Appendix B

Norton Sound Red King Crab CPUE Standardization

Note: This is an update of model by G. Bishop (SAFE 2013).

Methods

Data Source & Cleaning

Commercial fishery harvest data were obtained from a 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 crabs were either retained from 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

The data were separated into two periods: 1977-1992 and 1993-2016. The two periods represents before and after super exclusive status enacted since 1993.

Data Censoring

We first investigated distribution of fishing vessels by frequency of deliveries and years of operation (Table A2-4, 5). The number of vessels operated ranged from 2 (1988) to 48 (1995). None of vessels operated consecutively from 1977 to 2015, and many vessels operated only 1 year.

Norton Sound red king crab CPUE standardization

During 1977-92 period, vessels of 1 year of operation and/or 1 delivery per year harvested 20-90% of crabs (Table A2-5, Figure A2-2). For instance, all vessels did only 1 delivery in 1989, and in 1988 64% of crabs were harvested by 1 vessel that did only 1 delivery. On the other hand, during the 1993-2016 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 – 1992, 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. Further increasing years of operation would also limit the number of vessel to only 1 or 2. For 1993 – 2016, censoring was made for vessels of more than 5 years of operations and 5 deliveries per year.

Analyses

A GLM was constructed as

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

Where YR: Year, VSL: Vessel, MSA: Modified Statistical Area, WOY: Week of Year, PF: Week of Year (Table 1). All variables were treated as categorical. Inclusion of interaction terms were not considered because they were absent (SAFE 2013).

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)
```

The analyses were conducted for both censored and full data.

Results

Of the five variables included, the final model included four variables for 1977-1992, and all variables remained for 1993-2015 (Tables A2-6).

Norton Sound red king crab CPUE standardization

Model estimated standardized and observed CPUYE differed for 1977-1980 period, but similar for 1981 to 2015 (Figure A2-3, Tables A2-7,8). During 1977-1980 period, censored data model showed decline in 1978 and increase in 1979-1980, full data model showed steady decline from 1977 to 1980, and observed CPUE showed a peak in 1978 (Figure A2-3, Tables A2-7,8). Other notable difference was in 1989 when model estimated CPUE showed an increase while the observed CPUE showed a decline.

Table A2-1. 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
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 A2-2. 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	1992–2015
K09ZE	CDQ	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND CDQ, NSEDC	2000–2015
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

Norton Sound red king crab CPUE standardization

Appendix A2-3. 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 A2-4. The number of vessels by the number of years operated and deliveries made per year.

Years	1					2					3					4					>5					Total
Deliveries	1	2	3	4	>5	1	2	3	4	>5	1	2	3	4	>5	1	2	3	4	>5	1	2	3	4	>5	
1977	4							1					1					1								7
1978	1					1	1			1		1		1	1					2				1		10
1979	6	6	1		1	4	3	1		1	2	2		1		1	1		1	1	1	1				34
1980		1	1		1			1		1										1		1				7
1981	2	1	8	3	3	2	4	2		1	1	1	2		1	1	1				1			1	1	36
1982	1	1	1	1				2							1				1		1			2		11
1983	8					6	1				3	1				1					2	1				23
1984	1		2			1							1						1				2			8
1985	1				1	1				1					1										1	6
1986						1															2					3
1987			5	1												1					2					9
1988	1						1																			2
1989	5					2										1					2					10
1990	2																				1	1				4
1992	10	1				6										2					1					20
1993	3				4			1							3					1					5	17
1994	1	2	3		2		1			1					7					4		3			11	35
1995		2			9	1				9					5		1			4			1	1	15	48
1996		1		1	4	2		2	1	4	2	2			3					3	3	2	1		10	41
1997					2				1						1					2	1		1		5	13
1998										1	1				1						1				4	8
1999					1						1		1			1					1		2		3	10
2000					1								1		1							1		1	9	15
2001			1		2					1					1				1	2			1	1	20	30
2002		2			1	1				1					2	1				1	1	3	2	1	16	32
2003							1																	1	23	25
2004	1		1																	1			2	3	18	26
2005												1			1				1		1	1	1		24	30
2006	2											1			1					1			1		22	28
2007	2														2					1	2		3		20	30
2008						1														1	1				18	22
2009																	1							1	21	23
2010															1									1	21	23
2011														1							1				22	24
2012											1				1								1	1	25	29
2013											1									3					29	33
2014															2					3			1	2	25	33
2015			1				1							1	2					4				3	24	36
2016		1	1							1					2			2	1	2	1	2	1	2	20	36

Table A2-5. Proportion of red king crab harvest by the number of years operated and deliveries made per year.

Years	1					2					3					4					>5				
Deliveries	1	2	3	4	>5	1	2	3	4	>5	1	2	3	4	>5	1	2	3	4	>5	1	2	3	4	>5
1977	0.25	0	0	0	0	0	0	0.29	0	0	0	0	0.29	0	0	0	0	0.17	0	0	0	0	0	0	0
1978	0	0	0	0	0	0.04	0.04	0	0	0.2	0	0.08	0	0.15	0.09	0	0	0	0	0.26	0	0	0	0.13	0
1979	0.11	0.17	0.01	0	0.05	0.08	0.11	0.02	0	0.09	0.03	0.1	0	0.04	0	0.02	0.02	0	0.02	0.02	0.01	0.08	0	0	0
1980	0	0.04	0	0	0.19	0	0	0.24	0	0.19	0	0	0	0	0	0	0	0	0	0.13	0	0.2	0	0	0
1981	0.01	0.01	0.18	0.05	0.17	0.02	0.06	0.07	0	0.02	0	0.03	0.03	0	0.09	0.04	0.02	0	0	0	0.07	0	0	0.08	0.05
1982	0.01	0.04	0.03	0.03	0	0	0	0.07	0	0	0	0	0	0.06	0	0	0	0	0.04	0	0.32	0	0	0.4	0
1983	0.24	0	0	0	0	0.22	0.02	0	0	0	0.13	0.03	0	0	0	0.09	0	0	0	0	0.21	0.06	0	0	0
1984	0.01	0	0.11	0	0	0.19	0	0	0	0	0	0	0.08	0	0	0	0	0	0.17	0	0	0	0.44	0	0
1985	0.14	0	0	0	0.24	0.06	0	0	0	0.19	0	0	0	0	0.15	0	0	0	0	0	0	0	0	0	0.21
1986	0	0	0	0	0	0.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.93	0	0	0	0
1987	0	0	0.25	0.09	0	0	0	0	0	0	0	0	0	0	0	0.24	0	0	0	0	0.41	0	0	0	0
1988	0.64	0	0	0	0	0	0.36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	0.54	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0	0.11	0	0	0	0	0.27	0	0	0	0
1990	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.28	0.32	0	0	0
1992	0.51	0.17	0	0	0	0.21	0	0	0	0	0	0	0	0	0	0.02	0	0	0	0	0.09	0	0	0	0
1993	0.01	0	0	0	0.4	0	0	0.01	0	0	0	0	0	0	0.28	0	0	0	0	0	0	0	0	0	0.29
1994	0	0	0.01	0	0.1	0	0	0	0	0.01	0	0	0	0	0.31	0	0	0	0	0.12	0	0	0	0	0.45
1995	0	0	0	0	0.17	0	0	0	0	0.25	0	0	0	0	0.07	0	0	0	0	0.09	0	0	0	0	0.41
1996	0	0	0	0	0.1	0	0	0	0.02	0.26	0	0.01	0	0	0.2	0	0	0	0	0.06	0.01	0	0.01	0	0.33
1997	0	0	0	0	0.11	0	0	0	0.06	0	0	0	0	0	0.09	0	0	0	0	0.12	0.02	0	0.04	0	0.56
1998	0	0	0	0	0	0	0	0	0	0.09	0	0	0	0	0.08	0	0	0	0	0	0.01	0	0	0	0.82
1999	0	0	0	0	0.39	0	0	0	0	0	0	0	0.15	0	0	0.03	0	0	0	0	0	0	0.12	0	0.31
2000	0	0	0	0	0.1	0	0	0	0	0.02	0	0	0.01	0	0.1	0	0	0	0	0	0	0	0	0.01	0.77
2001	0	0	0.01	0	0.07	0	0	0	0	0.02	0	0	0	0	0.06	0	0	0	0.03	0.05	0	0	0.03	0	0.72
2002	0	0.01	0	0	0.05	0	0	0	0	0.07	0	0	0	0	0.04	0	0	0	0	0.04	0	0.04	0.02	0.01	0.72
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2004	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0.03	0.05	0.87
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0	0	0.02	0.02	0	0.93
2006	0.01	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0.04	0	0	0.01	0	0.92
2007	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0	0	0	0	0.06	0.01	0	0.05	0	0.85
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06	0	0	0	0.01	0.93
2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0.99
2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0.01	0.98
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.99
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0.01	0	0	0.98
2013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0	0	0	0	0.02	0	0	0	0	0.91
2014	0	0	0	0	0	0	0	0	0	0.07	0	0	0	0	0.07	0	0	0	0	0.03	0	0	0.01	0	0.81
2015	0	0	0	0	0	0	0	0	0	0.08	0	0	0	0.01	0.07	0	0	0	0	0.04	0	0	0	0.05	0.75

Table A2-6. Final generalized linear model formulae and associated R^2 selected for Norton Sound summer commercial red king crab fishery. The dependent variable is ln(CPUE) in numbers.

Time series	Years	Deliveries	Explanatory variables	Null dev.	Null df	Resid. dev.	Resid. df	AIC	R^2
1977–	All	All	YR+VSL+WOY+MSA	1163.1	797	445.4	653	2091	0.68
1992	≥2	≥1	YR+VSL+WOY+MSA	703.7	483	379.9	420	1188	0.60
1993–	All	All	YR+VSL+WOY+MSA+PF	5608.4	6459	3230.3	6364	14332	0.51
2015	≥5	≥5	YR+VSL+WOY+MSA+PF	3531.2	4971	2291.7	4880	10445	0.47

Table A2-7. Standardized (Censored/full data), and scaled arithmetic observed CPUE indices from 1977–1992.

Year	Censored		Full data		Observed
	CPUE	**SE**	**CPUE**	**SE**	**CPUE**
1977	4.18	0.34	3.43	0.34	2.08
1978	2.21	0.23	2.83	0.23	3.73
1979	3.09	0.18	2.59	0.17	1.62
1980	3.03	0.26	2.43	0.25	1.80
1981	0.89	0.19	0.74	0.17	0.64
1982	0.11	0.25	0.13	0.25	0.33
1983	1.00	0.22	0.90	0.22	0.68
1984	0.94	0.23	1.09	0.23	0.83
1985	0.34	0.20	0.37	0.21	0.62
1986	0.76	0.41	1.00	0.43	2.20
1987	0.57	0.32	0.63	0.32	0.58
1988	1.44	0.67	1.51	0.71	1.88
1989	1.80	0.32	1.61	0.33	0.89
1990	1.13	0.40	1.18	0.42	1.10
1991	NA	NA	NA	NA	NA
1992	0.30	0.31	0.26	0.31	0.25

Table A2-8. Standardized (Censored/full data), and scaled arithmetic observed CPUE indices from 1993–2016.

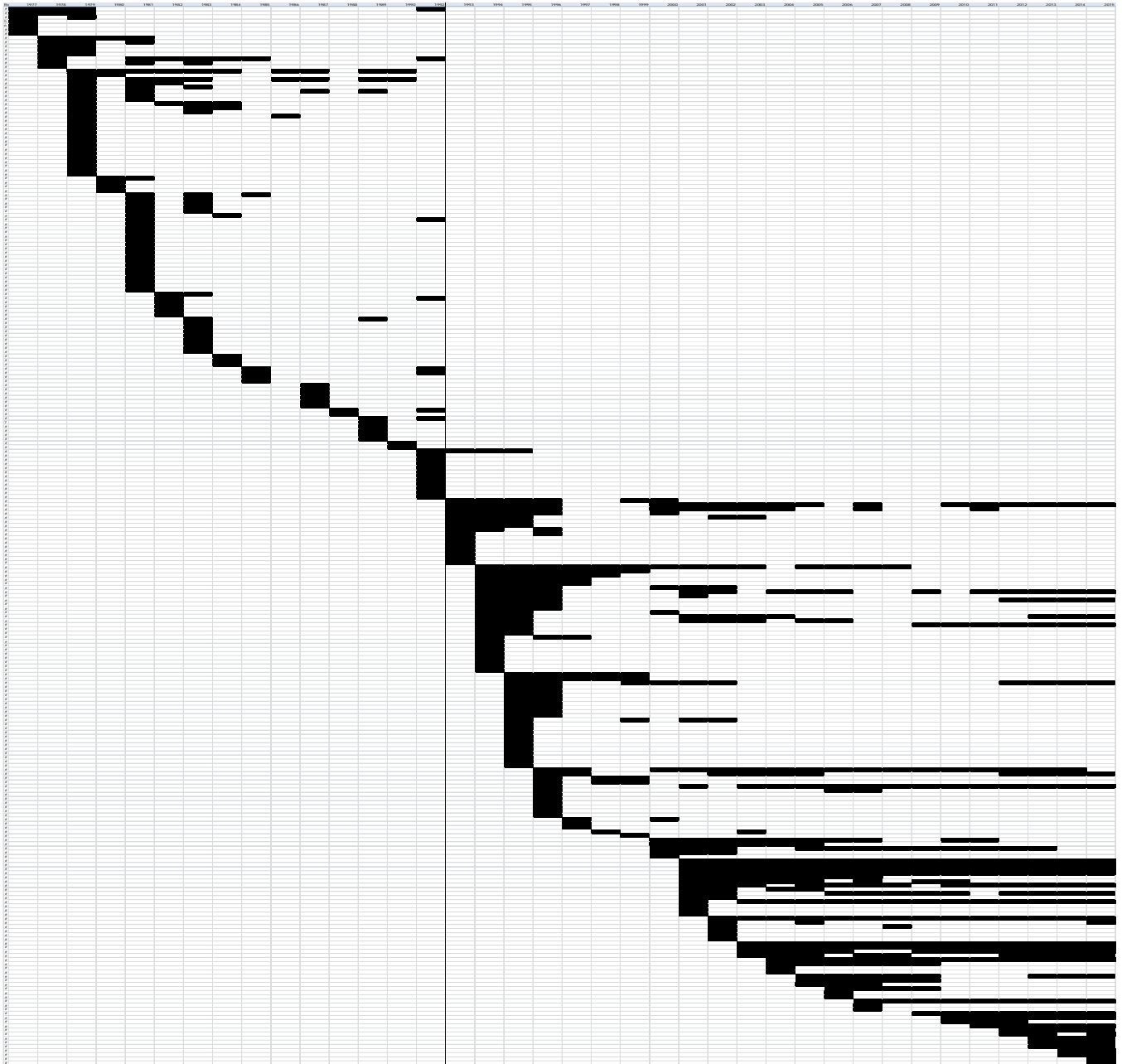| Year	Censored		Full data		Observed
	CPUE	SE	CPUE	SE	CPUE
1993	0.90	0.10	0.90	0.08	1.38
1994	0.80	0.06	0.80	0.05	0.79
1995	0.43	0.05	0.48	0.05	0.48
1996	0.53	0.08	0.46	0.06	0.60
1997	0.83	0.10	0.83	0.08	0.92
1998	0.78	0.13	0.73	0.12	0.56
1999	0.92	0.13	0.77	0.12	0.45
2000	1.25	0.06	1.23	0.06	1.49
2001	0.65	0.05	0.69	0.05	0.70
2002	1.22	0.06	1.18	0.06	1.13
2003	0.86	0.05	0.87	0.05	0.93
2004	1.33	0.05	1.34	0.05	1.27
2005	1.23	0.05	1.26	0.05	1.33
2006	1.36	0.05	1.42	0.05	1.46
2007	1.06	0.05	1.13	0.05	1.02
2008	1.38	0.05	1.43	0.05	1.39
2009	0.88	0.04	0.90	0.04	1.02
2010	1.23	0.04	1.28	0.04	1.30
2011	1.59	0.05	1.61	0.05	1.75
2012	1.34	0.04	1.37	0.04	1.35
2013	0.66	0.04	0.68	0.04	0.73
2014	1.12	0.05	1.16	0.04	1.08
2015	1.53	0.05	1.55	0.05	1.48
2016	1.40	0.06	1.27	0.05	1.76
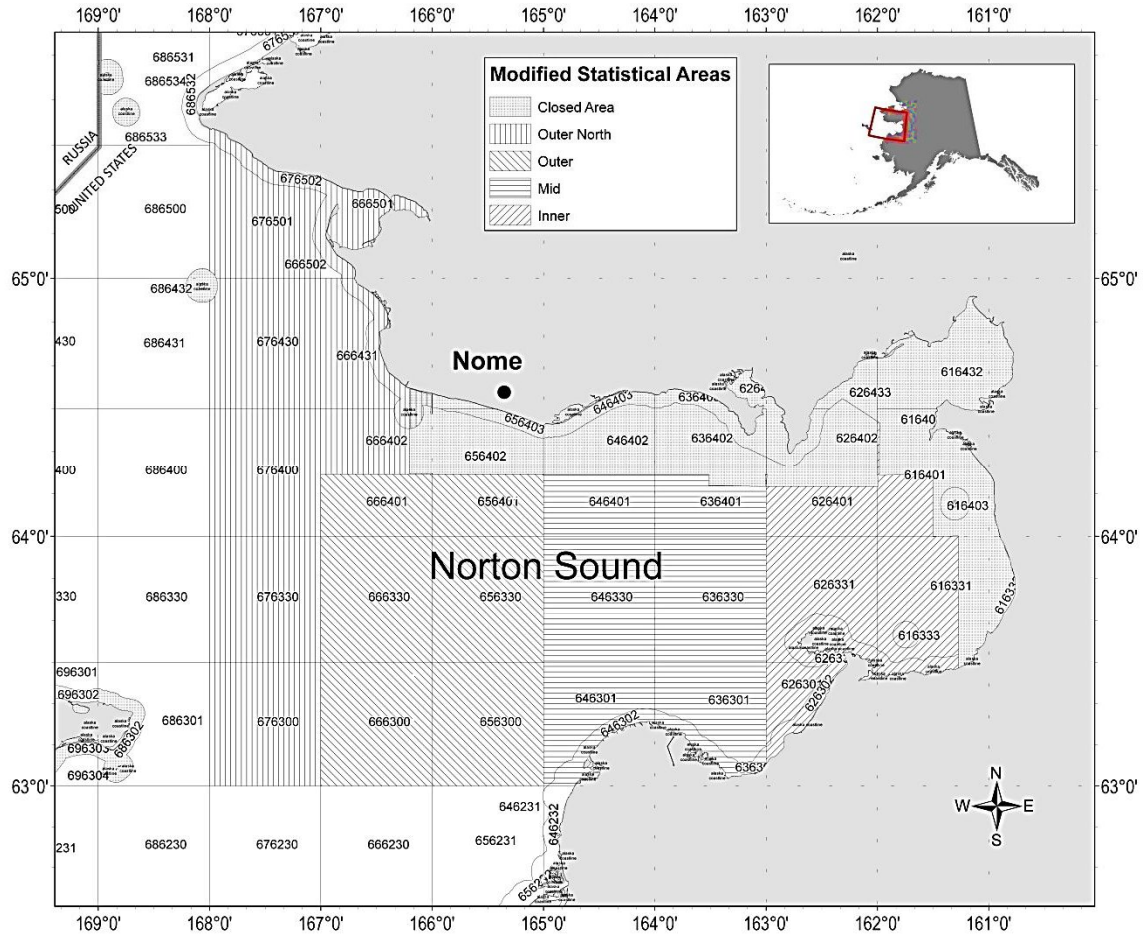
Figure A2-1. Closed area and statistical area boundaries used for reporting commercial harvest information for red king crab in Registration Area Q, Northern District, Norton Sound Section and boundaries of the new *Modified Statistical Areas* used in this analysis.

Figure A2-2. Distribution of unique vessel from 1976 (left) to 2015 (right). Each row indicates unique vessel, and each black represents the year vessel was operated. Vertical black line shows division between 1992 and 1993.
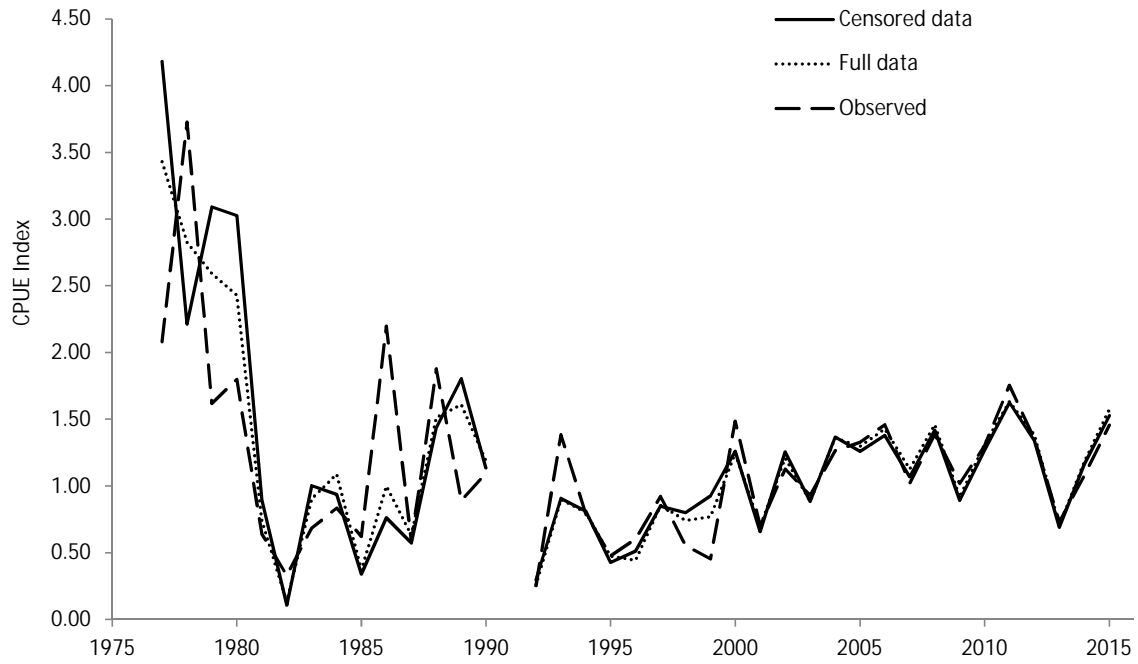
Figure A2-3. Comparison of CPUE among Observed, Standardized (censored data), and Standardized (full data) in 1977-2016.