Appendix B

Norton Sound Red King Crab CPUE Standardization

Note: This is an update of model by G. Bishop (NPFMC 2013). Please see SAFE 2013 for more detailed descriptions.

Methods

Model

Let U_{ijk} denote the observed CPUE, U_0 the reference CPUE, P_{ij} a factor i at level j, and let X_{ij} take a value of 1 when the j^{th} level of the factor P_{ij} is present and 0 when it is not. The lognormal distribution of U_{ijk} (Quinn and Deriso 1999), can be denoted as:

$$U_{ijk} = U_0 \prod_i \prod_j P_{ij}^{X_{ij}} e^{\varepsilon_{ijk}} \quad (1)$$

or

$$\ln(U_{ijk}) = \ln(U_0) + \sum_{i=1}^{p} \sum_{j=1}^{n_j - 1} X_{ij} \ln(P_{ij}) + \varepsilon_{ijk} .$$

where ε_{ijk}, ~ N(0, σ^2) observation error

Substituting $\ln(U_0)$ to β_0 and $\ln(P_{ij})$ to β_{ij}, we then obtain an additive GLM lognormal error distribution of U_{ijk}:

$$\ln(U_{ijk}) = \beta_0 + \sum_{i=1}^{p} \sum_{j=1}^{n_j - 1} X_{ij} \beta_{ij} + \varepsilon_{ijk} . \quad (2)$$

Standardized CPUE was calculated as follows:

1. Divide the coefficients β_{ij} by their geometric mean $\bar{\beta}$ to obtain canonical coefficients:

$$\beta_i{}' = \frac{\beta_i}{\bar{\beta}}. \quad (3)$$

2. Exponentiate the result to obtain the non-log space canonical coefficients:

$$b' = e^{\beta_i - \bar{\beta}}. \quad (4)$$

3. Subtract the year coefficient reference level to obtain standardized CPUE U_j for each year level j as:

$$U_{Yj} = e^{\beta'_{Yj} - \beta'_{Y0}}. \quad (5)$$

4. Base year CPUE index is calculated by eliminating all factors but *Year* in the GLM and following Equations 2 and 3, 4, and 5 above.

SE of the standardized CPUE is calculated as:

Standard errors of CPUE are standard errors of the Year coefficients, $\hat{\beta}_{yr}$. These are obtained from the square root of the diagonal elements of the estimated covariance matrix, cov ($\hat{\beta}$) , i.e., $\sqrt{\boldsymbol{C'\emptyset C}}$.

where C $= X(X^T X)^{-1}$, C' is transpose of C; and $\emptyset = \boldsymbol{\sigma^2 I_n}$
where X is the matrix of predictor variables, I_n is the identity matrix, and σ is the standard error of the GLM fit.

Data Source & Cleaning

Commercial fishery harvest data were obtained from ADF&G fish ticket database, which included: Landing Date, Fish Ticket Number, Vessel Number, Permit Fishery ID, Statistical Area(s) fished, Effort, and Number and Pounds of Crab harvested (Table A2-1,2,3, Figure A2-1). Fish ticket database may have multiple entries of identical Fish Ticket Number, Vessel Number, Permit Fishery ID, and Statistical Area.

In those cases, at least one Effort data are missing or zero with the Number and Pounds of Crab harvested. These entries indicate that crab were either retained from the commercial fishery (i.e., not sold), or dead loss.

Following data cleaning and combining methods were conducted.

1. Sum crab number and efforts by Fish Ticket Number, Vessel Number, Permit Fishery ID, Statistical Area.
2. Remove data of missing or zero Efforts, Number of Crab, Pounds of Crab (Those are considered as true missing data).
3. Calculate CPUE as Number of Crab/Effort.

Data cleaning and censoring.

Norton Sound commercial red king crab fishery can be largely divided into three periods: large vessel operation (1977-1993), small vessel superexclusive (1994-2007), and small vessel superexclusive and high grading (2008-2919). Pre-superexclusive fishery consists of a few large boats, occurring in west of 167 longitude, and few deliveries, while post superexclusive fishery consists of many small boats of local fishermen, occurring east of 167 longitude and near shore, and delivering frequently (Figure 1B). Post-superexclusive period can further divided into pre (1994-2007) and post (2008-2020) highgrading periods. The majority of commercially caught red king crab are sold to Norton Sound Economic Development Corporation (NSEDC). Since mid-2000s NSEDC preferred carapase width (CW) of 5 inch or greater as marketable that was greater than legal sized crab of CW 4.75 inch or larger. This preference became more explicit since 2008 and later. For the purpose of modeling, 2008 was chosen as high-grading periods.

The data were censored in

During 1977-93 period, vessels of 1 year of operation and/or 1 delivery per year harvested 20-90% of crab (Table A2-5, Figure A2-2). For instance, all vessels did only 1 delivery in 1989, and in 1988 64% of crab were harvested by 1 vessel that did only 1 delivery. On the other hand, during the 1993-2017 period

of post super-exclusive fishery status, the majority of commercial crab fishery and harvest was done by vessels with more than 5 years of operations and more than 5 deliveries per year. For 1977 – 1993, censoring was made for vessels of more than 2 years of operations. Increasing deliveries to more than one would result in no estimates for some years. For 1994 – 2018, censoring was made for vessels of more than 5 years of operations and 5 deliveries per year.

Analyses

A GLM was constructed as

$$\ln(CPUE) = YR + VSL + MSA + WOY + PF$$

Which was changed from the 2021 model of

$$\ln(CPUE) = YR + PD + VSL + MSA + WOY + PF$$

Where YR: Year, PD: Fishery periods of different fishery practices (1977-1993, 1994-2007,2008-2019), VSL: Vessel, MSA: Statistical Area, WOY: Week of Year, and PF: Permit vs open fishery (Table 1). All variables were treated as categorical. Inclusion of interaction terms was not considered because they were absent (SAFE 2013).

The CPUE strata consisted of the 3 periods based on changes in fishery operations.
1977-1993: Large Vessel fishery
1994-2007: Small boat fishery
2008-2019: Small boat and high-grading fishery

For selection of the best model, forward and backward stepwise selection was conducted. (R step function)

```
fit <- glm(L.CPUE.NO ~ factor(YR) + factor(VSL) + factor(WOY) +
factor(MSA) + factor(PF),data=NSdata.C)
step <- step(fit, direction='both', trace = 10)
best.glm<-glm(formula(step), data=NSdata.C)
```

Where YR: Year, PD: fishery strata, VSL: Vessel, MSA: Statistical Area, WOY: Week of Year, and PF: Permit vs open fishery (Table 1). All variables were treated as factor. Inclusion of interaction terms was not considered because they were absent (SAFE 2013).

Table B-1. List of variables in the fish ticket database. Variables in bold face were used for generalized linear modeling.

Variable	Description
YR	Year of commercial fishery
VSL	Unique vessel identification number
Fish Ticket Number	Unique delivery to a processor by a vessel
PF	Unique Permit Fishery categories
PD	Fishery period: 1977-1992, 1993-2004,2005-2018
Statistical Area	Unique fishery area.
MOA	Modified statistical area, combining each statistical area into 4 larger areas: Inner, Mid, Outer, Outer North
Fishing Beginning Date	Date of pots set
Landing Date	Date of crab landed to processor
WOY	Week of Landing Date **(calculated)**
Effort	The number of pot lift
Crab Numbers	Total number of crabs harvested from pots
Crab Pounds	Total pounds of crab harvested from pots
ln(CPUE)	ln(Crab Numbers/Effort) **(calculated)**

Table B-2. Permit fisheries, descriptions, and years with deliveries for Norton Sound summer commercial red king crab harvest data.

Permit fishery	Type	Description	Years
K09Q	Open access	KING CRAB , POT GEAR VESSEL UNDER 60', BERING SEA	1994–2002
K09Z	Open access	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND	1992–2019
K09ZE	CDQ	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND CDQ, NSEDC	2000–2019
K09ZF	CDQ	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND CDQ, YDFDA	2002–2004
K91Q	Open access	KING CRAB , POT GEAR VESSEL 60' OR OVER, BERING SEA	1978–1989
K91Z	Open access	KING CRAB , POT GEAR VESSEL 60' OR OVER, NORTON SOUND	1982–1994

Table B-3. Modified statistical area definitions used for analysis of Norton Sound summer commercial red king crab harvest data.

Modified statistical area	Statistical areas included
Inner	616331, 616401, 626331, 626401, 626402
Mid	636330, 636401, 636402, 646301, 646330, 646401, 646402
Outer	656300, 656330, 656401, 656402, 666230, 666300, 666330, 666401
Outer North	666402, 666431, 676300, 676330 ,676400, 676430, 676501, 686330

Table B-4. Final generalized linear model formulae and AIC selected for Norton Sound summer commercial red king crab fishery. The dependent variable is ln(CPUE) in numbers.

2021 Model

Var	Df	Deviance	Resid DF	Resid Dev	AIC
YR	41	1312.43	6274	5082.7	
VSL	90	574.57	6143	3770.3	
WOY	15	82.89	6129	3195.7	
MSA	3	65.83	6125	3047.0	
PF	6	20.14	6119	3026.9	13547

2022 Model

Periods: 1977-1993

Var	Df	Deviance	Resid DF	Resid Dev	AIC
YR	15	405.92	613	588.31	
VSL	46	176.38	567	411.93	
WOY	9	30.25	558	381.68	
MSA	3	10.07	555	371.61	
MOY	2	6.33	553	365.28	
					1597.2

Periods: 1994-2007

Var	Df	Deviance	Resid DF	Resid Dev	AIC
YR	13	396.63	2371	1462.9	
VSL	43	267.56	2328	1195.4	
WOY	15	71.08	2313	1124.3	
MSA	3	24.54	2310	1099.7	
					5074.1

Periods: 2008-2019

Var	Df	Deviance	Resid DF	Resid Dev	AIC
YR	11	463.2	3341	2002.8	
VSL	41	340.16	3300	1662.7	
WOY	13	63.91	3287	1598.8	
MSA	3	37.13	3284	1561.6	

MOY	3	4.11	3281	1557.5	7090.5

Table B-5. Standardized (censored/full data), and scaled arithmetic observed CPUE indices.

Year	St. CPUE 2022		St. CPUE 2021		Arithmetic
	CPUE	SE	CPUE	SE	CPUE
1977	3.61	0.30	3.29	0.68	2.77
1978	3.30	0.18	4.68	0.65	5.84
1979	1.92	0.19	2.87	0.64	2.21
1980	2.64	0.21	3.07	0.65	2.18
1981	0.84	0.14	0.86	0.64	0.85
1982	0.16	0.21	0.2	0.62	0.32
1983	0.69	0.21	0.9	0.65	0.77
1984	0.96	0.21	1.59	0.65	1.05
1985	0.50	0.16	0.5	0.66	0.69
1986	1.24	0.41	1.74	0.7	2.18
1987	0.55	0.35	0.61	0.64	0.69
1988	1.43	0.39	2.36	0.86	2.32
1989	1.56	0.34	1.21	0.61	1.13
1990	1.33	0.46	1.08	0.68	1.25
1991					
1992	0.28	0.30	0.17	0.6	0.31
1993	0.66	0.11	0.9	0.35	1.10
1994	0.97	0.06	0.81	0.34	0.65
1995	0.52	0.05	0.42	0.34	0.41
1996	0.63	0.08	0.51	0.34	0.51
1997	1.01	0.10	0.84	0.35	0.82
1998	0.85	0.13	0.79	0.36	0.51
1999	0.62	0.13	0.92	0.36	0.47
2000	1.59	0.07	1.24	0.34	1.29
2001	0.90	0.06	0.64	0.34	0.61
2002	1.66	0.07	1.23	0.34	0.95
2003	1.23	0.05	0.85	0.34	0.82
2004	1.95	0.06	1.27	0.34	1.29
2005	1.16	0.05	1.19	0.34	1.22
2006	1.35	0.05	1.31	0.34	1.29
2007	1.04	0.05	1.02	0.34	0.97
2008	1.35	0.05	1.32	0.34	1.31
2009	0.91	0.04	0.84	0.34	0.95
2010	1.26	0.04	1.22	0.34	1.20
2011	1.50	0.05	1.58	0.34	1.55
2012	1.32	0.04	1.29	0.34	1.42
2013	0.69	0.04	0.67	0.33	0.78
2014	1.10	0.04	1.12	0.34	1.14
2015	1.38	0.05	1.45	0.34	1.38
2016	1.17	0.05	1.27	0.34	1.43
2017	0.97	0.05	1.1	0.34	1.17
2018	0.61	0.05	0.64	0.34	0.74
2019	0.28	0.06	0.26	0.34	0.34

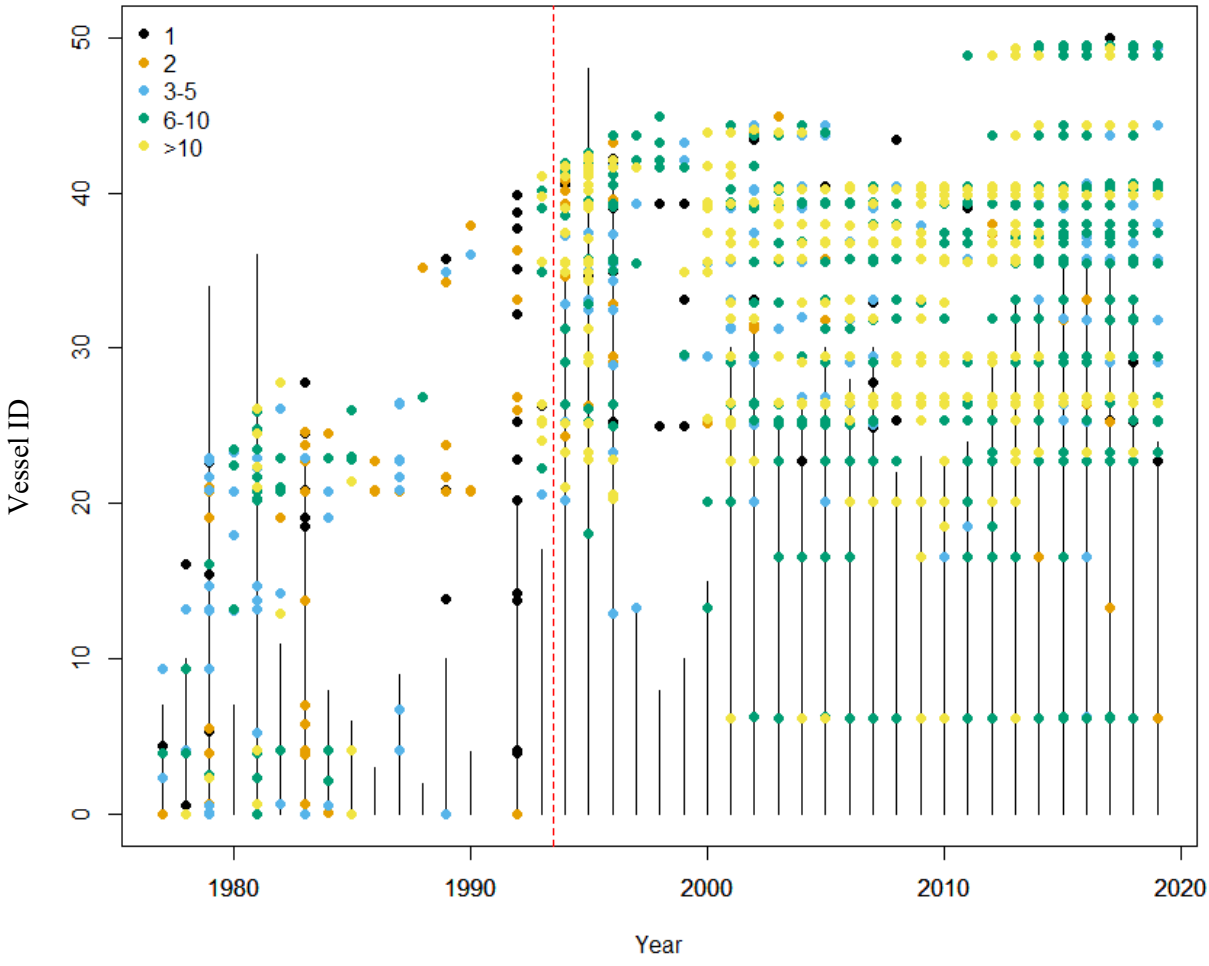

Figure B1. Number of fishing vessel (Vertical line) and distribution of unique vessel (dots) operated by year. Dot colors indicate the number of deliveries for each year by each vessel. Red vertical line indicates a break between pre (1977-1993) and post(1994-2019) Super exclusive fishery. No fishery occurred in 1993 and 2020.

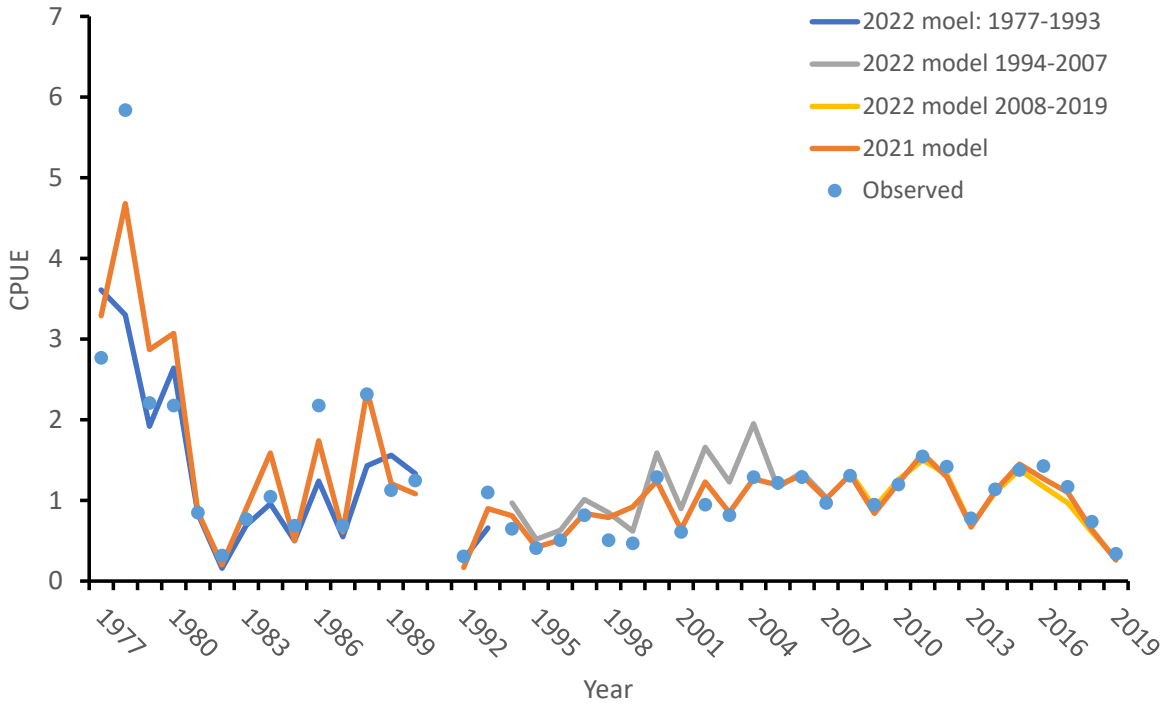

Figure B2. Comparison of standardized CPUE 2022 models, 2001 model, and observed CPUE.

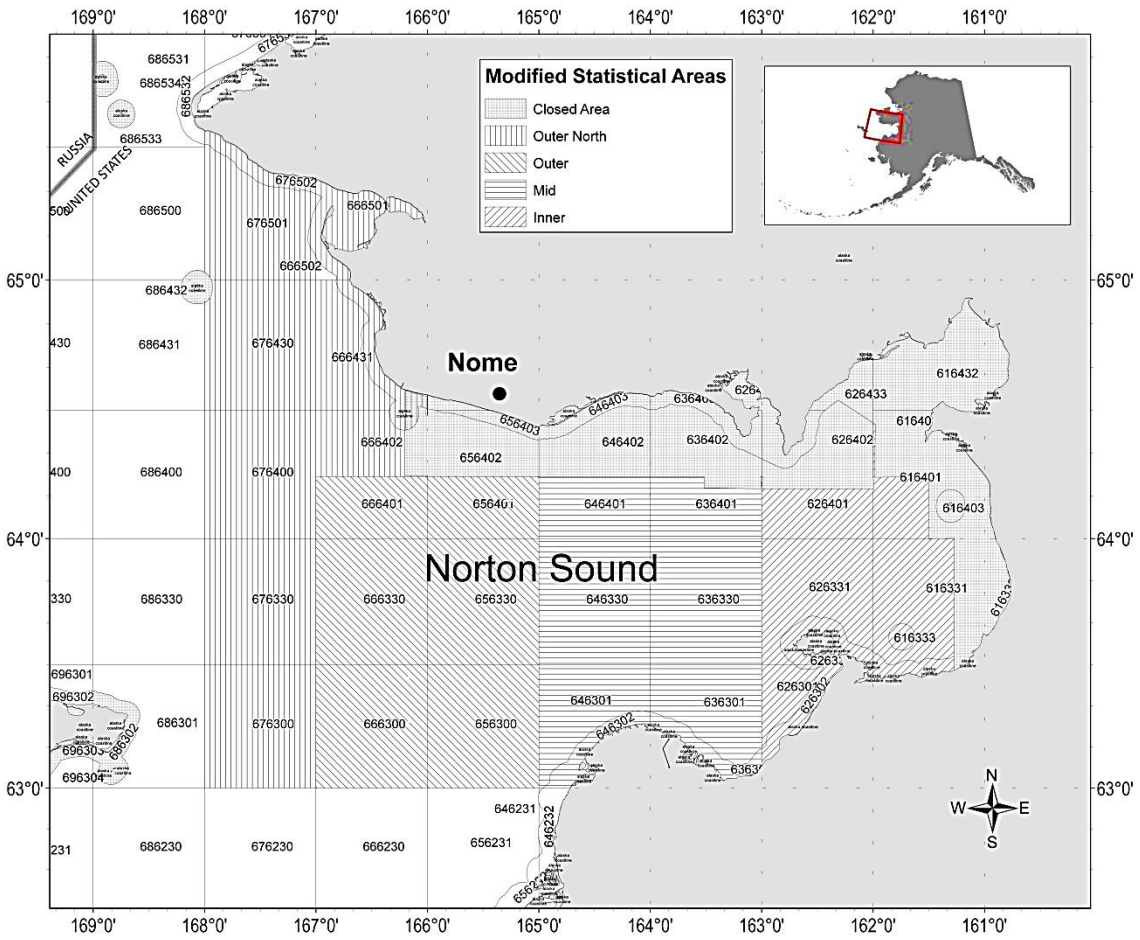

Figure A2-1. Closed area and statistical area boundaries used for reporting commercial harvest information for red king crab in Registration Area Q, Northern District, Norton Sound Section and boundaries of the new *Modified Statistical Areas* used in this analysis.