Norton Sound Red King Crab Stock Assessment for the fishing year 2018

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Executive Summary

1. Stock. Red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska.

2. Catches. This stock supports three important fisheries: summer commercial, winter commercial, and winter subsistence fisheries. Of those, the summer commercial fishery accounts for more than 90% of total harvest. The summer commercial fishery started in 1977, and catch peaked in the late 1970s with retained catch of over 2.9 million pounds. Since 1982, retained catches have been below 0.5 million pounds, averaging 0.275 million pounds, including several low years in the 1990s. Retained catches have increased to about 0.4 million pounds coincident with increases in estimated abundance in recent years.

3. Stock Biomass. Following a peak in 1977, abundance of the stock collapsed to a historic low in 1982. Estimated mature male biomass (MMB) has shown an increasing trend since 1997, but is highly uncertain due, in part, to infrequent trawl (every 3 to 5 years) and limited winter pot surveys.

4. Recruitment. Model estimated recruitment was weak during the late 1970s and high during the early 1980s, with a slightly downward trend from 1983 to 1993. Estimated recruitment has been highly variable but on an increasing trend in recent years.

5. Management performance.

Status and catch specifications (million lb.)

Year	MSST	Biomass (MMB)	GHL	Retained Commercial Catch	Total Retained Catch	Retained OFL	Retained ABC
2014/15	2.11^{A}	3.71	0.38	0.39	0.39	0.46^{A}	0.42
2015	2.41^{B}	5.13	0.39	0.40	0.52	0.72^{B}	0.58
2016	2.26^{C}	5.87	0.52	0.51	0.52	0.71^{C}	0.57
2017	2.31^{D}	5.14	0.50	0.49	0.50	0.67^{D}	0.54
2018	TBD	TBD	TBD	TBD	TBD	TBD	TBD

Status and catch specifications (1000t)

Year	MSST	Biomass (MMB)	GHL	Retained Commercial Catch	Total Retained Catch	Retained OFL	Retained ABC
2014/15	0.96[A]	1.68	0.17	0.18	0.18	0.21[A]	0.19
2015	1.09[B]	2.33	0.18	0.18	0.24	0.33[B]	0.26
2016	1.03[C]	2.66	0.24	0.23	0.24	0.32[C]	0.26
2017	1.05[D]	2.33	0.23	0.22	0.24	0.30[D]	0.24
2018	TBD	TBD	TBD	TBD	TBD	TBD	TBD

Notes:
MSST was calculated as $B_{MSY}/2$
A-Calculated from the assessment reviewed by the Crab Plan Team in May 2014
B-Calculated from the assessment reviewed by the Crab Plan Team in May 2015
C-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2016
D-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2017
E-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2018

Conversion to Metric ton: 1 Metric ton (t) = 2.2046×1000 lb

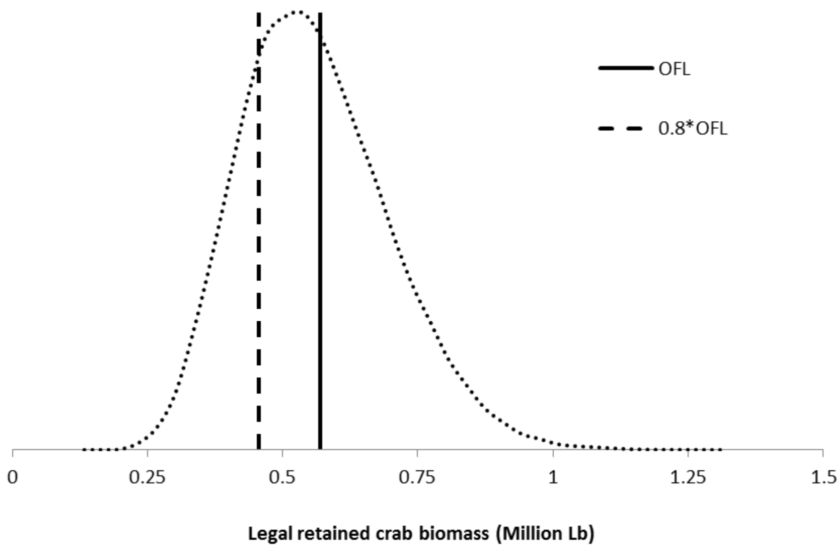
Biomass in millions of pounds

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	Retained ABC
2014/15	4b	4.19	3.71	0.9	0.16	1980-2014	0.18	0.9	0.42
2015	4a	4.81	5.13	1.1	0.18	1980-2015	0.18	0.8	0.58
2016	4a	4.53	5.87	1.3	0.18	1980-2016	0.18	0.8	0.57
2017	4a	4.62	5.14	1.1	0.18	1980-2017	0.18	0.8	0.54
2018	4b	TBD	TBD	TBD	0.18	1980-2018	0.18	0.8	TBD

Biomass in 1000t

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	Retained ABC
2014/15	4b	1.90	1.68	0.9	0.16	1980-2014	0.18	0.9	0.19
2015	4a	2.18	2.33	1.1	0.18	1980-2015	0.18	0.8	0.26
2016	4a	2.06	2.66	1.3	0.18	1980-2016	0.18	0.8	0.26
2017	4a	2.10	2.33	1.1	0.18	1980-2017	0.18	0.8	0.24
2018	4b	TBD	TBD	TBD	0.18	1980-2018	0.18	0.8	TBD

6. Probability Density Function of the OFL, OFL profile, and mcmc estimates.



7. The basis for the ABC recommendation

   For Tier 4 stocks, the default maximum ABC is based on P*=49% that is essentially identical to the OFL. Accounting for uncertainties in assessment and model results, the SSC chose to use 90% OFL (10% Buffer) for the Norton Sound red king crab stock from 2011 to 2014. In 2015, the buffer was increased to 20% (ABC = 80% OFL).

8. A summary of the results of any rebuilding analyses.

   N/A

A. Summary of Major Changes in 2017

1. Changes to the management of the fishery**:**

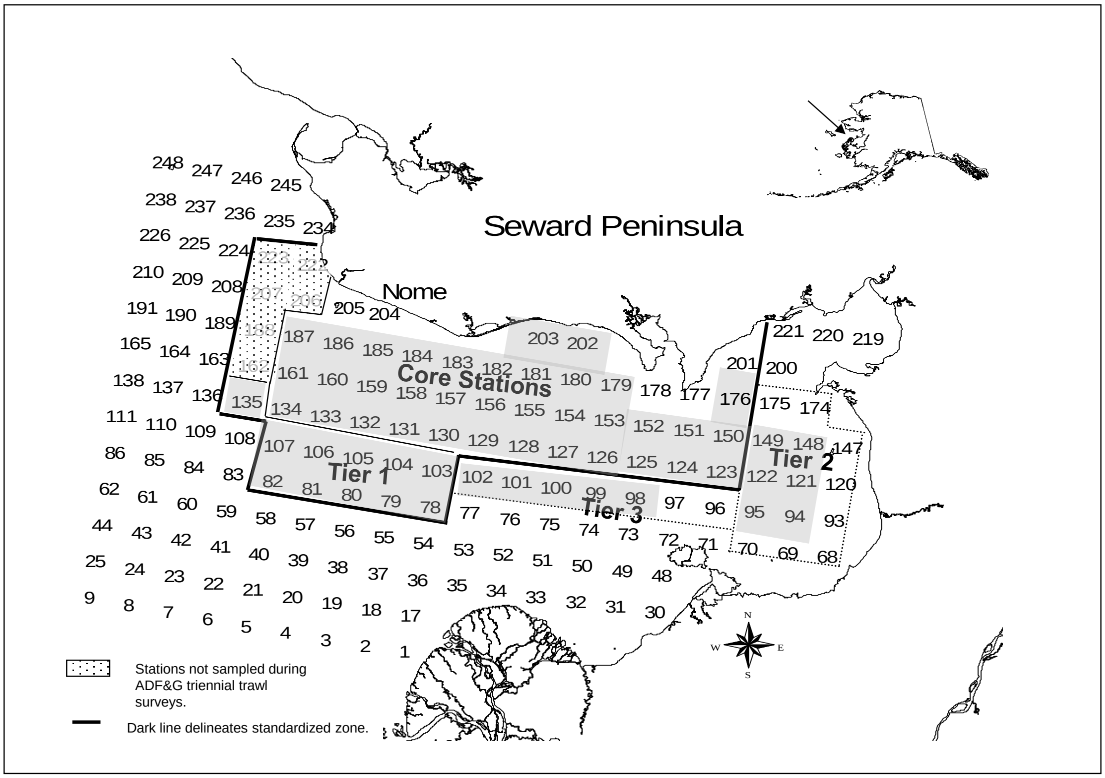
   Winter commercial GHL went into effect

2. Changes to the input data

   a. Data update: 1977-2017 standardized commercial catch CPUE and CV. No changes in standardization methodology (NPFMC 2013).

   b. Recalculation and standardization of 1996-2017ADFG trawl survey abundance.
      i. Size class was changed from ≥ 74mm to ≥ 64mm to be consistent with the modeled size range
      ii. Re-tow data were removed from abundance calculation, unless the first trawl failed.
      iii. Estimates of abundance are based on core, tier 1, and tier 3 area only.

iv. Abundance of untrawled stations within the standard station was considered zero crabs. All untrawled stations were outer edge of standard stations (Appendix E).



Gray shaded area is standard stations.

3. Changes to the assessment methodology:

   None

4. Changes to the assessment results.

   None

B. Response to SSC and CPT Comments

Crab Plan Team – January 17, 2017

- The CPT recommends breaking out natural mortality by size class for future model evaluation.

  Authors' reply:

  OFL calculation will change from

$$OFL = Legal\_B_w\left(1-e^{-(F_{OFL}+0.42M)}-(1-e^{-0.42M})\left(\frac{1-p(1-e^{-(F_{OFL}+0.42M)})}{1-p(1-e^{-0.42M})}\right)\right)$$

to

$$OFL = \sum_{l} \left[Legal\_B_{w,l} \left(1 - e^{-(F_{OFL,l}+0.42M_l)} - (1-e^{-0.42M_l}) \left(\frac{1-p(1-e^{-(F_{OFL,l}+0.42M_l)})}{1-p(1-e^{-0.42M_l})} \right) \right) \right]$$

- Assess which (2017 NOAA vs. ADFG survey) data inputs are most influential for the assessment.

Author reply: Model fit to ADFG trawl survey was better than NOAA trawl survey.

Model	Model 4 ADFG trawl	Model 4 NOAA trawl
No. Parameters	69	69
Total	261.0	266.2
TSA	8.0	9.1
St.CPUE	-30.7	-30.7
TLP	85.1	88.6
WLP	39.2	39.2
CLP	50.5	50.6
OBS	23.0	23.3
REC	13.8	13.7
TAG	72.2	72.5
MMB(mil.lb)	4.25	4.16

- Assess which (discard length data, survey data, etc.) data inputs are most influential for the assessment.

Author reply:
Likelihood was calculated as follows

Model	Model 3*	-TSA	-CPUE	-TLP	-WLP	-CLP	-OBS	-TAG
Total	260.0	244.8	283.6	159.2	215.8	193.9	222.3	182.7
TSA	8.5	ND	8.1	9.4	9.7	8.7	8.7	9.1
St.CPUE	-30.4	-31.8	ND	-33.7	-30.8	-29.3	-30.3	-29.8
TLP	84.0	83.0	81.6	ND	84.0	67.0	80.4	79.0
WLP	38.7	38.7	37.9	41.5	ND	38.2	39.4	22.0
CLP	50.2	49.0	49.0	39.2	46.5	ND	49.7	48.0
OBS	22.9	23.0	22.6	26.2	22.8	24.0	ND	22.0
REC	14.1	12.8	13.8	12.4	12.3	14.7	15.2	13.8
TAG	71.9	69.6	70.5	67.1	71.5	71.5	59.1	ND
MMB(mil.lb)	3.52	10.9	3.33	3.41	3.58	3.89	3.43	3.42
Legal (mil.lb)	3.05	9.1	2.80	2.87	3.03	3.39	2.87	2.88
Diff		-6.8	-6.8	-12.2	-5.7	-16.1	-12.7	+0.7

*: Model 3 is 2017 final model with commercial fishery selectivity changed to 2 parameters logistic function. (See alternative model section)
TSA: Trawl Survey Abundance
St. CPUE: Summer commercial catch standardized CPUE

TLP: Trawl survey length composition:
WLP: Winter pot survey length composition
CLP: Summer commercial catch length composition
REC: Recruitment deviation
OBS: Summer commercial catch observer discards length composition
TAG: Tagging recovery data composition
Legal: Exploitable legal male crab

See Appendix C6-C13 for standard output figures. Estimates of parameters for each model are available by request.

The most influential data for the assessment is trawl survey abundance data that determined biomass. For length proportion data, model seems to resolve conflicts among various data, so that removing one data would increase fit to other data.

- Explore bycatch data to see if it is possible to determine the OFL as total catch.

Author reply:
Only discard length data were collected during the summer observer surveys. The author appreciates CPT's guidance for estimating the number and biomass of discarded crab from the length data.

SSC – January 30

- SSC suggests that the author examine available evidence for higher mortality rates at larger sizes and perhaps an alternative way to parameterizing higher mortality at age rather than a step change at the largest size class.

Author's reply:

Because NSRKC has only 8 size classes, we examined step change for each length classes in the following scenario:

1. One mortality for the last 2 length classes (default: ms = 1)
2. Two separate mortalities for the last 2 length classes (ms = 2)
3. Three separate mortalities for the last 3 length classes (ms = 3)

The results showed that estimating mortality of the last 3 length classes seem to improve model fit, especially when fishery selectivity was converted from 1 parameter logistic to 2 parameters logistic model

Scenario	M	ms	Fishery Selectivity	Estimated Mortality
0	0.18	1	1p	0.558
1	0.18	2	1p	0.52, 0.63
2	0.18	3	1p	0.23, 0.52, 0.62
3	0.18	1	2p	0.571
4	0.18	2	2p	0.55,0.61
5	0.18	3	2p	0.34,0.55,0.58

1 parameter logistic selectivity model

$$S_l = \frac{1}{1+e^{(\phi(L_{\max}-L)+\ln(1/0.999-1))}}$$

2 parameters logistic selectivity model

$$S_l = \frac{1}{1+e^{-\alpha(L-\beta)}}$$

a. Evaluation of negative log likelihood alternative models results:

Model	Model 0	Model 1	Model 2	Model 3	Model 4	Model 5
No. Parameters	67	68	69	68	69	70
Total	272.5	272.1	271.7	260.0	259.9	256.5
TSA	8.4	8.4	8.6	8.5	8.4	9.0
St.CPUE	-30.4	-30.4	-30.3	-30.4	-30.4	-30.0
TLP	88.6	88.5	87.2	84.0	84.0	82.7
WLP	38.5	38.5	38.3	38.7	38.8	38.3
CLP	50.0	49.6	49.8	50.2	50.0	48.3
OBS	25.1	25.1	25.1	22.9	23.0	22.9
REC	13.6	13.7	13.7	14.1	14.1	14.5
TAG	78.6	78.7	78.6	71.9	72.0	70.8
MMB(mil.lb)	3.66	3.67	3.68	3.52	3.52	3.56
Legal (mil.lb)	3.21	3.21	3.21	3.05	3.06	3.03
OFL(mil.lb)						

TSA: Trawl Survey Abundance
St. CPUE: Summer commercial catch standardized CPUE
TLP: Trawl survey length composition:
WLP: Winter pot survey length composition
CLP: Summer commercial catch length composition
REC: Recruitment deviation
OBS: Summer commercial catch observer discards length composition
TAG: Tagging recovery data composition
Legal: Exploitable legal male crab

Crab Plan Team – Sept 20, 2017

- Include a graphic on where pot-pulls have been observed.

  Author's reply
  See Appendix D. The majority of observer surveys were conducted where the majority of crabs were harvested. This is expected. Observers can board on boats that are large enough that can harvest more crabs.

- Bring forward default model, model 3, 4, 5 for the January 2018 assessment

  Author's reply:
  Base model along with alternative model 3,4,5 were presented in the result section.

- Conduct likelihood profile on the M parameter

  Author's reply:
  See Appendix F.
  Likelihood profile shows that M = 0.26 appeared to be the lowest. Among the likelihood components, influential factors were trawl and summer commercial length compositions.

- Include results for 2014-2016 pot survey data (but not for assessment)
  This was conducted only for the model 3.

SSC – Oct 02, 2017

- Same as CPT

C. Introduction

1. Species: red king crab (*Paralithodes camtschaticus*) in Norton Sound, Alaska.
2. General Distribution: Norton Sound red king crab is one of the northernmost red king crab populations that can support a commercial fishery (Powell et al. 1983). It is distributed throughout Norton Sound with a westward limit of 167-168^{o} W. longitude, depths less than 30 m, and summer bottom temperatures above 4^{o}C. The Norton Sound red king crab management area consists of two units: Norton Sound Section (Q3) and Kotzebue Section (Q4) (Menard et al. 2011). The Norton Sound Section (Q3) consists of all waters in Registration Area Q north of the latitude of Cape Romanzof, east of the International Dateline, and south of 66°N latitude (Figure 1). The Kotzebue Section (Q4) lies immediately north of the Norton Sound Section and includes Kotzebue Sound. Commercial fisheries have not occurred regularly in the Kotzebue Section. This report deals with the Norton Sound Section of the Norton Sound red king crab management area.
3. Evidence of stock structure: Thus far, no studies have investigated possible stock separation within the putative Norton Sound red king crab stock.
4. Life history characteristics relevant to management: One of the unique life-history traits of Norton Sound red king crab is that they spend their entire lives in shallow water since Norton Sound is generally less than 40 m in depth. Distribution and migration patterns of Norton Sound red king crab have not been well studied. Based on the 1976-2006 trawl surveys, red king crab in Norton Sound are found in areas with a mean depth range of 19 ± 6 (SD) m and bottom temperatures of 7.4 ± 2.5 (SD) ^{o}C during summer. Norton Sound red king crab are consistently abundant offshore of Nome.

   Norton Sound red king crab migrate between deeper offshore and inshore shallow waters. Timing of the inshore mating migration is unknown, but is assumed to be during late fall to winter (Powell et al. 1983). Offshore migration occurs in late May - July (Jennifer Bell, ADF&G, personal communication). The results from a study funded by North Pacific Research Board (NPRB) during 2012-2014 suggest that older/large crab (> 104mm CL) stay offshore in winter, based on findings that large crab are not found nearshore during spring offshore migration periods (Jennifer Bell, ADF&G, personal communication). Timing of molting is unknown but likely occurs in late August – September, based on increase catches of newly-molted crab late in the fishing season (August- September) (Joyce Soong, ADF&G personal communication) and evaluation of molting hormone profiles in the hemolymph (Jennifer Bell, ADF&G, personal communication). Recent observations also indicate that mating may be biennial (Robert Foy, NOAA, personal communication). Trawl surveys show that crab distribution is dynamic with recent surveys showing high abundance on the southeast side of Norton Sound, offshore of Stebbins and Saint Michael.

5. Brief management history: Norton Sound red king crab fisheries consist of commercial and subsistence fisheries. The commercial red king crab fishery started in 1977 and occurs in summer (June – August) and winter (December – May). The majority of red king crab harvest occurs offshore during the summer commercial fishery, whereas the winter commercial and subsistence fisheries occur nearshore through ice.

<u>Summer Commercial Fishery</u>

A large-vessel summer commercial crab fishery started in 1977 in the Norton Sound Section (Table 1) and continued from 1977 through 1990. No summer commercial fishery occurred in 1991 because there were no staff to manage the fishery. In March 1993, the Alaska Board of Fisheries (BOF) limited participation in the fishery to small boats. Then on June 27, 1994, a super-exclusive designation went into effect for the fishery. This designation stated that a vessel registered for the Norton Sound crab fishery may not be used to take king crabs in any other registration areas during that registration year. A vessel moratorium was put into place before the 1996 season. This was intended to precede a license limitation program. In 1998, Community Development Quota (CDQ) groups were allocated a portion of the summer harvest; however, no CDQ harvest occurred until the 2000 season. On January 1, 2000 the North Pacific License Limitation Program (LLP) went into effect for the Norton Sound crab fishery. The program dictates that a vessel which exceeds 32 feet in length overall must hold a valid crab license issued under the LLP by the National Marine Fisheries Service. Changes in regulations and the location of buyers resulted in eastward movement of the harvest distribution in Norton Sound in the mid-1990s. In Norton Sound, a legal crab is defined as ≥ 4-3/4 inch carapace width (CW, Menard et al. 2011), which is approximately equivalent to ≥ 104 mm carapace length mm CL. Since 2005, commercial buyers (Norton Sound Economic Development Corporation) started accepting only legal crab of ≥ 5 inch CW. This may have increased discards; however, because discards have not been monitored until 2012, impact of this change on discards is unknown. This issue was also examined in assessment model selection, which showed no difference in estimates of selectivity functions before and after 2005 (NPFMC 2016).

Portions of Norton Sound area are closed to commercial fishing for red king crab. Since the beginning of the commercial fisheries in 1977, waters approximately 5-10 miles offshore of southern Seward Peninsula from Port Clarence to St. Michael have been closed to protect crab nursery grounds during the summer commercial crab fishery (Figure 2). The spatial extent of closed waters has varied historically.

CDQ Fishery

The Norton Sound and Lower Yukon CDQ groups divide the CDQ allocation. Only fishers designated by the Norton Sound and Lower Yukon CDQ groups are allowed to participate in this portion of the king crab fishery. Fishers are required to have a CDQ fishing permit from the Commercial Fisheries Entry Commission (CFEC) and register their vessel with the Alaska Department of Fish and Game (ADF&G) before begin fishing. Fishers operate under the authority of each CDQ group who decides how their crab quota is to be harvested. During the March 2002 BOF meeting, new regulations for the CDQ crab fishery were adopted that affected; closed-water boundaries were relaxed in eastern Norton Sound and waters west of Sledge Island. In March 2008, the BOF changed the start date of the Norton Sound open-access portion of the fishery to be opened by emergency order as early as June 15. The CDQ fishery may open at any time (as soon as ice is out), by emergency order. CDQ harvest share is 7.5% of total projected harvest.

Winter Commercial Fishery

The winter commercial crab fishery is a small fishery using hand lines and pots through the nearshore ice. On average 10 permit holders harvested 2,500 crabs during 1978-2009. From 2007 to 2015 the winter commercial catch increased from 3,000 crabs to over 40,000 (Table 2). In 2015 winter commercial catch reached 20% of total crab catch. The BOF responded in May 2015 by amending regulations to allocate 8% of the total commercial guideline harvest level (GHL) to the winter commercial fishery, which became in effect since 2017 season. The winter red king crab commercial fishing season was also set from January 15 to April 30, unless changed by emergency order. The new regulation became in effect since the 2016 season.

Subsistence Fishery

While the winter subsistence fishery has a long history, harvest information is available only since the 1977/78 season. The majority of the subsistence crab fishery harvest occurs using hand lines and pots through nearshore ice. Average annual winter subsistence harvest was 5,400 crab (1977-2010). Subsistence harvesters need to obtain a permit before fishing and record daily effort and catch. There are no size or sex specific harvest limits; however, the majority of retained catches are males of near legal size. The subsistence fishery catch is influenced not only by crab abundance, but also by changes in distribution, changes in gear (e.g., more use of pots instead of hand lines since 1980s), and ice conditions (e.g., reduced catch due to unstable ice conditions: 1987-88, 1988-89, 1992-93, 2000-01, 2003-04, 2004-05, and 2006-07).

The summer subsistence crab fishery harvest has been monitored since 2004 with an average harvest of 712 crab per year. Since this harvest is very small, the summer subsistence fishery was not included in the assessment model.

6. Brief description of the annual ADF&G harvest strategy

Since 1997 Norton Sound red king crab has been managed based on a guideline harvest level (GHL). From 1999 to 2011 the GHL for the summer commercial fishery was determined by a prediction model and the model estimated predicted biomass: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.5 million lb; (2) ≤ 5% of legal male abundance when the estimated legal biomass falls within the range 1.5-2.5 million lb; and (3) ≤ 10% of legal male when estimated legal biomass >2.5 million lb.

In 2012 a revised GHL for the summer commercial fishery was implemented: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.25 million lb; (2) ≤ 7% of legal male abundance when the estimated legal biomass falls within the range 1.25-2.0 million lb; (3) ≤ 13% of legal male abundance when the estimated legal biomass falls within the range 2.0-3.0 million lb; and (3) ≤ 15% of legal male biomass when estimated legal biomass >3.0 million lb.

In 2015 the Alaska Board of Fisheries passed the following regulations regarding winter commercial fisheries:

1. Revised GHL to include summer and winter commercial fisheries.
2. Set guideline harvest level for winter commercial fishery (GHL_w) at 8% of the total GHL
3. Dates of the winter red king crab commercial fishing season are from January 15 to April 30.

Year	Notable historical management changes
1976	The abundance survey started
1977	Large vessel commercial fisheries began
1991	Fishery closed due to staff constraints
1994	Super exclusive designation went into effect. The end of large vessel commercial fishery operation. The majority of commercial fishery subsequently shifted to east of 164°W longitude.
1998	Community Development Quota (CDQ) allocation went into effect
1999	Guideline Harvest Level (GHL) went into effect
2000	North Pacific License Limitation Program (LLP) went into effect.
2002	Change in closed water boundaries (Figure 2)
2005	Commercially accepted legal crab size changed from ≥ 4-3/4 inch CW to ≥ 5 inch CW
2006	The Statistical area Q3 section expanded (Figure 1)
2008	Start date of the open access fishery changed from July 1 to after June 15 by emergency order. Pot configuration requirement: at least 4 escape rings (>4½ inch diameter) per pot located within one mesh of the bottom of the pot, or at least ½ of the vertical surface of a square pot or sloping side-wall surface of a conical or pyramid pot with mesh size > 6½ inches.
2012	The Board of Fisheries adopted a revised GHL for summer fishery.
2016	Winter GHL for commercial fisheries was established and modified winter fishing season dates were implemented.

7. Summary of the history of the B_{MSY}.

NSRKC is a Tier 4 crab stock. Direct estimation of the B_{MSY} is not possible. The B_{MSY} proxy is calculated as mean model estimated mature male biomass (MMB) from 1980 to present. Choice of this period was based on a hypothesized shift in stock productivity a due to a climatic regime shift indexed by the Pacific Decadal Oscillation (PDO) in 1976-77. Stock status of the NSRKC was Tier 4a until 2013. In 2014 the stock fell to Tier 4b, but came back to Tier 4a for the 2015-2016 seasons.

D. Data

1. Summary of new information:

   Winter commercial and subsistence fishery:

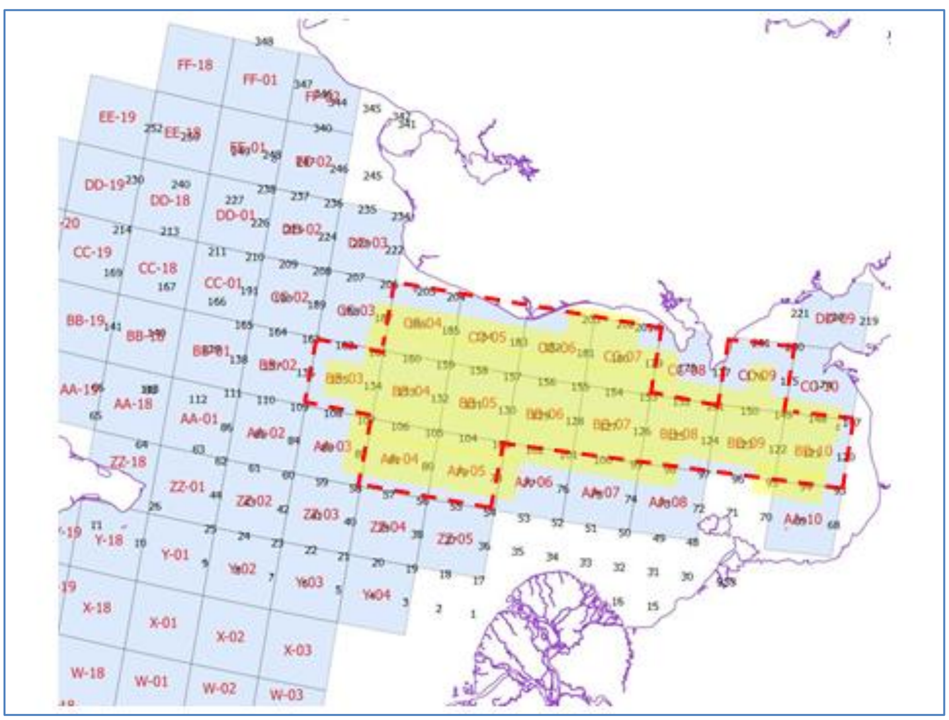
   Winter commercial fishery catch in 2017 was 26,008 crab (77,843 lb.), declined slightly from 2016. Subsistence retained crab catch was 6,039 and unretained was 1,146 or 16% of total catch (Table 2).

   Summer commercial fishery:

   The summer commercial fishery opened on June 26 and closed on July 25. Total of 135,322 crab (411,736 lb.) were harvested (Table 1).

   Total retained harvest for 2017 season was 167,369 crab (501,637 lb.) and did not exceed the 2017 ABC of 0.54 million lb.

   Summer Trawl abundance survey ADFG (7/28-8/08), and NOAA (8/18-829). Abundance estimated by ADFG survey was 1762.1 (x 1000) crab with CV 0.22, and that by NOAA survey was 1035.8 (x 1000) crab with CV 0.40 (Table 3). It should be noted that total estimation arear and survey station density differ between the two trawl surveys. ADFG survey is based on 10nm grids whereas NOAA survey is based on 20nm grids.



2017 ADFG trawl survey coverage (Yellow shade) and NOAA Trawl survey coverage where abundance estimates were made (Red hashed line)

2. Available survey, catch, and tagging data

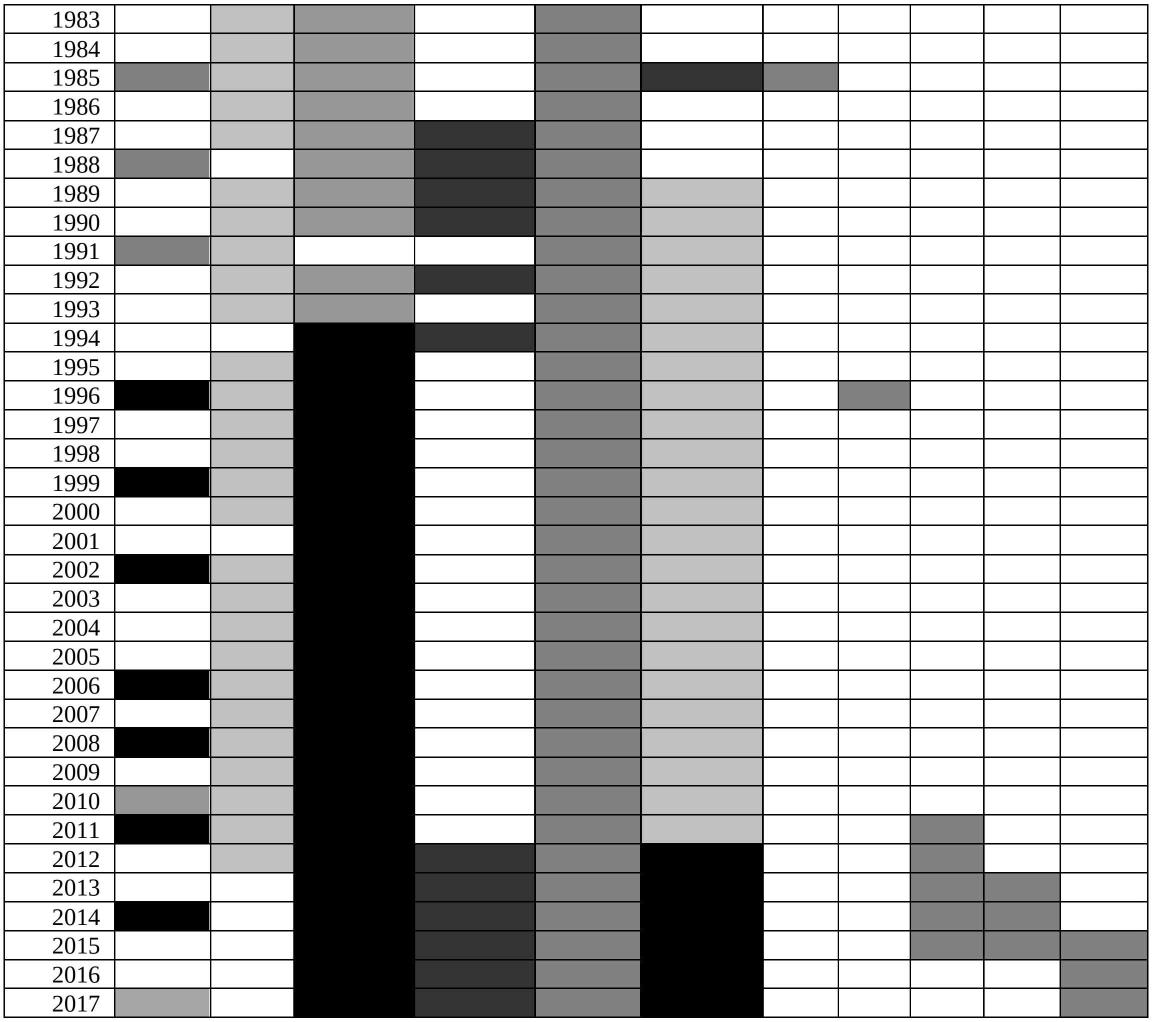
	Years	Data Types	Tables
Summer trawl survey	76,79,82,85,88,91,96, 99, 02,06,08,10,11, 14. 17	Abundance Length proportion	3 5
Winter pot survey	81-87, 89-91,93,95-00,02-12	Length proportion	6
Summer commercial fishery	76-90,92-17	Retained catch Standardized CPUE, Length proportion	1 1 4
Summer commercial Discards	87-90,92,94, 2012-2017	Length proportion (sublegal only)	7
Winter subsistence fishery	76-17	Total catch Retained catch	2 2
Winter commercial fishery	78-17	Retained catch	2
Tag recovery	80-17	Recovered tagged crab	8

Data available but not used for assessment

Data	Years	Data Types	Reason for not used
Summer pot survey	80-82,85	Abundance Length proportion	Uncertainties on how estimates were made.
Summer preseason survey	95	Length proportion	Just one year of data
Summer subsistence fishery	2005-2013	retained catch	Too few catches compared to commercial
Winter Pot survey	87, 89-91,93,95-00,02-12	CPUE, Length	CPUE data Not reliable due to ice conditions
Winter Commercial	2015-17	Length proportion	Years of data too short
Preseason Spring pot survey	2011-15	CPUE, Length proportion	Years of data too short
Postseason Fall pot survey	2013-15	CPUE, Length proportion	Years of data too short

Time series of available data

	Survey		Harvests			Tag	Data Not Used[3]				
	S. Trawl	W. Pot	S.Com	S.Com Discards	W. Com, Sub	Tag recovery	S. Pot	Pre fish	Sp. Tag	F. Tag,	W. Com
N[1]	N		H, CPUE		H						
Length[2]	X	X	X	X		X	X	X	X	X	X
1976											
1977											
1978											
1979											
1980											
1981											
1982											



1: Index of abundance data: N: Abundance, H: Harvest, CPUE: Catch cpue
2: Length data available
3: Data were not used for the assessment model because of short term data.
4: Different colors indicate changes in fishery characteristics or survey methodologies.

Catches in other fisheries

In Norton Sound, no other crab, groundfish, or shellfish fisheries exist.

	Fishery	Data availability
Bycatch in other crab fisheries	Does not exist	NA
Bycatch in groundfish pot	Does not exist	NA
Bycatch in groundfish trawl	Does not exist	NA
Bycatch in the scallop fishery	Does not exist	NA

3. Other miscellaneous data:

Satellite tag migration tracking (NOAA 2016)

Spring offshore migration distance and direction (2013-2015)

Monthly blood hormone level (indication of molting timing) (2014-2015)

Data aggregated:

Proportion of legal size crab, estimated from trawl survey and observer data. (Table 11)

Data estimated outside the model:

Summer commercial catch standardized CPUE (Table 1, Appendix A2)

E. Analytic Approach

1. History of the modeling approach.

The Norton Sound red king crab stock was assessed using a length-based synthesis model (Zheng et al. 1998). Since adoption of the model, the major challenge is a conflict between model projection and data, specifically the model projects higher abundance-proportion of large size class (> 123mm CL) of crab than observed. This problem was further exasperated when natural mortality *M* was set to 0.18 from previous *M* = 0.3 in 2011 (NPFMC 2011). This issue has been resolved by assuming (3-4 times) higher *M* for the length crabs (i.e., *M* = 1.8 for length classes ≤ 123mm, and higher M for > 123mm) (NPFMC 2012, 2013, 2014, 2015, 2016, 2017). Alternative assumptions have been explored, such as changing molting probability (i.e., crab matured quicker or delayed maturation), higher natural mortality, and dorm shaped selectivity (i.e., large crab are not caught, or moved out of fishery/survey grounds). However, those alternative assumptions did not produce better model fits. Model estimated length specific molting probability was similar to inverse logistic curve, and did not improve model fit (NPFMC 2016). Assuming constant across all length classes resulted in higher *M* (0.3-0.45) (NPFMC 2013, 2017). Assuming dome shaped selectivity resulted in large (>123mm CL) of crabs consisting of 50% of MMB move out of Norton Sound fishery and survey area and never been seen. For the 2018 gradual increase of *M* across length classes was assessed.

Historical Model configuration progression:

2011 (NPFMC 2011)
1. *M* =0.18
2. *M* of the last length class = 0.288
3. Include summer commercial discards mortality = 0.2
4. Weight of fishing effort = 20,
5. The maximum effective sample size for commercial catch and winter surveys = 100,

2012 (NPFMC 2012)
1. *M* of the last length class = 3.6×*M*
2. The maximum effective sample size for commercial catch and winter surveys = 50,
3. Weight of fishing effort = 50.

2013 (NPFMC 2013)
1. Standardize commercial catch cpue and replace likelihood of commercial catch efforts to standardized commercial catch cpue with weight = 1.0
2. Eliminate summer pot survey data from likelihood
3. Estimate survey *q* of 1976-1991 NMFS survey with maximum of 1.0
4. The maximum effective sample size for commercial catch and winter surveys = 20.

2014 (NPFMC 2014)
1. Modify functional form of selectivity and molting probability to improve parameter estimates (2 parameter logistic to 1 parameter logistic)
2. Include additional variance for the standardized cpue.
3. Include winter pot survey cpue (But was removed from the final model due to lack of fit)
4. Estimate growth transition matrix from tagged recovery data.

2015 (NPFMC 2015)
1. Winter pot survey selectivity is an inverse logistic, estimating selectivity of the smallest length group independently
2. Reduce Weight of tag-recovery: W = 0.5
3. Model parsimony: one trawl survey selectivity and one commercial pot selectivity

2016 (NPFMC 2016)
1. Length range extended from 74mm – 124mm above to 64mm – 134mm above.
2. Estimate multiplier for the largest (> 123mm) length classes.

2017 (NPFMC 2017)
1. Change molting probability function form 1 to 2 parameter logistic. Assume molting probability not reaching 1 for the smallest length class.

2. Model Description

a. Description of overall modeling approach:

The model is a male-only size structured model that combines multiple sources of survey, catch, and mark-recovery data using a maximum likelihood approach to estimate abundance, recruitment, catchability of the commercial pot gear, and parameters for selectivity and molting probabilities (See Appendix A for full model description).

Unlike other crab assessment models, NSRK modeling year is starts from February 1st to January 31st of the following year. This schedule was selected because Norton Sound winter crab fisheries can start when Norton Sound ice become thick enough to operate fishery safely, which can be as earliest as mid-late January.

b-f. See Appendix A.

g. Critical assumptions of the model:

i. Male crab mature at CL length 94mm.

Size at maturity of NSRKC (CL 94 mm) was determined by adjusting that of BBRKC (CL 120mm) reflect the slower growth and smaller size of NSRKC.

ii. Molting occurs in the fall after the summer fishery

iii. Instantaneous natural mortality *M* is 0.18 for all length classes, except for the last length group (> 123mm).

iv. Trawl survey selectivity is a logistic function with 1.0 for length classes 5-6. . Selectivity is constant over time.

v. Winter pot survey selectivity is a dome shaped function: Reverse logistic function of 1.0 for length class CL 84mm, and model estimate for CL < 84mm length classes. Selectivity is constant over time.

This assumption is based on the fact that a low proportion of large crab are caught in the nearshore area where winter surveys occur. Causes of this pattern may be that (1) large crab do not migrate into nearshore waters in winter or (2) large crab are fished out by winter fisheries where the survey occurs (i.e., local depletion). Recent studies suggest that the first explanation is more likely than second (Jennifer Bell, ADFG, personal communication).

vi. Summer commercial fisheries selectivity is an asymptotic logistic function of 1.0 at the length class CL 134mm. While the fishery changed greatly between the periods (1977-1992 and 1993-present) in terms of fishing vessel composition and pot configuration, the selectivity of each period was assumed to be identical. Model fits of separating and combining the two periods were examined in 2015, and showed no difference between the two models (NPFMC 2015). For model parsimony, the two were combined.

vii. Summer trawl survey selectivity is an asymptotic logistic function of 1.0 at the length of CL 124mm. While the survey changed greatly between NOAA (1976-1991) and ADF&G (1996-present) in terms of survey vessel and trawl net structure, selectivity of both periods was assumed to be identical. Model fits separating and combining the two surveys were examined in 2015. No differences between the two models were observed (NPFMC 2015) and for model parsimony the two were combined.

viii. Winter commercial and subsistence fishery selectivity and length-shell conditions are the same as those of the winter pot survey. All winter commercial and subsistence harvests occur February 1st.

Winter commercial king crab pots can be any dimension (5AAC 34.925(d)). No length composition data exists for crab harvested in the winter commercial or subsistence fisheries. However, because commercial fishers are also subsistence fishers, it is reasonable to assume that the commercial fishers used crab pots that they use for subsistence harvest, and hence both fisheries have the same selectivity.

ix. Growth increments are a function of length, are constant over time, estimated from tag recovery data.

x. Molting probability is an inverse logistic function of length for males.

xi. A summer fishing season for the directed fishery is short. All summer commercial harvests occur July 1st.

xii. Discards handling mortality rate for all fisheries is 20%.

No empirical estimate is available.

xiii. Annual retained catch is measured without error.

xiv. All legal size crab (≥ 4-3/4 inch CW) are retained, and sublegal size crab or commercially unacceptable size crab (< 5 inch CW, since 2005) are discarded.

Since 2005, buyers announced that only legal crab with ≥ 5 inch CW are acceptable for purchase. Since samples are taken at a commercial dock, it was anticipated that this change would lower the proportion of legal crab. However, the model was not sensitive to this change (NPFMC 2013, 2017).

xv. Length compositions have a multinomial error structure and abundance has a log-normal error structure.

h. Changes of assumptions since last assessment:

None.

3. Model Selection and Evaluation

a. Description of alternative model configurations.

Following CPT and SSC's recommendation in fall 2017, we brought base model (2017 assessment model), model 3, 4, and 5. Also, we examined potential impacts of spring survey data (model 6).

List of model scenarios explored:

Scenario	I	ms	Fishery Selectivity	Estimated *M*
0	0.18	1	1p	0.579
3	0.18	1	2p	0.595
4	0.18	2	2p	0.576, 0.634
5	0.18	3	2p	0.340, 0.547, 0.584
6	0.18	1	2p	0.592

ms=1: Estimate one mortality for the last 2 length classes (124mm, 134mm)
ms=2: Estimate two separate mortalities for the last 2 length classes (124mm, 134mm)
ms=3: Estimate three separate mortalities for the last 3 length classes (114mm,124mm, 134mm)

Fishery selectivity model function

1 parameter logistic selectivity model

$$S_l = \frac{1}{1 + e^{(\phi(L_{\max} - L) + \ln(1/0.999 - 1))}}$$

2 parameters logistic selectivity model

$$S_l = \frac{1}{1 + e^{-\alpha(L-\beta)}}$$

b. Evaluation of negative log-likelihood alternative models results:

Model	Model 0	Model 3	Model 4	Model 5	Model 6
No. Parameters	67	68	69	70	68
Total	281.1	269.2	269.1	265.44	286.01
TSA	9.1	9.1	9.1	9.36	9.24
St.CPUE	-30.6	-30.7	-30.7	-30.4	-30.6
TLP	95.1	90.6	90.6	89.8	90.8
WLP	38.7	39.1	39.1	38.5	39.3
CLP	50.8	51.4	51.2	49.2	51.3
OBS	25.2	23.2	23.2	23.1	23.0
REC	13.6	14.0	13.9	14.5	16.5
TAG	79.2	72.5	72.6	71.3	72.5
SP					14.0
MMB(mil.lb)	4.08	3.94	3.95	3.91	4.00
Legal crab Catchable (mil.lb)	3.55	2.58	2.60	2.13	2.63
OFL(mil.lb)	0.75	0.57	0.58	0.51	0.60

TSA: Trawl Survey Abundance
St. CPUE: Summer commercial catch standardized CPUE
TLP: Trawl survey length composition:
WLP: Winter pot survey length composition
CLP: Summer commercial catch length composition
REC: Recruitment deviation
OBS: Summer commercial catch observer discards length composition
TAG: Tagging recovery data composition
Legal: Exploitable legal male crab

See Appendix C1-C5 for standard output figures and estimated parameters.

a. Search for balance:

Changing to 2 parameters logistic model and stepwise length specific mortality decreased negative log-likelihood and improved model fit. Relative gain of model improvement was the largest from model 0 to model 3 (i.e., changing the shape of commercial pot selectivity). The majority of model fit was attributed to likelihood of Trawl survey and tag recovery length proportion (cf. Appendix C1, C2 Figures 11, 12, 13). Simultaneously, it should be noted that extent of reduction depends upon assumed input sample size. Subdividing natural mortality and increasing one more parameter size (from model 3 to 4) did not change model fit. Though some improvement was seen from model 4 to 5, it was argued that assuming natural mortality increase of crab size 114-123mm would be biologically unreasonable (CPT Sept 2017). Changing of fishery selectivity or subdividing mortality did not change MMB projections, but reduced legal crab biomass catchable to commercial fishery. This is because the shape of the selectivity became steeper (cf. Appendix C1, C2 Figure 3). Based on performance of improvement of model fit vs. additional parameters and biological realism we recommend the model 3 for the 2018 assessment of OFL and ABC.

4. Results

1. List of effective sample sizes and weighting factors (Figure 4)

"Implied" effective sample sizes were calculated as

$$n = \sum_{l} \hat{P}_{y,l}(1-\hat{P}_{y,l}) \Big/ \sum_{l}(P_{y,l} - \hat{P}_{y,l})^2$$

Where $P_{y,l}$ and $\hat{P}_{y,l}$ are observed and estimated length compositions in year *y* and length group *l*, respectively. Estimated effective sample sizes vary greatly over time.

Maximum sample sizes for length proportions:

Survey data	Sample size
Summer commercial, winter pot, and summer observer	minimum of 0.1 × actual sample size or 10
Summer trawl and pot survey	minimum of 0.5 × actual sample size or 20
Tag recovery	0.5× actual sample size

Weighting factor

Recruitment SD	0.5

2. Tables of estimates.
   a. Model parameter estimates (Tables 10, 11, 12, 13).
   b. Abundance and biomass time series (Table 13)
   c. Recruitment time series (Table 13).
   d. Time series of catch/biomass (Tables 13 and 14)

3. Graphs of estimates.
   a. Molting probability and trawl/pot selectivity (Figure 5)
   b. Trawl survey and model estimated trawl survey abundance (Figure 6)
   c. Estimated male abundances (recruits, legal, and total) (Figure 7)
   d. Estimated mature male biomass (Figure 8)
   e. Time series of standardized cpue for the summer commercial fishery (Figure 9).
   f. Time series of catch and estimated harvest rate (Figure 10).

4. Evaluation of the fit to the data.

a. Fits to observed and model predicted catches.

Not applicable. Catch is assumed to be measured without error; however fits of cpue are available (Figures 9, 11).

b. Model fits to survey numbers (Figures 6, 11).

All model estimated abundances of total crab were within the 95% confidence interval of the survey observed abundance, except for 1976 and 1979, where model estimates were higher than the observed abundances.

c. Fits of catch proportions by lengths (Figures 12, 13).

d. Model fits to catch and survey proportions by length (Figures 12, 14, 15, 16).

e. Marginal distribution for the fits to the composition data

f. Plots of implied versus input effective sample sizes and time-series of implied effective sample size (Figure 4).

g. Tables of RMSEs for the indices:

Trawl survey:
Summer commercial standardized CPUE: (Table 1)

h. QQ plots and histograms of residuals (Figure 11).

5. Retrospective analyses (Figure 17).

Mohn's rho was 0.345 from 2010-2017. Model did not converge for year 2009. Mohn's rho suggests that retrospective projections are more likely to overestimate abundance. However, Mohns' rho has NO statistical range criteria of whether an assessment model is deemed acceptable/ unacceptable.

6. Uncertainty and sensitivity analyses.

See Sections 2 and 5.

a) Calculation of the OFL

1. Specification of the Tier level and stock status.

The Norton Sound red king crab stock is placed in Tier 4. It is not possible to estimate the spawner-recruit relationship, but some abundance and harvest estimates are available to build a computer simulation model that captures the essential population dynamics. Tier 4 stocks are assumed to have reliable estimates of current survey biomass and instantaneous *M*; however, the estimates for the Norton Sound red king crab stock are uncertain.

Tier 4 level and the OFL are determined by the F_{MSY} proxy, B_{MSY} proxy, and estimated legal male abundance and biomass:

level	Criteria	F_{OFL}
a	$B/B_{MSY^{prox}} > 1$	$F_{OFL} = \gamma\, M$
b	$\beta < B/B_{MSY^{prox}} \le 1$	$F_{OFL} = \gamma\, M\, (B/B_{MSY^{prox}} - \alpha)/(1-\alpha)$
c	$B/B_{MSY^{prox}} \le \beta$	$F_{OFL} = bycatch\, mortality\ \&\, directed\ \ fishery\, F = 0$

where *B* is a mature male biomass (MMB), B_{MSY} proxy is average mature male biomass over a specified time period, $M = 0.18$, $\gamma = 1$, $\alpha = 0.1$, and $\beta = 0.25$

For Norton Sound red king crab, MMB is defined as the biomass of males > 94 mm CL on February 01 (Appendix A)**.** B_{MSY} proxy is

B_{MSY} proxy = average model estimated MMB from 1980-2018

Predicted mature male biomass in 2018 on February 01 is:

Mature male biomass: 3.938 (SD 0.53) million lb.

Estimated B_{MSY} proxy is:

4.47 million lb.

Since projected MMB is less than B_{MSY} proxy, **Norton Sound red king crab stock status is Tier 4b**

2. Calculation of OFL.

OFL was calculated for retained (OFL_r), un-retained (OFL_{ur}), and total (OFL_T) for legal sized crab, *Legal_B*, by applying F_{OFL}.

Legal_B is a biomass of legal crab subject to fisheries and is calculated as: Projected abundance by length crab × fishing selectivity by length class × Proportion of legal crab per length class × Average lb per length class.

For the Norton Sound red king crab assessment, *Legal_B* was defined as winter biomass catchable to summer commercial pot fishery gear $Legal\_B_w$, as

$$Legal\_B_w = \sum_l (N_{w,l,} + O_{w,l,}) S_{s,l} P_{lg,l} wm_l$$

The Norton Sound red king crab fishery consists of two distinct fisheries: winter and summer. The two fisheries are discontinuous with 5 months between the two fisheries during which natural mortalities occur. To incorporate this fishery, the CPT in 2016 recommended the following formula:

$$Legal\_B_s = Legal\_B_w (1 - \exp(-x \cdot F_{OFL})) e^{-0.42M}$$

$$OFL_r = (1 - \exp(-(1-x) \cdot F_{OFL})) Legal\_B_s$$

And $$p = \frac{Legal\_B_w (1 - \exp(-x \cdot F_{OFL}))}{OFL_r}$$

Where p is a specific proportion of winter crab harvest to total (winter + summer) harvest.

Solving x of the above, a revised retained OFL is

$$OFL = Legal\_B_w\left(1-e^{-(F_{OFl}+0.42M)}-(1-e^{-0.42M})\left(\frac{1-p\cdot(1-e^{-(F_{OFL}+0.42M)})}{1-p\cdot(1-e^{-0.42M})}\right)\right)$$

Accounting for difference in length specific natural mortality

$$OFL_r = \sum_l\left[Legal\_B_{w,l}\left(1-e^{-(F_{OF,l}+0.42M_l)}-(1-e^{-0.42M_l})\left(\frac{1-p\cdot(1-e^{-(F_{OFL,l}+0.42M_l)})}{1-p\cdot(1-e^{-0.42M_l})}\right)\right)\right]$$

Unretained OFL (OFL_{ur}) is a sub-legal crab biomass catchable to summer commercial pot fisheries calculated as: Projected legal abundance (Feb 1st) × Commercial pot selectivity × Proportion of sub-legal crab per length class × Average lb per length class × handling mortality (hm =0.2)

$$OFL_{ur} = \sum_l\left[Sub\_legal\_B_{w,l}\left(1-e^{-(F_{OFL,l}+0.42M_l)}-(1-e^{-0.42M_l})\left(\frac{1-p\cdot(1-e^{-(F_{OFL,l}+0.42M_l)})}{1-p\cdot(1-e^{-0.42M_l})}\right)\right)\right]\cdot hm$$

The total male OFL is

$$OFL_T = OFL_r + OFL_{ur}$$

For calculation of the OFL 2018, we specified p = 0.16.

Legal male biomass catchable to fishery (Feb 01): 2.60 million lb
OFL_r = 0.57 million lb. or 0.26 kMT
OFL_{nr} = 0.09 million lb. or 0.04 kMT
OFL_T = 0.66 million lb. or 0.30 kMT

b) Calculation of the ABC

1. Specification of the probability distribution of the OFL.

Probability distribution of the OFL was determined based on the CPT recommendation in January 2015 of 20% buffer:

Retained ABC for legal male crab is 80% of OFL

ABC = 0.46 million lb or 0.21 kMT

c) Rebuilding Analyses

Not applicable

d) Data Gaps and Research Priorities

The major data gap is the fate of crab greater than 123 mm.

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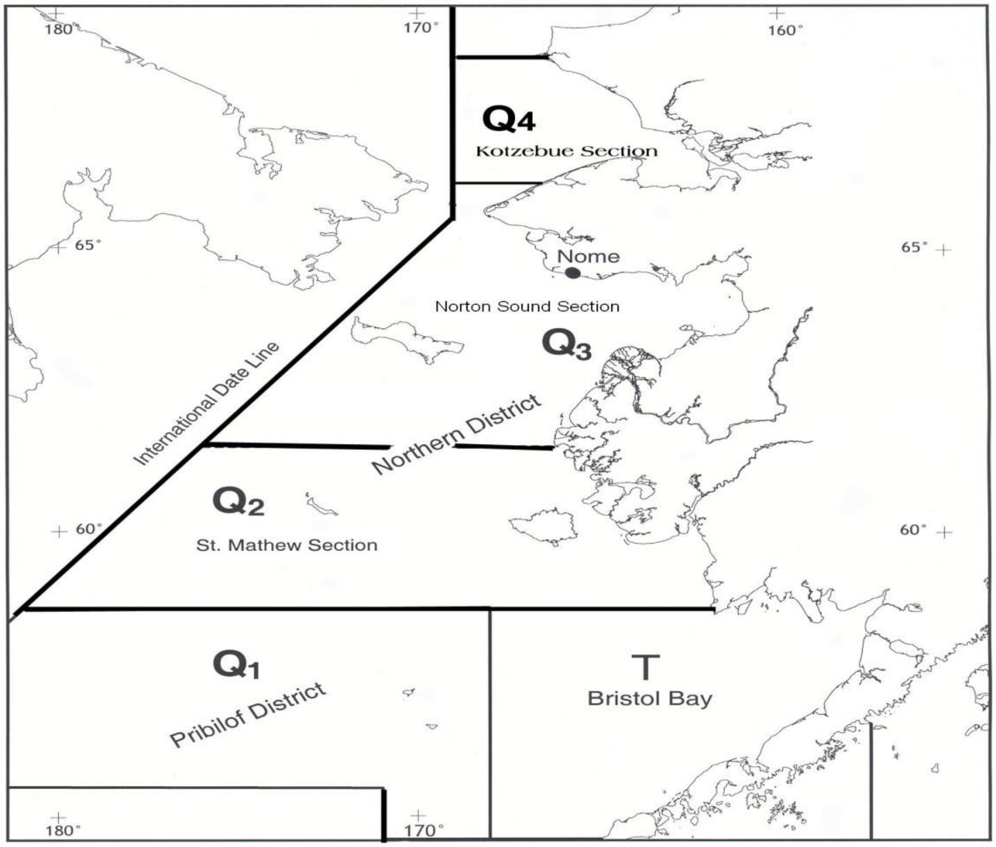


Figure 1. King crab fishing districts and sections of Statistical Area Q.

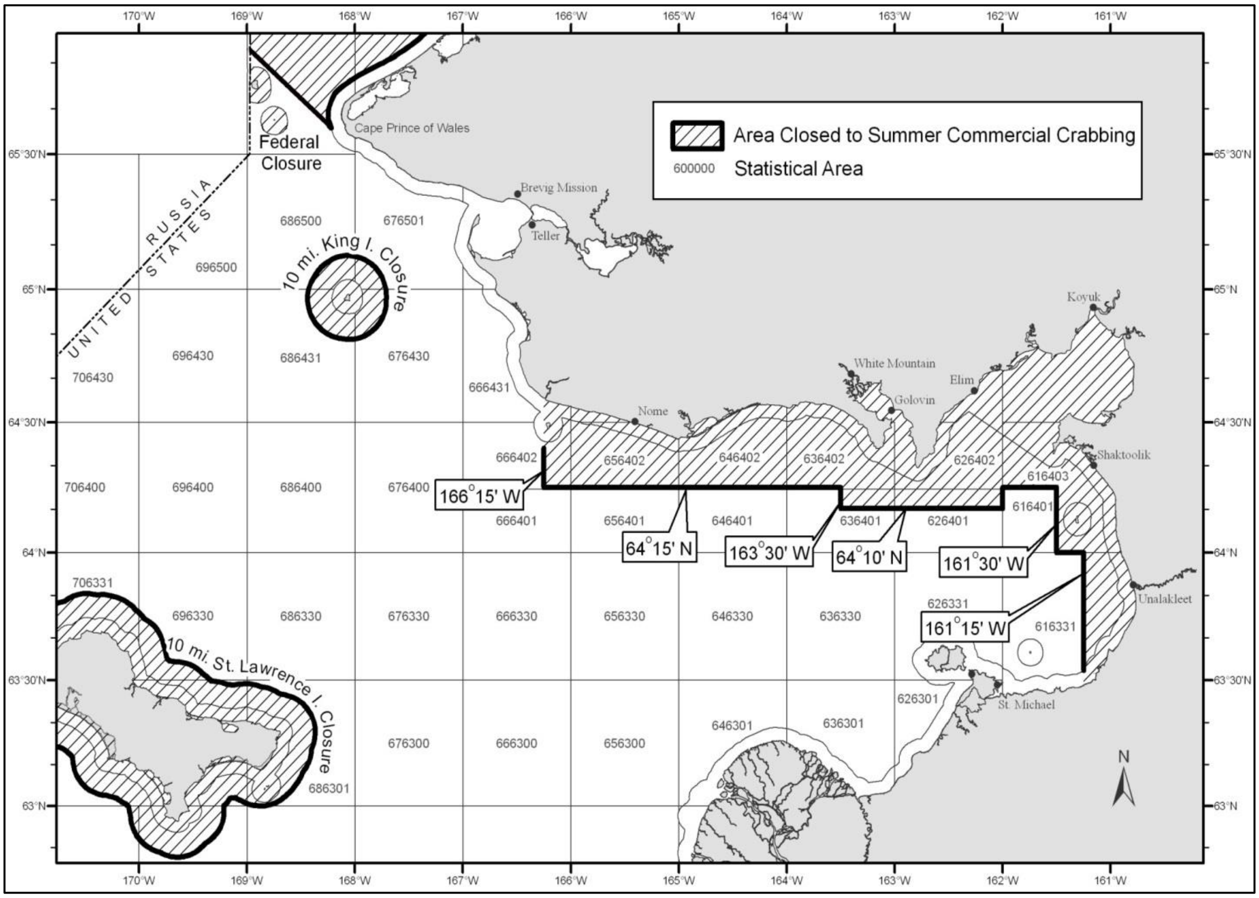


Figure 2. Closed water regulations in effect for the Norton Sound commercial crab fishery. Line around the coastline delineates the 3-mil3 state waters zone.

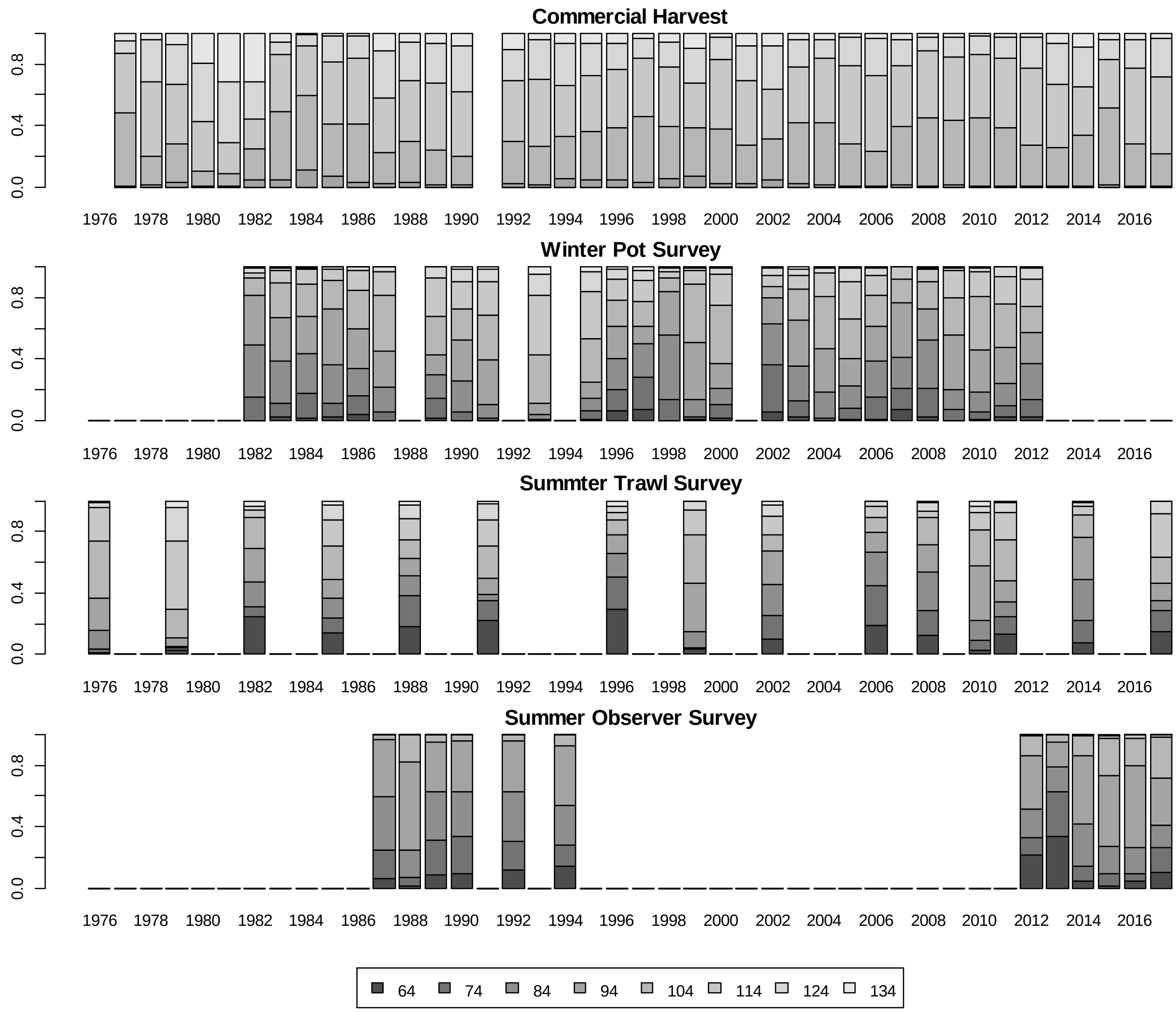


Figure 3. Observed length compositions during 1976-2017.

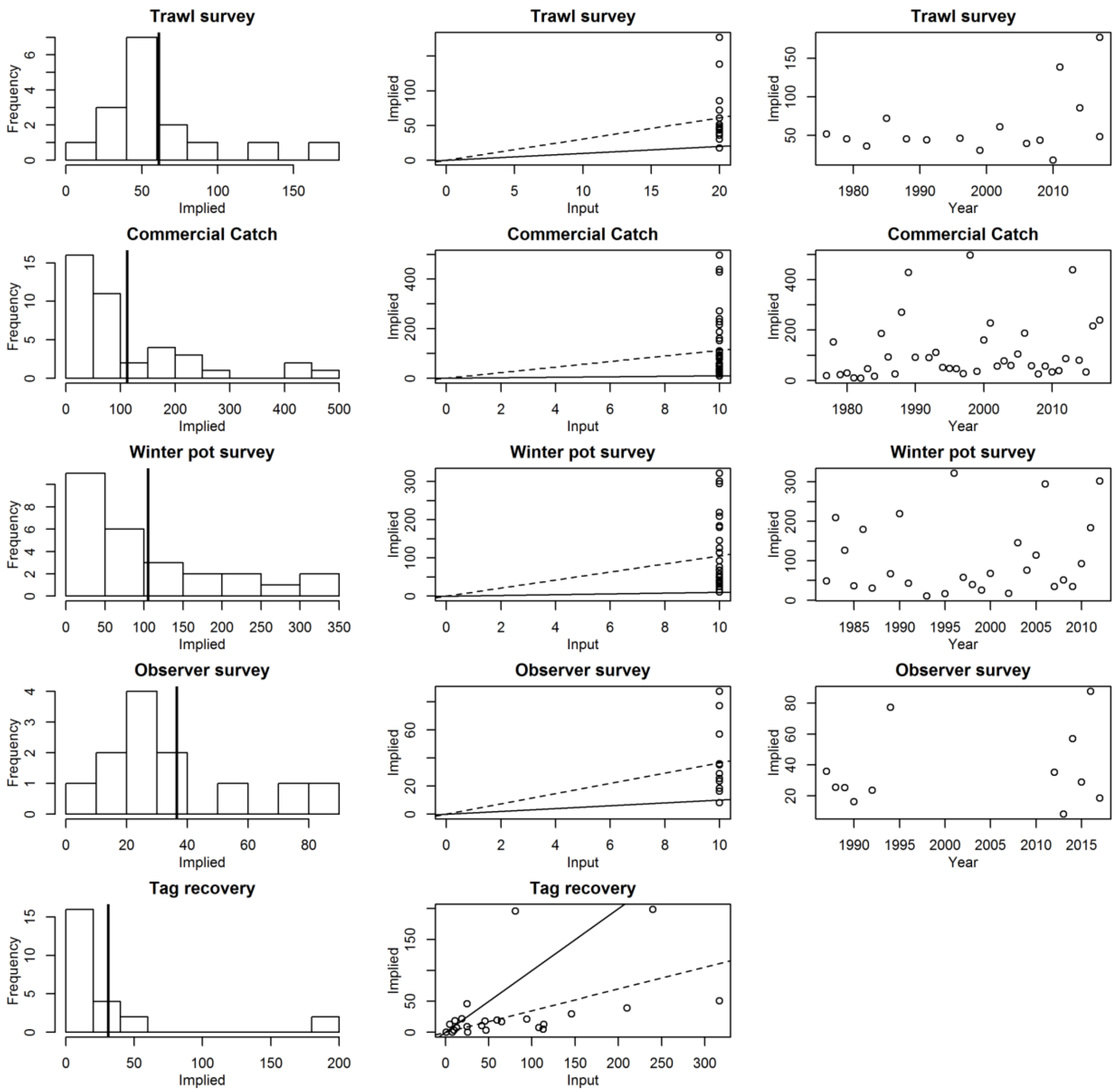


Figure 4. Effective sample size vs. implied (Input) sample size. Figures in the first column show effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the implied sample size. Figures in the second column show implied sample sizes (x-axis) vs. effective sample sizes (y-axis). Dashed line indicates the linear regression slope, and solid line is 1:1 line. Figures in the third column show years (x-axis) vs. effective sample sizes (y-axis).

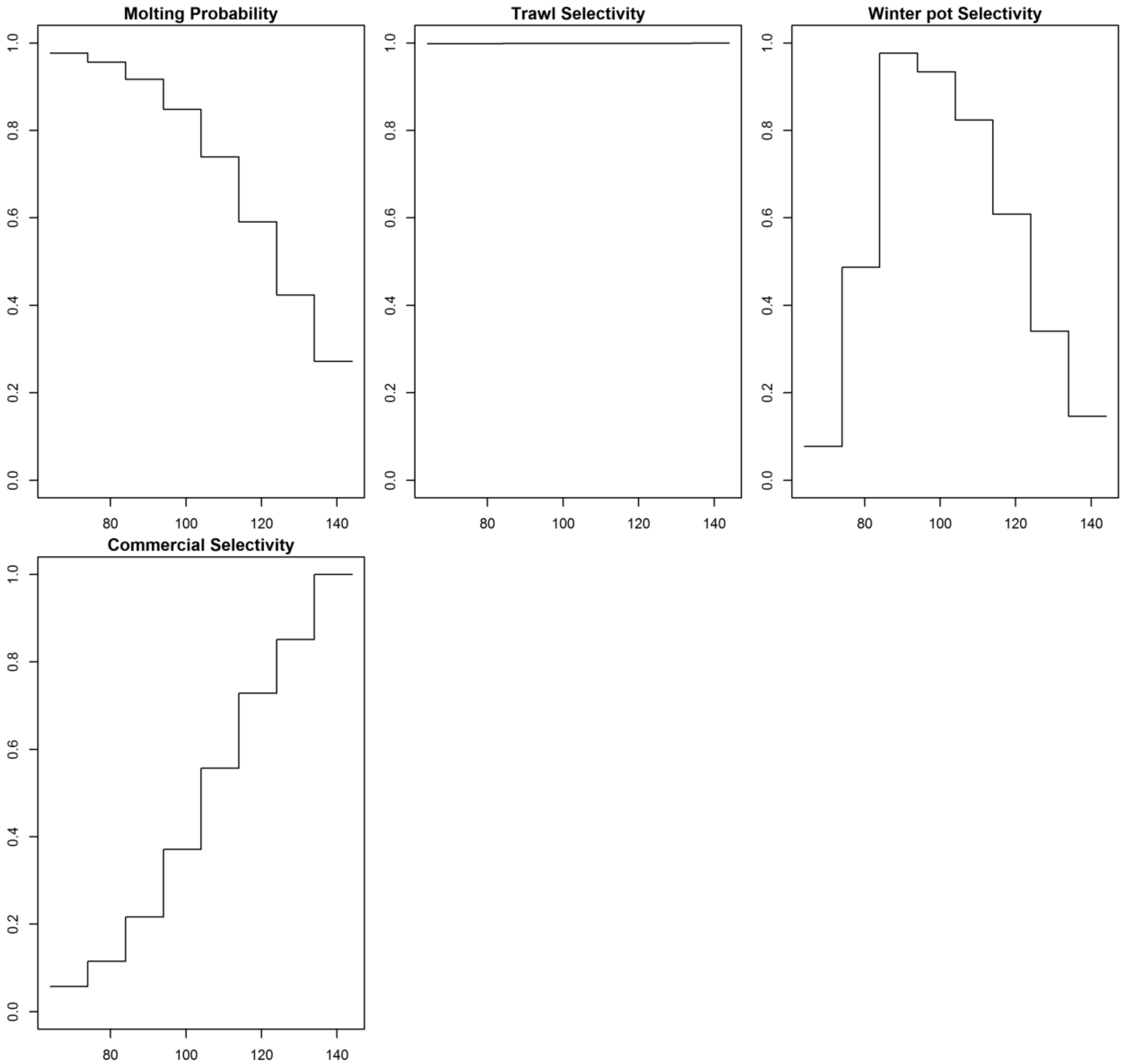


Figure 5. Model estimated annual molting probability, trawl survey selectivity, winter pot survey selectivity, and summer commercial fishery selectivity. X-axis is carapace length (mm).

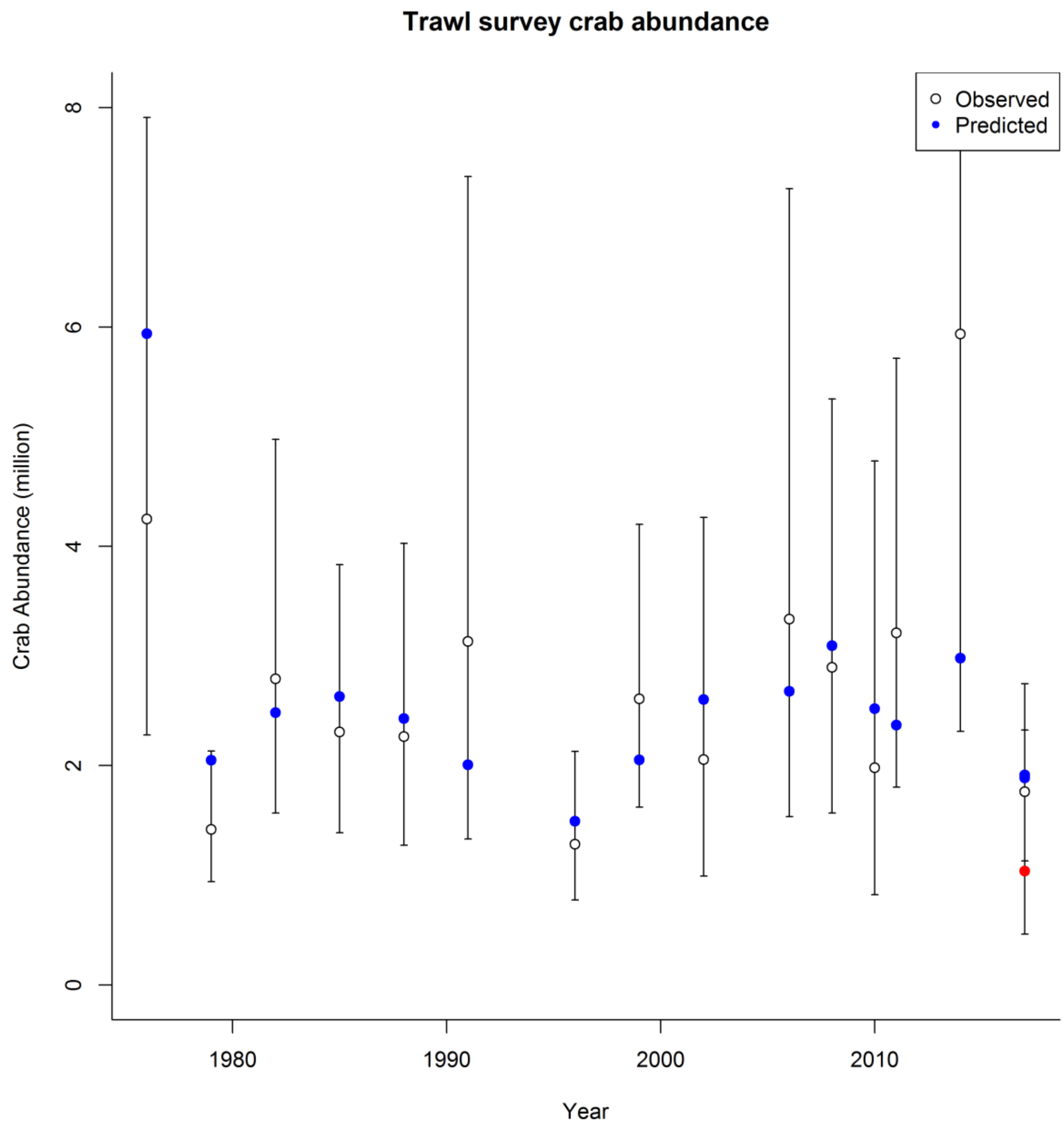


Figure 6. Observed and model estimated trawl survey male abundances with 95% lognormal Confidence Intervals (1976-1991:crab ≥ 74 mm CL, 1996-2017:crab ≥ 64 mm CL.

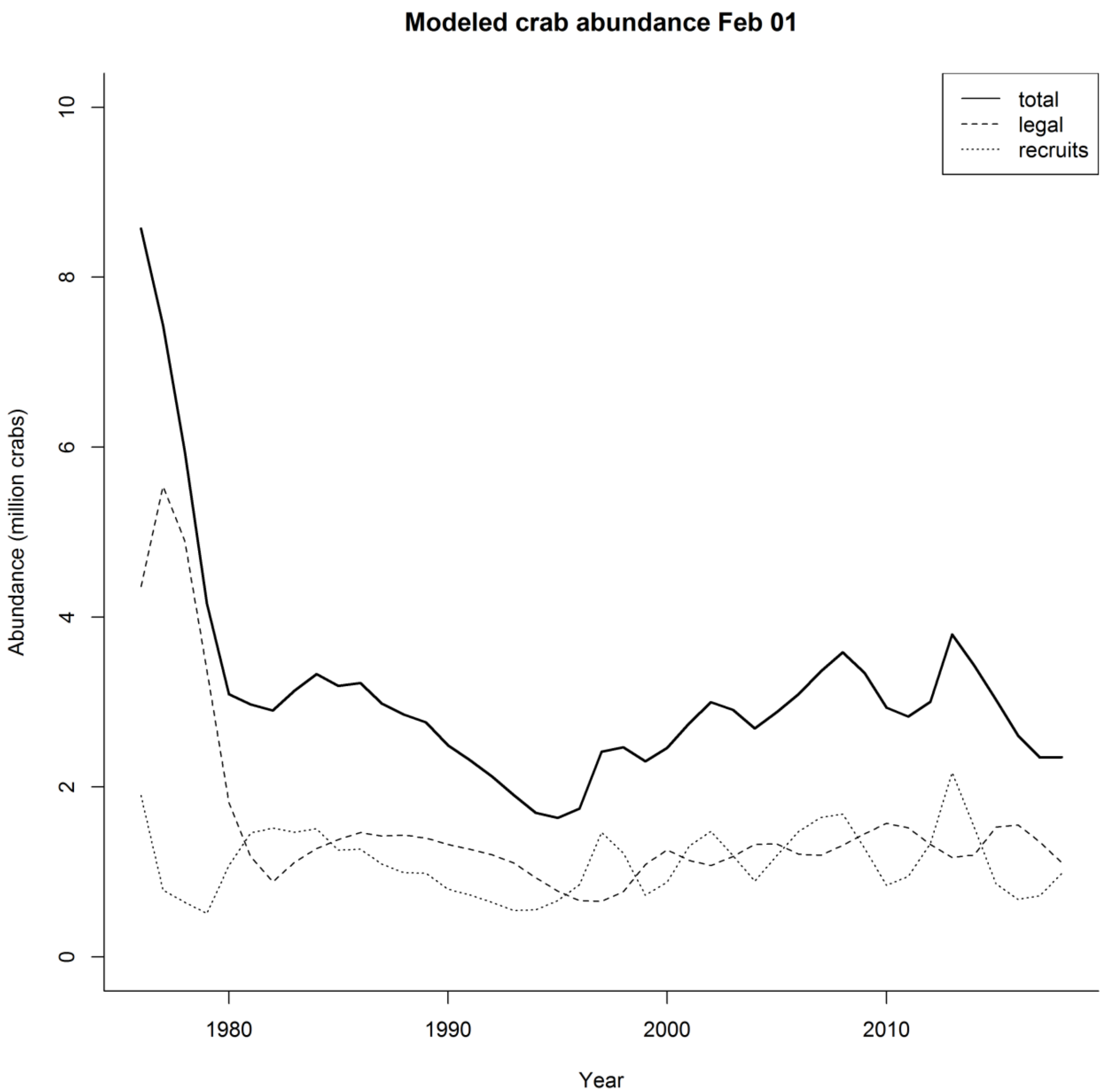


Figure 7. Estimated abundances of legal and recruit males during1976-2018.

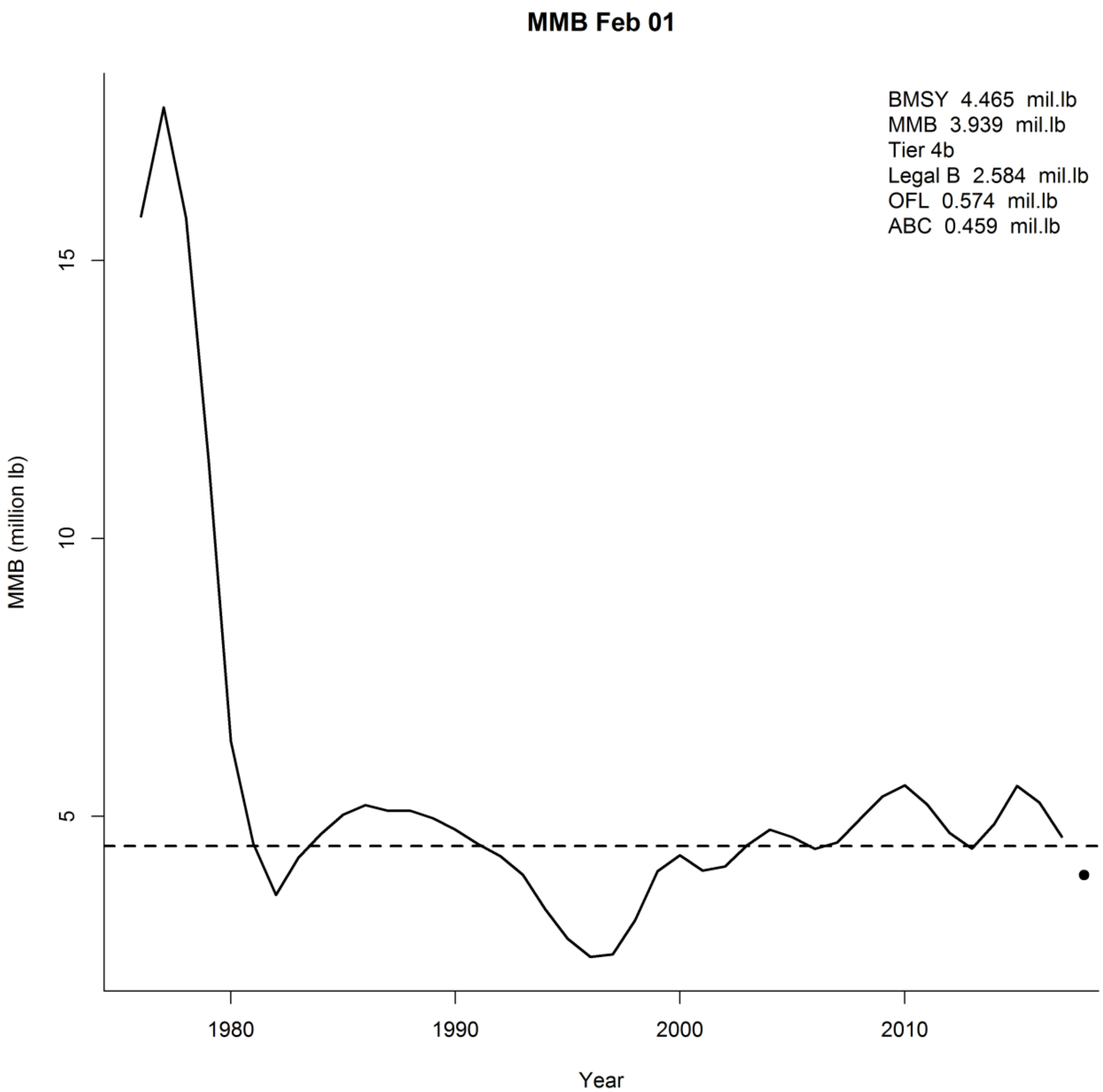


Figure 8. Estimated MMB during 1976-2018. Dash line shows Bmsy (Average MMB of 1980-2018). The black point indicates the projected MMB of 2018.

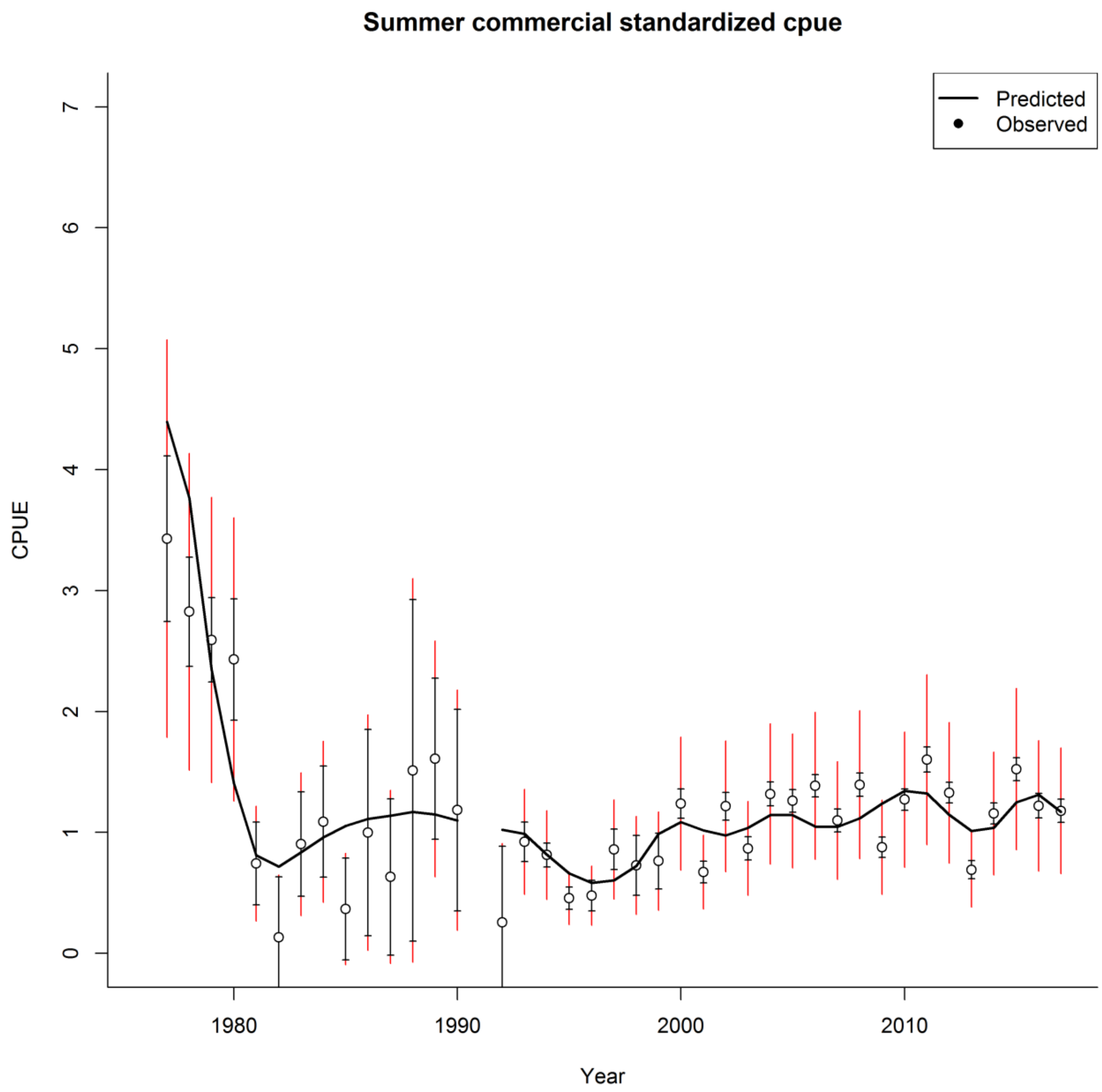


Figure 9. Summer commercial fishery standardized cpue. Vertical black lines are input SD and red lines are input and estimated additional SD.

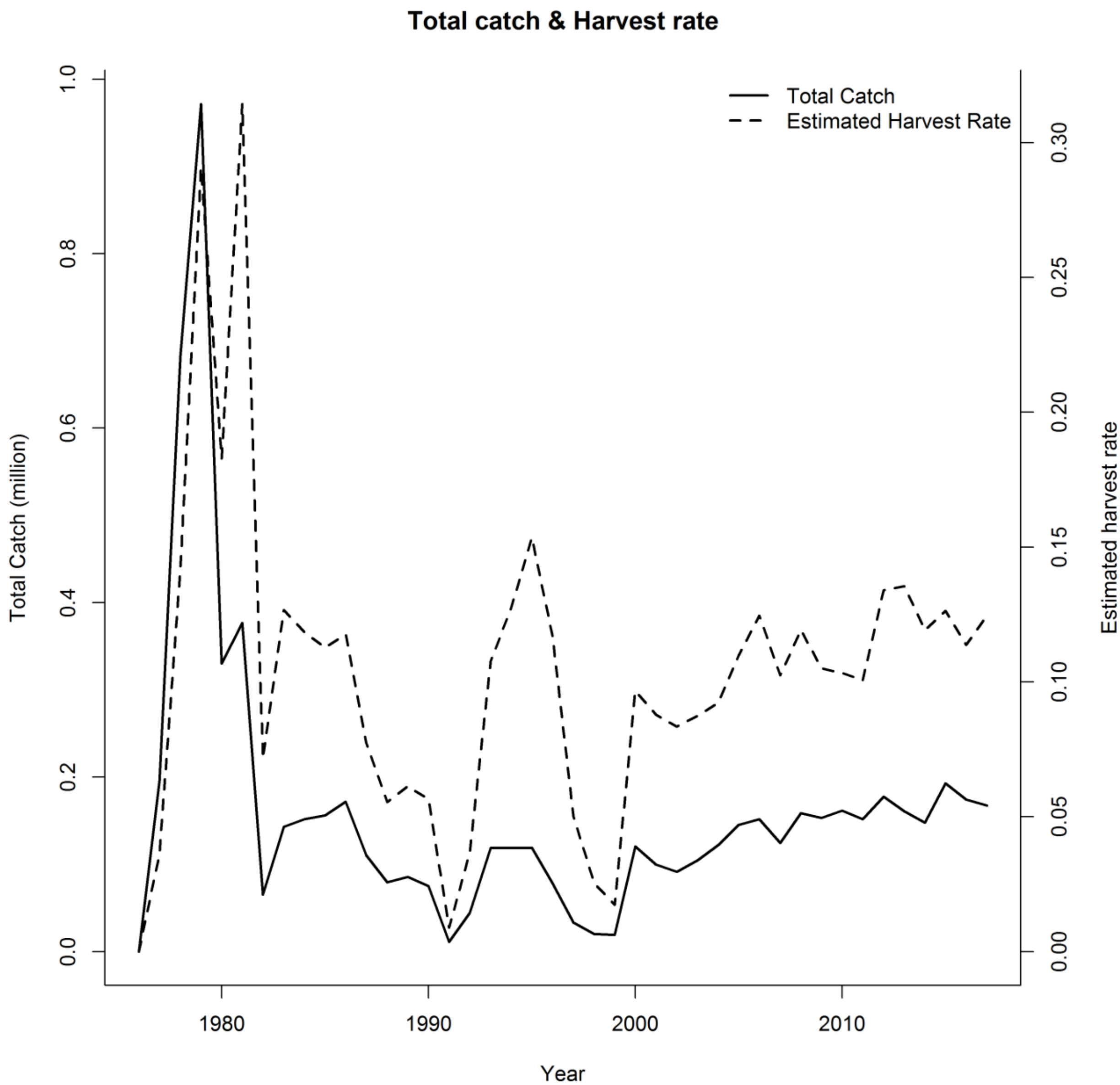


Figure 10. Commercial catch and estimated harvest rates of legal males over time.

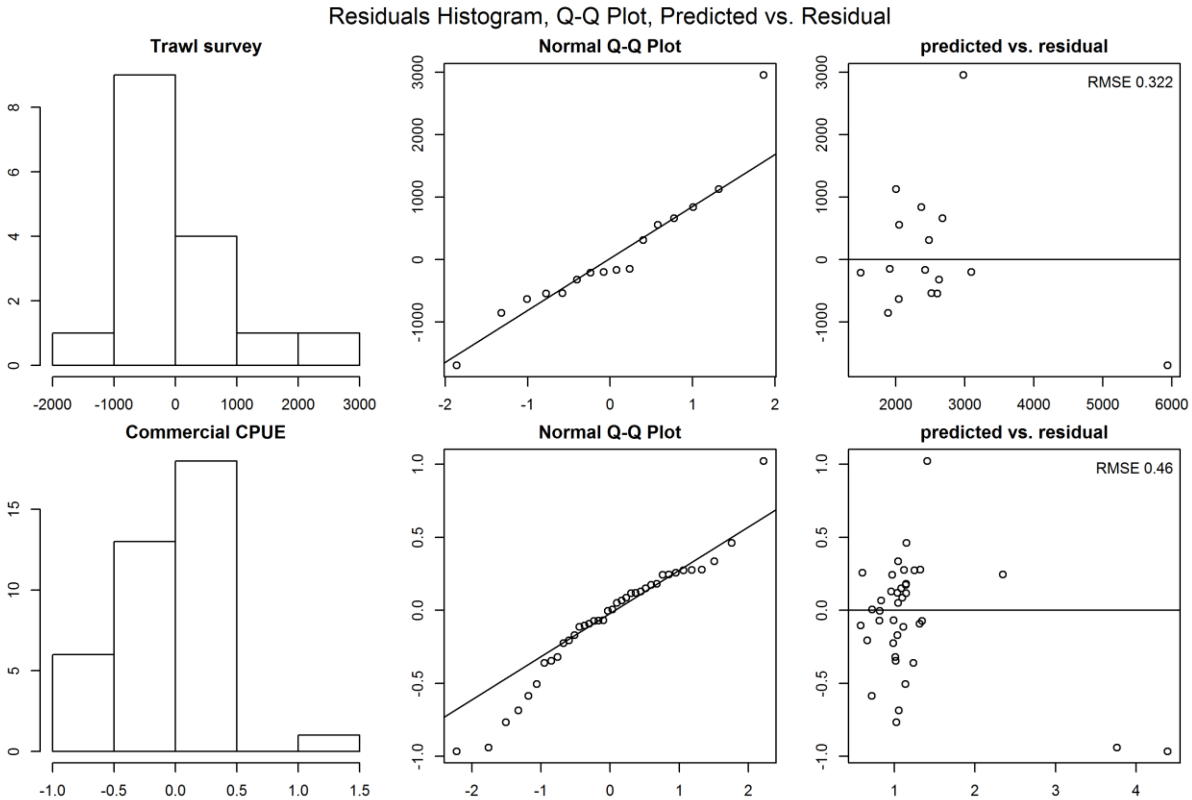
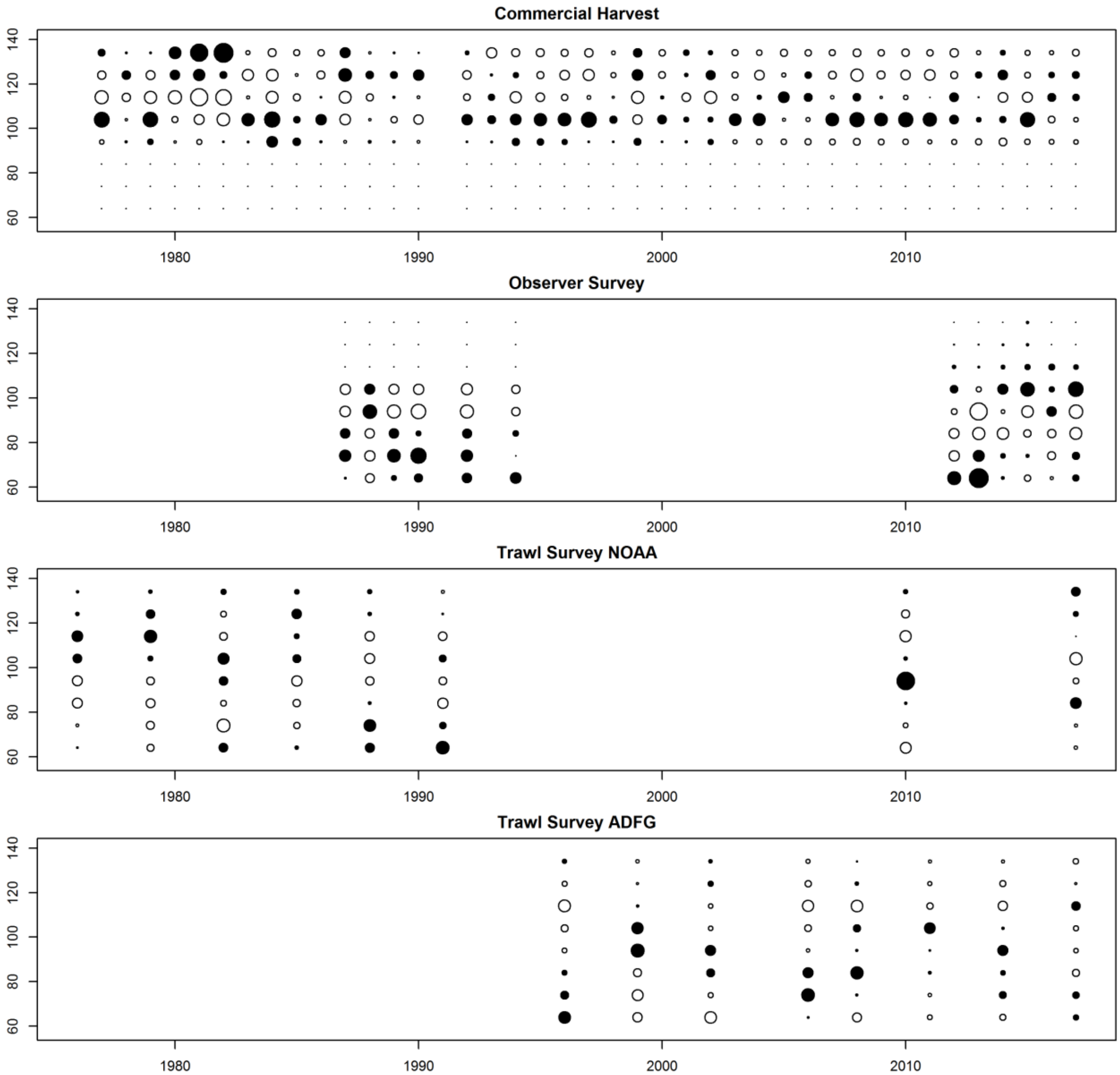


Figure 11. QQ plots of trawl survey abundance and commercial CPUE residuals.


Commercial Harvest
Observer Survey
Trawl Survey NOAA
Trawl Survey ADFG
60
80
100
120
140
1980
1990
2000
2010

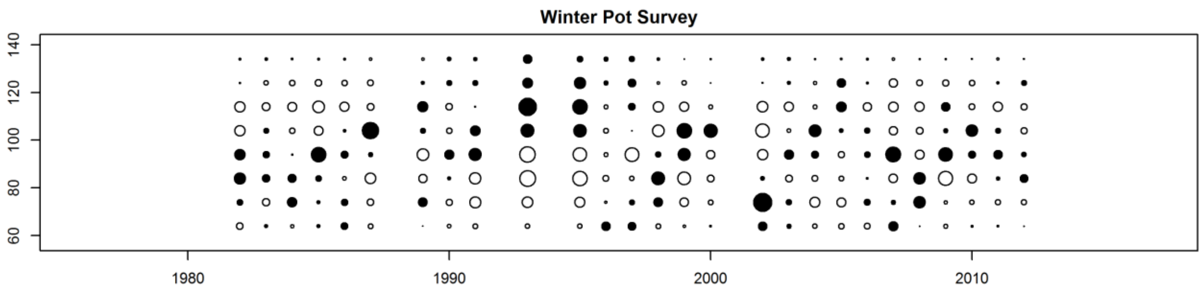


Figure 12. Bubble plot of predicted and observed length proportions (Alternative model 3). Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

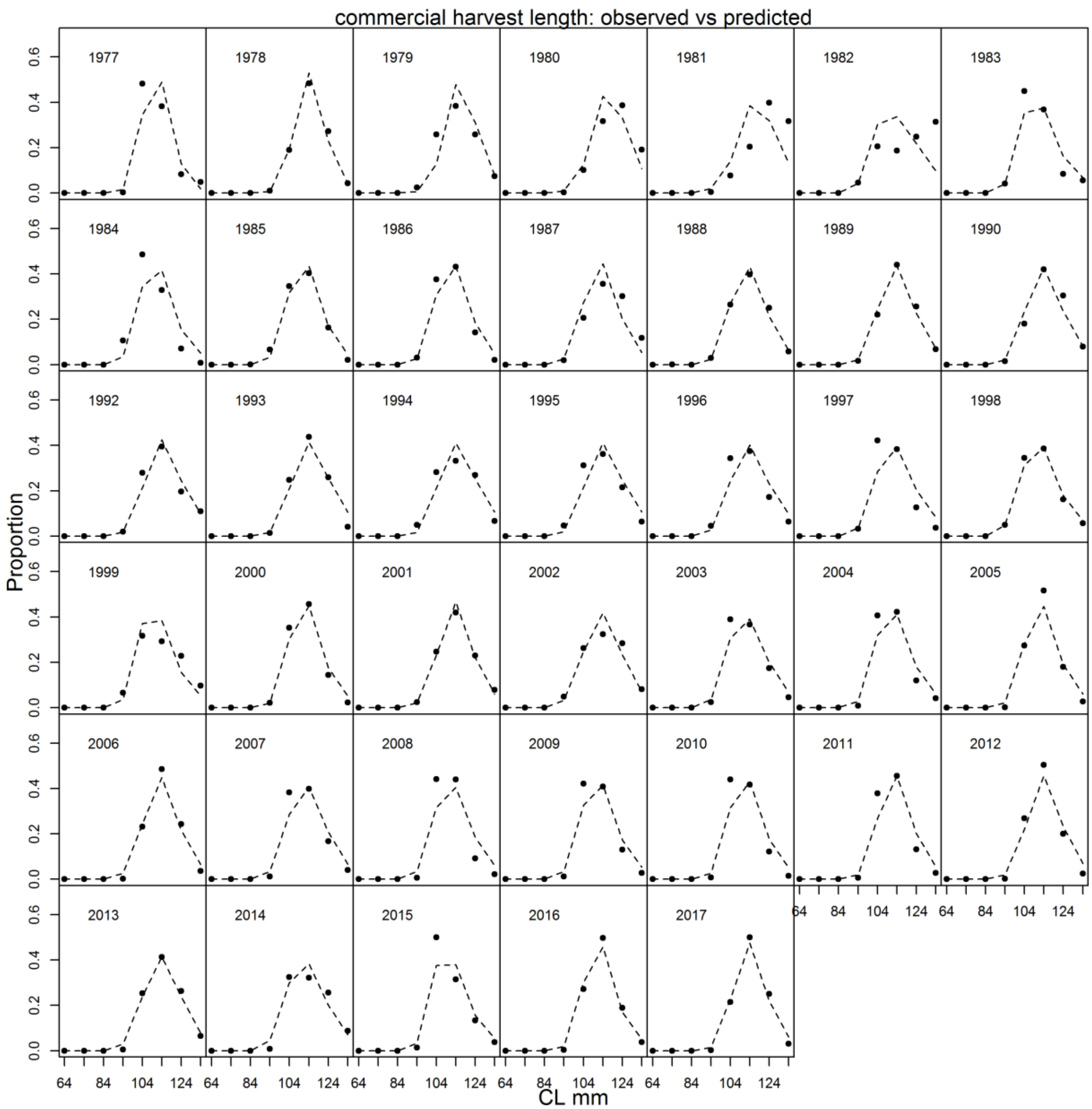


Figure 13. Predicted (dashed line) vs. observed (black dots) length class proportions for the summer commercial catch.

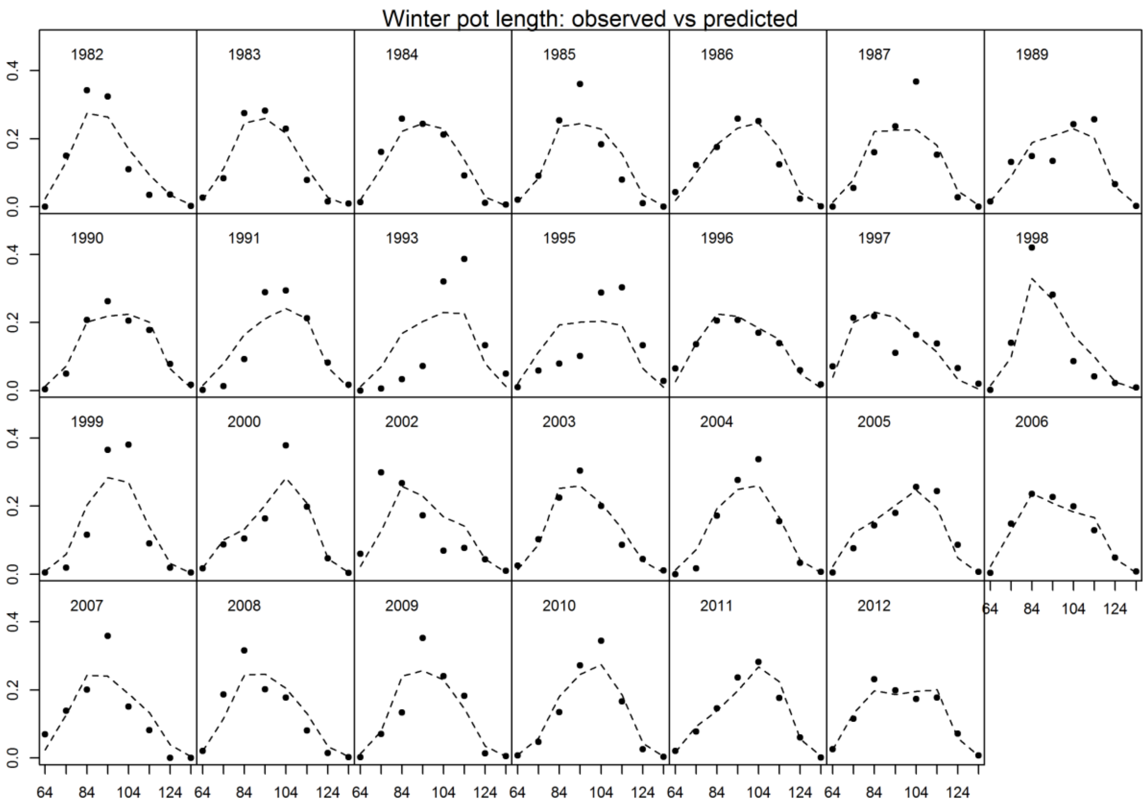


Figure 14. Predicted vs. observed length class proportions for winter pot survey.

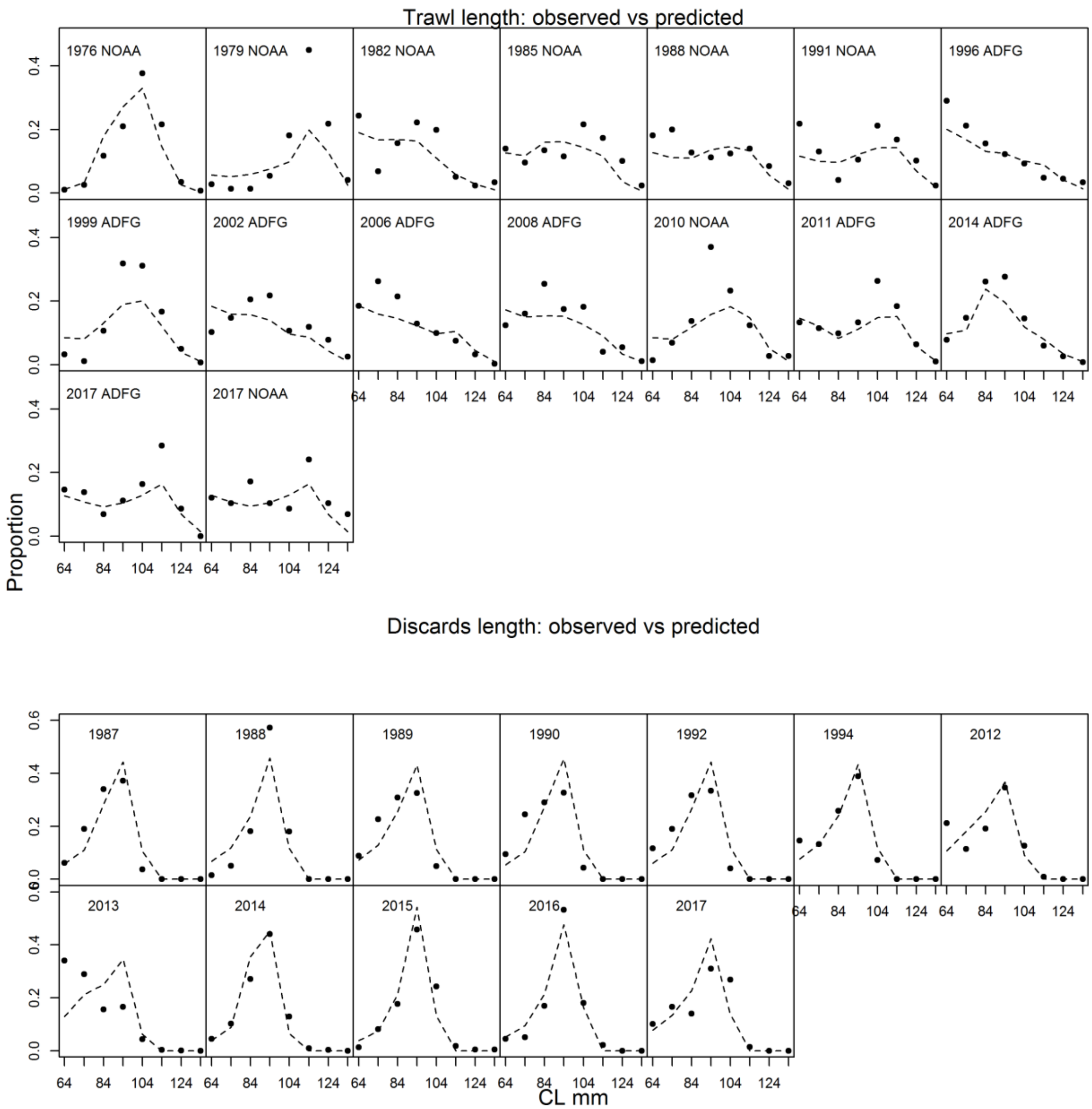


Figure 15. Predicted vs. observed length class proportions for trawl survey and commercial observer data.

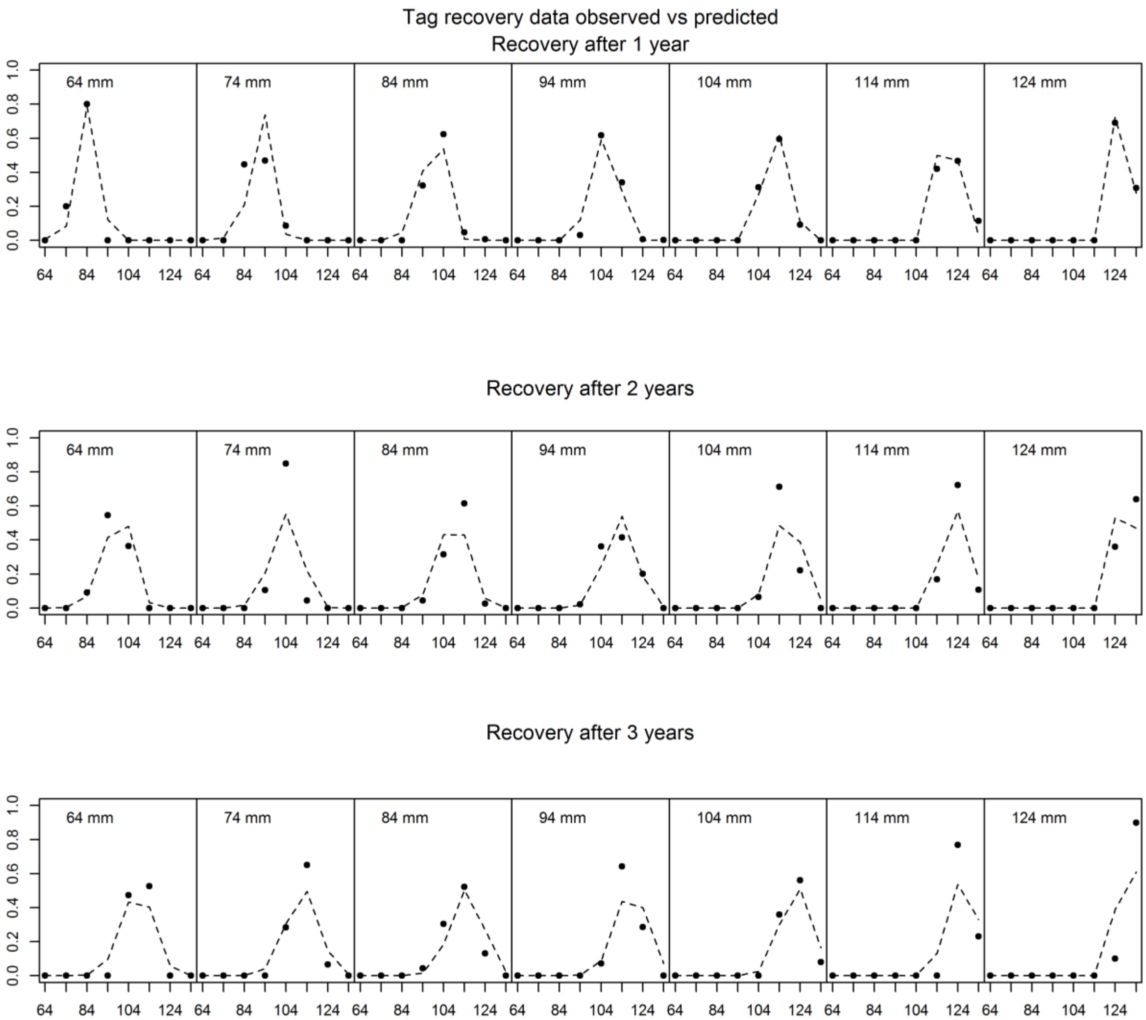


Figure 16. Predicted vs. observed length class proportions for tag recovery data.

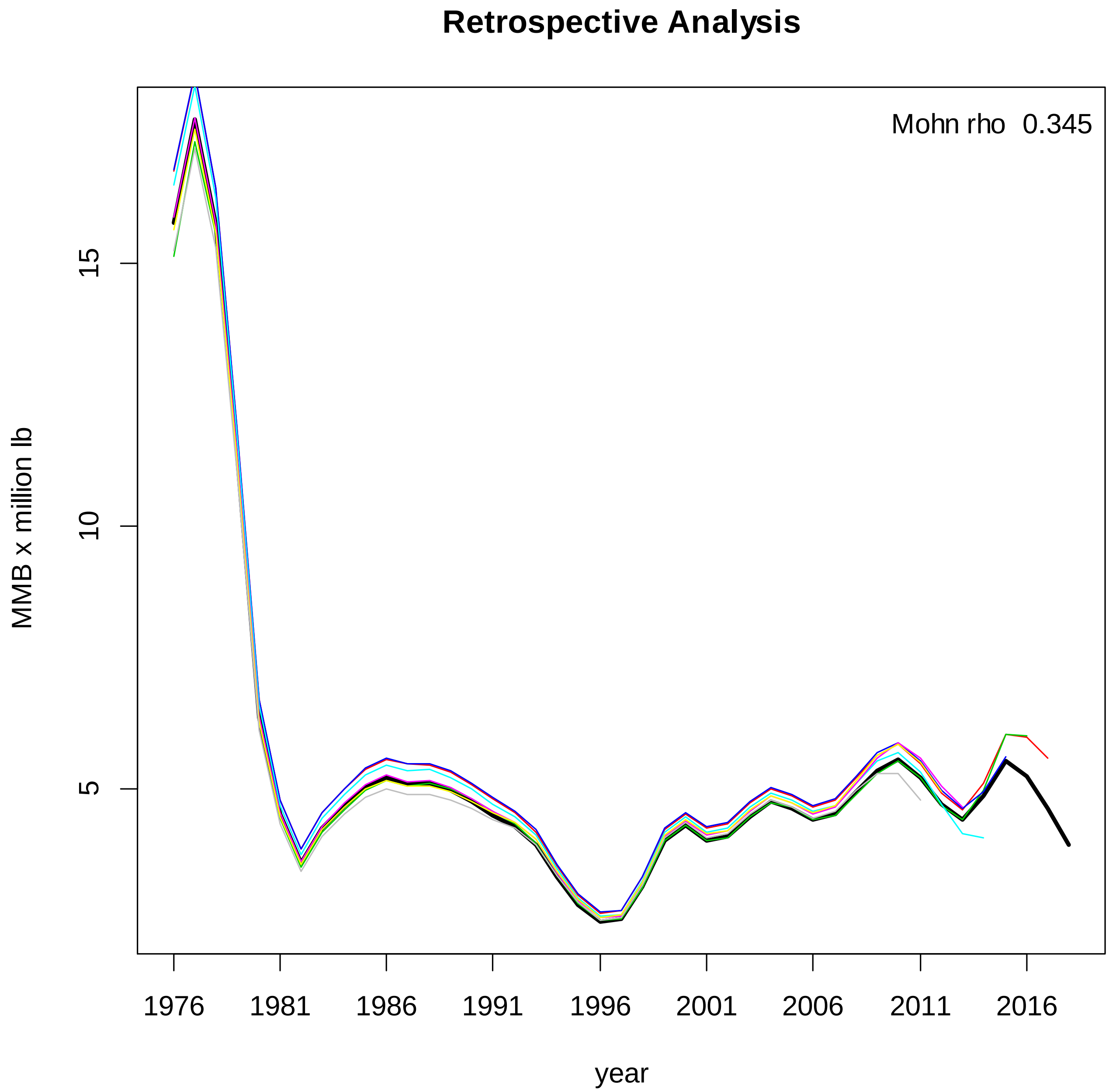


Figure 17. Retrospective analyses. Each line shows a series of retrospective MMB.

Table 1. Historical summer commercial red king crab fishery economic performance, Norton Sound Section, eastern Bering Sea, 1977-2017. Bold type shows data that are used for the assessment model.

	Guideline Harvest	Commercial Harvest (lb) [a, b]												**Mid-day from July**
	Level	Open		**Number**	Total Number (Open Access)			Total Pots		**ST CPUE**		Season Length		
Year	(lb) [b]	Access	CDQ	**Harvest**	Vessels	Permits	Landings	Registered	Pulls	**CPUE**	**SD**	Days	Dates	
1977	[c]	517.787		**195,877**	7	7	13		5,457	**3.43**	**0.34**	60	[c]	**0.049**
1978	3,000.000	2,091.961		**660,829**	8	8	54		10,817	**2.83**	**0.23**	60	6/07-8/15	**0.142**
1979	3,000.000	2,931.672		**970,962**	34	34	76		34,773	**2.59**	**0.17**	16	7/15-7/31	**0.088**
1980	1,000.000	1,186.596		**329,778**	9	9	50		11,199	**2.43**	**0.25**	16	7/15-7/31	**0.066**
1981	2,500.000	1,379.014		**376,313**	36	36	108		33,745	**0.74**	**0.17**	38	7/15-8/22	**0.096**
1982	500.000	228.921		**63,949**	11	11	33		11,230	**0.13**	**0.25**	23	8/09-9/01	**0.151**
1983	300.000	368.032		**132,205**	23	23	26	3,583	11,195	**0.90**	**0.22**	3.8	8/01-8/05	**0.096**
\1984	400.000	387.427		**139,759**	8	8	21	1,245	9,706	**1.09**	**0.23**	13.6	8/01-8/15	**0.110**
1985	450.000	427.011		**146,669**	6	6	72	1,116	13,209	**0.37**	**0.21**	21.7	8/01-8/23	**0.118**
1986	420.000	479.463		**162,438**	3	3		578	4,284	**1.00**	**0.43**	13	8/01-8/25	**0.153**
1987	400.000	327.121		**103,338**	9	9		1,430	10,258	**0.63**	**0.32**	11	8/01-8/12	**0.107**
1988	200.000	236.688		**76,148**	2	2		360	2,350	**1.51**	**0.71**	9.9	8/01-8/11	**0.110**
1989	200.000	246.487		**79,116**	10	10		2,555	5,149	**1.61**	**0.33**	3	8/01-8/04	**0.096**
1990	200.000	192.831		**59,132**	4	4		1,388	3,172	**1.18**	**0.42**	4	8/01-8/05	**0.099**
1991	340.000			**0**	No Summer Fishery									
1992	340.000	74.029		**24,902**	27	27		2,635	5,746	**0.26**	**0.31**	2	8/01-8/03	**0.093**
1993	340.000	335.790		**115,913**	14	20	208	560	7,063	**0.92**	**0.08**	52	7/01-8/28	**0.093**
1994	340.000	327.858		**108,824**	34	52	407	1,360	11,729	**0.81**	**0.05**	31	7/01-7/31	**0.044**
1995	340.000	322.676		**105,967**	48	81	665	1,900	18,782	**0.46**	**0.05**	67	7/01-9/05	**0.093**
1996	340.000	224.231		**74,752**	41	50	264	1,640	10,453	**0.48**	**0.06**	57	7/01-9/03	**0.101**
1997	80.000	92.988		**32,606**	13	15	100	520	2,982	**0.86**	**0.08**	44	7/01-8/13	**0.074**
1998	80.000	29.684	0.00	**10,661**	8	11	50	360	1,639	**0.73**	**0.12**	65	7/01-9/03	**0.110**
1999	80.000	23.553	0.00	**8,734**	10	9	53	360	1,630	**0.76**	**0.12**	66	7/01-9/04	**0.104**
2000	336.000	297.654	14.87	**111,728**	15	22	201	560	6,345	**1.24**	**0.06**	91	7/01- 9/29	**0.126**
2001	303.000	288.199	0	**98,321**	30	37	319	1,200	11,918	**0.67**	**0.05**	97	7/01- 9/09	**0.104**
2002	248.000	244.376	15.226	**86,666**	32	49	201	1,120	6,491	**1.22**	**0.06**	77	6/15-9/03	**0.060**
2003	253.000	253.284	13.923	**93,638**	25	43	236	960	8,494	**0.87**	**0.05**	68	6/15-8/24	**0.058**
2004	326.500	314.472	26.274	**120,289**	26	39	227	1,120	8,066	**1.32**	**0.05**	51	6/15-8/08	**0.033**
2005	370.000	370.744	30.06	**138,926**	31	42	255	1,320	8,867	**1.26**	**0.05**	73	6/15-8/27	**0.058**
2006	454.000	419.191	32.557	**150,358**	28	40	249	1,120	8,867	**1.39**	**0.05**	68	6/15-8/22	**0.052**
2007	315.000	289.264	23.611	**110,344**	38	30	251	1,200	9,118	**1.10**	**0.05**	52	6/15-8/17	**0.036**
2008	412.000	364.235	30.9	**143,337**	23	30	248	920	8,721	**1.39**	**0.05**	73	6/23-9/03	**0.079**
2009	375.000	369.462	28.125	**143,485**	22	27	359	920	11,934	**0.88**	**0.04**	98	6/15-9/20	**0.090**
2010	400.000	387.304	30	**149,822**	23	32	286	1,040	9,698	**1.27**	**0.04**	58	6/28-8/24	**0.074**
2011	358.000	373.990	26.851	**141,626**	24	25	173	1,040	6,808	**1.60**	**0.05**	33	6/28-7/30	**0.038**
2012	465.450	441.080	34.91	**161,113**	40	29	312	1,200	10,041	**1.33**	**0.04**	72	6/29-9/08	**0.093**
2013	495.600	373.278	18.585	**130,603**	37	33	460	1,420	15,058	**0.69**	**0.04**	74	7/3-9/14	**0.110**
2014	382.800	360.860	28.148	**129,657**	52	33	309	1,560	10,127	**1.16**	**0.04**	52	6/25-8/15	**0.052**
2015	394.600	371.520	29.595	**144,255**	42	36	251	1,480	8,356	**1.52**	**0.05**	26	6/29-7/24	**0.033**
2016	517.200	416.576	3,583	**138,997**	36	37	220	1,520	8,009	**1.22**	**0.05**	25	6/27-7/21	**0.025**
2017	496,800	411,736	0	**135,322**	36	36	270	1640	9,440	**1.18**	**0.05**	30	6/26-7/25	**0.027**

[a] Deadloss included in total. [b] Millions of pounds. [c] Information not available.

Table 2. Historical winter commercial and subsistence red king crab fisheries, Norton Sound Section, eastern Bering Sea, 1977-2016. Bold typed data are used for the assessment model.

		Commercial			Subsistence				
					Permits			Total Crab	
Model Year	Year[a]	# of Fishers	# of Crab Harvested	Winter[b]	Issued	Returned	Fished	Caught[c]	Retained[d]
1978	1978	37	**9,625**	1977/78	290	206	149	**NA**	**12,506**
1979	1979	1[f]	**221**[f]	1978/79	48	43	38	**NA**	**224**
1980	1980	1[f]	**22**[f]	1979/80	22	14	9	**NA**	**213**
1981	1981	0	**0**	1980/81	51	39	23	**NA**	**360**
1982	1982	1[f]	**17**[f]	1981/82	101	76	54	**NA**	**1,288**
1983	1983	5	**549**	1982/83	172	106	85	**NA**	**10,432**
1984	1984	8	**856**	1983/84	222	183	143	**15,923**	**11,220**
1985	1985	9	**1,168**	1984/85	203	166	132	**10,757**	**8,377**
1986	1985/86	5	**2,168**	1985/86	136	133	107	**10,751**	**7,052**
1987	1986/87	7	**1,040**	1986/87	138	134	98	**7,406**	**5,772**
1988	1987/88	10	**425**	1987/88	71	58	40	**3,573**	**2,724**
1989	1988/89	5	**403**	1988/89	139	115	94	**7,945**	**6,126**
1990	1989/90	13	**3,626**	1989/90	136	118	107	**16,635**	**12,152**
1991	1990/91	11	**3,800**	1990/91	119	104	79	**9,295**	**7,366**
1992	1991/92	13	**7,478**	1991/92	158	105	105	**15,051**	**11,736**
1993	1992/93	8	**1,788**	1992/93	88	79	37	**1,193**	**1,097**
1994	1993/94	25	**5,753**	1993/94	118	95	71	**4,894**	**4,113**
1995	1994/95	42	**7,538**	1994/95	166	131	97	**7,777**	**5,426**
1996	1995/96	9	**1,778**	1995/96	84	44	35	**2,936**	**1,679**
1997	1996/97	2[f]	**83**[f]	1996/97	38	22	13	**1,617**	**745**
1998	1997/98	5	**984**	1997/98	94	73	64	**20,327**	**8,622**
1999	1998/99	5	**2,714**	1998/99	95	80	71	**10,651**	**7,533**
2000	1999/00	10	**3,045**	1999/00	98	64	52	**9,816**	**5,723**
2001	2000/01	3	**1,098**	2000/01	50	27	12	**366**	**256**
2002	2001/02	11	**2,591**	2001/02	114	61	45	**5,119**	**2,177**
2003	2002/03	13	**6,853**	2002/03	107	70	61	**9,052**	**4,140**
2004	2003/04	2[f]	**522** [f]	2003/04[g]	96	77	41	**1,775**	**1,181**
2005	2004/05	4	**2,091**	2004/05	170	98	58	**6,484**	**3,973**
2006	2005/06	1[f]	**75**[f]	2005/06	98	97	67	**2,083**	**1,239**
2007	2006/07	8	**3,313**	2006/07	129	127	116	**21,444**	**10,690**
2008	2007/08	9	**5,796**	2007/08	139	137	108	**18,621**	**9,485**
2009	2008/09	7	**4,951**	2008/09	105	105	70	**6,971**	**4,752**
2010	2009/10	10	**4,834**	2009/10	125	123	85	**9,004**	**7,044**
2011	2010/11	5	**3,365**	2010/11	148	148	95	**9,183**	**6,640**
2012	2011/12	35	**9,157**	2011/12	204	204	138	**11,341**	**7,311**
2013	2012/13	26	**22,639**	2012/13	149	148	104	**21,524**	**7,622**
2014	2013/14	21	**14,986**	2013/14	103	103	75	**5,421**	**3,252**
2015	2014/15	44	**41,062**	2014/15	155	153	107	**9,840**	**7,651**
2016	2015/16	25	**29,792**	2015/16	139	97	64	**6,468**	**5,340**
2017	2016/17	43	**26,008**	2016/17	163	163	109	**7,185**	**6,039**

a Prior to 1985 the winter commercial fishery occurred from January 1 - April 30. As of March 1985, fishing may occur from November 15 - May 15.
b The winter subsistence fishery occurs during months of two calendar years (as early as December, through May).
c The number of crab actually caught; some may have been returned.
d The number of crab retained is the number of crab caught and kept.
f Confidentiality was waived by the fishers.
h Prior to 2005, permits were only given out of the Nome ADF&G office. Starting with the 2004-5 season, permits were given out in Elim, Golovin, Shaktoolik, and White Mountain.

Table 3. Summary of triennial trawl survey Norton Sound male red king crab abundance estimates (CL ≥ 64mm) . Trawl survey abundance estimate is based on 10×10 nmil^2 grid, except for 2010 (20×20 nmil^2). Bold typed data are used for the assessment model.

				Survey coverage			Abundance ≥74 mm (1982-1991) ≥64 mm (1996- 2007)	
Year	Dates	Survey Agency	Survey method	Total surveyed stations	Stations w/ NSRKC	n mile^2 covered		CV
1976	9/02 – 9/25	NMFS	Trawl	103	62	10260	**4247.5**	**0.31**
1979	7/26 - 8/05	NMFS	Trawl	85	22	8421	**1417.2**	**0.20**
1980	7/04 - 7/14	ADFG	Pots				2092.3	N/A
1981	6/28 - 7/14	ADFG	Pots				2153.4	N/A
1982	7/06 - 7/20	ADFG	Pots				1140.5	N/A
1982	9/05 - 9/11	NMFS	Trawl	58	37	5721	**2791.7**	**0.29**
1985	7/01 - 7/14	ADFG	Pots				2320.4	0.083
1985	9/16 -10/01	NMFS	Trawl	78	49	7688	**2306.3**	**0.25**
1988	8/16 - 8/30	NMFS	Trawl	78	41	7721	**2263.4**	**0.29**
1991	8/22 - 8/30	NMFS	Trawl	52	38	5183	**3132.5**	**0.43**
1996	8/07 - 8/18	ADFG	Trawl	50	30	4938	**1283.0**	**0.25**
1999	7/28 - 8/07	ADFG	Trawl	52	31	5221	**2608.0**	**0.24**
2002	7/27 - 8/06	ADFG	Trawl	57	37	5621	**2056.0**	**0.36**
2006	7/25 - 8/08	ADFG	Trawl	114	45	10008	**3336.0**	**0.39**
2008	7/24 - 8/11	ADFG	Trawl	86	44	7330	**2894.2**	**0.31**
2010[a]	7/27 - 8/09	NMFS	Trawl	35	15	5841	**1980.1**	**0.44**
2011	7/18 - 8/15	ADFG	Trawl	65	34	6447	**3209.3**	**0.29**
2014	7/18 - 7/30	ADFG	Trawl	47	34	4700	**5934.6**	**0.47**
2017	7/28 - 8/08	ADFG	Trawl	60	41	6000	**1762.1**	**0.22**
2017	8/18 – 8/29	NMFS	Trawl	35	18	5841	**1035.8**	**0.40**

Table 4. Summer commercial catch size/shell compositions. Sizes in this and Tables 5-10 and 12 are mm carapace length. Legal size (4.75 inch carapace width is approximately equal to 124 mm carapace length.

		New Shell								Old Shell							
Year	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1977	1549	0	0	0	0.00	0.42	0.34	0.08	0.05	0	0	0	0.00	0.06	0.04	0.01	0.00
1978	389	0	0	0	0.01	0.19	0.47	0.26	0.04	0	0	0	0.00	0.01	0.01	0.01	0.00
1979	1660	0	0	0	0.03	0.23	0.38	0.26	0.07	0	0	0	0.00	0.03	0.00	0.00	0.01
1980	1068	0	0	0	0.00	0.10	0.31	0.37	0.18	0	0	0	0.00	0.00	0.01	0.02	0.01
1981	1784	0	0	0	0.00	0.07	0.15	0.28	0.23	0	0	0	0.00	0.00	0.05	0.12	0.09
1982	1093	0	0	0	0.04	0.19	0.16	0.22	0.29	0	0	0	0.00	0.01	0.02	0.03	0.03
1983	802	0	0	0	0.04	0.41	0.36	0.06	0.03	0	0	0	0.00	0.04	0.01	0.02	0.02
1984	963	0	0	0	0.10	0.42	0.28	0.06	0.01	0	0	0	0.01	0.07	0.05	0.01	0.00
1985	2691	0	0	0.00	0.06	0.31	0.37	0.15	0.02	0	0	0	0.00	0.03	0.03	0.01	0.00
1986	1138	0	0	0	0.03	0.36	0.39	0.12	0.02	0	0	0	0.00	0.02	0.04	0.02	0.00
1987	1985	0	0	0	0.02	0.18	0.29	0.27	0.11	0	0	0	0.00	0.03	0.06	0.03	0.01
1988	1522	0	0.00	0	0.02	0.20	0.30	0.18	0.04	0	0	0	0.01	0.06	0.10	0.07	0.02
1989	2595	0	0	0	0.01	0.16	0.32	0.17	0.05	0	0	0	0.00	0.06	0.12	0.09	0.02
1990	1289	0	0	0	0.01	0.14	0.35	0.26	0.07	0	0	0	0.00	0.04	0.07	0.05	0.01
1991																	
1992	2566	0	0	0	0.02	0.20	0.27	0.14	0.09	0	0	0	0.00	0.08	0.13	0.06	0.02
1993	17804	0	0	0	0.01	0.23	0.39	0.23	0.03	0	0	0	0.00	0.02	0.04	0.03	0.01
1994	404	0	0	0	0.02	0.09	0.08	0.07	0.02	0	0	0	0.02	0.19	0.25	0.20	0.05
1995	1167	0	0	0	0.04	0.26	0.29	0.15	0.05	0	0	0	0.01	0.05	0.07	0.06	0.01
1996	787	0	0	0	0.03	0.22	0.24	0.09	0.05	0	0	0	0.01	0.12	0.14	0.08	0.02
1997	1198	0	0	0	0.03	0.37	0.34	0.10	0.03	0	0	0	0.00	0.06	0.04	0.03	0.01
1998	1055	0	0	0	0.03	0.23	0.24	0.08	0.03	0	0	0	0.02	0.11	0.14	0.08	0.03
1999	562	0	0	0	0.06	0.29	0.24	0.18	0.09	0	0	0	0.00	0.02	0.05	0.04	0.00
2000	17213	0	0	0	0.02	0.30	0.39	0.11	0.02	0	0	0	0.00	0.05	0.07	0.04	0.01
2001	20030	0	0	0	0.02	0.22	0.37	0.21	0.07	0	0	0	0.00	0.02	0.05	0.02	0.01
2002	5219	0	0	0	0.04	0.23	0.28	0.25	0.07	0	0	0	0.00	0.03	0.04	0.03	0.01
2003	5226	0	0	0	0.02	0.37	0.32	0.12	0.03	0	0	0	0.00	0.02	0.05	0.05	0.01
2004	9606	0	0	0	0.01	0.38	0.39	0.11	0.03	0	0	0	0.00	0.03	0.03	0.01	0.01
2005	5360	0	0	0	0.00	0.25	0.47	0.16	0.02	0	0	0	0.00	0.02	0.05	0.02	0.01
2006	6707	0	0	0	0.00	0.18	0.35	0.17	0.02	0	0	0	0.00	0.05	0.14	0.07	0.01
2007	6125	0	0	0	0.01	0.36	0.34	0.14	0.03	0	0	0	0.00	0.02	0.06	0.03	0.01
2008	5766	0	0	0	0.00	0.35	0.35	0.06	0.01	0	0	0	0.00	0.09	0.09	0.04	0.01
2009	6026	0	0	0	0.01	0.34	0.33	0.11	0.02	0	0	0	0.00	0.08	0.08	0.02	0.01
2010	5902	0	0	0	0.01	0.39	0.36	0.10	0.01	0	0	0	0.00	0.05	0.05	0.02	0.00
2011	2552	0	0	0	0.00	0.32	0.40	0.12	0.02	0	0	0	0.00	0.06	0.06	0.02	0.00
2012	5056	0	0	0	0.00	0.24	0.46	0.18	0.02	0	0	0	0.00	0.03	0.04	0.02	0.00
2013	6072	0	0	0	0.00	0.24	0.37	0.24	0.06	0	0	0	0.00	0.01	0.04	0.02	0.00
2014	4682	0	0	0	0.01	0.28	0.24	0.18	0.07	0	0	0	0.00	0.04	0.09	0.07	0.02
2015	4173	0	0	0	0.01	0.48	0.28	0.10	0.03	0	0	0	0.00	0.02	0.03	0.03	0.01
2016	1542	0	0	0	0.00	0.25	0.47	0.16	0.03	0	0	0	0.00	0.02	0.02	0.03	0.01
2017	3972	0	0	0	0.00	0.18	0.38	0.20	0.02	0	0	0	0.00	0.04	0.12	0.05	0.01

Table 5. Summer Trawl Survey size/shell compositions.

			New Shell								Old Shell							
Year	Survey	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1976	NOAA	1326	0.01	0.02	0.10	0.19	0.34	0.18	0.02	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.01	0.01
1979	NOAA	220	0.01	0.01	0.00	0.02	0.05	0.05	0.03	0.01	0.01	0.00	0.01	0.04	0.14	0.40	0.19	0.03
1982	NOAA	327	0.22	0.07	0.16	0.23	0.17	0.03	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.02	0.03
1985	NOAA	350	0.11	0.11	0.19	0.17	0.16	0.06	0.01	0.00	0.00	0.00	0.00	0.02	0.05	0.08	0.05	0.01
1988	NOAA	366	0.16	0.19	0.12	0.13	0.11	0.06	0.03	0.00	0.00	0.00	0.01	0.01	0.03	0.07	0.05	0.03
1991	NOAA	340	0.18	0.08	0.02	0.03	0.06	0.03	0.01	0.01	0.03	0.06	0.02	0.08	0.16	0.14	0.09	0.02
1996	ADFG	269	0.29	0.21	0.13	0.09	0.05	0.00	0.00	0.01	0.00	0.00	0.03	0.03	0.04	0.04	0.04	0.03
1999	ADFG	283	0.03	0.01	0.10	0.29	0.26	0.13	0.03	0.01	0.00	0.00	0.00	0.03	0.05	0.04	0.02	0.00
2002	ADFG	244	0.09	0.12	0.14	0.11	0.02	0.03	0.02	0.01	0.01	0.03	0.07	0.10	0.09	0.09	0.05	0.02
2006	ADFG	373	0.18	0.26	0.21	0.11	0.06	0.04	0.02	0.00	0.00	0.00	0.00	0.02	0.04	0.04	0.01	0.00
2008	ADFG	275	0.12	0.15	0.21	0.11	0.10	0.03	0.02	0.01	0.00	0.01	0.04	0.06	0.08	0.01	0.04	0.00
2010	NOAA	69	0.01	0.04	0.06	0.17	0.06	0.03	0.00	0.00	0.00	0.03	0.09	0.20	0.19	0.07	0.03	0.01
2011	ADFG	315	0.13	0.11	0.09	0.11	0.18	0.14	0.03	0.01	0.00	0.00	0.01	0.02	0.09	0.04	0.03	0.00
2014	ADFG	387	0.08	0.15	0.24	0.18	0.09	0.02	0.01	0.01	0.00	0.00	0.03	0.10	0.05	0.04	0.01	0.00
2017	ADFG	116	0.14	0.12	0.05	0.09	0.10	0.04	0.00	0.00	0.01	0.02	0.02	0.02	0.07	0.18	0.04	0.00
2017	NOAA	58	0.09	0.10	0.14	0.05	0.05	0.05	0.05	0.03	0.03	0.00	0.03	0.05	0.03	0.19	0.05	0.03

Table 6. Winter pot survey size/shell compositions.

			New Shell								Old Shell							
Year	CPUE	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1981/82	NA	719	0.00	0.10	0.23	0.21	0.07	0.02	0.02	0.00	0.00	0.05	0.11	0.11	0.04	0.02	0.02	0.00
1982/83	24.2	2583	0.03	0.08	0.28	0.28	0.21	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.01
1983/84	24.0	1677	0.01	0.16	0.26	0.23	0.15	0.06	0.01	0.00	0.00	0.00	0.00	0.02	0.06	0.03	0.01	0.01
1984/85	24.5	789	0.02	0.09	0.25	0.35	0.16	0.06	0.01	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.00	0.00
1985/86	19.2	594	0.04	0.12	0.17	0.24	0.19	0.08	0.01	0.00	0.00	0.00	0.00	0.01	0.06	0.04	0.01	0.00
1986/87	5.8	144	0.00	0.06	0.15	0.19	0.07	0.04	0.00	0.00	0.00	0.00	0.01	0.04	0.30	0.11	0.03	0.00
1987/88																		
1988/89	13.0	500	0.02	0.13	0.15	0.13	0.19	0.17	0.03	0.00	0.00	0.00	0.00	0.00	0.05	0.08	0.03	0.00
1989/90	21.0	2076	0.00	0.05	0.21	0.26	0.18	0.12	0.06	0.01	0.00	0.00	0.00	0.00	0.03	0.06	0.02	0.00
1990/91	22.9	1283	0.00	0.01	0.09	0.29	0.27	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.12	0.07	0.02
1992/93	5.5	181	0.00	0.01	0.03	0.06	0.13	0.12	0.03	0.00	0.00	0.00	0.00	0.02	0.19	0.27	0.10	0.05
1993/94																		
1994/95	6.2	858	0.01	0.06	0.08	0.10	0.26	0.23	0.07	0.01	0.00	0.00	0.00	0.00	0.03	0.07	0.06	0.02
1995/96	9.9	1580	0.06	0.14	0.20	0.19	0.11	0.07	0.03	0.00	0.00	0.00	0.00	0.01	0.06	0.07	0.03	0.01
1996/97	2.9	398	0.07	0.21	0.22	0.11	0.15	0.11	0.05	0.01	0.00	0.00	0.00	0.00	0.02	0.03	0.01	0.01
1997/98	10.9	881	0.00	0.14	0.41	0.27	0.05	0.02	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.02	0.01
1998/99	10.7	1307	0.00	0.02	0.12	0.36	0.36	0.08	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.01	0.00
1999/00	6.2	575	0.02	0.09	0.10	0.16	0.33	0.18	0.03	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.01	0.00
2000/01	3.1	44																
2001/02	13.0	828	0.05	0.29	0.26	0.17	0.06	0.06	0.04	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00
2002/03	9.6	824	0.02	0.10	0.22	0.28	0.18	0.06	0.02	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.02	0.01
2003/04	3.7	296	0.00	0.02	0.16	0.26	0.32	0.14	0.01	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.02	0.01
2004/05	4.4	405	0.00	0.07	0.14	0.18	0.22	0.19	0.07	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.01	0.00
2005/06	6.0	512	0.00	0.14	0.23	0.21	0.16	0.05	0.02	0.00	0.00	0.01	0.01	0.02	0.04	0.07	0.03	0.01
2006/07	7.3	159	0.07	0.14	0.19	0.35	0.13	0.04	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.00	0.00
2007/08	25.0	3552	0.01	0.14	0.25	0.17	0.14	0.07	0.01	0.00	0.01	0.04	0.07	0.03	0.03	0.01	0.01	0.00
2008/09	21.9	525	0.00	0.07	0.13	0.35	0.20	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.00	0.00
2009/10	25.3	578	0.01	0.05	0.13	0.21	0.24	0.11	0.02	0.00	0.00	0.00	0.01	0.06	0.10	0.05	0.01	0.00
2010/11	22.1	596	0.02	0.08	0.13	0.20	0.17	0.13	0.05	0.00	0.00	0.00	0.01	0.03	0.11	0.05	0.01	0.00
2011/12	29.4	675	0.03	0.11	0.23	0.19	0.12	0.13	0.04	0.00	0.00	0.00	0.00	0.01	0.05	0.05	0.03	0.00

Table 7. Summer commercial1987-1994, 2012-2017 observer discards size/shell compositions.

		New Shell								Old Shell							
Year	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1987	1146	0.06	0.19	0.32	0.33	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.00	0.00	0.00	0.00
1988	722	0.01	0.04	0.15	0.48	0.14	0.00	0.00	0.00	0.00	0.01	0.03	0.10	0.04	0.00	0.00	0.00
1989	1000	0.07	0.19	0.24	0.22	0.03	0.00	0.00	0.00	0.02	0.03	0.07	0.11	0.03	0.00	0.00	0.00
1990	507	0.08	0.23	0.27	0.27	0.04	0.00	0.00	0.00	0.02	0.02	0.02	0.05	0.01	0.00	0.00	0.00
1992	580	0.11	0.17	0.30	0.29	0.03	0.00	0.00	0.00	0.01	0.02	0.02	0.04	0.01	0.00	0.00	0.00
1994	850	0.07	0.06	0.11	0.15	0.02	0.00	0.00	0.00	0.07	0.07	0.15	0.24	0.05	0.00	0.00	0.00
2012	939	0.21	0.11	0.19	0.32	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00
2013	2617	0.34	0.29	0.16	0.16	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	1755	0.05	0.10	0.26	0.41	0.12	0.01	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.00	0.00	0.00
2015	824	0.01	0.08	0.18	0.44	0.23	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00
2016	426	0.04	0.05	0.17	0.50	0.17	0.02	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.00
2017	544	0.10	0.16	0.13	0.31	0.26	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00

Table 8. The number of tagged data released and recovered after 1 year (Y1) – 3 year (Y3) during 1980-1992 and 1993-2017 periods.

Release Length Class	Recap Length Class	1980-1992			1993-2017		
		Y1	Y2	Y3	Y1	Y2	Y3
64 – 73	64 – 73						
64 – 73	74 - 83	1					
64 – 73	84 - 93	1	1		3		
64 – 73	94 - 103		1			5	
64 – 73	104 – 113		1			3	6
64 – 73	114 – 123						7
64 – 73	124 – 133						
64 – 73	134+						
74 - 83	74 - 83						
74 - 83	84 - 93	3			18		
74 - 83	94 - 103	7			15	11	
74 - 83	104 – 113		13		4	79	14
74 - 83	114 – 123		1	2		4	22
74 - 83	124 – 133						2
74 - 83	134+						
84 - 93	84 - 93						
84 - 93	94 - 103	15	1		34	4	1
84 - 93	104 – 113	19	5	1	72	21	11
84 - 93	114 – 123		5	2	7	53	5
84 - 93	124 – 133				1	2	2
84 - 93	134+						
94 - 103	94 - 103	4	1		6	1	
94 - 103	104 – 113	53	5	1	143	20	
94 - 103	114 – 123	31	5	7	77	8	9
94 - 103	124 – 133	2	2	2		11	6
94 - 103	134+				1		
104 – 113	104 – 113	18			57	2	
104 – 113	114 – 123	38	15	3	105	27	3
104 – 113	124 – 133	7	8	4	15	3	8
104 – 113	134+						1
114 – 123	114 – 123	17	2		71	5	
114 – 123	124 – 133	27	10	2	71	31	8
114 – 123	134+	5	1		19	4	3
124 – 133	124 – 133	15			41	6	
124 – 133	134+	10	4	2	15	8	6
134+	134+	15	6	1	11		

Table 9. Summary of initial input parameter values and bounds for a length-based population model of Norton Sound red king crab. Parameters with "log_" indicate log scaled parameters.

Parameter	Parameter description	Equation Number in Appendix A	Lower	Upper
log_$q_{1,2}$	Commercial fishery catchability (1977-92, 1993-2017)	(22)	-20.5	20
log_N_{76}	Initial abundance	(1)	2.0	15.0
R_0	Mean Recruit	(13)	2.0	12.0
log_σ_R^2	Recruit standard deviation	(13)	-40.0	40.0
a_{1-7}	Intimal length proportion	(2)	0	10.0
r_1	Proportion of length class 1 for recruit	(14)	0	10.0
log_α	Inverse logistic molting parameter	(15)	-5.0	-1.0
log_β	Inverse logistic molting parameter	(15)	1.0	5.5
log_ϕ_{st1}	Logistic trawl selectivity parameter	(16)	-5.0	1.0
log_ϕ_{w1}	Inverse logistic winter pot selectivity parameter	(18)	-5.0	1.0
log_ϕ_{w2}	Inverse logistic winter pot selectivity parameter	(18)	0.0	6.0
$Sw_{1,2}$	Winter pot selectivity of length class 1,2	(18)	0.1	1.0
log_ϕ_1	Logistic commercial catch selectivity parameter	(17)	-5.0	1.0
log_ϕ_2	Logistic commercial catch selectivity parameter	(17)	0.0	6.0
w^2_t	Additional variance for standard CPUE	(31)	0.0	6.0
ms	Natural mortality multipliers		0.5	5.0
q	Survey q for NMFS trawl 1976-91	(31)	0.1	1.0
σ	Growth transition sigma	(19)	0.0	30.0
β_1	Growth transition mean	(19)	0.0	20.0
β_2	Growth transition increment	(19)	0.0	20.0

Table 10. Summary of parameter estimates and standard deviations of Norton Sound red king crab. (Model 3)

name	Estimate	std.dev
log_q_1	-6.575	0.222
log_q_2	-6.467	0.185
log_N_{76}	9.056	0.125
R_0	6.415	0.087
log_R_{76}	-0.179	0.408
log_R_{77}	-0.629	0.365
log_R_{78}	-0.754	0.355
log_R_{79}	0.371	0.320
log_R_{80}	0.423	0.303
log_R_{81}	0.412	0.270
log_R_{82}	0.352	0.328
log_R_{83}	0.434	0.292
log_R_{84}	0.067	0.295
log_R_{85}	0.298	0.284
log_R_{86}	-0.068	0.293
log_R_{87}	-0.018	0.248
log_R_{88}	-0.023	0.261
log_R_{89}	-0.397	0.288
log_R_{90}	-0.302	0.255
log_R_{91}	-0.554	0.290
log_R_{92}	-0.679	0.306
log_R_{93}	-0.560	0.295
log_R_{94}	-0.333	0.269
log_R_{95}	-0.060	0.231
log_R_{96}	0.594	0.219
log_R_{97}	-0.106	0.318
log_R_{98}	-0.610	0.327
log_R_{99}	0.052	0.321
log_R_{00}	0.401	0.275
log_R_{01}	0.401	0.258
log_R_{02}	-0.009	0.331
log_R_{03}	-0.248	0.345
log_R_{04}	0.354	0.252
log_R_{05}	0.437	0.236
log_R_{06}	0.530	0.253

name	Estimate	std.dev
log_R_{07}	0.512	0.248
log_R_{08}	0.016	0.311
log_R_{09}	-0.395	0.304
log_R_{10}	0.080	0.255
log_R_{11}	0.416	0.278
log_R_{12}	0.959	0.203
log_R_{13}	-0.100	0.307
log_R_{14}	-0.353	0.325
log_R_{15}	-0.460	0.301
log_R_{16}	-0.271	0.270
a_1	1.161	4.625
a_2	2.152	4.263
a_3	3.850	4.051
a_4	4.269	4.033
a_5	4.463	4.025
a_6	3.646	4.054
a_7	2.177	4.318
r1	10.000	0.822
r2	9.701	0.848
log_a	-2.695	0.094
log_b	4.820	0.016
log_ϕ_{st1}	-5.000	0.174
log_ϕ_{wa}	-2.206	0.371
log_ϕ_{wb}	4.808	0.032
Sw1	0.078	0.038
Sw2	0.487	0.123
log_ϕ_1	-2.582	0.147
log_ϕ_2	4.659	0.046
w^2_t	0.046	0.014
q	0.783	0.135
σ	4.021	0.220
β_1	11.280	0.755
β_2	7.794	0.183
ms78	3.304	0.299

Table 11. Estimated selectivity, mortality, molting probabilities, and proportions of legal crab by length class (mm CL) for Norton Sound male red king crab.

				Selectivity			
Length Class	Legal Proportion	Mean weight (lb)	Natural mortality (*M*)	Trawl	Winter Pot	Summer Fishery	Molting Probability
64 - 73	0.00	0.44	0.18	1.00	0.07	0.06	0.98
74 - 83	0.00	0.87	0.18	1.00	0.49	0.11	0.96
84 - 93	0.00	1.31	0.18	1.00	0.98	0.22	0.92
94 - 103	0.14	1.80	0.18	1.00	0.93	0.37	0.85
104 - 113	0.88	2.37	0.18	1.00	0.83	0.56	0.74
114 - 123	1.00	3.04	0.18	1.00	0.61	0.73	0.59
124 - 133	1.00	3.80	0.59	1.00	0.34	0.85	0.43
134+	1.00	4.60	0.59	1.00	0.15	1.00	0.27

Table 12. Estimated molting probability incorporated transition matrix.

Without molting probability

Pre-molt Length Class	Post-molt Length Class 64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
64 – 73	0.00	0.15	0.77	0.07	0.00	0.00	0.00	0.00
74 - 83		0.00	0.32	0.66	0.02	0.00	0.00	0.00
84 - 93			0.01	0.53	0.46	0.01	0.00	0.00
94 - 103				0.03	0.70	0.26	0.00	0.00
104 – 113					0.10	0.78	0.12	0.00
114 – 123						0.22	0.73	0.04
124 – 133							0.42	0.58
134+								1.00

With molting probability

Pre-molt Length Class	Post-molt Length Class 64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
64 - 73	0.02	0.15	0.76	0.07	0.00	0.00	0.00	0.00
74 - 83		0.05	0.31	0.63	0.02	0.00	0.00	0.00
84 - 93			0.09	0.48	0.42	0.00	0.00	0.00
94 - 103				0.18	0.60	0.22	0.00	0.00
104 - 113					0.33	0.59	0.09	0.00
114 - 123						0.54	0.43	0.02
124 - 133							0.75	0.25
134+								1.00

Table 13. Annual abundance estimates (million crab) and mature male biomass (Feb 01) (MMB, million lb) for Norton Sound red king crab estimated by a length-based analysis from 1976 to 2017.

	Abundance			Legal (≥ 104 mm)				MMB	
Year	Recruits	Total (≥ 64 mm)	Mature (≥ 94 mm)	Abundance	S.D	Biomass	S.D	Biomass	S.D.
1976	0.51	8.57	6.67	4.35	0.93	11.42	2.62	15.79	2.95
1977	0.33	7.43	6.65	5.40	0.76	15.34	2.30	17.76	2.37
1978	0.29	5.95	5.30	4.80	0.57	14.76	1.84	15.76	1.87
1979	0.89	4.16	3.65	3.34	0.41	10.84	1.36	11.44	1.39
1980	0.93	3.09	2.02	1.80	0.28	5.95	0.97	6.35	1.00
1981	0.92	2.97	1.51	1.20	0.20	3.93	0.70	4.51	0.76
1982	0.87	2.90	1.38	0.91	0.19	2.71	0.60	3.59	0.72
1983	0.94	3.14	1.67	1.13	0.21	3.25	0.62	4.25	0.75
1984	0.65	3.33	1.82	1.28	0.23	3.67	0.67	4.68	0.81
1985	0.82	3.19	1.93	1.39	0.24	4.01	0.72	5.03	0.86
1986	0.57	3.23	1.96	1.46	0.26	4.27	0.76	5.20	0.89
1987	0.60	2.98	1.89	1.42	0.25	4.23	0.77	5.10	0.88
1988	0.60	2.85	1.86	1.43	0.24	4.29	0.74	5.10	0.85
1989	0.41	2.76	1.78	1.40	0.23	4.25	0.70	4.96	0.79
1990	0.45	2.49	1.69	1.33	0.21	4.06	0.64	4.76	0.72
1991	0.35	2.32	1.59	1.26	0.19	3.89	0.58	4.50	0.64
1992	0.31	2.13	1.48	1.20	0.16	3.75	0.51	4.28	0.55
1993	0.35	1.90	1.36	1.10	0.14	3.47	0.44	3.95	0.48
1994	0.44	1.70	1.15	0.93	0.12	2.92	0.38	3.32	0.41
1995	0.58	1.64	0.98	0.77	0.10	2.42	0.33	2.80	0.36
1996	1.11	1.75	0.89	0.67	0.09	2.05	0.29	2.47	0.33
1997	0.55	2.42	0.95	0.67	0.09	1.99	0.28	2.51	0.34
1998	0.33	2.47	1.24	0.80	0.10	2.30	0.31	3.13	0.39
1999	0.64	2.30	1.58	1.09	0.14	3.10	0.38	4.01	0.48
2000	0.91	2.46	1.58	1.25	0.15	3.66	0.44	4.30	0.50
2001	0.91	2.75	1.44	1.13	0.14	3.44	0.43	4.02	0.48
2002	0.61	3.00	1.52	1.10	0.14	3.31	0.42	4.09	0.50
2003	0.48	2.91	1.71	1.20	0.15	3.52	0.45	4.48	0.55
2004	0.87	2.69	1.80	1.32	0.17	3.86	0.49	4.76	0.58
2005	0.95	2.88	1.69	1.32	0.17	3.92	0.50	4.63	0.57
2006	1.04	3.10	1.62	1.22	0.16	3.67	0.48	4.41	0.55
2007	1.02	3.36	1.72	1.21	0.16	3.59	0.47	4.53	0.56
2008	0.62	3.59	1.90	1.33	0.17	3.87	0.49	4.94	0.59
2009	0.41	3.35	2.06	1.46	0.18	4.22	0.53	5.35	0.63
2010	0.66	2.94	2.09	1.57	0.19	4.57	0.55	5.56	0.63
2011	0.93	2.83	1.88	1.51	0.18	4.50	0.54	5.21	0.60
2012	1.59	3.00	1.66	1.33	0.16	4.06	0.50	4.70	0.55
2013	0.55	3.79	1.62	1.19	0.15	3.61	0.46	4.42	0.53
2014	0.43	3.43	1.90	1.24	0.16	3.63	0.47	4.86	0.57
2015	0.39	3.03	2.17	1.53	0.18	4.34	0.52	5.54	0.62
2016	0.47	2.61	1.93	1.53	0.18	4.49	0.54	5.25	0.61
2017	0.69	2.35	1.63	1.34	0.17	4.09	0.52	4.63	0.57

Table 14. Summary of catch and estimated discards (million lb) for Norton Sound red king crab. Assumed average crab weight is 2.5 lb for the winter commercial catch, 2.0 lb for the subsistence catch, and 1.0 lb for Winter subsistence discards. Summer and winter commercial discards were estimated from the model.

Year	Summer Com	Winter Com	Winter Sub	Discards Summer	Discards Winter Sub	Discards Winter com	Total	Catch/ MMB
1977	0.52	0.000	0.000	0.013	0.000	0.000	0.533	0.030
1978	2.09	0.024	0.025	0.022	0.008	0.001	2.17	0.138
1979	2.93	0.001	0.000	0.027	0.000	0.000	2.958	0.259
1980	1.19	0.000	0.000	0.014	0.000	0.000	1.204	0.190
1981	1.38	0.000	0.001	0.037	0.000	0.000	1.418	0.314
1982	0.23	0.000	0.003	0.012	0.001	0.000	0.246	0.069
1983	0.37	0.001	0.021	0.022	0.006	0.000	0.42	0.099
1984	0.39	0.002	0.022	0.020	0.005	0.000	0.439	0.094
1985	0.43	0.003	0.017	0.020	0.002	0.001	0.473	0.094
1986	0.48	0.005	0.014	0.018	0.004	0.001	0.522	0.100
1987	0.33	0.003	0.012	0.011	0.002	0.000	0.358	0.070
1988	0.24	0.001	0.005	0.007	0.001	0.000	0.254	0.050
1989	0.25	0.001	0.012	0.007	0.002	0.000	0.272	0.055
1990	0.19	0.009	0.024	0.005	0.004	0.001	0.233	0.049
1991	0	0.010	0.015	0.000	0.002	0.001	0.028	0.006
1992	0.07	0.019	0.023	0.002	0.003	0.002	0.119	0.028
1993	0.33	0.004	0.002	0.008	0.000	0.001	0.345	0.087
1994	0.32	0.014	0.008	0.008	0.001	0.002	0.353	0.106
1995	0.32	0.019	0.011	0.010	0.002	0.003	0.365	0.130
1996	0.22	0.004	0.003	0.009	0.001	0.001	0.238	0.096
1997	0.09	0.000	0.001	0.005	0.001	0.000	0.097	0.039
1998	0.03	0.002	0.017	0.002	0.012	0.001	0.064	0.020
1999	0.02	0.007	0.015	0.001	0.003	0.001	0.047	0.012
2000	0.3	0.008	0.011	0.010	0.004	0.001	0.334	0.078
2001	0.28	0.003	0.001	0.010	0.000	0.001	0.295	0.073
2002	0.25	0.006	0.004	0.012	0.003	0.002	0.277	0.068
2003	0.26	0.017	0.008	0.014	0.005	0.004	0.308	0.069
2004	0.34	0.001	0.002	0.014	0.001	0.000	0.358	0.075
2005	0.4	0.005	0.008	0.013	0.003	0.001	0.43	0.093
2006	0.45	0.000	0.002	0.018	0.001	0.000	0.471	0.107
2007	0.31	0.008	0.021	0.016	0.011	0.002	0.368	0.081
2008	0.39	0.014	0.019	0.022	0.009	0.003	0.457	0.093
2009	0.4	0.012	0.010	0.020	0.002	0.002	0.446	0.083
2010	0.42	0.012	0.014	0.016	0.002	0.002	0.466	0.084
2011	0.4	0.008	0.013	0.011	0.003	0.001	0.436	0.084
2012	0.47	0.023	0.015	0.015	0.004	0.004	0.531	0.113
2013	0.35	0.057	0.015	0.019	0.014	0.016	0.471	0.107
2014	0.39	0.037	0.007	0.025	0.002	0.012	0.473	0.097
2015	0.40	0.103	0.019	0.019	0.005	0.015	0.561	0.101
2016	0.42	0.080	0.011	0.011	0.001	0.008	0.531	0.101
2017	0.41	0.078	0.012	0.009	0.001	0.007	0.517	0.112