Norton Sound Red King Crab Stock Assessment for the fishing year 2020

Toshihide Hamazaki[1] and Jie Zheng [2]
Alaska Department of Fish and Game Commercial Fisheries Division
[1]333 Raspberry Rd., Anchorage, AK 99518-1565
Phone: 907-267-2158
Email: Toshihide.Hamazaki@alaska.gov
[2]P.O. Box 115526, Juneau, AK 99811-5526
Phone : 907-465-6102
Email : Jie.Zheng@alaska.gov

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, the Norton Sound Crab fishery operated as super exclusive. For the 2019 fishery season, Norton Sound Red King Crab harvest consisted of 1,050 crab (3,295 lb.) by winter commercial, 1,545 crab (3,100 lb) by winter subsistence, and 24,506 crab (75,023 lb) by summer commercial, totaling 27,099 crab (81,418 lb). Total harvests were below ABC of 0.19 million lb. The harvest decline was due to 1) late ice buildup preventing winter fisheries and 2) low catch CPUE and declined summer commercial fishery participation.

3. Stock Biomass. The Norton Sound Red King Crab stock has been monitored by triennial surveys since 1976 by NOAA (1976-1991) and ADF&G (1996-present), with survey catch ranged from 1.41 million to 5.9 million crab. In 2019, abundance by trawl survey by ADF&G was 4.66 million crab with a CV of 0.60, whereas the survey by NMFS was 2.43 million crab with a CV of 0.26. The difference is partially due to 1) ADF&G survey had high crab catch in one station, and 2) high crab catch of NMFS survey occurred outside of the standard survey area.

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
2016	2.26[A]	5.87	0.52	0.51	0.52	0.71[A]	0.57
2017	2.31[B]	5.14	0.50	0.49	0.50	0.67[B]	0.54
2018	2.41[C]	4.08	0.30	0.31	0.34	0.43[C]	0.35
2019	2.24[D]	3.12	0.15	0.08	0.08	0.24[D]	0.19
2020	2.29[E]	3.73	TBD	TBD	TBD	0.29[E]	0.23

Status and catch specifications (1000t)

Year	MSST	Biomass (MMB)	GHL	Retained Commercial Catch	Total Retained Catch	Retained OFL	Retained ABC
2016	1.03[A]	2.66	0.24	0.23	0.24	0.32[A]	0.26
2017	1.05[B]	2.33	0.23	0.22	0.24	0.30[B]	0.24
2018	1.09[C]	1.85	0.13	0.14	0.15	0.20[C]	0.16
2019	1.03[D]	1.41	0.07	0.04	0.04	0.11[D]	0.09
2020	1.04[E]	1.69	TBD	TBD	TBD	0.13[E]	0.10

Notes:
MSST was calculated as $B_{MSY}/2$
A-Calculated from the assessment reviewed by the Crab Plan Team in May 2016
B-Calculated from the assessment reviewed by the Crab Plan Team in May 2017
C-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2018
D-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2019
E-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2020

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

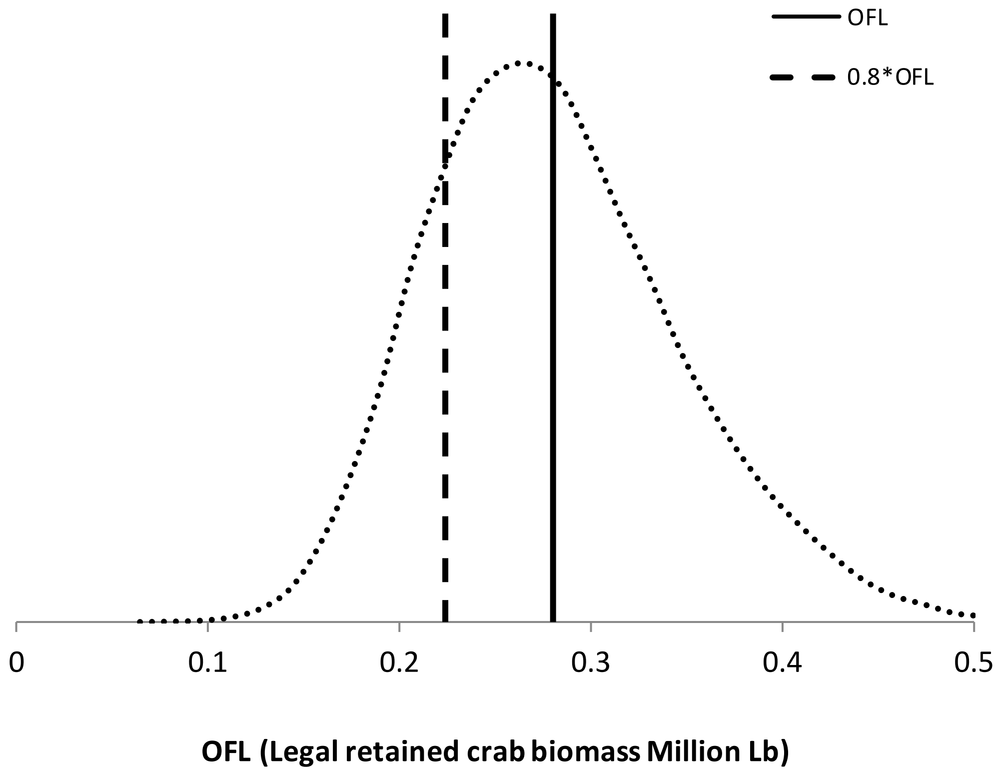
Biomass in millions of pounds

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	Retained ABC
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	4.57	3.12	0.7	0.12	1980-2019	0.18	0.8	0.19
2020	4b	4.58	3.73	0.8	0.14	1980-2020	0.18	0.8	0.23

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
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	2.06	1.41	0.7	0.12	1980-2019	0.18	0.8	0.09
2020	4b	2.08	1.69	0.8	0.14	1980-2020	0.18	0.8	0.10

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) for standardization with other stocks.

8. A summary of the results of any rebuilding analysis

   N/A

A. Summary of Major Changes in 2019

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

   None

2. Changes to the input data

   a. Data update:

      i. 1977-2019 standardized commercial catch CPUE and CV. Standardized CPUE was calculated for entire dataset, instead of separating two (1977-1993, 1994-2019) time periods.

      ii. Winter and Summer commercial fishery harvest, discards, and length composition data. Retained size composition data were not collected for 2019 winter commercial due to low harvest.

      iii. Tag recovery data 2019 (14 crab).

      iv. Trawl surveys: abundance, length-shell compositions:

      ADFG and NMFS 2019

3. Changes to the assessment methodology:

   None

4. Changes to the assessment results.

   Model estimated mature male biomass increased from 3.12 million lb. in 2019 to 3.73 million lb. in 2020. Estimated OFL also increased from 0.24 million lb. in 2019 to 0.29 million lb. in 2020.

B. *Response to SSC and CPT Comments*

Crab Plan Team – January 23-25, 2019

- Continue to evaluate methods to improved ADF&G bottom trawl survey biomass estimation, including model based approaches such as VAST.

  Authors' reply: VAST modeling has been applied to historical trawl survey data. However, we were not able to generate estimates. **Authors request experts' instruction and assistance for implementation.**

- Conduct a sensitivity analysis to evaluate the effect of mark-recapture data by fitting the model only marks that are liberty for one year.

  Authors' reply:

  Alternative model: 19.1

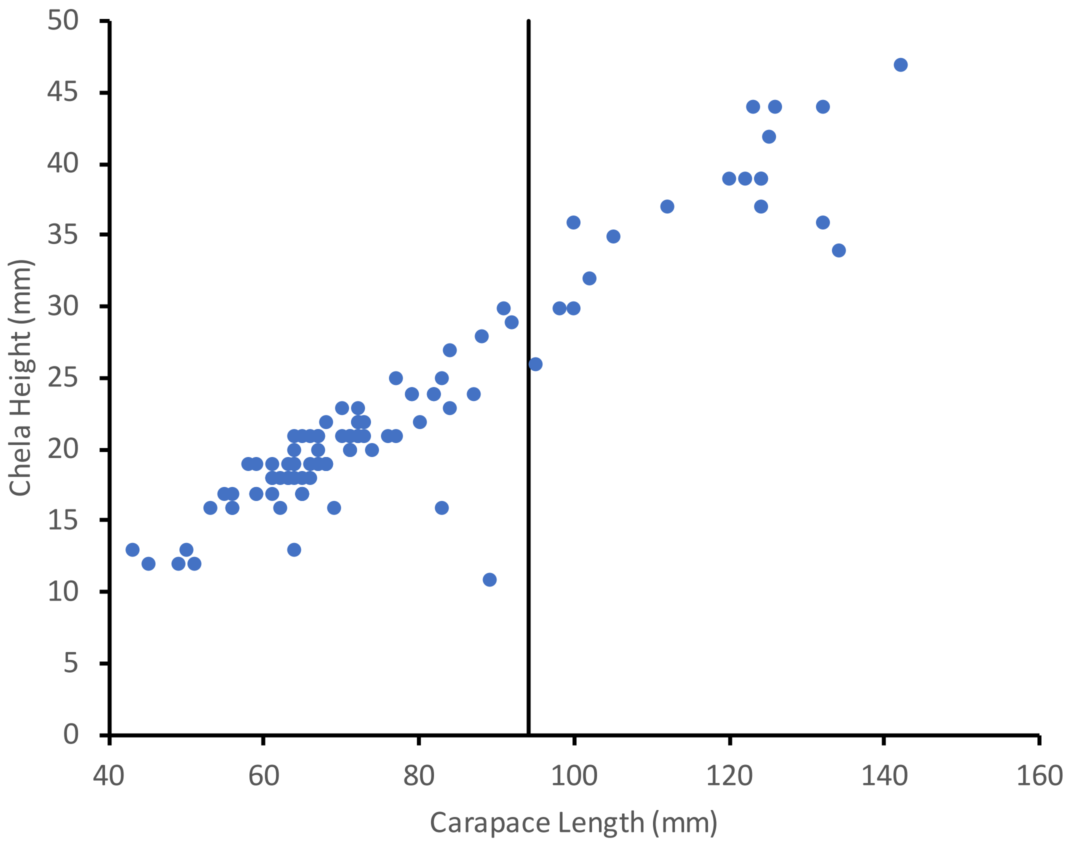
- Evaluate potential differences in survey Q between NOAA and ADFG bottom trawl surveys.

  Authors' reply: Alternative model 19.2 and 19.3

- Collect more chela-carapace data, especially at the small size ranges, to improve the size at maturity estimate.

  Author's reply

  In 2019 97 male samples were collected during the annual bottom trawl survey. The vertical line shows current maturity cut-off length (95mm). No distinctive break point has been present.



SSC – February 4-6 2019

- The model choice does not have much impact on the results, or on the Tier 4 reference points, hence the focus for the stock assessment should be on the input data.

  Authors' reply:

  We fully concur. We are collecting more data as budget allows.

- Bring forward total catch OFLs and ABCs or provide rationale why the retained catch OFL and ABC are still more appropriate at this time.

  Authors' reply:

  Estimating total catch OFL requires estimating the number of discards in summer commercial fisheries. Thus far, no formal estimates of discards have not been established for NSRKC. See Appendix C for 2002-2018 preliminary discards estimates.

- Include options with an estimated constant M across size classes (including the largest class) and a dome-shaped selectivity for the summer commercial fishery and for the summer survey.

  Authors' reply: Alternative model 19.4 and 19.5

- Spatial distribution and modeling. a thorough examination of the spatial distribution of red king crab, in particular spatial differences in size composition, across the northern Bering Sea beyond Norton Sound would be helpful. Available data include the 2010 and 2017-2018 NMFS bottom trawl surveys.

  Authors' reply: We believe that this request is more suited to NMFS that conducted the trawl surveys.

- Spatial modeling: Compare the ADF&G and NMFS surveys using appropriate methods for zero-inflated distributions, such as those offered in various R packages (e.g., pscl, gamlss, INLA, VAST, glmmfields).

  Author's reply:

  We are not familiar with those packages and spatial modeling. **Authors request experts instruction and assistance for implementation.**

  It should also be noted that ADF&G and NMFS surveys are NOT "paired" (i.e., side-by-side survey). ADF&G and NMFS surveys differ in **survey protocols (e.g., tow distance), trawl gears, survey spatial extent and timing. Thus, it is expected that the two surveys would**

differ in abundance and spatial distribution. Thus, model expected survey abundances also differ (based on survey timing, incorporating amount of harvest by the mid-point survey date) in the assessment model.

- Survey time series: Explore using two catchability parameters for the differing time blocks of the survey time series shown in Figure 7 which uses a different length range after 1995 to compute the abundance index.

Author's reply:

The NMFS survey abundance prior to 1995 were provided by NMFS (NPFMC 2014) when NSRKC model was based on 74mm and above. When this was changed to 64mm and above survey abundances after 1995 were updated by the authors (NPFMC2016), but not for the pre-1995 NMFS surveys. This was because the assessment model was already estimating q (q ~ 0.7) for pre-1995 survey abundance. In this assessment, the pre-1995 survey abundance was updated to 64mm and above. We also included differences in abundance estimation methodologies between pre-1995 NMFS and post 1995 trawl surveys (Table 3). Combining with application of VAST, we will further explore improvement of trawl survey abundance.

- Local and traditional knowledge: Encourage through collaborations at the local level to consider these sources of knowledge

Author's reply:

Authors request SSC and experts' instructions how to collaborate and incorporate local and traditional knowledge into assessment.

- Male maturity: new maturity studies are clearly needed to improve the assessment. Explore Russian data on maturity if available. Also, the relationship between maturity and temperature across stocks should be explored for potential predictive capability for Norton Sound.

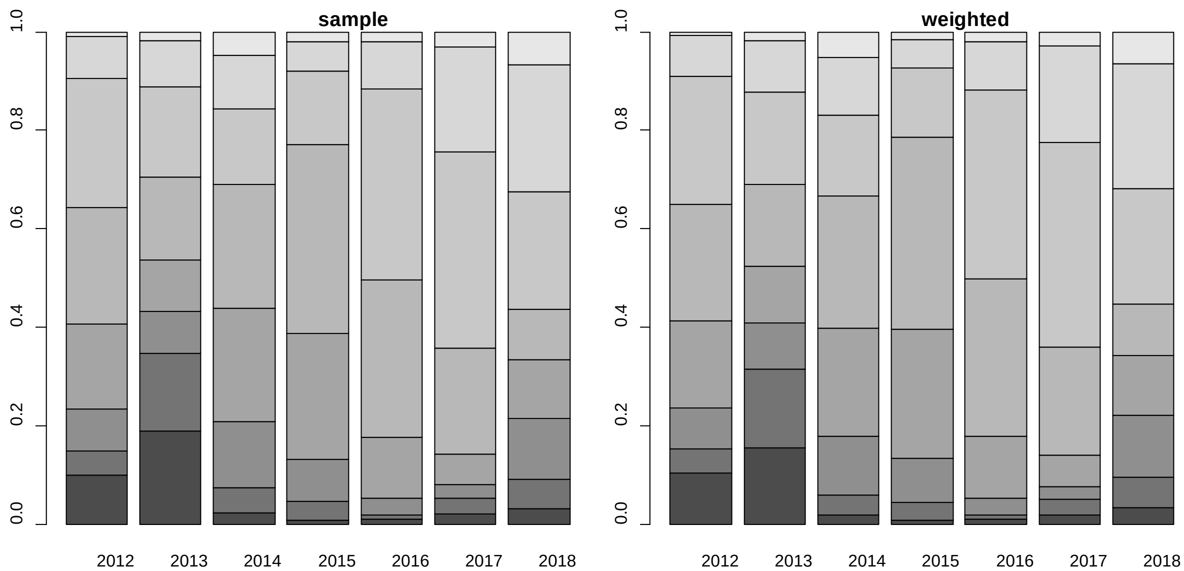
Authors' reply:

We are eager to incorporate SSC's suggestions on data weighting; however, we are not familiar with the dataset mentioned. **Authors request experts' instruction and assistance for implementation.**

- Consider estimating observer length composition weighted by catch/strata.

Authors' reply:

While weighted length composition is considered more accurate than simple unweighted one, there is little difference between the two.



- Consider data weighting based on iterative tuning, number of hauls, or other approaches.

  Authors' reply:

  Francis' (2011, 2017) iterative weighting was applied for size composition and tag recovery data. However, the calculated weights were greater than current model weights, and application of the weights resulted in lower fits trawl survey abundance data. The number of length classes (8) for NSRKC may be too few to apply Francis' weighting (André Punt, personal communication).

- Include before/after variables in CPUE standardization to account for a change in commercially acceptable size limit. Clarify if the time series of CPUE is showing different measures of CPUE for the time periods prior to and after 1995.

  Authors' reply:

  In the original CPUE standardization, the CPUE data were separated in two periods: 1976-1992 and 1993-present, and two regressions were run. In this revision, we included time stage variables PD, 1976-1992, 1993-2014, 2015-present, and ran a single regression model. The PD variable turned out to be insignificant and was removed from the final regression model. Furthermore, this also increased model sd, so that model estimated additional variance (advar) became 0.

- Use revised Mohn's rho.

  Authors' reply:

  Will be implemented for final assessment. However, more fundamental note, CPT has not established standardized criterion for Mohn's rho (e.g., min-max rho value) for selection of the best alternative model, or an adjustment of predicted biomass or determining OFL/ABC buffer. In that sense, Mohn's rho whether original or revised is just a relative index that can inform relative retrospective performance among alternative candidate models. Since retrospective analyses are done for identical years (e.g. past 10 years) for each candidate models, both sum and mean deviation function the same way for evaluating relative performance. **Authors appreciate SSC's directive for potential application of revised Mohn's rho for improvement of the NSRKC assessment model.**

- Parameters r_1 and log-phi$_{st1}$ hitting bounds.

Authors' reply:

r_1 is a parameter for normalization for estimating proportion, pi = exp(ri)/[1+sum(exp(r))], (see equation 2 of Appendix A), so that hitting bounds is acceptable. log-phi$_{st1}$ is the trawl survey selectivity curve in log scale (see equation (16) Appendix A). Since trawl selectivity was estimated to be 1.0 across all lengths, hitting bound does not affect results of the assessment model. SSC (NPFMC 2017) suggested setting trawl survey selectivity to 1.0 for all length.

Crab Plan Team – April 29, 2019

- Draft assessment in GMACS will potentially be provided in September 2019.

Authors' reply:

We are eager to incorporate SSC's suggestions on data weighting and are working on implementation.

Crab Plan Team – Sept 16-20, 2019

SSC – Sept 30-Oct 2, 2019

- No additional requests.

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 (Jenefer 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 (Jenefer Bell, ADF&G, personal communication). Molt timing 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 (Jenefer 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.

<u>CDQ Fishery</u>

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. CDQ harvest share is 7.5% of total projected harvest, which can be prosecuted in both summer and winter fisheries season.

<u>Winter Commercial Fishery</u>

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 crab during 1978-2009. From 2007 to 2015 the winter commercial catch increased from 3,000 crab 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.

<u>Subsistence Fishery</u>

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.

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.

Note that harvest of both commercial and subsistence winter fisheries is influenced largely by availability of stable ice condition. Regardless of crab abundance, low harvest can occur due to poor ice condition.

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 the winter commercial fisheries:

1) Revised GHL to include summer and winter commercial fisheries.
2) Set guideline harvest level for the 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 (Legal size ≥ 5 inch CW)**
1978	**Legal size changes to ≥ 4.75 inch CW**
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	**Commercially accepted legal crab size changed from ≥ 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 (>4.5 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 > 6.5 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 2015-2017 seasons. Since 2018 the stock has been under Tier 4b status.

D. Data

1. Summary of new information:

Winter commercial and subsistence fisheries:

The winter commercial fishery catch in 2019 was 9,189 crab (20,118 lb.). Subsistence retained crab catch was 4,424 and unretained was 1,343 crab or 23 % of total catch (Table 2).

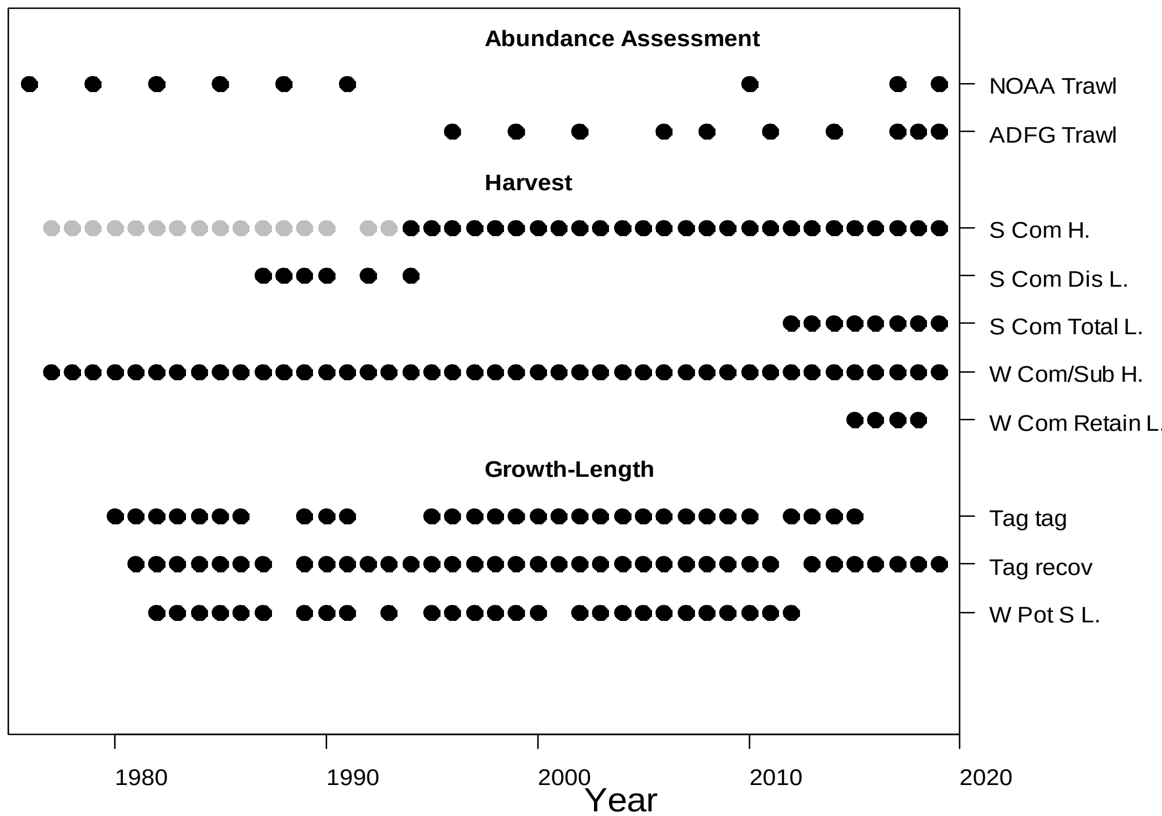
Summer commercial fishery:

The summer commercial fishery opened on 6/25/2019 and closed on 9/03/2019. Total of 75,023 crab (24,506 lb.) were harvested (Table 1). This is the lowest harvest since 2000.

Total retained harvest for 2019 season was 88,646 crab (34,811 lb. or 0.035 million lb) and did not exceed the 2019 ABC of 0.19 million lb.

Summer Trawl abundance survey by ADFG (7/22-7/29) was estimated to be 4.67 million (CV 60%) and that by NMFS (8/4-8/7) was 2.53 million (CV 26%) (Table 3). These discrepancies were also present in 2017 (Table 3).

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, 18,19	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	77-90,92-19	Retained catch Standardized CPUE, Length-shell comp	1 1 4
Summer Com total catch	12-19	Length-shell comp	9
Summer Com Discards	87-90,92,94	Length-shell comp	8
Winter subsistence fishery	76-19	Total & Retained catch	2
Winter commercial fishery	78-19	Retained catch	2
	15-18	Retained Length-Shell	5
Tag recovery	80-19	Recovered tagged crab	10

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
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

Catches in other fisheries

In Norton Sound, the directed Pacific Cod pot fishery was issued in 2018 under the CDQ permit. From 2015 to 2018 fishery seasons a total of 19 kg (12 ~ 14 crab) of NSRKC were taken from the groundfish fisheries (CPT 2019). This is small enough to ignore.

	Fishery	Data availability
Other crab fisheries	Does not exist	NA
Groundfish pot	Pacific Cod	Y (Confidential)
Groundfish trawl	Does not exist	NA
Scallop fishery	Does not exist	NA

3. Other miscellaneous data:
   - Satellite tag migration tracking (NOAA 2016)
   - Spring offshore migration distance and direction (2012-2015)
   - Monthly blood hormone level (indication of molting timing) (2014-2015)

Data aggregated:

Proportions 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* = 0.18 for length classes ≤ 123mm, and higher M for > 123mm) (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 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). Constant *M* across all length classes resulted in higher *M* (0.3-0.45) (NPFMC 2013, 2017). Dome shaped selectivity (i.e., assume large crab were not caught/not surveyed/moved out of survey and fishing area) increased MMB twice higher than other models. A model with gradual increase of *M* across length classes resulted in *M* increase staring at size 94mm. However, this did not improve overall model fit and was rejected for model consideration (NPFMC 2018). With addition of total catch length data in summer and retention length data in winter commercial fisheries, 2019 model specification examined estimation of retention curve for both summer and winter fishery, and evaluation of OFL under Tier 3 formula.

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 from 1 to 2 parameter logistic. Assume molting probability not reaching 1 for the smallest length class.

2018 (NPFMC 2018)
No major model change request

2019 (NPFMC 2019)
1) Fit total catch length composition and estimate retention probability for summer and winter commercial fishery.
2) Include winter commercial retained length data.

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, NSRKC modeling year 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 class 8. 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) fewer large crab 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 the second (Jenefer 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 134mm. 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 exist for crab harvested in the winter commercial and 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, constant over time and 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 mid-point (date 50% of harvest was taken) of annual commercial fishery.

xii. Discards handling mortality rate for all fisheries is 20%.
No empirical estimates are available.

xiii. Annual retained catch is measured without error.

xiv. Retained curve is estimated for summer and winter commercial fisheries and constant overtime.

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.

- For 2020 preliminary assessment, we explored all alternative modeling suggestions by CPT and SSC (See Authors' responses). The baseline model (Model 19.0) is Model 18.2b adopted for the 2019 assessment. Model 19.1 explores the effects of tagging data on molting and growth transition matrix. Models 19.2 and 19.3 reexamine validity of assumptions about trawl survey q set in 2013 (NPFMC 2013). Finally, Model 19.4 reexamines the assumption of size dependent mortality (i.e., higher *M* for larger crab) by estimating natural mortality and dome shape selectivity, which was examined in 2017 (NPFMC 2017). In 2017 model assessment, estimating size invariant M resulted in higher *M*, and dome shaped selectivity resulted in assuming large number of crab never observed and caught by the fisheries. Model 19.4-19.5 combines that two alternatives examined previously. The same selectivity for each size class as 2017 was estimated directly with selectivity of one size class assumed to be 1.0. Smoothing penalty was also included in likelihood.

In September 2019 draft assessment, we examined alternative models of
Model 19.0: Baseline: Model 18.2b
Model 19.1: Model 19.0 + Tag recovery data just for 1 year
Model 19.2: Model 19.0 + NOAA trawl survey Q =1.0, Est: ADFG survey Q
Model 19.3: Model 19.0 + Est survey Qs NOAA and ADFG
Model 19.4: Model 19.0 + Est *M* equal for all lengths + Dome shape selectivity for trawl and summer commercial (max sel 94-103 for trawl, 104-113 for com)
Model 19.5: Model 19.0 + Est *M* equal for all lengths + Dome shape selectivity for trawl and summer commercial (max sel 104-113 for trawl, 114-123 for com)

From those, CPT/SSC recommended Model 19.0 with final updated data for assessment in January 2020.

b. Evaluation of negative log-likelihood values with alternative models:

	Jan 2020	Sept 2019					
Model	**Model 19.0**	Model 19.0	Model 19.1	Model 19.2	Model 19.3	Model 19.4	Model 19.5
Additional Parameters					+1	+14	+14
Total	315.9	306.1	254.4	306.2	305.8	296.5	288.6
TSA	10.0	9.8	9.6	9.9	9.7	8.8	9.4
St.CPUE	-24.1	-24.1	-24.1	-24.1	-23.8	-23.2	-23.2
TLP	115.3	110.8	109.7	110.5	110.6	108.4	105.4
WLP	38.5	39.0	39.6	38.6	38.8	41.4	42.5
CLP	49.3	48.4	48.9	48.3	48.3	54.1	50.2
OBS	24.8	20.4	19.9	20.3	20.4	19.4	20.2
REC	2.7	2.6	2.7	2.4	2.5	1.8	1.9
WN	17.8	18.1	18.3	18.1	18.1	18.8	18.8
TAG	81.5	81.2	30.0	81.2	81.2	65.0	61.8
BMSY(mil.lb)	4.58	4.66	4.70	3.40	4.00	6.72	5.13
MMB(mil.lb)	3.73	3.98	3.87	2.86	3.35	5.45	4.66
Legal crab Catchable (mil.lb)	2.43	2.53	2.46	1.78	2.10	2.37	2.18
OFL(mil.lb)	0.29	0.31	0.29	0.22	0.26	0.46	0.60
NOAA q	0.71	0.70	0.68	1	0.81	0.66	0.71
ADFG q	1	1	1	1.40	1.20	1	1
M	0.18/0.58	018/0.58	018/0.64	018/0.52	018/0.55	0.31	0.43

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.

Search for balance:

SSC noted in 2019 that model choice does not have much impact on the results, or on the Tier 4 reference points, which was also true for the 2020 assessment. The only meaningful change occurs when we change assumptions about survey and fishery data selectivity and q, natural mortality, and fate of large crab, in other words, changing assumptions and understandings about biology of the NSRKC that are significantly lacking support.

Using only 1st year molting tagged crab (Model 19.0 vs. 19.1) resulted in slight changes in transition matrix (Table 14), and this did not improve model fit, MMB, and likelihood (Figure 4,8,9,11). Thus, including more than 1 years of recovery data appeared to have little effects on estimation of size transition matrix and the NSRKC assessment model. Estimating ADF&G survey q was greater than 1.0 (Models 19.2, 19.3), indicating that ADFG trawl survey overestimates NSRKC abundance (Figure 7). This lowered MMB and OFL from the baseline model (Figure 5). Assuming domed shape selectivity and estimating *M* (Model 19.4, 19.5) resulted in higher natural mortality and higher MMB (Figure 6), indicating that NSRKC having a greater natural mortality than assumed 0.18 and that larger crab exist in Norton Sound that have never been observed or caught by summer trawl survey or summer commercial fishery. Under the Tier 4 harvest control rule, a higher natural mortality results in a higher OFL (though they are lower than Tier 3 OFL (NPFMC 2019)).

Authors recommended Model 19.0 or 19.1 for final assessment. The question to decide between the two models are whether to include tag-recovery data of 2 and 3 years at liberty, given that the data had little/no influence on assessment model results. CPT recommended and authors concurred Model 19.0 with updated data for the final assessment for January 2020.

4. **Results**

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

   "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 11, 12).

b. Abundance and biomass time series (Table 13).

c. Recruitment time series (Table 13).

d. Time series of catch/biomass (Tables 14).

3. Graphs of estimates.

a. Molting probability and trawl/pot selectivity (Figure 3).

b. Estimated male abundances (recruits, legal, and total) (Figure 4).

c. Estimated mature male biomass (Figure 5).

e. Time series of catch and estimated harvest rate (Figure 6).

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.

1. Time series of trawl survey (Figure 7).
2. Time series of standardized cpue for the summer commercial fishery (Figure 8).

c. Model fits to catch and survey proportions by length (Figures 9-13).

d. Marginal distribution for the fits to the composition data.

e. Plots of implied versus input effective sample sizes and time-series of implied effective sample size (Figure 15).

f. RMSEs of trawl survey and standardized CPUE (Figure 17).

QQ plots and histograms of residuals of trawl survey and standardized CPUE (Figure 17).

5. Retrospective analyses (Figure 18).

6. Uncertainty and sensitivity analyses.

F. 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.

Tire 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 1980-2020.

Estimated B_{MSY} proxy is: 4.561 million lb / 2.07 thousand ton.

Predicted mature male biomass in 2020 on February 01

Mature male biomass: 3.664 (SE 0.452) million lb.

Since projected MMB is less than B_{MSY} proxy,

Norton Sound red king crab stock status is Tier 4b,

Where F_{OFL} is calculated by

$$F_{OFL} = \gamma\, M\, (B / B_{MSY^{prox}} - \alpha)/(1-\alpha)$$

F_{OFL} of 0.141 for all length classes.

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 × fishery 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 the summer commercial pot fishery 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 2020, we specified p = 0.16.

Legal male biomass catchable to fishery (Feb 01): 2.428 (SE 0.30) million lb and
OFL_r = 0.287 million lb.

G. 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 = 0.229 million lb.

H. Rebuilding Analyses

Not applicable

I. Data Gaps and Research Priorities

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

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References

Fournier, D., and C.P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 39:1195-1207.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Menard, J., J. Soong, and S. Kent 2011. 2009 Annual Management Report Norton Sound, Port Clarence, and Kotzebue. Fishery Management Report No. 11-46.

Methot, R.D. 1989. Synthetic estimates of historical abundance and mortality for northern anchovy. Amer. Fish. Soc. Sym. 6:66-82.

Mohn, R. 1999. The retrospective problem in sequential population analysis: An investigation using cod fishery and simulated data. ICES Journal of Marine Science, 56:473-488.

NPFMC 2011. Stock assessment and fishery evaluation report for the King and Tanner crab fisheries of the Bering Sea and Aleutian Islands regions. 2011 Crab SAFE. North Pacific Fishery Management Council, Anchorage, AK, USA.

NPFMC 2012. Stock assessment and fishery evaluation report for the King and Tanner crab fisheries of the Bering Sea and Aleutian Islands regions. 2012 Crab SAFE. North Pacific Fishery Management Council, Anchorage, AK, USA.

NPFMC 2013. Stock assessment and fishery evaluation report for the King and Tanner crab fisheries of the Bering Sea and Aleutian Islands regions. 2013 Crab SAFE. North Pacific Fishery Management Council, Anchorage, AK, USA.

NPFMC 2014. Stock assessment and fishery evaluation report for the King and Tanner crab fisheries of the Bering Sea and Aleutian Islands regions. 2014 Crab SAFE. North Pacific Fishery Management Council, Anchorage, AK, USA.

NPFMC 2015. Stock assessment and fishery evaluation report for the King and Tanner crab fisheries of the Bering Sea and Aleutian Islands regions. 2015 Crab SAFE. North Pacific Fishery Management Council, Anchorage, AK, USA.

NPFMC 2016. Stock assessment and fishery evaluation report for the King and Tanner crab fisheries of the Bering Sea and Aleutian Islands regions. 2016 Crab SAFE. North Pacific Fishery Management Council, Anchorage, AK, USA.

NPFMC 2017. Stock assessment and fishery evaluation report for the King and Tanner crab fisheries of the Bering Sea and Aleutian Islands regions. 2017 Crab SAFE. North Pacific Fishery Management Council, Anchorage, AK, USA.

NPFMC 2018. Stock assessment and fishery evaluation report for the King and Tanner crab fisheries of the Bering Sea and Aleutian Islands regions. 2018 Crab SAFE. North Pacific Fishery Management Council, Anchorage, AK, USA.

Powell, G.C., R. Peterson, and L. Schwarz. 1983. The red king crab, *Paralithodes camtschatica* (Tilesius), in Norton Sound, Alaska: History of biological research and resource utilization through 1982. Alaska Dept. Fish and Game, Inf. Leafl. 222. 103 pp.

Zheng, J., G.H. Kruse, and L. Fair. 1998. Use of multiple data sets to assess red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska: A length-based stock synthesis approach. Pages 591-612 *In* Fishery Stock Assessment Models, edited by F. Funk, T.J. Quinn II, J. Heifetz, J.N. Ianelli, J.E. Powers, J.F. Schweigert, P.J. Sullivan, and C.-I. Zhang, Alaska Sea Grant College Program Report No. AK-SG-98-01, University of Alaska Fairbanks.