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 = $X(X^TX)^{-1}$, 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 B2-1,2,3, Figure B2-1). The fish ticket database may

have multiple entries of identical Fish Ticket Number, Vessel Number, Permit Fishery ID, and Statistical Area.

The following data cleaning and combining methods were conducted:

1. Sum crab number and efforts by Fish Ticket Number, Vessel Number, Permit Fishery ID, and Statistical Area.
2. Remove data with missing or zero values in Effort, Number of Crab, or Pounds of Crab; (these are considered 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 (2008-2019). The pre-superexclusive fishery consisted of a few large boats, fishing west of 167 longitude, and few deliveries, while the post-superexclusive fishery consists of many small boats operated by local fishermen, fishing east of 167 longitude and near shore, and delivering frequently (Figure B1). The post-superexclusive period can further be divided into pre- (1994-2007) and post (2008-2020) high grading periods. The majority of commercially caught red king crab are sold to Norton Sound Economic Development Corporation (NSEDC). Beginning in the mid-2000s NSEDC's market-preferred size of 5 inch or greater carapace width (CW) t was greater than legal-sized crab of 4.75 inch or larger CW. This preference has become more explicit since 2008. For the purpose of modeling, 2008 was chosen as the start of the high-grading period.

Censoring data

During 1977-93 period, vessels of 1 year of operation and/or 1 delivery per year harvested 20-90% of crab (Table B2-5, Figure B2-2). For instance, all vessels made only 1 delivery in 1989, and in 1988 64% of crab were harvested by 1 vessel that made only 1 delivery. On the other hand, during the 1993-2022 period of post-superexclusive 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 – 2022, the data were censored to vessels that fished more than 5 years and delivered crab more than 5 times per year.

Analyses

A GLM was constructed as

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

Where YR: Year, 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 fishery strata (PD) consisted of the 3 periods based on changes in fishery operations, and model was run for each fishery periods.

1977-1993: Large Vessel fishery
1994-2007: Small boat fishery
2008-2022: 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)
```

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	1992–2022
K09ZE	CDQ	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND CDQ, NSEDC	2000–2022
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.

Periods: 1977-1993

Var	Df	Deviance	Resid DF	Resid Dev	AIC
YR	14	269.56	377	265.4	
MSA	3	11.91	374	253.5	
MOY	2	6.134	372	247.4	
					974.01

Periods: 1994-2007

Var	Df	Deviance	Resid DF	Resid Dev	AIC
VSL	43	451.6	2401	1465.6	
YR	14	232.8	2387	1232.8	
WOY	15	72.3	2372	1160.5	
MSA	3	24.1	2369	1130.4	
					8577.0

Periods: 2008-2022

Var	Df	Deviance	Resid DF	Resid Dev	AIC
YR	12	470.3	3357	2041.5	
VSL	42	329.9	3315	1711.4	
WOY	13	65.5	3302	1645.9	
MSA	3	31.4	3299	1614.5	
MOY	3	3.2	3296	1611.3	
					7227

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

Year	St. CPUE		Arithmetic
	CPUE	CV	CPUE
1977	2.03	0.32	2.06
1978	3.87	0.16	4.31
1979	1.30	0.23	1.78
1980	1.64	0.27	1.86
1981	0.57	0.19	0.72
1982	0.25	0.15	0.30
1983	0.50	0.18	0.65
1984	1.13	0.19	0.96
1985	0.69	0.17	0.66
1986	2.24	0.47	2.01
1987	0.88	0.33	0.68
1988	2.16	0.41	1.66
1989	0.99	0.29	0.79
1990	2.03	0.32	2.06
1991			
1992	1.47	0.47	1.24
1993	0.17	0.22	0.18
1994	1.02	0.09	1.22
1995	0.43	0.17	0.79
1996	1.08	0.13	0.49
1997	1.01	0.09	0.64
1998	1.14	0.09	1.03
1999	1.30	0.13	0.74
2000	0.97	0.10	0.63
2001	2.08	0.11	1.56
2002	0.76	0.26	0.78
2003	0.76	0.10	1.23
2004	1.65	0.09	1.02
2005	1.36	0.07	1.59
2006	0.64	0.12	1.48
2007	0.93	0.10	1.62
2008	0.89	0.23	1.18
2009	1.35	0.05	1.20
2010	0.92	0.04	0.87
2011	1.35	0.04	1.11
2012	1.54	0.05	1.43
2013	1.36	0.04	1.31
2014	0.71	0.04	0.70
2015	1.08	0.04	1.03
2016	1.33	0.05	1.25
2017	1.17	0.05	1.26
2018	1.00	0.05	1.05
2019	0.58	0.05	0.71
2020			
2021			
2022	1.51	0.07	1.72

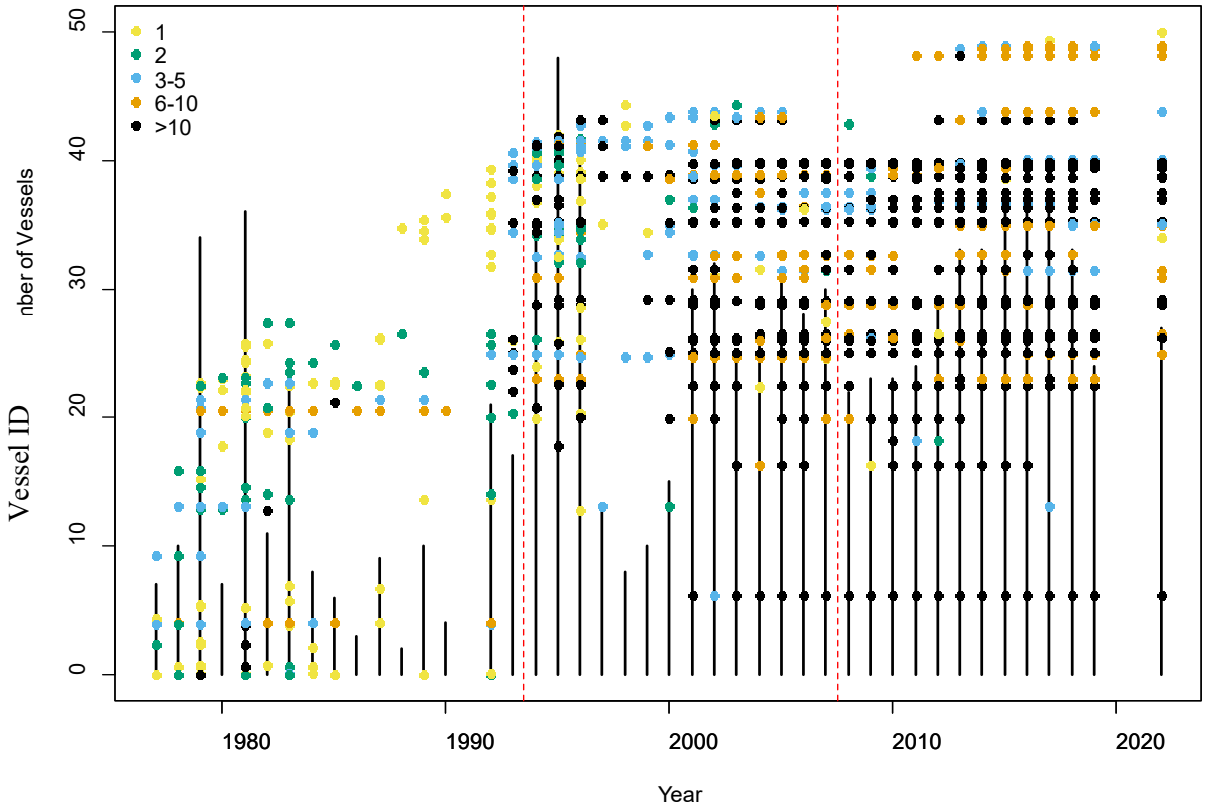

Figure B1. Number of fishing vessel (Vertical line) and distribution of unique vessel (dots) operated by year. Dot colors indicate the number of deliveries for each year by each vessel. Dashed red vertical line indicates a break between pre- (1977-1993) and post- (1994-2019) superexclusive fishery. No fishery occurred in 1993, and no fishery harvest occurred in 2020 and 2021.

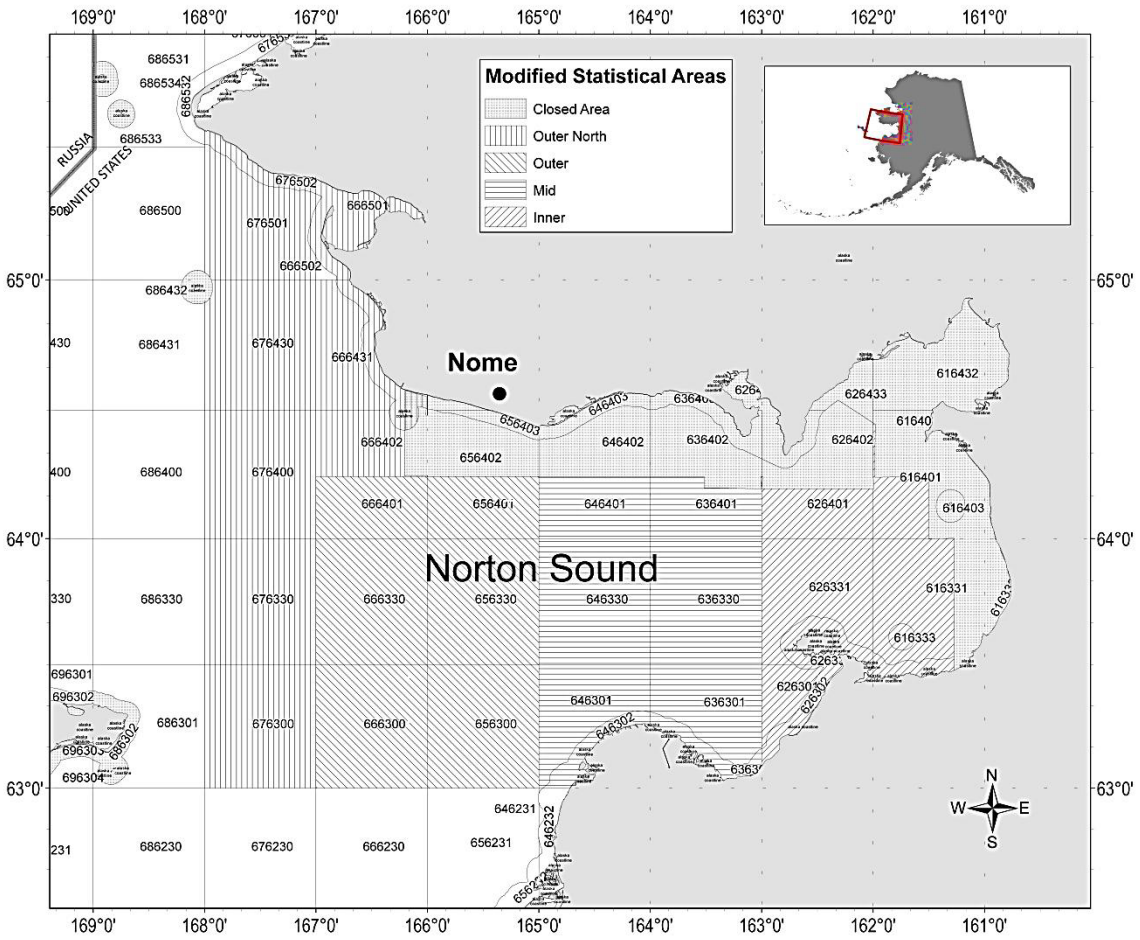

Figure A2-1. Closed area and statistical area boundaries used for reporting commercial harvest information for red king crab in Registration Area Q, Northern District, Norton Sound Section and boundaries of the new *Modified Statistical Areas* used in this analysis.