

**Norton Sound Red King Crab Stock Assessment for the fishing year 2019**

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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 85% of total harvest. The summer commercial fishery started in 1977. Catch peaked in the late 1970s with retained catch of over 2.9 million pounds. Since 1994, Norton Sound Crab fishery operated as super exclusive. For 2018 fishery season, Norton Sound Red King Crab harvest consisted of: 9,189 crab (20,118 lb.) by winter commercial, 4,424 (8,848 lb) by winter subsistence, and 89,613 crab (298,396 lb.) by summer commercial, totaling 103,217 crab (338,574 lb.) below ABC of 0.35 million lb.
3. Stock Biomass. Norton Sound Red King Crab stock has been monitored by triennial survey since 1976 by NOAA (1976-1991) and ADF&G (1996-present), ranged from 1.41 million to 5.9 million crab. In 2018, abundance by trawl survey was 1.11 million crab with CV 0.25.
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
2015	2.41 <sup>A</sup>	5.13	0.39	0.40	0.52	0.72 <sup>A</sup>	0.58
2016	2.26 <sup>B</sup>	5.87	0.52	0.51	0.52	0.71 <sup>B</sup>	0.57
2017	2.31 <sup>C</sup>	5.14	0.50	0.49	0.50	0.67 <sup>C</sup>	0.54
2018	2.41 <sup>D</sup>	4.08	0.30	0.31	0.34	0.43 <sup>D</sup>	0.35
2019	TBD	TBD	TBD	TBD	TBD	TBD	TBD

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Status and catch specifications (1000t)

Year	MSST	Biomass (MMB)	GHL	Retained Commercial Catch	Total Retained Catch	Retained OFL	Retained ABC
2015	1.09 <sup>A</sup>	2.33	0.18	0.18	0.24	0.33 <sup>A</sup>	0.26
2016	1.03 <sup>B</sup>	2.66	0.24	0.23	0.24	0.32 <sup>B</sup>	0.26
2017	1.05 <sup>C</sup>	2.33	0.23	0.22	0.24	0.30 <sup>C</sup>	0.24
2018	1.09 <sup>D</sup>	1.85	0.13	0.14	0.15	0.20 <sup>D</sup>	0.16
2019	TBD	TBD	TBD	TBD	TBD	TBD	TBD

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Notes:

MSST was calculated as  $B_{MSY}/2$

A-Calculated from the assessment reviewed by the Crab Plan Team in May 2015

B-Calculated from the assessment reviewed by the Crab Plan Team in May 2016

C-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2017

D-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2018

E-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2019

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
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	4.82	4.08	0.9	0.15	1980-2018	0.18	0.8	0.35
2019	4b	TBD	TBD	TBD	TBD	1980-2019	0.18	0.8	TBD

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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
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	2.18	1.85	0.9	0.15	1980-2018	0.18	0.8	0.16
2019	4b	TBD	TBD	TBD	TBD	1980-2019	0.18	0.8	TBD

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

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TBD in January

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 2018**

1. Changes to the management of the fishery:

None

2. Changes to the input data

a. Data update:

- i. 1977-2018 standardized commercial catch CPUE and CV. No changes in standardization methodology (NPFMC 2013).
- ii. Winter and Summer fishery harvest, discards, and length composition data
- iii. Tag recovery data
- iv. Trawl survey: abundance, length-shell composition

b. New data:

- i. Winter commercial retained length-shell data

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 9, 2018

- Evaluate methods to improved ADF&G bottom trawl survey biomass estimation, including model based approaches.

Authors' reply:

- Quantitatively evaluate the representativeness of observer sampling.

Authors' reply:

From 2012 to 2017 distribution of samples taken by stat area differed greatly from those of commercial fishery. Further analyses are needed to examine spatial difference in length-shell composition.

- Estimate fishery retention curve. Consider alternative (2-parameter and 1-parameter) curves for both retention and selectivity

Authors' reply:

Retention curve can be estimated by estimating total catch selectivity (fitting to total catch length/shell distribution) and multiples of total catch selectivity with retention curve (fitting to retained catch length/shell distribution). In Norton Sound, total catch data are available only for 7 years from 2012 to 2018. During 1986-1995 samples of retained and discarded crabs were collected independently (600~1000 for each). Total number of retained and discarded catch are unknown during the 1986-1995 surveys. Thus, **only 2012-2018 data were used to estimate total catch selectivity**, and **1987-1994 discards data were removed from the mode**. Inclusion of retained curve also changed observer data. In the base lime model,

Model and Data configuration

Model	Observer data	Available Years	Likelihood Commercial Retained	Likelihood Observer
Baseline	Discards length-shell comp	1986-1995, 2012-2018	TS *PL	TS *(1-PL)
With Retention selectivity	Total catch length-shell comp	2012-2018	TS*RS	TS

TS: Total catch selectivity, PL: observed legal proportion by length class, RS: Retention selectivity

- Provide Tier 3 calculations and evaluate its suitability for Tier 3 status.

Author's reply

We calculated F35% for base model that resulted to 1.86 with B35% of 1.22 million lb. Based on 2019 projected MMB of 3.11 million lb and legal biomass of 2.50 million lb, OFL retained legal biomass by Tier 3 calculation is 1.86 million lb that was 7.75 times higher than Tier 4 OFL of 0.24 million lb.



Station	ADFG	NOAA	ADFG	NOAA	ADFG	NOAA
79	0	0	0	0	0	0
81	0	42.96	0	0	44.29	21.48
121	0	0	0	0	0	0
123	44.28	381.53	44.29	178.05	88.58	50.87
125	132.86	259.80	221.44	129.90	88.58	0
127	0	0	88.58	0		0
129	0	22.94	0	0	88.58	0
131	44.29	0	0	27.16	88.58	81.47
133	0	22.21	132.86	22.21	708.60	111.04
135	0	0	0	0	0	125.47
176	0	48.34	44.29	120.84	0	0
180	44.29	99.67	0	124.58	0	224.24
182	0	0	0	0	0	0
184	0	0	265.73	0	88.58	24.07
186	0	0	0	0	88.58	23.85
Average	17.72	58.50	56.94	40.18	91.74	47.32

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- Consider whether switch of commercial buyers in 2005 may have affected the apparent CPUE and its standardization.

Authors’ reply:

In the standardization of commercial CPUE (Appendix B), variable “Year of commercial fishery” was identified as the most influential factor. The variable, in effect, addresses any deviations associated with particular year of fishing, including changes in regulation.

- Request to include Quantitative Baseline of Annual Community Engagement and Dependency .

Author’s reply:

This will be done by Economic SAFE, but not in this chapter.

### 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° W. longitude, depths less than 30 m, and summer bottom temperatures above 4°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

1 not occurred regularly in the Kotzebue Section. This report deals with the Norton Sound  
2 Section of the Norton Sound red king crab management area.

3 3. Evidence of stock structure: Thus far, no studies have investigated possible stock separation  
4 within the putative Norton Sound red king crab stock.

5 4. Life history characteristics relevant to management: One of the unique life-history traits of  
6 Norton Sound red king crab is that they spend their entire lives in shallow water since Norton  
7 Sound is generally less than 40 m in depth. Distribution and migration patterns of Norton  
8 Sound red king crab have not been well studied. Based on the 1976-2006 trawl surveys, red  
9 king crab in Norton Sound are found in areas with a mean depth range of  $19 \pm 6$  (SD) m and  
10 bottom temperatures of  $7.4 \pm 2.5$  (SD) °C during summer. Norton Sound red king crab are  
11 consistently abundant offshore of Nome.

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

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

### 32 33 Summer Commercial Fishery

34 A large-vessel summer commercial crab fishery started in 1977 in the Norton Sound Section  
35 (Table 1) and continued from 1977 through 1990. No summer commercial fishery occurred  
36 in 1991 because there were no staff to manage the fishery. In March 1993, the Alaska Board  
37 of Fisheries (BOF) limited participation in the fishery to small boats. Then on June 27, 1994,  
38 a super-exclusive designation went into effect for the fishery. This designation stated that a  
39 vessel registered for the Norton Sound crab fishery may not be used to take king crabs in any  
40 other registration areas during that registration year. A vessel moratorium was put into place  
41 before the 1996 season. This was intended to precede a license limitation program. In 1998,  
42 Community Development Quota (CDQ) groups were allocated a portion of the summer  
43 harvest; however, no CDQ harvest occurred until the 2000 season. On January 1, 2000 the

1 North Pacific License Limitation Program (LLP) went into effect for the Norton Sound crab  
2 fishery. The program dictates that a vessel which exceeds 32 feet in length overall must hold  
3 a valid crab license issued under the LLP by the National Marine Fisheries Service. Changes  
4 in regulations and the location of buyers resulted in eastward movement of the harvest  
5 distribution in Norton Sound in the mid-1990s. In Norton Sound, a legal crab is defined as  $\geq$   
6 4-3/4 inch carapace width (CW, Menard et al. 2011), which is approximately equivalent to  $\geq$   
7 104 mm carapace length mm CL. Since 2005, commercial buyers (Norton Sound Economic  
8 Development Corporation) started accepting only legal crab of  $\geq$  5 inch CW. This may have  
9 increased discards; however, because discards have not been monitored until 2012, impact of  
10 this change on discards is unknown. This issue was also examined in assessment model  
11 selection, which showed no difference in estimates of selectivity functions before and after  
12 2005 (NPFMC 2016).

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

#### 18 19 CDQ Fishery

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

#### 32 33 Winter Commercial Fishery

34 The winter commercial crab fishery is a small fishery using hand lines and pots through the  
35 nearshore ice. On average 10 permit holders harvested 2,500 crabs during 1978-2009. From  
36 2007 to 2015 the winter commercial catch increased from 3,000 crabs to over 40,000 (Table  
37 2). In 2015 winter commercial catch reached 20% of total crab catch. The BOF responded in  
38 May 2015 by amending regulations to allocate 8% of the total commercial guideline harvest  
39 level (GHL) to the winter commercial fishery, which became in effect since 2017 season.  
40 The winter red king crab commercial fishing season was also set from January 15 to April 30,  
41 unless changed by emergency order. The new regulation became in effect since the 2016  
42 season.

1        Subsistence Fishery

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

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

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

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

22       In 2012 a revised GHL for the summer commercial fishery was implemented: (1) 0% harvest  
 23       rate of legal crab when estimated legal biomass < 1.25 million lb; (2) ≤ 7% of legal male  
 24       abundance when the estimated legal biomass falls within the range 1.25-2.0 million lb; (3) ≤  
 25       13% of legal male abundance when the estimated legal biomass falls within the range 2.0-3.0  
 26       million lb; and (3) ≤ 15% of legal male biomass when estimated legal biomass >3.0 million  
 27       lb.

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

- 30           1. Revised GHL to include summer and winter commercial fisheries.
- 31           2. Set guideline harvest level for winter commercial fishery (GHL<sub>w</sub>) at 8% of the total  
 32           GHL
- 33           3. Dates of the winter red king crab commercial fishing season are from January 15 to  
 34           April 30.

Year	Notable historical management changes
1976	The abundance survey started
1977	<b>Large vessel commercial fisheries began (Legal size ≥ 5 inch CW)</b>
1978	<b>Legal size changes to ≥ 4.75 inch CW</b>
1991	Fishery closed due to staff constraints
1994	Super exclusive designation went into effect. The end of large vessel commercial fishery operation.
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	<b>Commercially accepted legal crab size changed from <math>\geq 5</math> inch CW</b>
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. <b>Pot configuration requirement: at least 4 escape rings (&gt;4.5 inch diameter) per pot located within one mesh of the bottom of the pot, or at least <math>\frac{1}{2}</math> of the vertical surface of a square pot or sloping side-wall surface of a conical or pyramid pot with mesh size &gt; 6.5 inches.</b>
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.

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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 2015-2017 seasons. In 2018 the stock again fell to Tier 4b.

**D. Data**

1. Summary of new information:

Winter commercial and subsistence fishery:

Winter commercial fishery catch in 2018 was 9,189 crab (20,118 lb.). Subsistence retained crab catch was 4,424 and unretained was 1,343 or 23 % of total catch (Table 2).

Summer commercial fishery:

The summer commercial fishery opened on 6/25/2018 d closed on 7/28/2018. Total of 89,613 crab (298,396 lb.) were harvested (Table 1).

Total retained harvest for 2018 season was 103,217 crab (338,574 lb.) and did not exceed the 2018 ABC of 0.35 million lb.

Summer Trawl abundance survey ADFG (7/22-7/29).

Abundance estimated by ADFG survey was 1108.9 (x 1000) crab with CV 25% (Table 3).

2. Available survey, catch, and tagging data

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	Years	Data Types	Tables
Summer trawl survey	76,79,82,85,88,91,96, 99, 02,06,08,10,11,14,17, 18	Abundance Length-shell comp	3 6
Winter pot survey	81-87, 89-91,93,95-00,02-12	Length-shell comp	7
Summer commercial fishery	76-90,92-18	Retained catch Standardized CPUE, Length-shell comp	1 1 4
Summer commercial total catch	2012-2018	Length-shell comp	9
Summer commercial Discards	87-90,92,94, 2012-2018	Length-shell comp	8
Winter subsistence fishery	76-18	Total catch Retained catch	2 2
Winter commercial fishery	78-18 16-18	Retained catch Retained Length-Shell	2 5
Tag recovery	80-18	Recovered tagged crab	10

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4 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	CPUE data Not reliable due to ice conditions
Winter Commercial	2016-18	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

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6 Time series of available data

	Survey		Harvests			Tag	Data Not Used <sup>3</sup>				
	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 <sup>1</sup>	N		H, CPUE		H		N				
Length <sup>2</sup>	X	X	X	X		X	X	X	X	X	X
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1980											



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- 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 13)
- Data estimated outside the model:
  - Summer commercial catch standardized CPUE (Table 1, Appendix B)

***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  $\leq 123$ mm, and higher  $M$  for  $> 123$ mm) (NPFMC 2012, 2013, 2014, 2015, 2016, 2017, 2018). Alternative assumptions have been explored, such as changing molting probability (i.e., crab matured quicker or delayed maturation), higher natural mortality, and dome 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, which showed that  $M$  increased gradually starting size 94mm. However, this did not improve overall model fit (NPFMC 2018) and was rejected for model consideration.

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

- 1 4. Weight of fishing effort = 20,  
2 5. The maximum effective sample size for commercial catch and winter surveys = 100,  
3

4 2012 (NPFMC 2012)

- 5 1.  $M$  of the last length class =  $3.6 \times M$   
6 2. The maximum effective sample size for commercial catch and winter surveys = 50,  
7 3. Weight of fishing effort = 50.  
8

9 2013 (NPFMC 2013)

- 10 1. Standardize commercial catch cpue and replace likelihood of commercial catch  
11 efforts to standardized commercial catch cpue with weight = 1.0  
12 2. Eliminate summer pot survey data from likelihood  
13 3. Estimate survey  $q$  of 1976-1991 NMFS survey with maximum of 1.0  
14 4. The maximum effective sample size for commercial catch and winter surveys = 20.  
15

16 2014 (NPFMC 2014)

- 17 1. Modify functional form of selectivity and molting probability to improve parameter  
18 estimates (2 parameter logistic to 1 parameter logistic)  
19 2. Include additional variance for the standardized cpue.  
20 3. Include winter pot survey cpue (But was removed from the final model due to lack of  
21 fit)  
22 4. Estimate growth transition matrix from tagged recovery data.  
23

24 2015 (NPFMC 2015)

- 25 1. Winter pot survey selectivity is an inverse logistic, estimating selectivity of the  
26 smallest length group independently  
27 2. Reduce Weight of tag-recovery:  $W = 0.5$   
28 3. Model parsimony: one trawl survey selectivity and one commercial pot selectivity  
29

30 2016 (NPFMC 2016)

- 31 1. Length range extended from 74mm – 124mm above to 64mm – 134mm above.  
32 2. Estimate multiplier for the largest ( $> 123$ mm) length classes.  
33

34 2017 (NPFMC 2017)

- 35 1. Change molting probability function from 1 to 2 parameter logistic. Assume molting  
36 probability not reaching 1 for the smallest length class.  
37

38 2018 (NPFMC 2018)

- 39 1. No model change.  
40

41 **2. Model Description**

- 42 a. Description of overall modeling approach:

43 The model is a male-only size structured model that combines multiple sources of  
44 survey, catch, and mark-recovery data using a maximum likelihood approach to  
45 estimate abundance, recruitment, catchability of the commercial pot gear, and

1 parameters for selectivity and molting probabilities (See Appendix A for full model  
2 description).

3 Unlike other crab assessment models, NSRK modeling year is starts from February  
4 1<sup>st</sup> to January 31<sup>st</sup> of the following year. This schedule was selected because Norton  
5 Sound winter crab fisheries can start when Norton Sound ice become thick enough to  
6 operate fishery safely, which can be as earliest as mid-late January.

7  
8 b-f. See Appendix A.

9  
10 g. Critical assumptions of the model:

11  
12 i. Male crab mature at CL length 94mm.

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

15 ii. Molting occurs in the fall after the summer fishery

16 iii. Instantaneous natural mortality  $M$  is 0.18 for all length classes, except for the last  
17 length group ( $> 123\text{mm}$ ).

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

20  
21 v. Winter pot survey selectivity is a dome shaped function: Reverse logistic function  
22 of 1.0 for length class CL 84mm, and model estimate for CL  $< 84\text{mm}$  length  
23 classes. Selectivity is constant over time.

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

30  
31  
32 vi. Summer commercial fisheries selectivity is an asymptotic logistic function of 1.0  
33 at the length class CL 134mm. While the fishery changed greatly between the  
34 periods (1977-1992 and 1993-present) in terms of fishing vessel composition and  
35 pot configuration, the selectivity of each period was assumed to be identical.  
36 Model fits of separating and combining the two periods were examined in 2015,  
37 and showed no difference between the two models (NPFMC 2015). For model  
38 parsimony, the two were combined.

39  
40 vii. Summer trawl survey selectivity is an asymptotic logistic function of 1.0 at the  
41 length of CL 124mm. While the survey changed greatly between NOAA (1976-  
42 1991) and ADF&G (1996-present) in terms of survey vessel and trawl net

1 structure, selectivity of both periods was assumed to be identical. Model fits  
2 separating and combining the two surveys were examined in 2015. No differences  
3 between the two models were observed (NPFMC 2015) and for model parsimony  
4 the two were combined.

- 5 viii. Winter commercial and subsistence fishery selectivity and length-shell conditions  
6 are the same as those of the winter pot survey. All winter commercial and  
7 subsistence harvests occur February 1<sup>st</sup>.

8 Winter commercial king crab pots can be any dimension (5AAC 34.925(d)). No  
9 length composition data exists for crab harvested in the winter commercial or  
10 subsistence fisheries. However, because commercial fishers are also subsistence  
11 fishers, it is reasonable to assume that the commercial fishers used crab pots that  
12 they use for subsistence harvest, and hence both fisheries have the same  
13 selectivity.  
14

- 15 ix. Growth increments are a function of length, are constant over time, estimated  
16 from tag recovery data.  
17

- 18 x. Molting probability is an inverse logistic function of length for males.  
19

- 20 xi. A summer fishing season for the directed fishery is short. All summer commercial  
21 harvests occur July 1<sup>st</sup>.

- 22  
23 xii. Discards handling mortality rate for all fisheries is 20%.  
24 No empirical estimate is available.  
25

- 26 xiii. Annual retained catch is measured without error.  
27

- 28 xiv. All legal size crab ( $\geq 4\text{-}3/4$  inch CW) are retained, and sublegal size crab or  
29 commercially unacceptable size crab ( $< 5$  inch CW, since 2005) are discarded  
30

31 Since 2005, buyers announced that only legal crab with  $\geq 5$  inch CW are acceptable for  
32 purchase. Since samples are taken at a commercial dock, it was anticipated that this  
33 change would lower the proportion of legal crab. However, the model was not sensitive  
34 to this change (NPFMC 2013, 2017).  
35

- 36 xv. Length compositions have a multinomial error structure and abundance has a log-  
37 normal error structure.  
38

- 39 h. Changes of assumptions since last assessment:

40 None.  
41  
42

### 43 3. Model Selection and Evaluation

44

a. Description of alternative model configurations.

We examined alternative models of

Model 0: Baseline: assumed retention curve

Model 1: Summer commercial retention curve estimated

Model 2: Model 0 + include winter commercial retained catch data and estimate retention curve for winter commercial.

Model 0 is a baseline model adopted for 2018 assessment. Alternative models Model 1 was suggested by CPT (January 2018). Model 2 is a feasibility, assessing utility of winter commercial retained catch data. Model 2 is not considered for assessment model alternative at this moment.

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

Model	Model 0	Model 1	Model 2
No. Parameters		+2	+2
Total	299.7	272.5	304.4
TSA	9.5	9.6	9.7
St.CPUE	-29.2	-29.2	-28.9
TLP	103.3	103.6	104.7
WLP	38.7	38.5	39.0
CLP	52.0	49.9	50.6
OBS	30.7	<b>8.2</b>	30.8
REC	14.6	15.2	14.0
TAG	80.1	<b>76.7</b>	80.0
WN			4.4
MMB(mil.lb)	3.11	3.09	3.12
Legal crab Catchable (mil.lb)	2.50	2.47	2.50
OFL(mil.lb)	0.24	0.24	0.25
B35%(mil.lb)	1.22	<1.39	1.24
F35%	1.86	> 2.0	1.92
F40%	1.18	1.34	1.21

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 retention catch length composition

REC: Recruitment deviation

OBS: Summer commercial catch observer discards (Baseline) or total catch (Alternative models) length composition

TAG: Tagging recovery data composition

WN: Winter Commercial length-shell composition

See Appendix C1-C3 for standard output figures and estimated parameters.

1 a. Search for balance:  
 2 Direct comparison of total likelihood between Model 0 and Model 1 is not appropriate  
 3 because of changes in input model data. Summer commercial retention curve estimated by  
 4 Model 1 is similar to empirical legal retained proportion (Model 0), though slightly lower  
 5 (Table 13). Model 1 also lowered summer commercial selectivity for sublegal (< 103mm)  
 6 length classes. This resulted in reduction of summer commercial retained catch length-shell  
 7 composition likelihood (CLP) by 2 points. Model 1 also improved fit of tag-recovery data  
 8 (TAG) by 3 points. Those were slight model improvement at the cost of increasing 2  
 9 parameters. Considering the above, we recommend base model (Model 0) for January 2019  
 10 assessment.

11  
 12  
 13 **4. Results :**

14  
 15 1. List of effective sample sizes and weighting factors (Figure 4)

16 “Implied” effective sample sizes were calculated as

$$n = \frac{\sum_l \hat{P}_{y,l}(1-\hat{P}_{y,l})}{\sum_l (P_{y,l} - \hat{P}_{y,l})^2}$$

17  
 18 Where  $P_{y,l}$  and  $\hat{P}_{y,l}$  are observed and estimated length compositions in year  $y$  and length  
 19 group  $l$ , respectively. Estimated effective sample sizes vary greatly over time.  
 20

21 Maximum sample sizes for length proportions:

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

22  
 23  
 24 Weighting factor

25 Recruitment SD 0.5

26  
 27 2. Tables of estimates.

28 a. Model parameter estimates (Tables 11, 12).

29  
 30 b. Abundance and biomass time series (Table 15) (Will be shown on Jan 2019 final  
 31 assessment)

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c. Recruitment time series (Table 15). (Will be shown on Jan 2019 final assessment)

d. Time series of catch/biomass (Tables 16)

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.

b. Model fits to survey numbers (Figures 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.

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

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. RMSEs of trawl survey and standardized CPUE (Figure 11)

h. QQ plots and histograms of residuals of trawl survey and standardized CPUE (Figure 11).

5. Retrospective analyses (Figure 17). Will be presented on Jan 2019 final assessment.

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6. Uncertainty and sensitivity analyses.

See Sections 2 and 5.

**A. Calculation of the OFL: TBD in Jan 2019**

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.

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

---

Leve	Criteria	$F_{OFL}$
A	$B / B_{MSY^{prox}} > 1$	$F_{OFL} = \gamma M$
B	$\beta < B / B_{MSY^{prox}} \leq 1$	$F_{OFL} = \gamma M (B / B_{MSY^{prox}} - \alpha) / (1 - \alpha)$
C	$B / B_{MSY^{prox}} \leq \beta$	$F_{OFL} = \text{bycatch mortality \& directed fishery } F = 0$

---

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

$$B_{MSY} \text{ proxy} = \text{average model estimated MMB from 1980-2019}$$

Predicted mature male biomass in 2019 on February 01 is:

Mature male biomass : (SD ) million lb.

1  
 2 Estimated  $B_{MSY}$  proxy is:  
 3  
 4 million lb.

5  
 6 Since projected MMB is less than  $B_{MSY}$  proxy, **Norton Sound red king crab stock status is**  
 7 **Tier 4b**

8  
 9 2. Calculation of OFL.

10  
 11 OFL was calculated for retained ( $OFL_r$ ), un-retained ( $OFL_{ur}$ ), and total ( $OFL_T$ ) for legal sized crab,  
 12  $Legal\_B$ , by applying  $F_{OFL}$ .

13  
 14  $Legal\_B$  is a biomass of legal crab subject to fisheries and is calculated as: Projected abundance by  
 15 length crab  $\times$  fishing selectivity by length class  $\times$  Proportion of legal crab per length class  $\times$   
 16 Average lb per length class.

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

19 
$$Legal\_B_w = \sum_l (N_{w,l} + O_{w,l}) S_{s,l} P_{lg,l} w m_l$$

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

24 
$$Legal\_B_s = Legal\_B_w (1 - \exp(-x \cdot F_{OFL})) e^{-0.42M}$$
  
 25 
$$OFL_r = (1 - \exp(-(1-x) \cdot F_{OFL})) Legal\_B_s$$

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

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

28  
 29 Solving  $x$  of the above, a revised retained OFL is

30 
$$OFL = Legal\_B_w \left( 1 - e^{-(F_{OFL} + 0.42M)} - (1 - e^{-0.42M}) \left( \frac{1 - p \cdot (1 - e^{-(F_{OFL} + 0.42M)})}{1 - p \cdot (1 - e^{-0.42M})} \right) \right)$$

31  
 32 Accounting for difference in length specific natural mortality

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

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

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

8  
9

The total male OFL is

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

10  
11

For calculation of the OFL 2019, we specified  $p = 0.16$ .

13  
14  
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18

- Legal male biomass catchable to fishery (Feb 01): million lb
- $OFL_r$  = million lb. or kMT
- $OFL_{ur}$  = million lb. or kMT
- $OFL_T$  = million lb. or kMT

19 **B. Calculation of the ABC :TBD Jan 2019**

20

21 1. Specification of the probability distribution of the OFL.

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

24 Retained ABC for legal male crab is 80% of OFL

25  
26

ABC = million lb or kMT

27  
28

29 **C. Rebuilding Analyses**

30 Not applicable

31

32 **D. Data Gaps and Research Priorities**

1  
2 The major data gap is the fate of crab greater than 123 mm.

3  
4  
5 **Acknowledgments**

6 We thank all CPT members for all review of the assessment model and suggestions for  
7 improvements and diagnoses. We also thank Dr. Shareef Siddeek for critical review of draft.

8  
9  
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