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[A]	5.13	0.39	0.40	0.52	0.72[A]	0.58
2016	2.26[B]	5.87	0.52	0.51	0.52	0.71[B]	0.57
2017	2.31[C]	5.14	0.50	0.49	0.50	0.67[C]	0.54
2018	2.41[D]	4.08	0.30	0.31	0.34	0.43[D]	0.35
2019	TBD	TBD	TBD	TBD	TBD	TBD	TBD

Status and catch specifications (1000t)

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

Notes:
MSST was calculated as $B_{MSY}/2$
A-Calculated from the assessment reviewed by the Crab Plan Team in May 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

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

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

TBD in Janauary

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: VAST modeling approach has been considered. However, validity of the application of this method need to be evaluated before this approach is used for model assessment.

- 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)
Retention selectivity	Total catch length-shell comp	2012-2018	TS*RS	TS
	Discards length-shell comp	1986-1995	TS*RS	TS*(1-RS)

  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.

SSC – February 5 2018

- Requests more information on the evidence of biennial mating and some consideration of the implications, if any, on fishery harvest strategy.

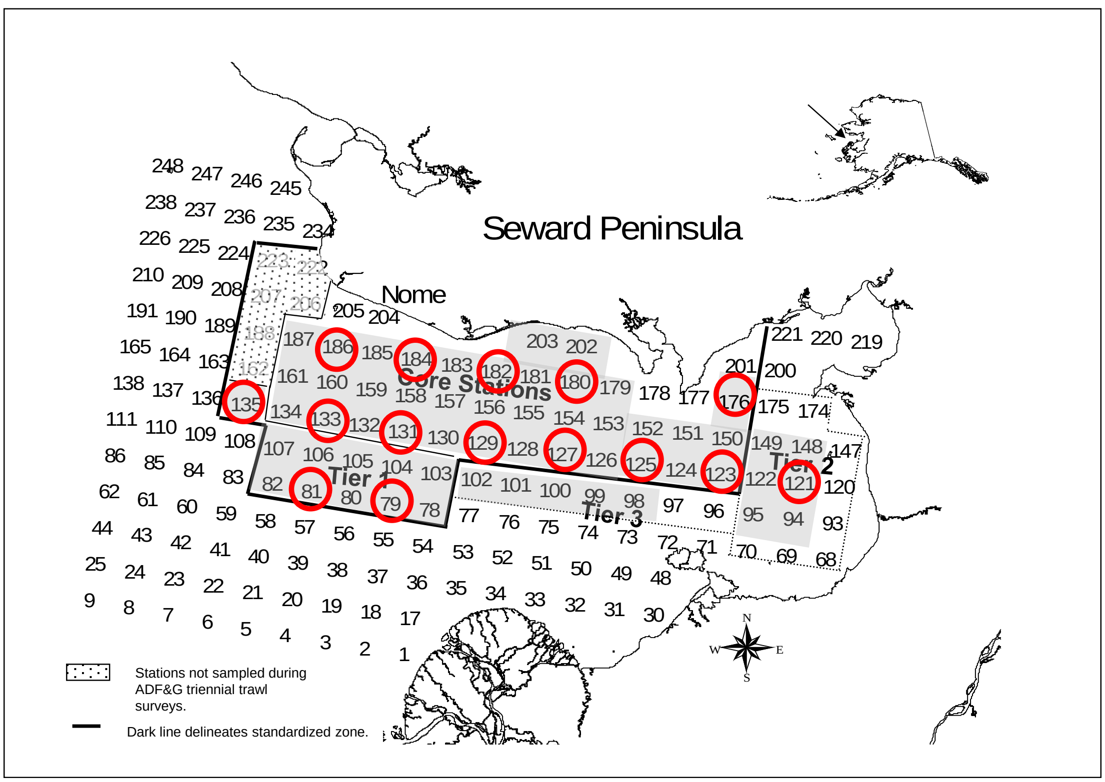
  Author Reply

  Further researches are needed to confirm.

- Recommend a spatial comparison of the ADFG and NMFS trawl survey 2017.

  Author Reply

  12 stations were surveyed by both ADFG and NMFS trawl survey in 2017. On average, swept area of NMFS survey (0.042 km^2) was about twice of ADFG (0.023 km^2). Average CPUE (# of crabs/km^2) of males of CL greater and equal to 64mm of ADFG (91.7) was about twice of NMFS (47.3). CPUE of ADFG trawl was also higher for small males. On the other hand, NMFS trawl caught more than 3 time higher females (58.5) than ADFG (17.7). Simultaneously, there was high variations among stations.



Gray shaded area is standard stations. Red circles are NMFS trawl survey stations.

Table: Comparison of CPUE between ADFG and NMFS trawl survey in 2017.

	Female		Male < 64mm CL		Male ≥ 64mm CL	
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

- 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.

CIE-Review: June

Crab Plan Team – September 12, 2018

- Limit the January discussion to Tier 3 vs. Tier 4. The CPT does not need to see all of the model description again.

Author Reply: Model results with updated data were included in the report. However, the results would not be presented at the CPT.

- A key concern is determining if Tier 3 status is appropriate for NSRKC. A thorough examination of the understanding (based on NSRKC-specific studies) of the processes that determine F35% is needed to make this determination.

Author Reply: We concur with CPT.

- The CPT suggests comparing the calculated OFLs when the increased natural mortality on the plus group is included when computing a Tier 4 OFL to support the decision between Tier 3 vs. 4 status. A relevant question is what would happen if the stock was fished at *M* uniformly, as there is no assumed selectivity in Tier 4 rules. The basic thrust of these questions is to ensure that the OFLs presented for Tier 3 and Tier 4 are fair comparisons.

Author Reply: Tier 4 OFL* based on increased M on the large group is presented. OFL* (0.44 mil lb) was higher than CPT specified OFL (0.24 mil lb), but still lower than Tier 3 OFL (1.55-1.64 mil lb) (See Model selection and Evaluation section).

- A summary slide of the pros and cons of Tier 3 vs. Tier 4 for this stock would be useful.

Author Reply: The slide is provided:

Tier 3:

Pro: Harvest limit based entirely on biological process.
Con: High uncertainties about model assumed/estimated biological process.

Tier 4:

Pro: Conventional
Con: *Ad hoc* harvest limit rule that may not be biologically justifiable.

Impacts on fishery

Tier 4 OFL/ABC is generally lower than GHL, and thus current fishery harvest is limited by Tier 4 ABC. Under Tier 3 OFL/ABC harvest will more likely be limited by GHL. For example, under model 18.0, the maximum allowable harvest under GHL will be 0.32 million lb (up to 13% of projected legal catchable crab biomass of 2.50 million lb,). This GHL is higher than Tier 4b OFL of 0.24 mil lb but lower than Tier 3 OFL of 1.55 mil lb.

- Perform sensitivities to the assumed knife-edge cutoff for maturity. Search out data to inform the appropriateness of the assumptions about maturity.

Author Reply: While information about maturity size is biologically important, because the model does not include spawner-recruit relationship (i.e., Recruitment = f(matured)), **maturity information is used solely for calculation of MMB, B_{MSY}, B_{pred}, (B_{pred}/B_{MSY}), and ultimately FOFL**.

FOFL is very little affected by the change of maturity criteria.

(Example, default model 18.0)

Maturity criteria	B_{MSY}	B_{pred}	B_{pred}/B_{MSY}	FOFL
Default (≥94mm)	4.58	3.14	0.68	0.65γM
Alt 1 (≥104mm)	3.87	2.61	0.67	0.64γM
Alt 2 (≥84mm)	5.04	3.53	0.71	0.68γM
Alt 3 (Alt 1+ .5·94mm)	4.23	2.87	0.68	0.64γM
Alt 4 (Default+ .5·84mm)	4.81	3.33	0.69	0.66γM

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. The CDQ fishery may open at any time by emergency order. CDQ harvest share is 7.5% of total projected harvest.

<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 crabs during 1978-2009. From 2007 to 2015 the winter commercial catch increased from 3,000 crabs to over 40,000 (Table 2). In 2015 winter commercial catch reached 20% of total crab catch. The BOF responded in May 2015 by amending regulations to allocate 8% of the total commercial guideline harvest level (GHL) to the winter commercial fishery, which became in effect since 2017 season. The winter red king crab commercial fishing season was also set from January 15 to April 30, unless changed by emergency order. The new regulation became in effect since the 2016 season.

<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. The subsistence fishery catch is influenced not only by crab abundance, but also by changes in distribution, changes in gear (e.g., more use of pots instead of hand lines since 1980s), and ice conditions (e.g., reduced catch due to unstable ice conditions: 1987-88, 1988-89, 1992-93, 2000-01, 2003-04, 2004-05, and 2006-07).

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

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

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

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

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

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

Year	Notable historical management changes
1976	The abundance survey started
1977	**Large vessel commercial fisheries began (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. 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

	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	77-90,92-18	Retained catch Standardized CPUE, Length-shell comp	1 1 4
Summer Com total catch	12-18	Length-shell comp	9
Summer Com Discards	87-90,92,94, 2012-2018	Length-shell comp	8
Winter subsistence fishery	76-18	Total & Retained catch	2
Winter commercial fishery	78-18	Retained catch	2
	15-18	Retained Length-Shell	5
Tag recovery	80-18	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

Time series of available data. Different shades indicate that survey agency, survey methods, or type of data collected differ among years.

	Survey		Harvests			Tag	Data Not Used[3]				
	S. Trawl	W. Pot	S.Com	S.Com Discards	W. Com, Sub	Tag recovery	S. Pot	Pre fish	Sp. Tag	F. Tag,	W. Com
N[1]	N		H, CPUE		H		N				
Length[2]	X	X	X	X		X	X	X	X	X	X
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1: Index of abundance data: N: Abundance, H: Harvest, CPUE: Catch cpue,
2: Length/shell proportion data available
3: Data were not used for the assessment model because of short term data.

4: Different colors indicate changes in fishery characteristics, survey methodologies, or different survey agencies.

Catches in other fisheries

In Norton Sound, directed Pacific Cod pot fishery was issued in 2018 under the CDQ permit. However, the fishery did not occur. This fishery may develop in the future.

	Fishery	Data availability
Other crab fisheries	Does not exist	NA
Groundfish pot	Pacific Cod (Planned, but not executed)	NA
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:

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 ≤ 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 crabs were not caught/not surveyed/moved out of survey and fishing area) increased MMB twicer 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)

1. No model changes. Same as 2017 model configuration

2. Model Description

a. Description of overall modeling approach:

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

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

b-f. See Appendix A.

g. Critical assumptions of the model:

i. Male crab mature at CL length 94mm.

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

ii. Molting occurs in the fall after the summer fishery

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

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

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

This assumption is based on the fact that a low proportion of large crab are caught in the nearshore area where winter surveys occur. Causes of this pattern may be that (1) large crab do not migrate into nearshore waters in winter or (2) large crab are fished out by winter fisheries where the survey occurs (i.e., local depletion). Recent studies suggest that the first explanation is more likely than second (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 124mm. While the survey changed greatly between NOAA (1976-1991) and ADF&G (1996-present) in terms of survey vessel and trawl net structure, selectivity of both periods was assumed to be identical. Model fits separating and combining the two surveys were examined in 2015. No differences between the two models were observed (NPFMC 2015) and for model parsimony the two were combined.

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

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

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

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

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

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

xiii. Annual retained catch is measured without error.

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

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

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

h. Changes of assumptions since last assessment:

None.

3. Model Selection and Evaluation

a. Description of alternative model configurations.

For 2019 assessment, we incorporated newly available data: summer commercial total catch length-shell comp data 2012 – 2018 (Model 18.1x), and winter commercial retained length-shell comp data 2015 – 2018 (Model 18.2x). Because winter data were short, our modeling strategy was evaluating effectiveness of summer data (Model 18.1x) first, and then add winter data (Model 18.2x).

Baseline model assumes fixed retention selectivity and uses retention and discards length-shell data to estimate catch selectivity. Combination of total and retention length-shell data is used to estimate fishery catch and retention selectivity. Simultaneously, this poses question of using 1986 – 95 discards only shell-length data. One option (Model, 18.1a) is not using data, second (Model, 18.1b) is separately fitting discards length-shell likelihood. Further option is separating retention selectivity (Model 18.1c) or total catch selectivity (Model 18.1d) into two periods (pre and post super-exclusive).

In similar way, use of winter commercial retention data will be used to estimate retention selectivity for winter commercial. We examined 3 alternatives of model specifications with winter data: 1) to default model (Model 18.0), 2) to Model 18.1a, and 3) to Model 18.1b.

We examined alternative models of
Model 18.0: Baseline: assumed retention selectivity
Model 18.1a: Summer commercial retention curve estimated: use only 2012 – 2018 data
Model 18.1b: Model 18.1a with 1986 – 1995 data
Model 18.1c: Model 18.1b with 2 retention selectivity

Model 18.1d: Model 18.1b with 2 total selectivity
Model 18.2: Model 18.0 + winter commercial retention
Model 18.2a: Model 18.1a + winter commercial retention
Model 18.2b: Model 18.1b + winter commercial retention

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

Model	Model 18.0	Model 18.1a	Model 18.1b	Model 18.1c	Model 18.1d	Model 18.2	Model 18.2a	Model 18.2b
Additional Parameters		+2	+2	+4	+4	+2	+4	+4
Total	301.0	273.9	289.4	289.0	298.7	304.0	276.6	292.3
TSA	9.5	9.6	9.5	9.5	9.6	9.6	9.7	9.5
St.CPUE	-29.2	-29.2	-29.4	-29.5	-29.5	-29.5	-29.1	-29.3
TLP	103.7	104.1	104.0	103.9	103.4	105.7	106.1	105.9
WLP	38.7	38.5	38.8	38.8	38.8	39.0	38.9	39.1
CLP	52.0	49.8	49.7	49.3	49.7	50.1	48.1	47.9
OBS	30.7	**8.0**	**20.6**	**20.6**	**21.1**	30.5	**7.7**	**20.3**
REC	14.6	15.1	14.9	14.9	15.1	14.7	15.2	15.1
TAG	81.1	**77.8**	81.3	81.3	90.5	80.9	**77.6**	81.1
WN						2.5	2.4	2.5
MMB(mil.lb)	3.12	3.10	3.11	3.11	3.11	2.93	3.11	3.11
Legal crab Catchable (mil.lb)	2.50	2.47	2.50	2.50	2.50	2.50	2.50	2.50
OFL(mil.lb)	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
OFL* (mil.lb)	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
B35%(mil.lb)	1.22	1.38	1.21	1.21	1.21	1.24	1.21	1.22
F35%	1.87	2.34	1.85	1.87	2.1	1.91	2.42	1.89
F40%	1.19	1.34	1.18	1.18	1.27	1.21	1.36	1.20
OFL:F35%	1.55	1.72	1.54	1.55	1.64	1.57	1.75	1.56
OFL:F40%	1.19	1.28	1.18	1.18	1.24	1.20	1.29	1.20

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
OFL* : Tier 4 OFL where F_{OFL} is size dependent (i.e. higher F_{OFL} for the last two length classes).

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

a. Search for balance:

It should be noted that comparison of total and Observer (OBS) likelihood among Model 18.0, 18.1x, 18.2x are in appropriate because data set and likelihood calculations differ. Examining other likelihoods, estimating retention selectivity did not change fit to population dynamics (TSA, st.CPUE), but improved fits of commercial retention (CLP) and tag recovery data (TAG) that inform transition matrix and molt probability. Separating catch or retention selectivity (Model 18.1c, 18.1d) did not improve model. Given that summer total catch and winter retention data will be taken annually, incorporating those two datasets (Model 18.2a, b) is desirable, although estimating winter retention selectivity did not improve model fit of winter retention (WIN). This is probably because winter retention selectivity was similar to assumed selectivity (Figure 3). As for consequences of alternative models in management parameters, all models estimated nearly similar projected MMB, and OFL. Thus, **for data simplicity, we recommend 18.2a for an assessment of 2019 OFL and ABC.** The other difference between the two models is Tier 3 calculation of F35% and F40%. This is due to difference in the shape of commercial catch selectivity. Selectivity of Model 18.2a are generally lower than 18.0 and 18.2b (Figure 3). This probably resulted in higher F.

4. **Results :**

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

“Implied” effective sample sizes were calculated as

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

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

Maximum sample sizes for length proportions:

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

Weighting factor

Recruitment SD 0.5

2. Tables of estimates.

   a. Model parameter estimates (Tables 11, 12).
   b. Abundance and biomass time series (Table 15)
   c. Recruitment time series (Table 15).
   d. Time series of catch/biomass (Tables 16)

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).

   d. Model fits to catch and survey proportions by length (Figures 9-14).

   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 15).

   g. RMSEs of trawl survey and standardized CPUE (Figure 16)

   h. QQ plots and histograms of residuals of trawl survey and standardized CPUE (Figure 16).

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

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:

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 1980-2019

Predicted mature male biomass in 2019 on February 01

Mature male biomass : 3.11 (SE 0.39) million lb.

Estimated B_{MSY} proxy is:

4.52 million lb.

Since projected MMB is less than B_{MSY} proxy, **Norton Sound red king crab stock status is Tier 4b with FOFL of 0.118**

2. Calculation of OFL.

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

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

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

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

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

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

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

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

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

Solving x of the above, a revised retained OFL is

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

Accounting for difference in length specific natural mortality

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

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

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

The total male OFL is

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

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

Legal male biomass catchable to fishery (Feb 01): 2.49 (SE: 0.37) million lb
OFL_r = 0.24 million lb. or 0.11 kMT
OFL_{nr} = 0.07 million lb. or 0. 03 kMT
OFL_T = 0.31 million lb. or 0.14 kMT

B. Calculation of the ABC :TBD Jan 2019

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 = 0.19 million lb or 0.09 kMT

C. Rebuilding Analyses

Not applicable

D. Data Gaps and Research Priorities

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

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