201	429	*6,817*	1,811	299	81	370	4	12,517
2016	4,509	7,147	251	529	*7,927*	2,336	323	99	479	5	15,678
2017	5,551	10,292	348	779	*11,419*	3,398	372	131	627	5	21,503

Figures

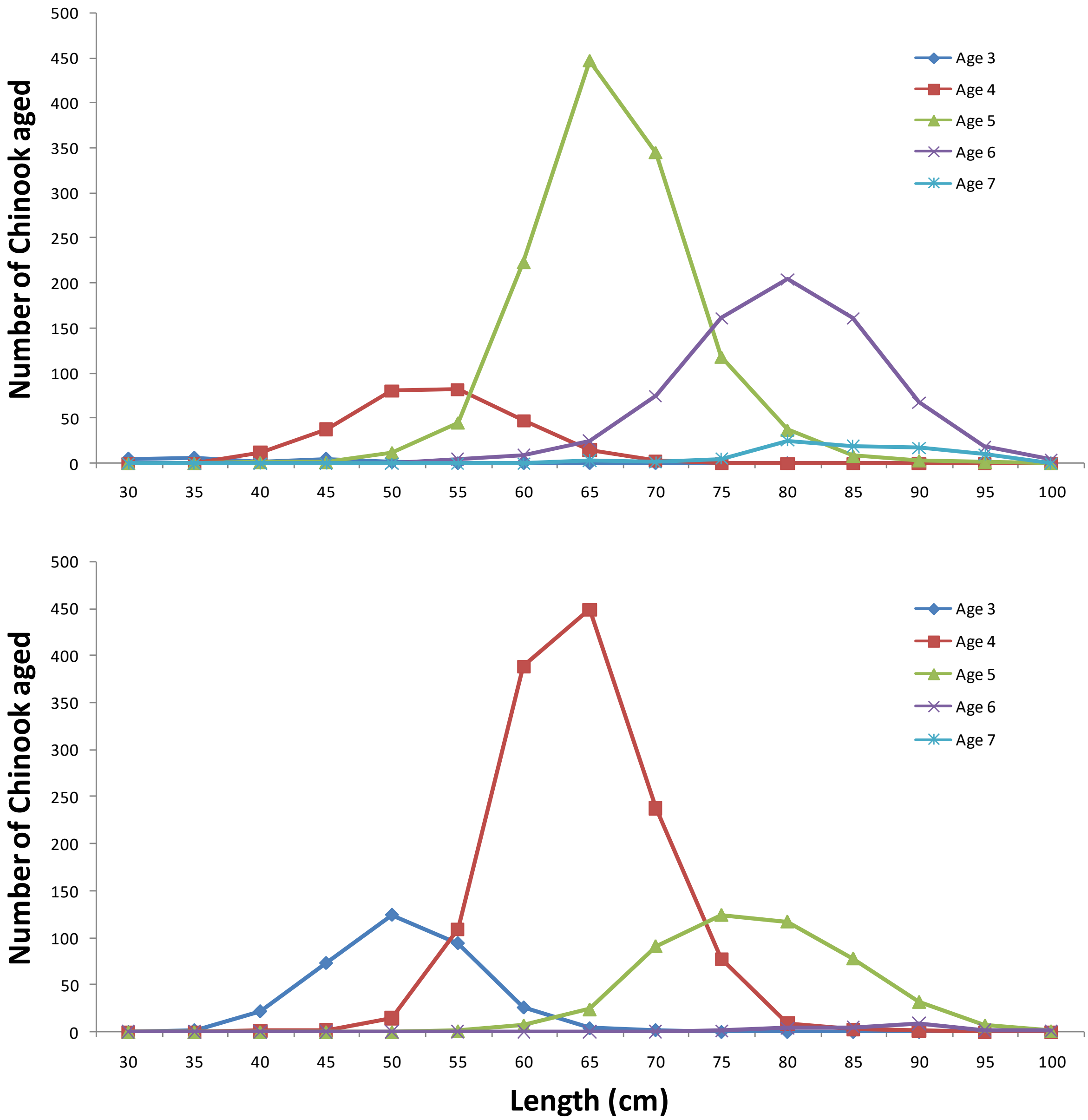


Fig. 1. Summary distribution of age samples by length collected by the NMFS groundfish observer program during 1997–1999 and analyzed by University of Washington scientists (Myers et al. 2003) for the A-season (top panel) and B season (bottom panel).

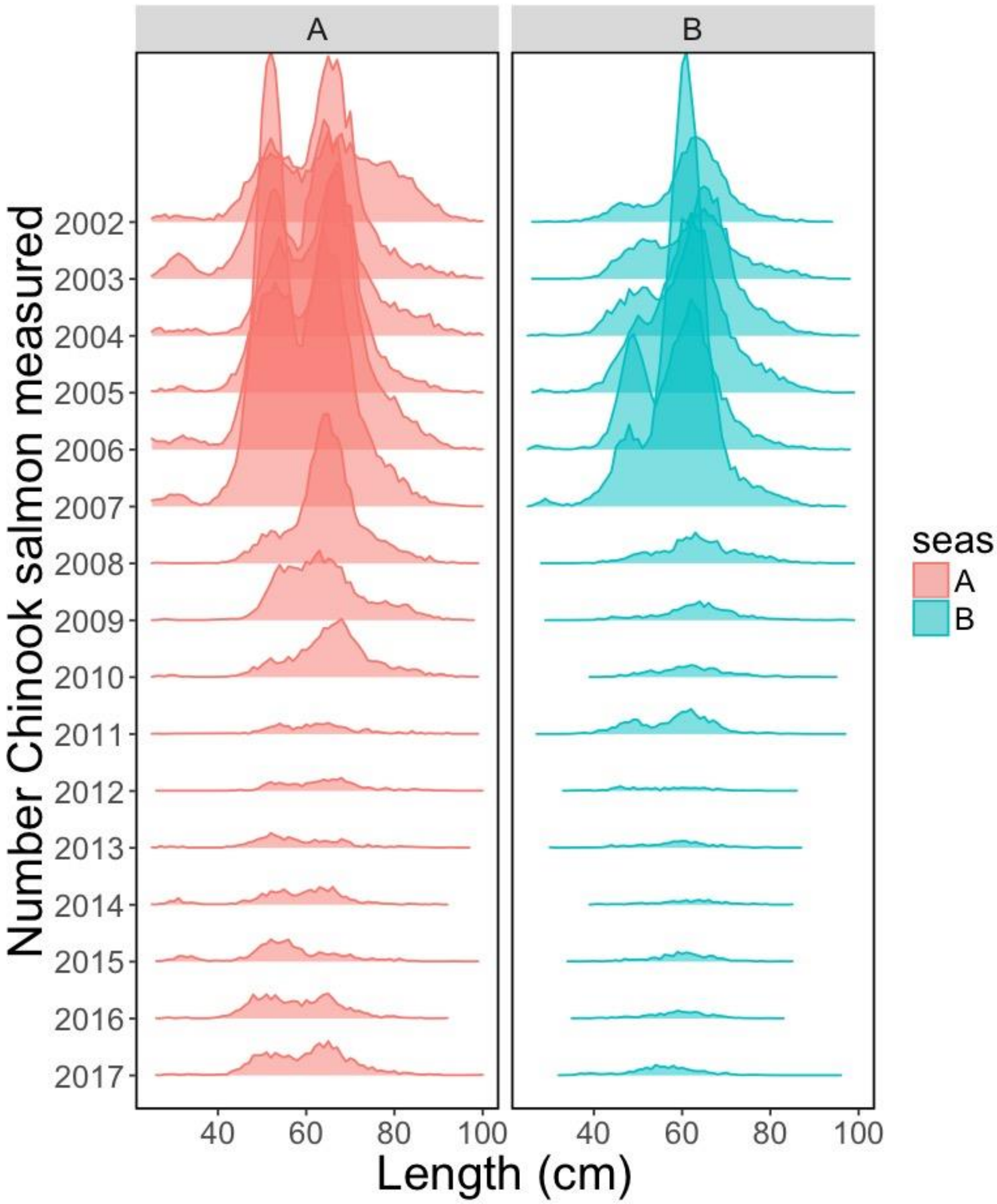


Fig. 2. Length frequency measurements collected by NMFS observers by season and year of Chinook salmon occurring as bycatch in the pollock fishery. This figure indicates the change in sampling intensity for length measurements of Chinook salmon bycatch.

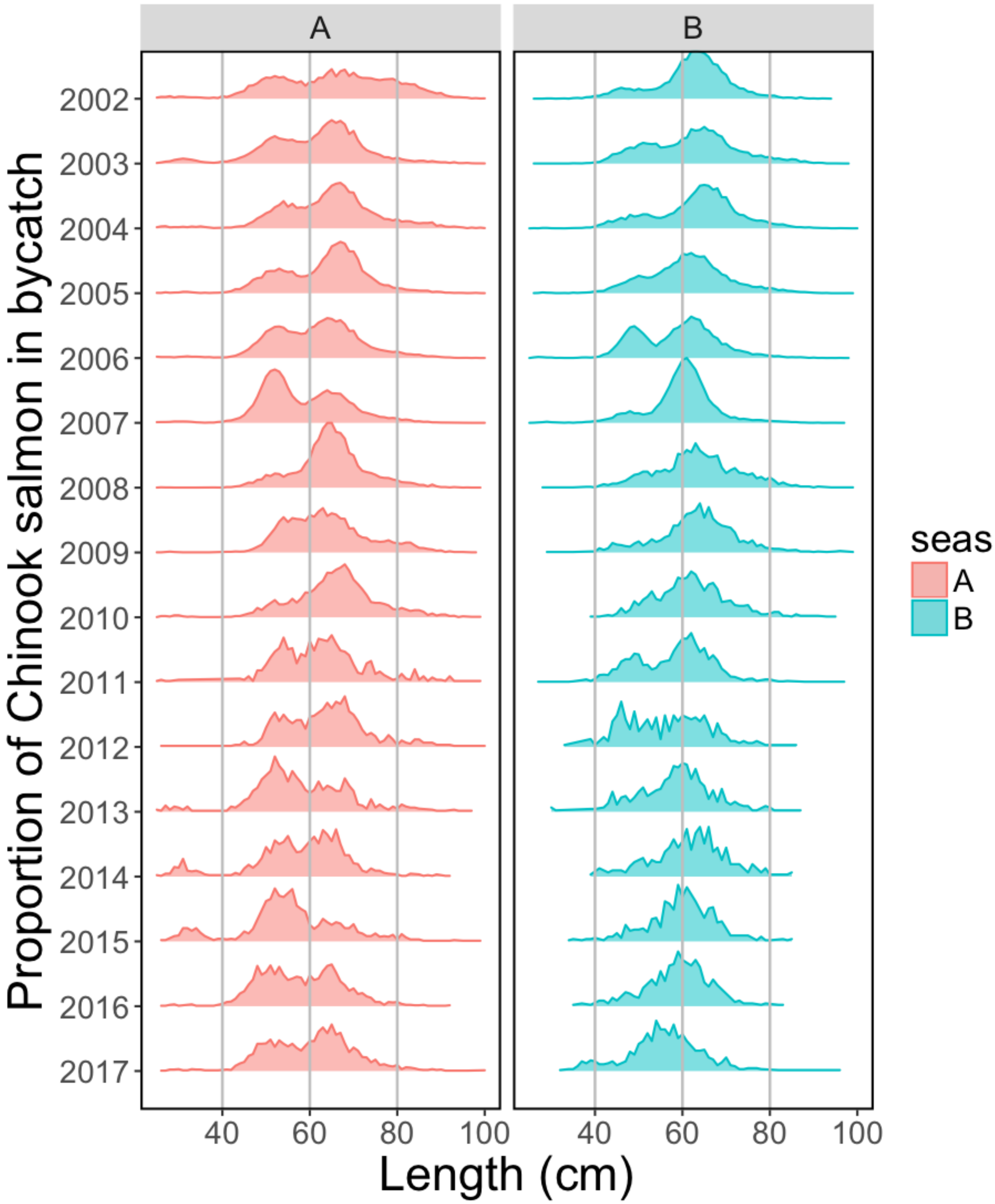
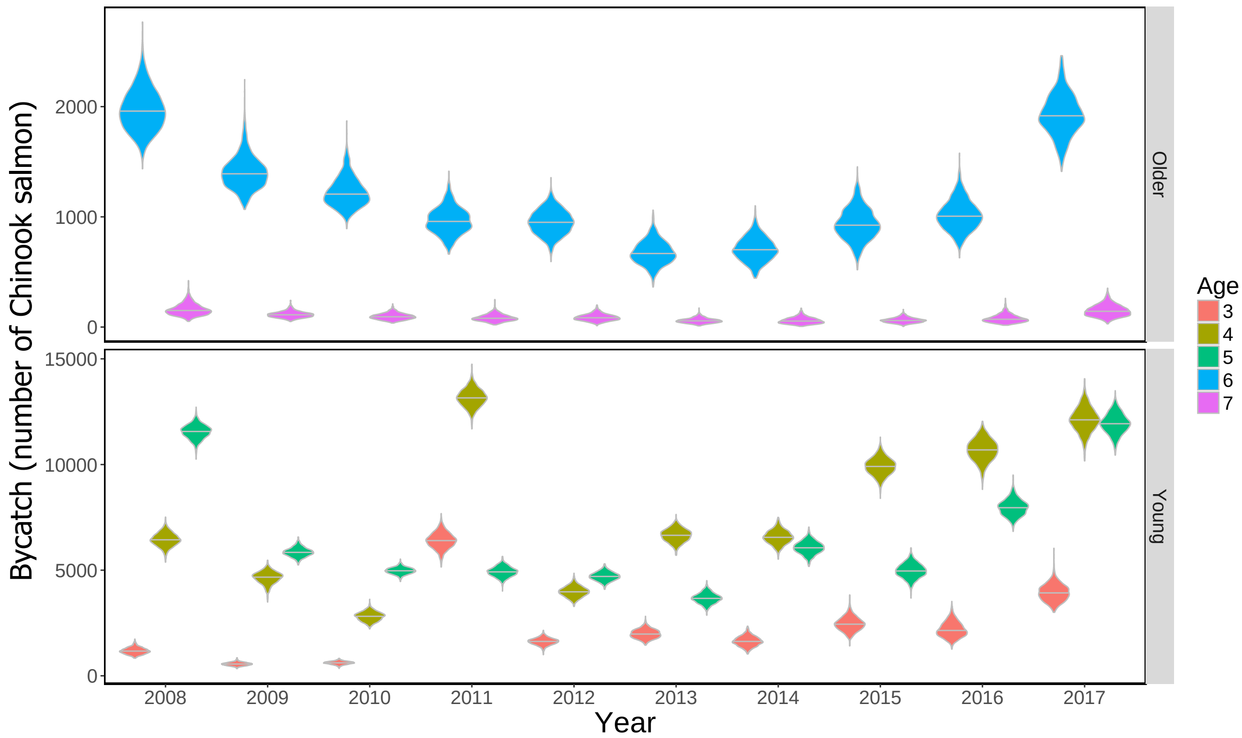


Fig. 3 Length frequency proportions by season and year of Chinook salmon occurring as bycatch in the pollock fishery.



Year

Fig. 4. Chinook salmon bycatch age composition by year and relative age with older (top) and younger (bottom) by estimated age. Vertical spread of blobs represent uncertainty as estimated from the two-stage bootstrap re-sampling procedure.

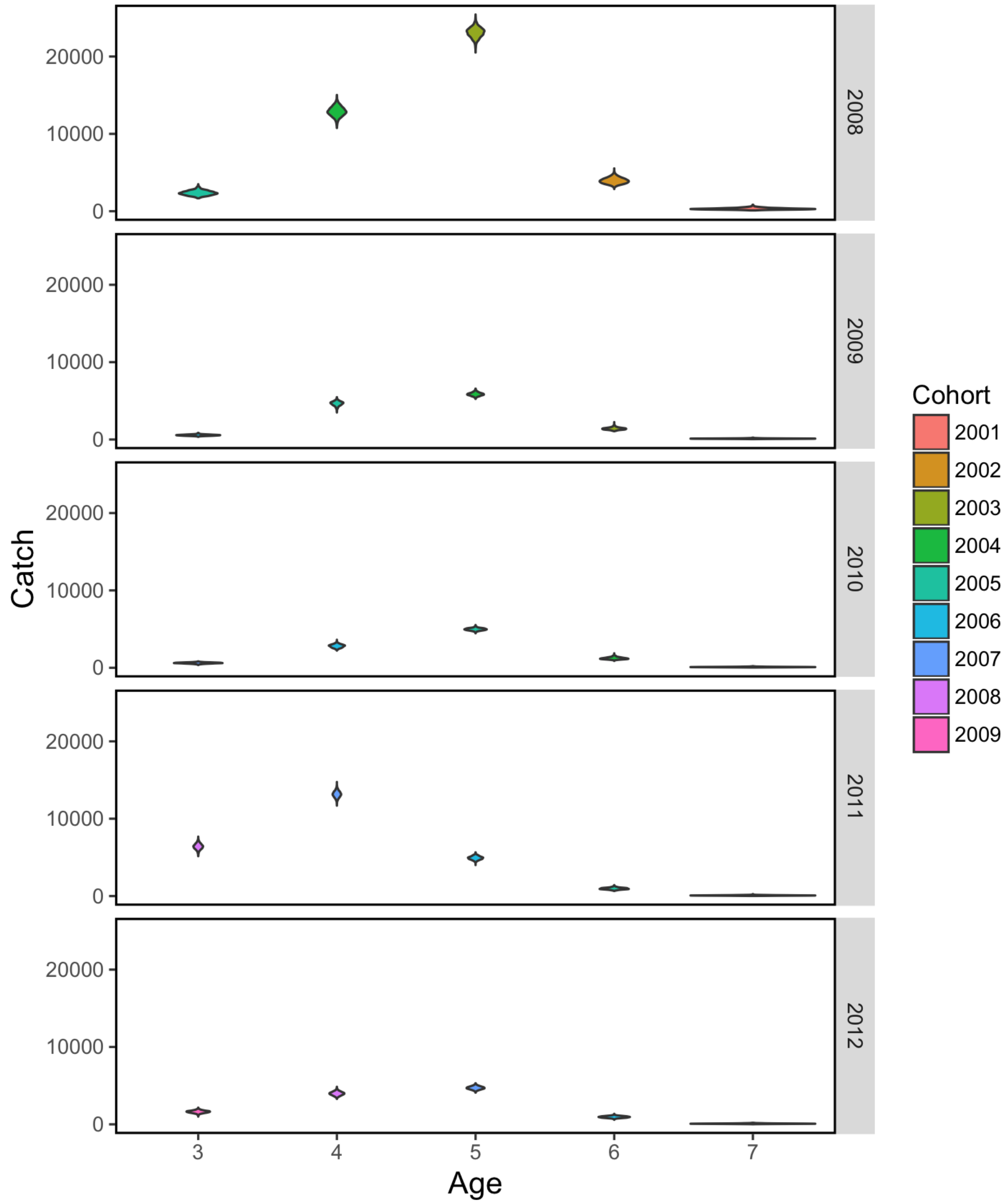


Fig. 5. Time series of Chinook adult equivalent bycatch from the pollock fishery, 2007–2016 compared to the annual totals under different assumptions about ocean mortality rates.

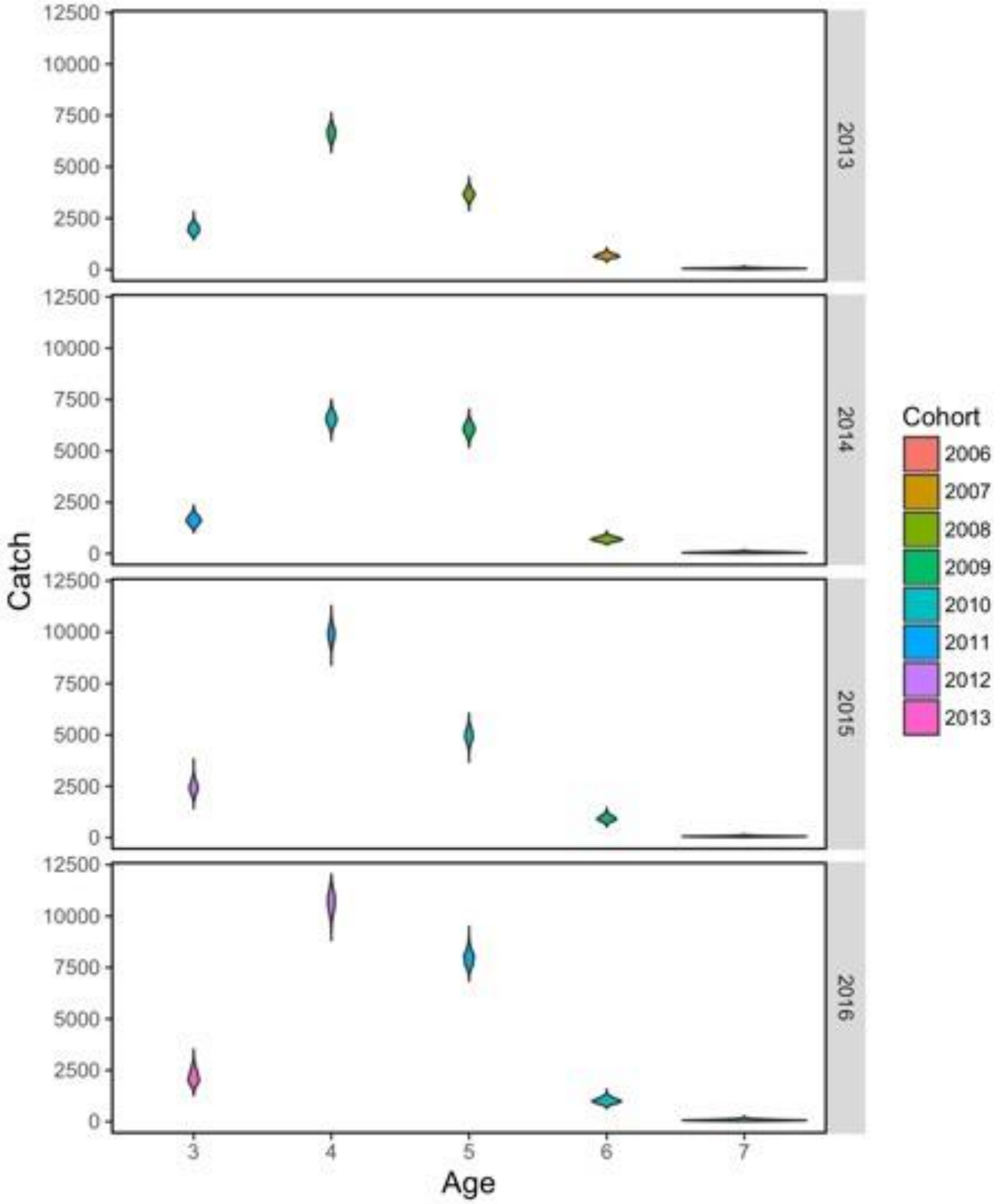


Fig. 5. (continued) Time series of Chinook adult equivalent bycatch from the pollock fishery, 2007–2016 compared to the annual totals under different assumptions about ocean mortality rates.

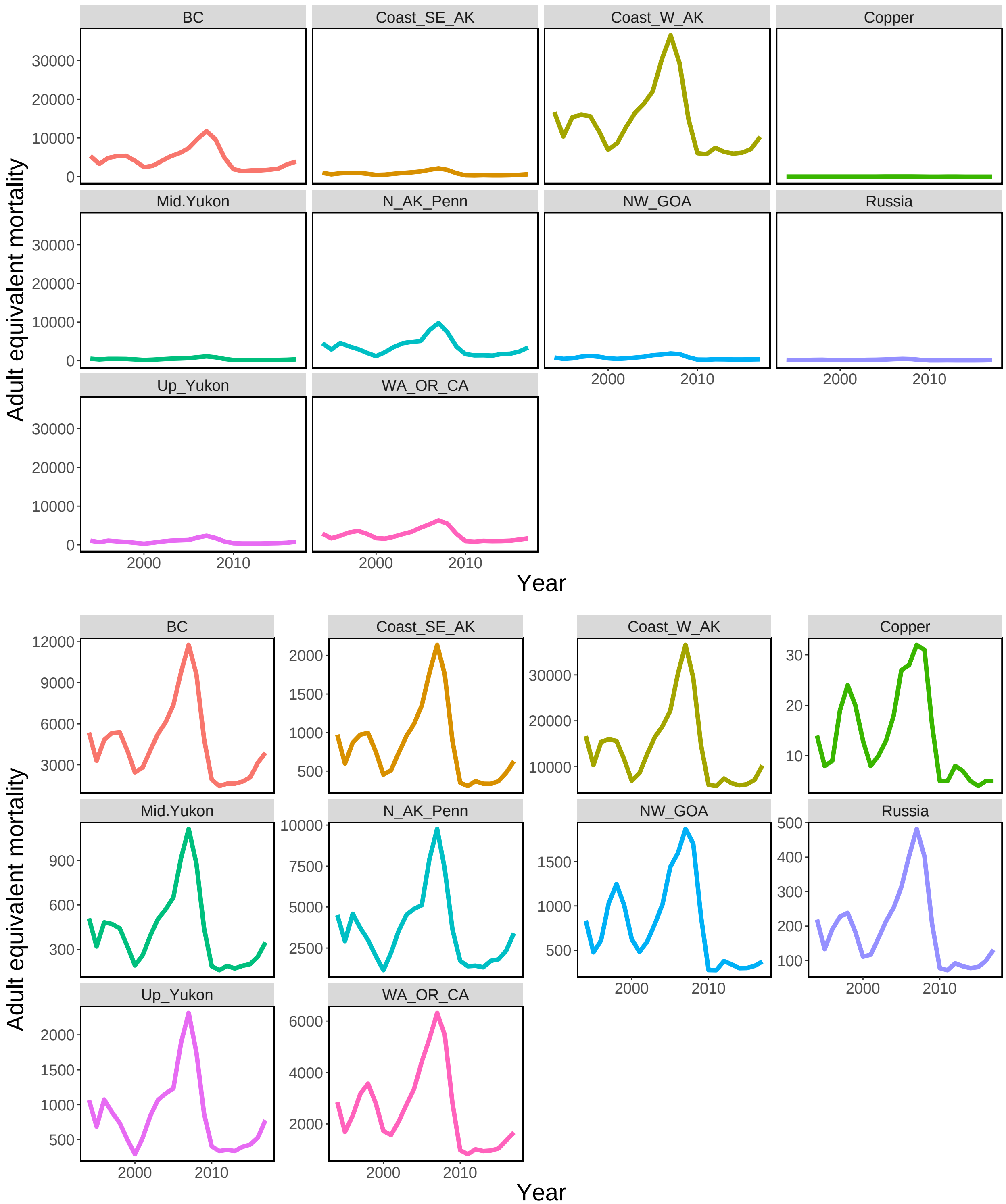


Fig. 6. Time series of Chinook salmon adult equivalent bycatch estimates from the pollock fishery, 1994–2017 with constant vertical scale (top set of figures) and where vertical scales vary between stock groupings (bottom set of figures).

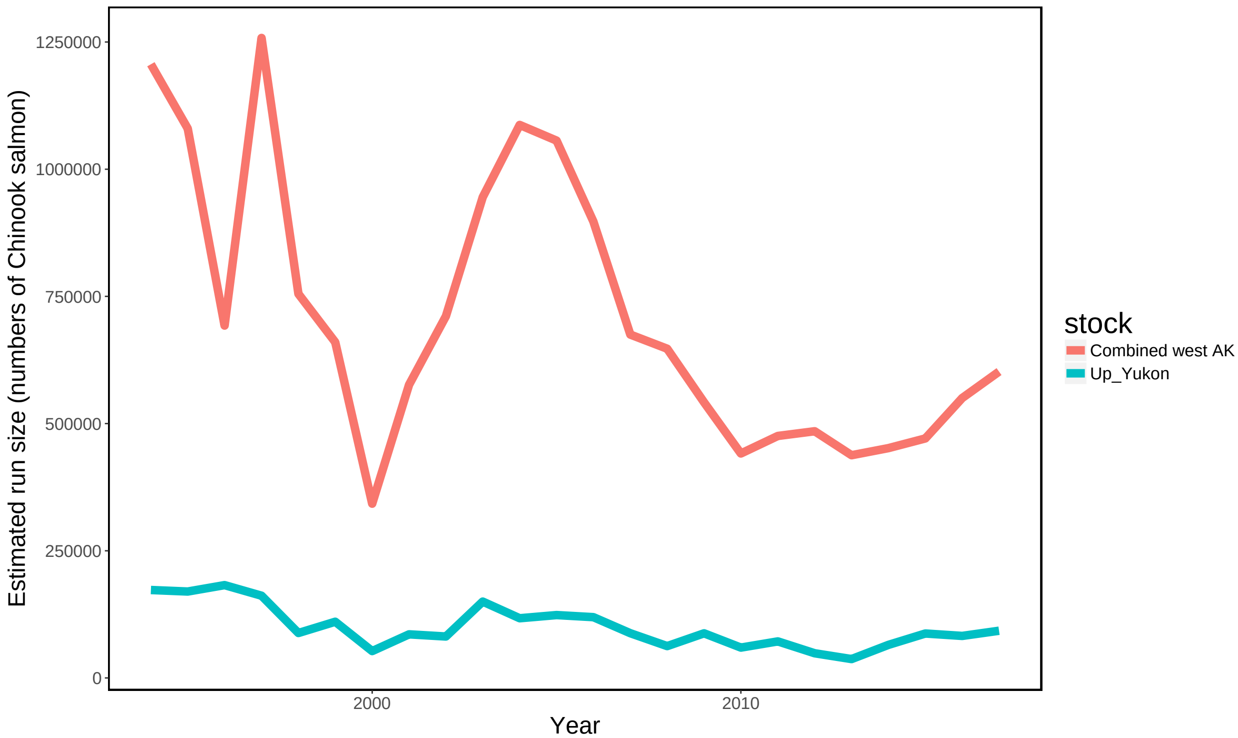
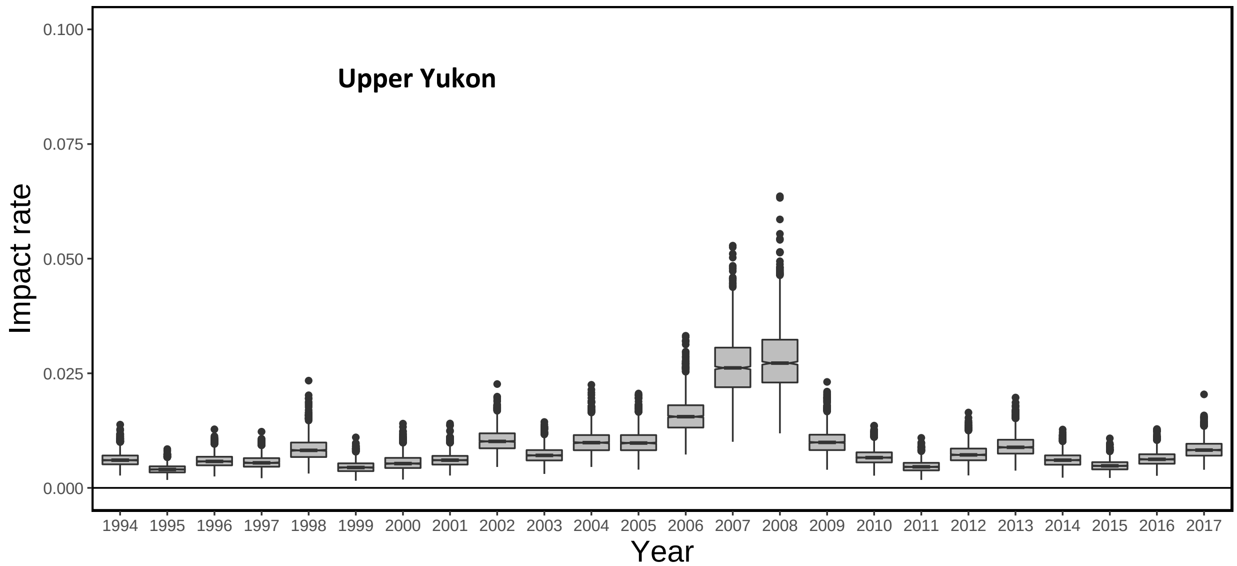


Fig. 7. Time series of Chinook salmon run strength estimates for western Alaska (includes coastal west Alaska stocks plus lower and middle Yukon River) and for the Canadian portion of the upper Yukon River, 1994–2017. *Source K. Howard ADFG.*



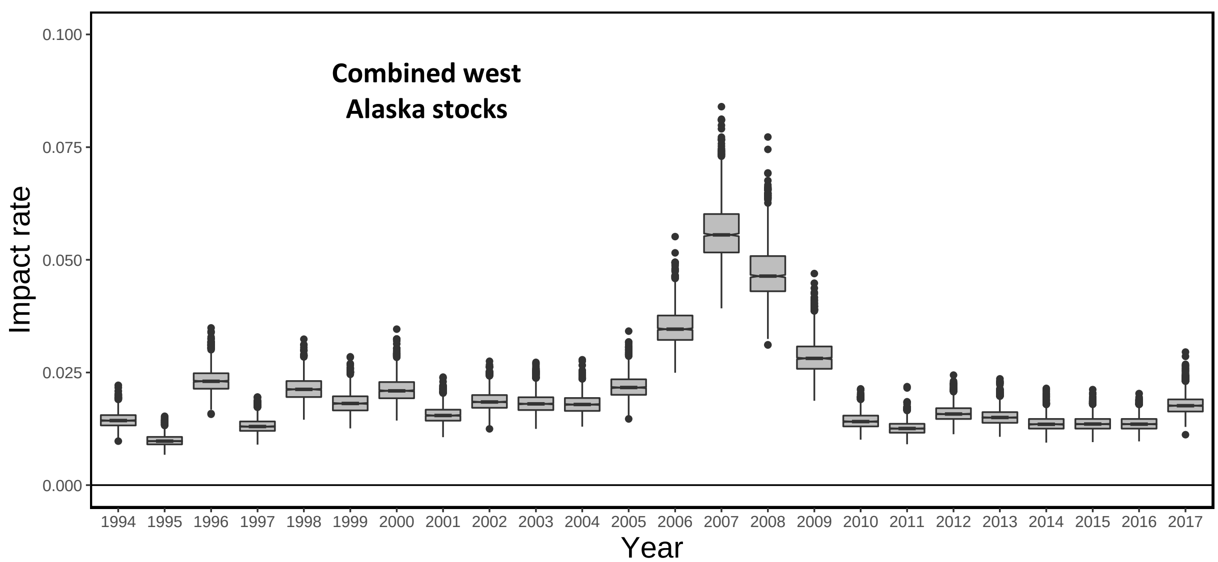


Figure 8. Estimated impact of the BS pollock fishery on the Upper Yukon stock (top) and combined west Alaska (which includes the "middle Yukon"; bottom), 1994–2017. Vertical axis is the ratio of AEQ over the point estimates of total run sizes.

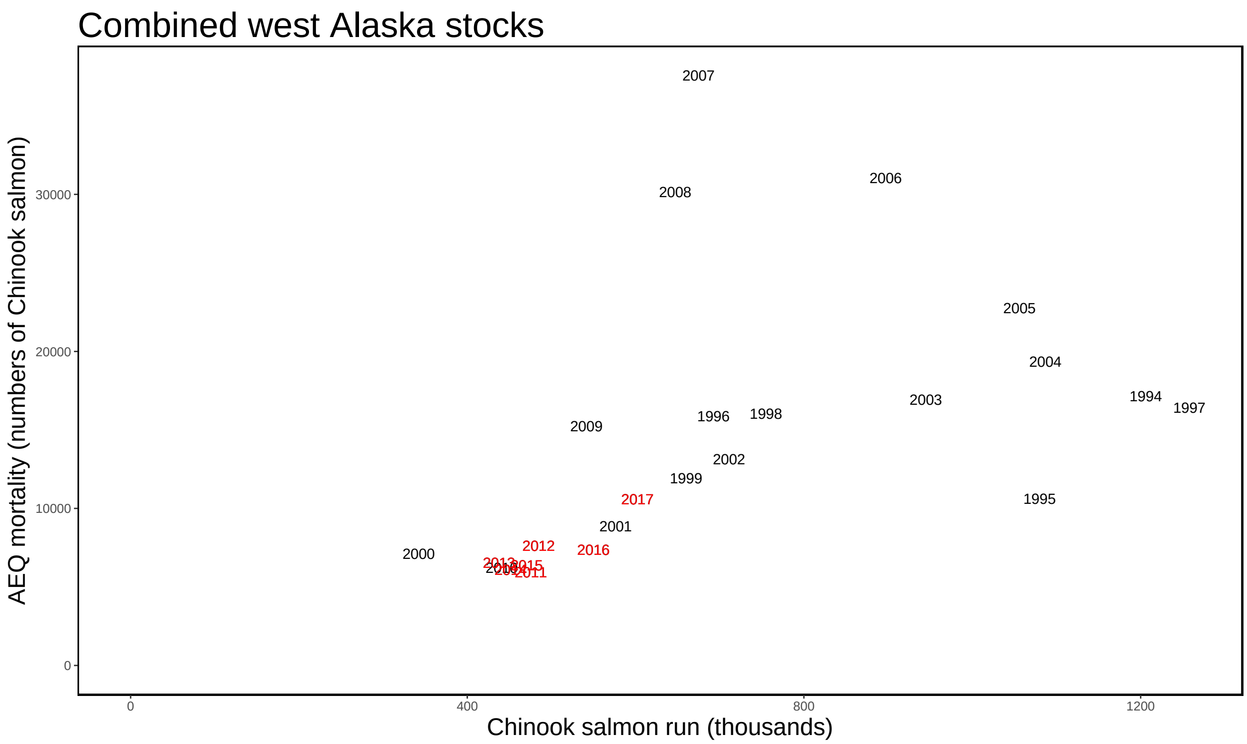


Fig. 9. Combined western Alaska Chinook salmon adult equivalent mortality estimates (vertical scale) compared to combined in-river returns (horizontal scale, thousands), 1994–2017. This represesnts the genetic stock ID estimates applied to AEQ for the lower and middle Yukon River plus the “coastal west Alaska” stocks (Kuskokwim, Nushagak, and Norton Sound). Recent years are indicated in red.