Tanner Crab Catch Survey Analysis - Updated

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Background

Catch Survey Analysis (CSA) aims to extract the real signal of stock abundance from otherwise noisy survey data by smoothing through a simple dynamic model (Collie and Sissenwine 1983; Mensil 2003). CSAs are particularly useful for small stocks for which survey estimates are available (though often with large observation errors) and / or other information that may inform a more data intensive stage structured model (e.g., any of the large BSAI crab assessments), or the resources that support those models, are limited. ADF&G uses CSA to evaluate the stock biomass and inform fishery management decisions for SEAK RKC and Tanner crab stocks.

Tanner Crab CSA

A three-stage CSA based on that developed by Collie et al. (2005) was fitted to survey abundance indices of 'pre-recruits', 'recruits', and 'post-recruits'. Pre-recruits were male crab 114 - 139 mm carapace width, recruits were male crab 140 - 164 mm carapace width of 'new' shell condition, and post recruits were male crab 140 - 164 mm carapace width of 'old' shell condition, or 165 mm carapace and larger regardless of shell condition. Post recruit abundance is modeled as

$$P_{t+1} = (R_t + P_t)e^{-M\tau_s} - C_t e^{-M_t \tau_{cs}} \tag{1}$$

where P represents the survey index of post recruits, R is the survey index of recruits, C is annual commercial fishery harvest, M is natural mortality, and τ_s and τ_{cs} are the fraction of year between sequential surveys, and the fishery and survey, respectively. Recruit abundance is estimated as

$$R_{t+1} = \phi N_t e^{-m\tau_s} \tag{2}$$

where N is pre-recruit abundance, m is stage specific natural morality for pre-recruits, and ϕ is the probability of transitioning between pre-recruit and recruit stages. Annual pre-recruit abundance is estimated as

$$N_t = (1-\phi)N_{t-1}e^{-m\tau_s} + N_{r,t} \tag{3}$$

where $N_{r,t}$ is recruitment to the pre-recruit size class (not to be confused with the recruit stage).

Two versions of the CSA were considered. One model assumes ϕ is known and estimates m, while the other set $m = M$ and estimates ϕ. Other estimable parameters include the annual index of recruiting, pre-recruit abundance, initial recruit and post-recruit indices, and catchability (q), which is used to scale survey indices to harvest and population abundance. Unlike Collie et al. (2005), all stages are assumed to have equal catchabilities.

Model parameters are estimated by minimizing the following objective function

$$SSQ = \sum_{t=1}^{y} \sum_{i=1}^{s} w(\ln \hat{\eta}_i - \ln \eta_i)^2 \tag{4}$$

where η_i represents the predicted ($\hat{\eta}_i$) and observed survey index of s stages: pre-recruits, recruits, and post-recruits. A vector of weights (w) can be used to weight years or stages based on relative errors (see Collie et al. 2005 for weighting by stage). For now, equal weighting was assumed. In the case that observed or predicted indices equaled zero, a small modifier was added so that the function remained defined. See Collie et al. (2005) for more details on general model structure and estimation.

Though the CSA model does not include random effects, I implement the model within the R package *Template Model Builder* (TMB; Kristensen et al. 2016). TMB compiles a C++ model template which is minimized in the R environment, and in this case simply provides a more efficient means of function minimization with standard errors. For the time being, parameters are not bounded and it has not presented any obvious problems. . . yet.

Kodiak Eastside

Initial CSA conditions included a stage transition probability of $\phi = 1$ and natural mortality of $M = 0.3$, consistent with SE Tanner crab stocks that use CSA. Area swept estimates were computed for each stage and used as a relative index of abundance for estimation (Table 5). The median date of survey tows with a year and the average of the fishery opening and closing date for each season were used to compute τ_s and τ_{cs} (Table 6). Retained catch (number of crab) was compiled from fish ticket data (Table 7).

SE Tanner crab stocks assume a natural mortality on fully recruited crab of $M = 0.3$ and the EBS Tanner crab assessment assumes $M = 0.23$ and estimates a multiplier for different life history stages (Stockhausen 2020). In addition, the EBS assessment includes bycatch mortality from multiple fisheries, which in this less parameterized model may be incorporated into M, therefore it is reasonable to assume the optimal value of M may be greater than expected. I profiled M by re-fitting the model over a series a range of M values and found that $M = 0.6$ resulted in the best model fit (i.e., minimum objective function) (Figure 1).

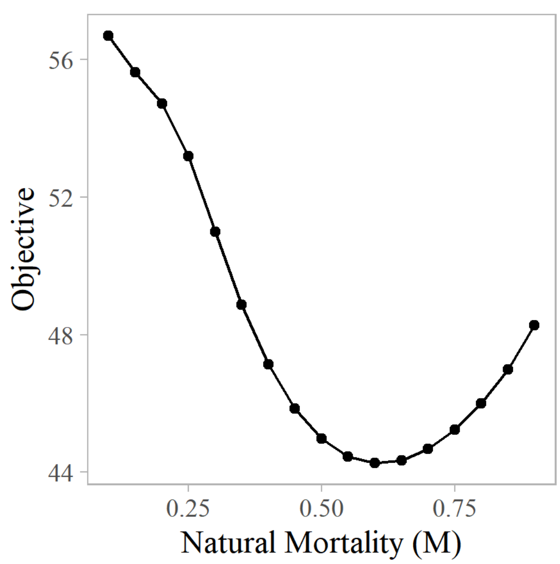

Figure 1: Objective function profile of natural mortality M for CSA, Kodiak Eastside 1988 - 2020.

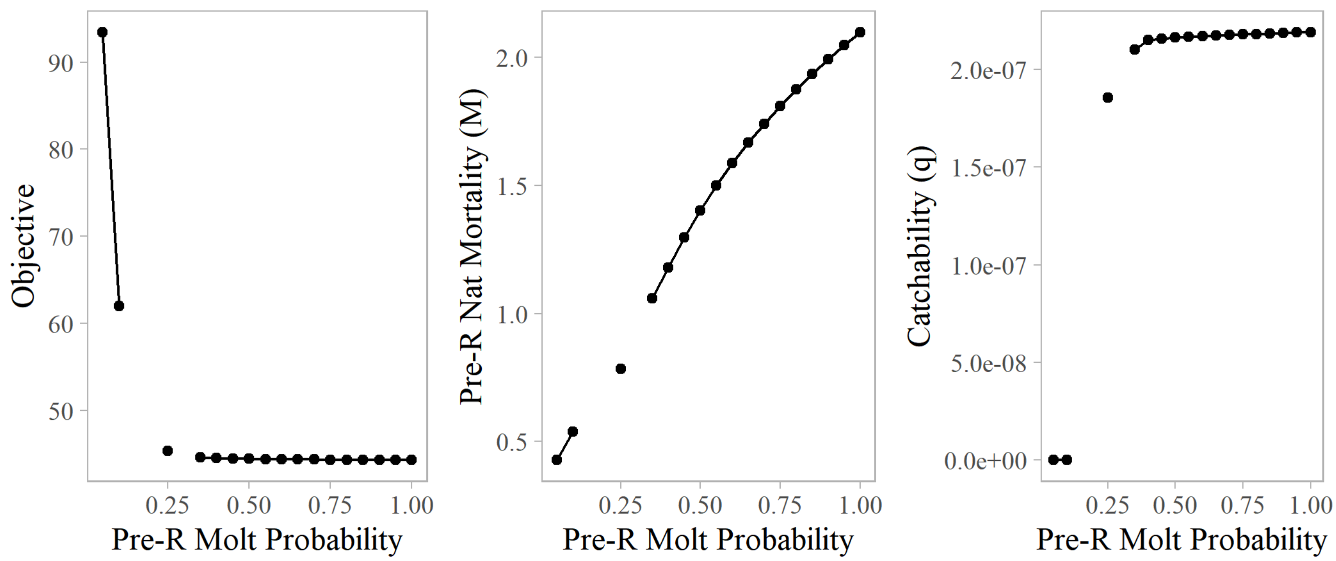

Figure 2: Objective function profile of transition probability ϕ as well as profiled estimates of pre-recruit mortality and catchability for CSA, Kodiak Eastside 1988 - 2020.

The CSA was re-fit assuming $M = 0.6$. Increasing M improved fits to legal male indices without having substantial impacts on catchability, pre-recruit natural mortality, or annual pre-recruit abundance. The pre-recruit stage is large (~30 mm), likely making the assumption that $\phi = 1$ unrealistic, and leading to estimates of pre-recruit natural mortality that seem usually high ($m > 2$). I profiled ϕ by the same method used for natural mortality and demonstrated that values of ϕ ranging from 0.35-1 achieve similar model performance, while having a strong impact on m (Figure 2), which was expected. Since size composition data are available annually, I estimated a time varying value of ϕ outside the model via

$$\hat{\phi}_t = \frac{\sum_{i=1}^{h} n_{i,t}(1-\theta_i)}{\sum_{i=1}^{h} n_{i,t}} \tag{5}$$

$$\theta = \frac{1}{1 + e^{-0.081(CW-109.17)}} \tag{6}$$

where is $n_{i,t}$ is the observed survey abundance of pre-recruit crab in 1 mm size bin i, and θ_i is the probability of being morphometrically mature based on the a binomial regression fit to data collected throughout the timeseries in the Kodiak District and the distribution based cut-line (see Knutson *in prep* for more detail). CW refers to carapace width. By this method it was assumed that the average probability that an individual crab within a given year is immature, is equivalent to the probability that it would molt and transition stages the following year. Estimated ϕ ranged narrowly from 0.17-0.24. Allowing for time varying ϕ did not improve overall fit, so ϕ remained fixed at 1.

Model A.2 appears to perform the best relative to the others evaluated (see below).

Table 1: Parameterization of various models fit to Kodiak Eastside data."$*$" denotes an estimable parameter.

Parameter	A.1	A.2	A.3	B.1	B.2
ln Init N	$*$	$*$	$*$	$*$	$*$
ln Init R	$*$	$*$	$*$	$*$	$*$
ln Init P	$*$	$*$	$*$	$*$	$*$
ln $N_{r,t}$	$*$	$*$	$*$	$*$	$*$
ϕ	1	1	0.17-0.24	$*$	$*$
q	$*$	$*$	$*$	$*$	$*$
M	0.3	0.6	0.6	0.3	0.6
m	$*$	$*$	$*$	0.3	0.6

Table 2: Parameter estimates, objective function, and convergence (0 - successful, 1 - not successful) for different CSA model scenarios fit to Kodiak Eastside data 1988 - 2020.

	A.1	A.2	A.3	B.1	B.2
ln_N_init	0.317	0.116	0.341	0.338	0.241
ln_R_init	-1.227	-1.357	-1.378	-1.301	-1.340
ln_P_init	-2.397	-2.435	-2.442	-2.418	-2.429
ln_N_1989	1.364	0.665	0.343	0.821	0.371
ln_N_1990	1.956	1.539	1.356	0.934	1.252
ln_N_1991	1.891	1.149	0.430	-39.803	-0.034
ln_N_1992	0.441	0.131	-17.734	-33.564	-38.840
ln_N_1993	-0.184	-0.437	-1.478	-33.319	-1.946
ln_N_1994	-0.749	-0.851	-1.847	-33.423	-1.868
ln_N_1995	-0.326	-0.353	-0.498	-1.484	-0.715
ln_N_1996	0.319	0.399	0.291	-0.337	0.088
ln_N_1997	0.520	0.617	0.370	-0.249	0.191
ln_N_1998	1.229	1.397	1.371	0.661	1.150
ln_N_1999	1.204	1.439	0.727	-1.104	0.448
ln_N_2000	0.089	0.116	-23.245	-29.139	-52.672
ln_N_2001	0.407	0.458	0.197	-0.649	-0.046
ln_N_2002	0.318	0.318	-0.317	-0.911	-0.384
ln_N_2003	1.919	1.988	1.932	1.574	1.816
ln_N_2004	2.561	2.803	2.778	1.458	2.518
ln_N_2005	1.766	1.890	-1.227	-16.753	-16.573
ln_N_2006	0.957	1.005	-2.065	-21.145	-18.937
ln_N_2007	0.472	0.478	-0.613	-25.285	-0.776
ln_N_2008	1.683	1.935	1.898	1.239	1.763
ln_N_2009	2.212	2.687	2.738	0.789	2.382
ln_N_2010	1.675	2.033	-16.385	-32.029	-14.755
ln_N_2011	1.000	1.204	-20.046	-32.813	-52.618
ln_N_2012	-0.492	-0.493	-31.442	-33.603	-66.953
ln_N_2013	-1.105	-1.138	-29.772	-35.203	-59.866
ln_N_2014	-0.608	-0.590	-0.928	-2.459	-0.986
ln_N_2015	0.193	0.292	0.150	-0.321	0.028
ln_N_2016	1.353	1.602	1.591	0.980	1.421
ln_N_2017	1.232	1.304	0.238	-1.841	-0.171
ln_N_2018	0.018	-0.056	-26.779	-42.830	-60.068
ln_N_2019	0.509	0.431	0.077	-0.345	0.016
ln_N_2020	1.918	1.918	1.826	1.777	1.824
ln_N_natM	0.816	0.742	-0.354		
ln_q	-14.105	-15.334	-15.813	-14.295	-15.268
phi				0.185	0.248
obj	50.995	44.258	44.694	61.105	46.339
convergence	0.000	0.000	0.000	1.000	1.000

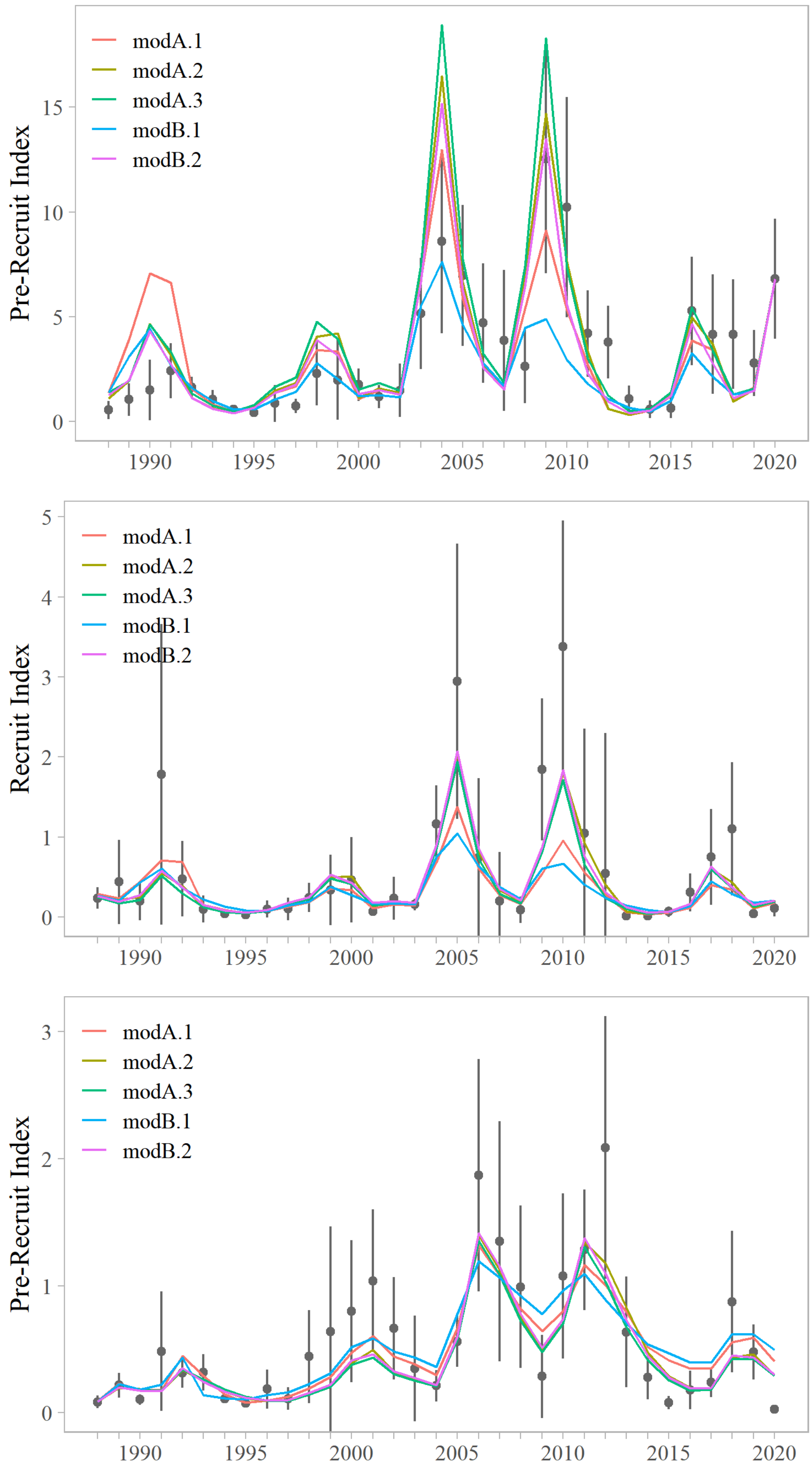

Figure 3: CSA fits to pre-recruit, recruit, and post-recruit indices based on different model scenarios.

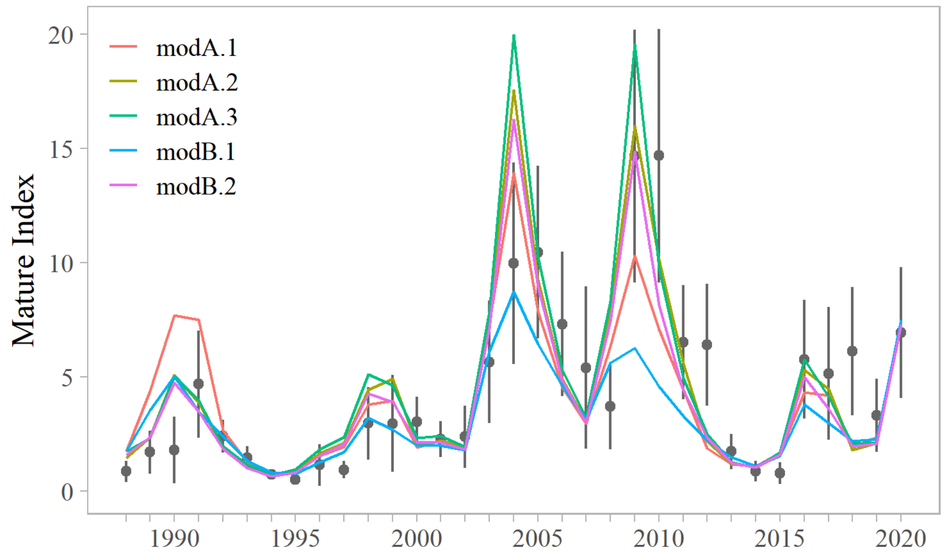

Figure 4: CSA fits to mature male index based on different model scenarios.

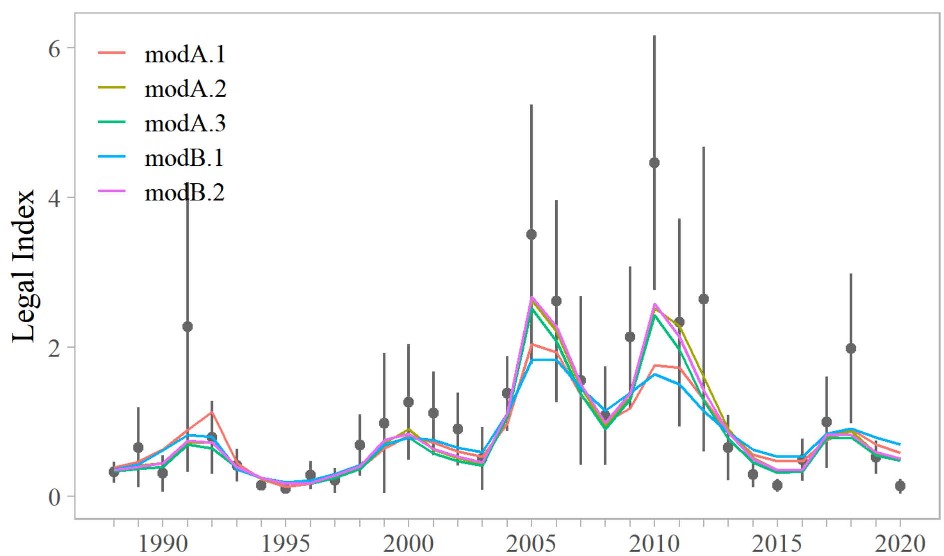

Figure 5: CSA fits to legal male index based on different model scenarios.

Kodiak Southeast —-

Model A.2 (above) was also fit to Kodiak Southeast data, and successfully reached convergence. Again, a high natural mortality (M) provides the optimal fit to the data. Input data is in Appendix 1, and CSA model results are below.

Table 3: Parameter estimates for CSA fit to Kodiak Southeast data 1988 - 2020.

Parameter	Estimate	Std Error
ln_N_init	-0.874	0.464
ln_R_init	-2.243	0.471
ln_P_init	-3.090	0.565
ln_N_1989	-0.449	0.460
ln_N_1990	-0.045	0.476
ln_N_1991	-1.176	0.513
ln_N_1992	-1.029	0.494
ln_N_1993	-0.490	0.473
ln_N_1994	-0.430	0.482
ln_N_1995	-1.406	0.512
ln_N_1996	-2.681	0.516
ln_N_1997	-2.047	0.541
ln_N_1998	0.317	0.486
ln_N_1999	-1.395	0.573
ln_N_2000	-0.839	0.552
ln_N_2001	-1.348	0.496
ln_N_2002	-1.146	0.455
ln_N_2003	-0.363	0.379
ln_N_2004	-0.980	0.377
ln_N_2005	-2.042	0.395
ln_N_2006	-0.702	0.483
ln_N_2007	-7.631	0.506
ln_N_2008	1.518	0.450
ln_N_2009	2.257	0.460
ln_N_2010	1.573	0.500
ln_N_2011	-0.608	0.512
ln_N_2012	-0.410	0.511
ln_N_2013	-1.786	0.498
ln_N_2014	-0.414	0.507
ln_N_2015	-0.471	0.509
ln_N_2016	0.187	0.462
ln_N_2017	-6.096	0.506
ln_N_2018	-0.105	0.449
ln_N_2019	1.406	0.506
ln_N_2020	1.455	0.707
ln_N_natM	0.841	0.068
ln_q	-34.539	

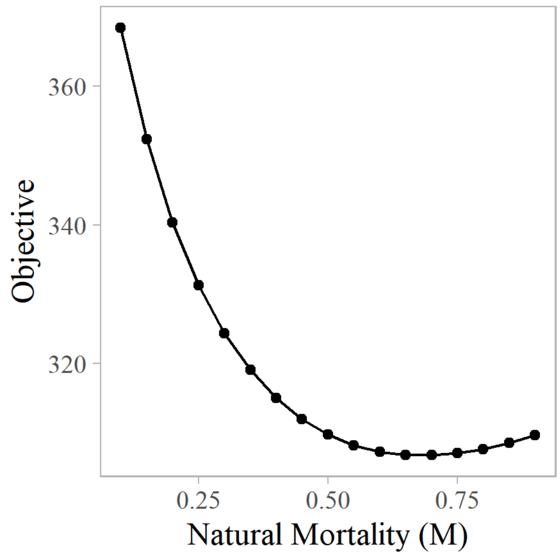

Figure 6: Objective function profile of natural mortality M for CSA, Kodiak Southeast 1988 - 2020.

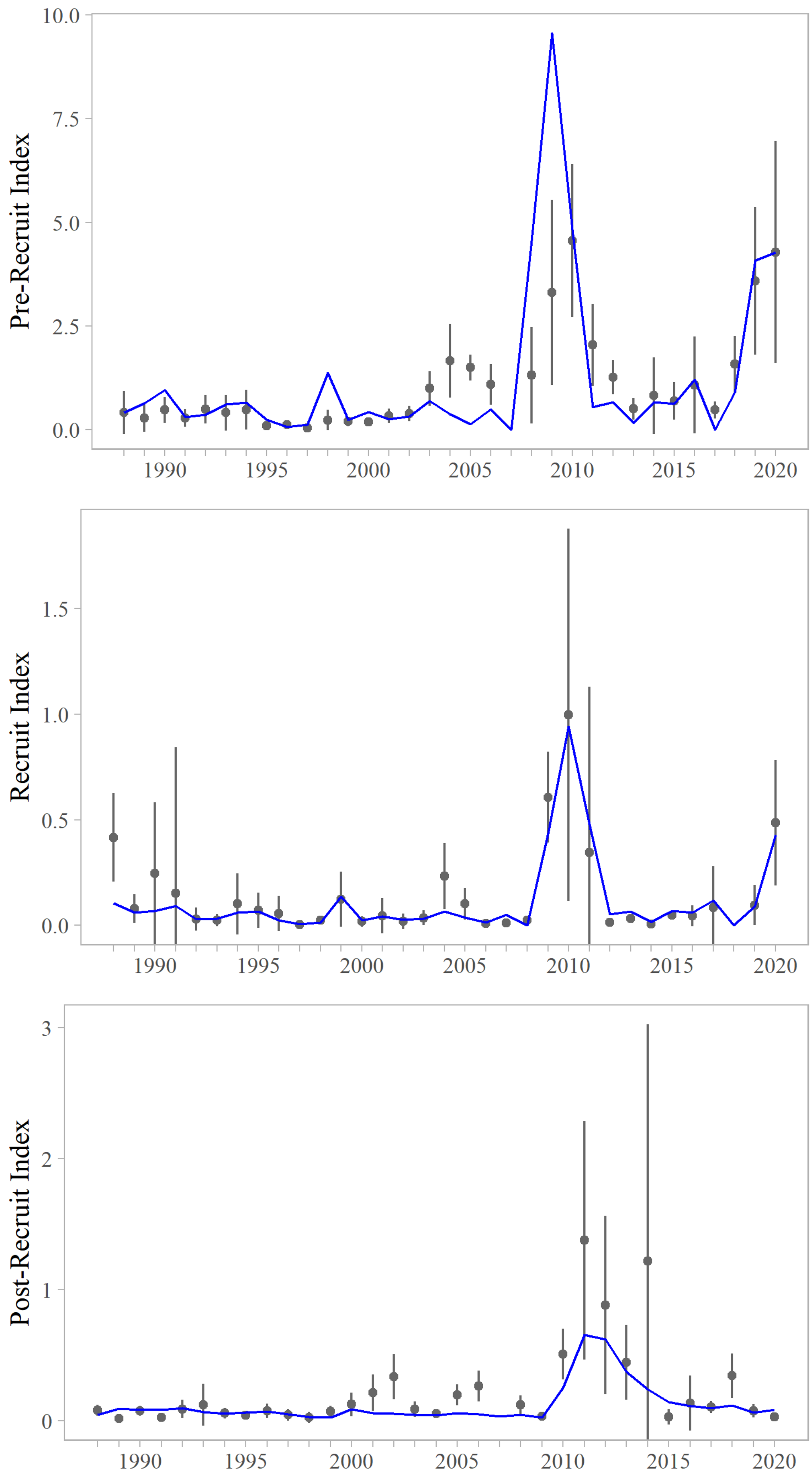

Figure 7: CSA fits to pre-recruit, recruit, and post-recruit indices for Kodiak Southeast 1988 - 2020.

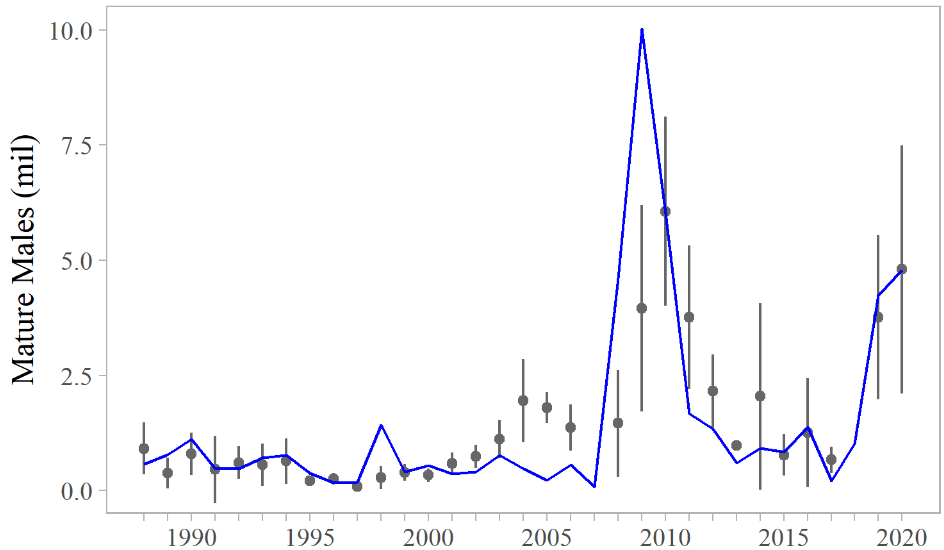

Figure 8: CSA fits to mature male index for Kodiak Southeast 1988 - 2020.

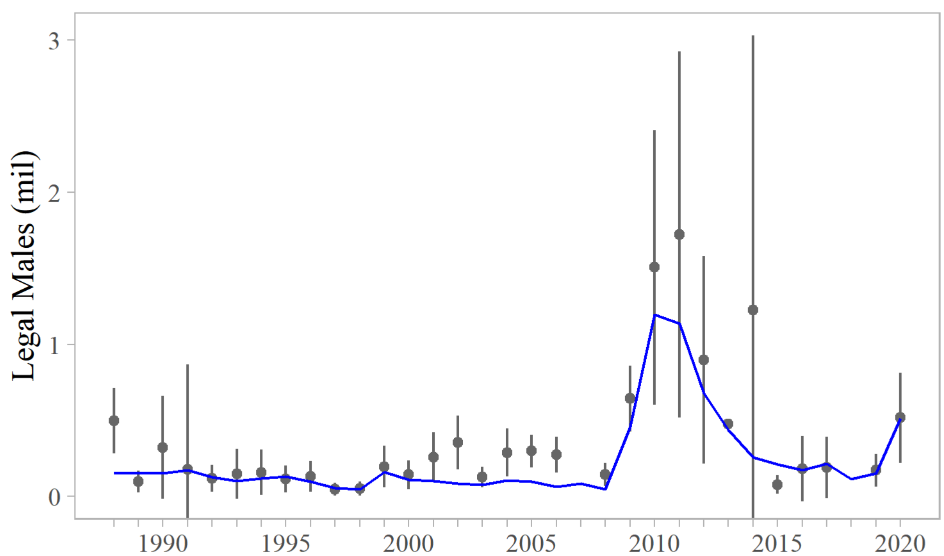

Figure 9: CSA fits to legal male index for Kodiak Southeast 1988 - 2020.

Kodiak Northeast —-

Model A.2 (above) was also fit to Kodiak Northeast data, and successfully reached convergence but did not produce standard errors on parameters. Again, a high natural mortality (M) provides the optimal fit to the data. Input data is in Appendix 1, and CSA model results are below.

Table 4: Parameter estimates for CSA fit to Kodiak Northeast data 1988 - 2020.

Parameter	Estimate	Std Error
ln_N_init	-0.399	
ln_R_init	-2.031	
ln_P_init	-3.637	
ln_N_1989	-0.117	
ln_N_1990	-0.239	
ln_N_1991	-0.324	
ln_N_1992	-0.391	
ln_N_1993	-0.775	
ln_N_1994	-2.051	
ln_N_1995	-1.762	
ln_N_1996	-0.904	
ln_N_1997	-0.030	
ln_N_1998	0.642	
ln_N_1999	0.328	
ln_N_2000	-0.113	
ln_N_2001	0.349	
ln_N_2002	0.644	
ln_N_2003	1.245	
ln_N_2004	1.062	
ln_N_2005	0.371	
ln_N_2006	-0.015	
ln_N_2007	0.308	
ln_N_2008	1.071	
ln_N_2009	1.019	
ln_N_2010	0.156	
ln_N_2011	-0.655	
ln_N_2012	-0.868	
ln_N_2013	-1.849	
ln_N_2014	-1.371	
ln_N_2015	-1.756	
ln_N_2016	-1.401	
ln_N_2017	-1.385	
ln_N_2018	-1.222	
ln_N_2019	-0.161	
ln_N_2020	-0.553	
ln_N_natM	0.862	
ln_q	-34.539	

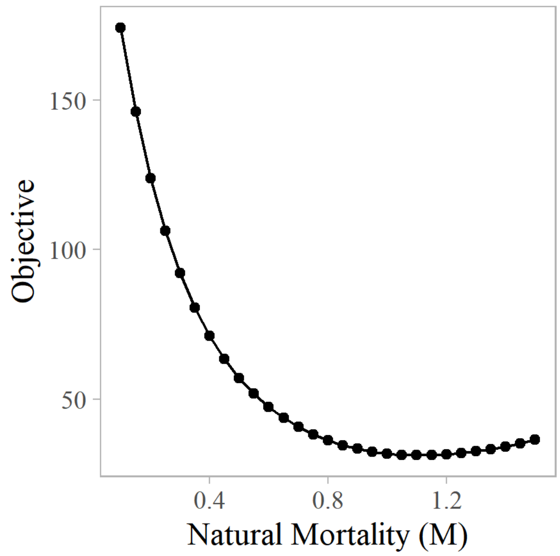

Figure 10: Objective function profile of natural mortality M for CSA, Kodiak Northeast 1988 - 2020.

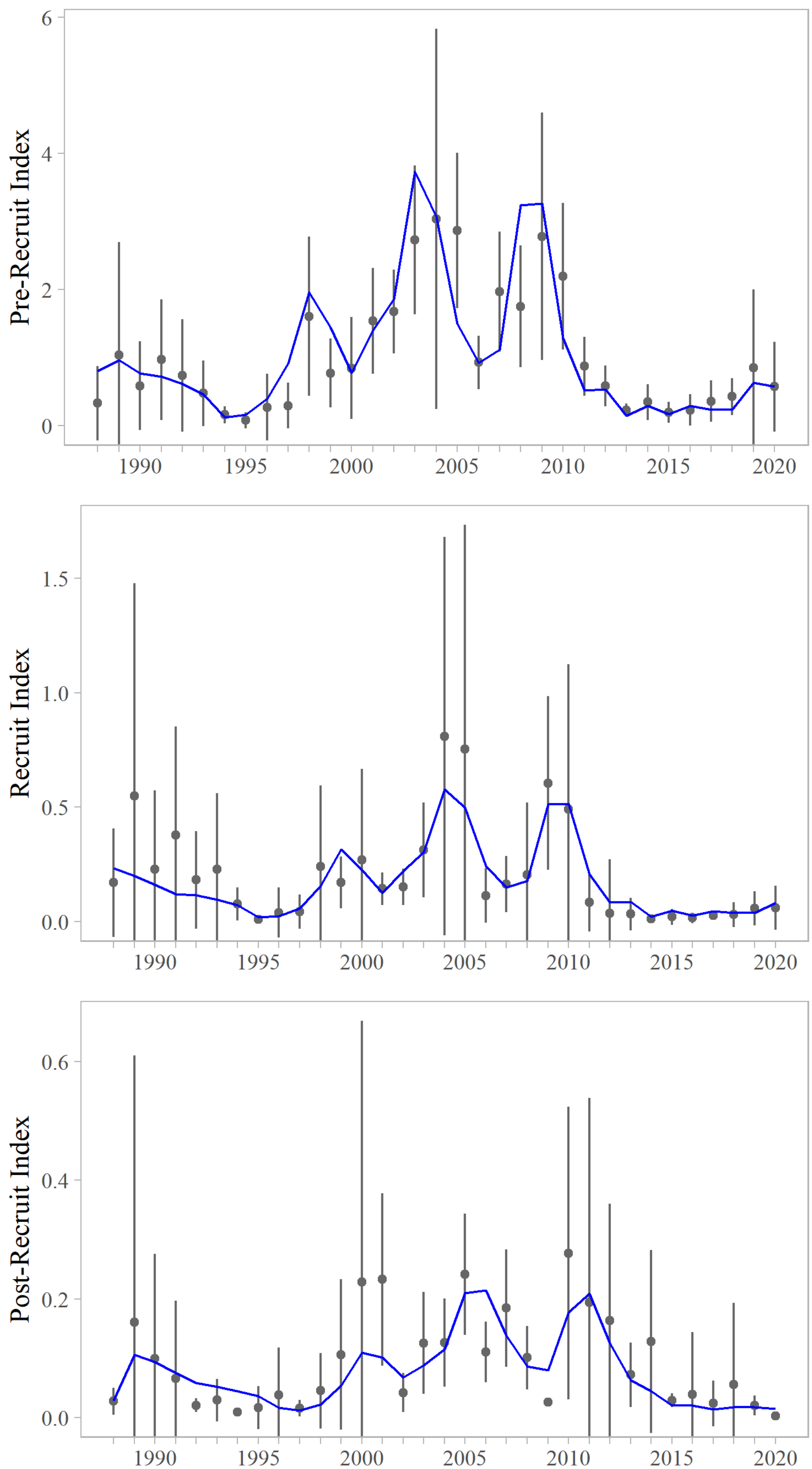

Figure 11: CSA fits to pre-recruit, recruit, and post-recruit indices for Kodiak Northeast 1988 - 2020.

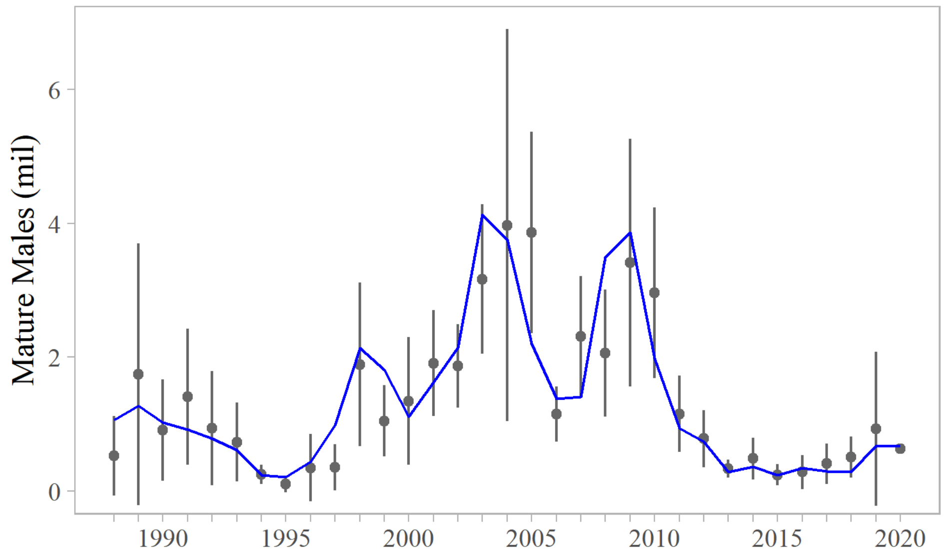

Figure 12: CSA fits to mature male index for Kodiak Northeast 1988 - 2020.

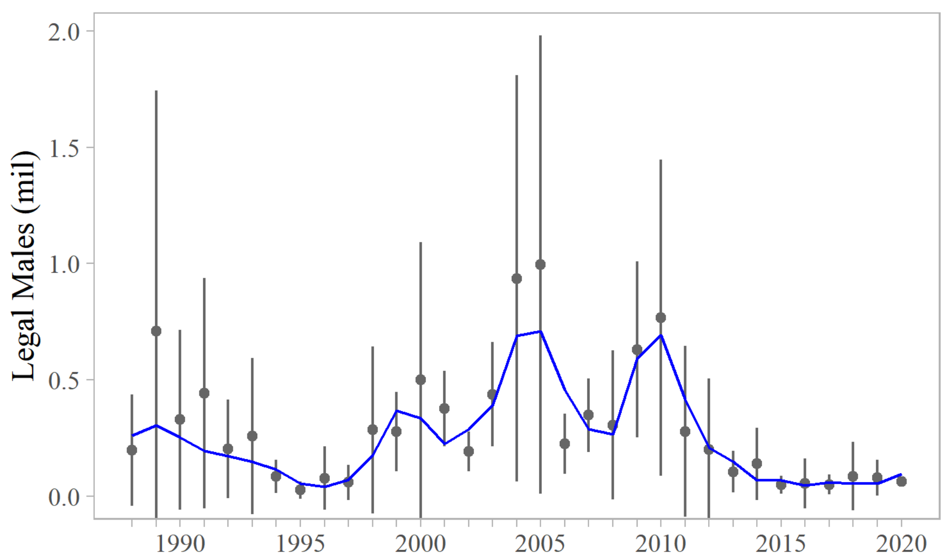

Figure 13: CSA fits to legal male index for Kodiak Northeast 1988 - 2020.

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Appendix 1 - CSA Inputs

Table 5: Pre-recruit, recruit, and post-recruit relative abundance indices (millions) and associated CVs for Kodiak Eastside from 1988-2020.

Year	Pre-Recruit (N)	Recruit (R)	Post Recruit (P)
1988	0.55 (0.41)	0.238 (0.28)	0.085 (0.3)
1989	1.054 (0.38)	0.44 (0.61)	0.216 (0.23)
1990	1.496 (0.49)	0.204 (0.6)	0.103 (0.2)
1991	2.422 (0.28)	1.784 (0.54)	0.483 (0.5)
1992	1.628 (0.16)	0.477 (0.5)	0.314 (0.19)
1993	1.05 (0.22)	0.101 (0.84)	0.316 (0.23)
1994	0.588 (0.16)	0.044 (0.12)	0.108 (0.15)
1995	0.423 (0.17)	0.028 (0.47)	0.075 (0.14)
1996	0.864 (0.52)	0.1 (0.55)	0.185 (0.43)
1997	0.731 (0.24)	0.101 (0.71)	0.111 (0.4)
1998	2.287 (0.34)	0.244 (0.38)	0.443 (0.42)
1999	1.984 (0.49)	0.34 (0.66)	0.641 (0.66)
2000	1.766 (0.22)	0.465 (0.58)	0.799 (0.36)
2001	1.182 (0.24)	0.071 (0.39)	1.039 (0.28)
2002	1.485 (0.44)	0.236 (0.58)	0.664 (0.31)
2003	5.158 (0.26)	0.157 (0.24)	0.349 (0.61)
2004	8.598 (0.26)	1.164 (0.21)	0.212 (0.3)
2005	6.962 (0.25)	2.944 (0.3)	0.56 (0.18)
2006	4.705 (0.31)	0.741 (0.69)	1.87 (0.25)
2007	3.86 (0.44)	0.201 (1.56)	1.351 (0.36)
2008	2.646 (0.34)	0.092 (0.9)	0.991 (0.33)
2009	12.534 (0.22)	1.844 (0.25)	0.287 (0.58)
2010	10.228 (0.26)	3.381 (0.24)	1.077 (0.31)
2011	4.201 (0.25)	1.045 (0.64)	1.283 (0.19)
2012	3.779 (0.23)	0.547 (1.64)	2.088 (0.25)
2013	1.094 (0.29)	0.014 (0.25)	0.636 (0.35)
2014	0.589 (0.37)	0.013 (0.37)	0.277 (0.31)
2015	0.649 (0.38)	0.067 (0.52)	0.079 (0.34)
2016	5.287 (0.25)	0.309 (0.4)	0.18 (0.43)
2017	4.17 (0.35)	0.751 (0.41)	0.24 (0.25)
2018	4.162 (0.32)	1.101 (0.39)	0.874 (0.32)
2019	2.799 (0.29)	0.046 (0.51)	0.478 (0.23)
2020	6.81 (0.21)	0.109 (0.46)	0.028 (0.24)

Table 6: τ_s and τ_{cs} for Kodiak Eastside from 1988-2020.

Year	τ_s	τ_{cs}
1988		0.68
1989	0.78	0.46
1990	0.96	0.41
1991	1.02	0.42
1992	1.00	0.42
1993	1.02	0.45
1994	0.99	0.47
1995	0.99	1.00
1996	1.00	1.00
1997	1.04	1.00
1998	0.97	1.00
1999	1.00	1.00
2000	1.01	1.00
2001	1.00	0.46
2002	0.99	0.42
2003	1.00	0.35
2004	1.02	0.36
2005	0.99	0.44
2006	1.00	0.45
2007	1.00	0.45
2008	1.00	0.44
2009	1.01	0.45
2010	1.00	0.45
2011	1.00	0.45
2012	1.00	0.43
2013	1.01	0.45
2014	0.99	1.00
2015	0.98	1.00
2016	1.02	1.00
2017	1.00	1.00
2018	1.02	0.44
2019	0.99	0.40
2020	0.98	1.00

Table 7: Landings (number of crab) for Kodiak Eastside fisheries from 1988-2020.

Year	Retained crab
1988	109,679
1989	257,083
1990	423,899
1991	324,075
1992	831,108
1993	285,986
1994	168,719
1995	0
1996	0
1997	0
1998	0
1999	0
2000	0
2001	139,730
2002	89,502
2003	140,421
2004	96,140
2005	289,885
2006	539,126
2007	279,624
2008	131,217
2009	121,754
2010	212,426
2011	404,819
2012	246,962
2013	213,666
2014	0
2015	0
2016	0
2017	0
2018	115,076
2019	213,685
2020	127,910

Table 8: Pre-recruit, recruit, and post-recruit relative abundance indices (millions) and associated CVs for Kodiak Southeast from 1988-2020.

Year	Pre-Recruit (N)	Recruit (R)	Post Recruit (P)
1988	0.417 (0.63)	0.416 (0.26)	0.082 (0.27)
1989	0.282 (0.6)	0.079 (0.44)	0.02 (0.39)
1990	0.475 (0.33)	0.245 (0.7)	0.077 (0.24)
1991	0.28 (0.39)	0.151 (2.34)	0.026 (0.61)
1992	0.491 (0.36)	0.029 (0.97)	0.089 (0.4)
1993	0.408 (0.54)	0.024 (0.62)	0.124 (0.66)
1994	0.48 (0.5)	0.101 (0.73)	0.058 (0.34)
1995	0.094 (0.23)	0.071 (0.61)	0.044 (0.35)
1996	0.125 (0.32)	0.055 (0.77)	0.076 (0.37)
1997	0.046 (0.32)	0.003 (0)	0.045 (0.48)
1998	0.232 (0.54)	0.025 (0.37)	0.026 (0.84)
1999	0.199 (0.3)	0.124 (0.54)	0.072 (0.3)
2000	0.189 (0.29)	0.018 (0.71)	0.125 (0.37)
2001	0.334 (0.26)	0.044 (0.97)	0.214 (0.33)
2002	0.388 (0.24)	0.019 (0.97)	0.336 (0.26)
2003	0.993 (0.21)	0.036 (0.5)	0.09 (0.33)
2004	1.658 (0.27)	0.234 (0.34)	0.056 (0.24)
2005	1.499 (0.11)	0.101 (0.37)	0.197 (0.21)
2006	1.094 (0.23)	0.008 (0.13)	0.267 (0.23)
2007	NA (NA)	0.01 (0.73)	NA (NA)
2008	1.315 (0.45)	0.023 (0.47)	0.121 (0.3)
2009	3.314 (0.34)	0.607 (0.18)	0.036 (0.42)
2010	4.555 (0.21)	0.997 (0.45)	0.51 (0.19)
2011	2.045 (0.25)	0.344 (1.17)	1.378 (0.34)
2012	1.264 (0.16)	0.014 (0.37)	0.885 (0.39)
2013	0.502 (0.26)	0.032 (NaN)	0.445 (0.33)
2014	0.822 (0.57)	0.006 (0.6)	1.221 (0.75)
2015	0.692 (0.33)	0.047 (0.11)	0.032 (0.94)
2016	1.078 (0.55)	0.046 (0.56)	0.135 (0.78)
2017	0.477 (0.22)	0.084 (1.19)	0.106 (0.22)
2018	1.578 (0.22)	NA (NA)	0.344 (0.25)
2019	3.587 (0.25)	0.095 (0.51)	0.078 (0.33)
2020	4.283 (0.32)	0.487 (0.31)	0.03 (0.23)

Table 9: τ_s and τ_{cs} for Kodiak Southeast from 1988-2020.

Year	τ_s	τ_{cs}
1988		1.00
1989	0.83	0.47
1990	0.96	0.44
1991	1.02	0.44
1992	1.01	1.00
1993	1.03	1.00
1994	0.99	1.00
1995	0.98	1.00
1996	1.00	1.00
1997	1.04	1.00
1998	0.97	1.00
1999	1.00	1.00
2000	1.01	1.00
2001	1.00	1.00
2002	0.99	1.00
2003	0.99	1.00
2004	1.02	0.45
2005	0.99	0.37
2006	1.00	0.37
2007	1.00	1.00
2008	1.00	1.00
2009	1.01	1.00
2010	1.00	0.45
2011	1.00	0.47
2012	1.00	0.47
2013	0.99	0.42
2014	1.00	1.00
2015	0.98	1.00
2016	1.01	1.00
2017	1.00	1.00
2018	1.02	1.00
2019	0.99	0.36
2020	0.97	0.42

Table 10: Landings (number of crab) for Kodiak Southeast fisheries from 1988-2020.

Year	Retained crab
1988	420,258
1989	466,649
1990	202,243
1991	155,346
1992	0
1993	0
1994	0
1995	0
1996	0
1997	0
1998	0
1999	0
2000	0
2001	0
2002	0
2003	0
2004	39,255
2005	40,179
2006	53,162
2007	0
2008	0
2009	0
2010	45,214
2011	93,135
2012	129,344
2013	49,547
2014	0
2015	0
2016	0
2017	0
2018	0
2019	48,727
2020	43,771