Norton Sound Red King Crab Stock Assessment for the fishing year 2022

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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, the Norton Sound Crab fishery operated as super exclusive.

   For the 2021 fishery season, Norton Sound Red King Crab harvest consisted of 320 crab (922 lb.) by winter commercial, 2,892 crab (5,784 lb) by winter subsistence, and 0 crab (0 lb) by summer commercial, totaling **3212** crab (**6,766** lb). Total harvests were below ABC of 0.35 million lb. Overfishing did not occur in 2021.

3. Stock Biomass. The Norton Sound Red King Crab stock has been monitored by triennial surveys since 1976 by NOAA (1976-1991), NOAA NBS (2010, 2017, 2019), and ADF&G (1996-2020), with survey abundance ranged from 1.41 million to 5.9 million crab (> 63mm). In 2021 trawl survey by ADF&G abundance crab (CL > 63mm) was 2.4 million crab with survey CV of 0.6.

4. Recruitment. Model estimated recruitment since 1980s were around 0.7 million ranging from 0.2 to 1.6 million.

5. Management performance.

Status and catch specifications (million lb.)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2018	2.41	4.08	0.30	0.31	0.34	0.43	0.35
2019	2.24	3.12	0.15	0.08	0.08	0.24	0.19
2020	2.28	3.67	0.17	Conf.	Conf.	0.29	0.21
2021	2.25	5.05	0.31	0.007	0.007	0.59	0.35
2022			TBD	TBD	TBD	TBD	TBD

Notes:
MSST was calculated as $B_{MSY}/2$
OFL-ABC 2018-2020 are retained only
2021 Total Catch is NA because discards was not estimated. On bord observer survey program was terminated indefinitely.
2022 MSST, MMB, OFL, and ABC are CPT adopted.

Status and catch specifications (1000t)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2018	1.09	1.85	0.13	0.14	0.15	0.20	0.16
2019	1.03	1.41	0.07	0.04	0.04	0.11	0.09
2020	1.04	1.66	0.08	Conf.	Conf.	0.13	0.09
2021	1.02	2.29	0.14	0.003	0.003	0.20	0.16
2022			TBD	TBD	TBD	TBD	TBD

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	ABC
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	4.56	3.66	0.8	0.14	1980-2020	0.18	0.7	0.21
2021	4a	4.53	5.05	1.1	0.18	1980-2021	0.18	0.6	0.35
2022	4a				0.18	1980-2022	0.18	TBD	TBD

Biomass in 1000t

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	ABC
2018	4b	2.07	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	2.07	1.66	0.8	0.14	1980-2020	0.18	0.7	0.09
2021	4a	2.05	2.29	1.1	0.18	1980-2021	0.18	0.6	0.16
2022	4a				0.18	1980-2022	0.18	TBD	TBD

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

   Not calculated for September 2021 draft report

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. The buffer was increased to 20% (ABC = 80% OFL) in 20015, to 30% (ABC = 70% OFL) in 2020, and to 40% (ABC = 60% OFL) in 2021.

8. A summary of the results of any rebuilding analysis

   Not Applicable

A. *Summary of Major Changes in 2021*

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

   None

2. Changes to the input data

   Data update:

   Winter subsistence harvest. Winter and summer commercial crab fishery.

   Trawl surveys: abundance, length-shell compositions: ADFG 2021

   Standardized CPUE

3. Changes to the assessment methodology:

   None

4. Changes to the assessment results.
   None – draft version for 2022

B. *Response to SSC and CPT Comments*

Following the request by SSC, CPT-SSC's requests/review and authors' responses were arranged by topic. Requests are italicized.

I. NSRKC Biology-Ecology

Natural Mortality

Revisit natural mortality assumptions. Both the assumed natural mortality for small crab and the larger natural mortality for crab greater than 123 mm CL should be better justified. The author noted that the maximum age observed in the tagging studies was 12 years, which is much lower than the assumed value of 25 years. Further, the "1% method" used by the authors to calculate a natural mortality generally provides lower estimates of M than empirical studies (see the tool at Barefoot Ecologist Toolbox for examples).

Authors reply:

Natural mortality M was originally set to be 0.2 for Bering Sea red king crab stock (NPFMC 1998) and was changed to 0.18 with Amendment 24. Under this, M of NSRKC assessment model was to 0.18, though the original assessment model set M to be 0.3. Since the inception of the crab SAFE and adoption of NSRKC assessment model, CPT has been requested to revisit M assumptions for NSRKC. All those past attempts suggested that M would be higher than 0.18 and more likely between 0.25 to 0.45 (NPFMC 2010, 2013, 2017). Under the Tier 4 harvest control, increasing M will also **increase OFL because default $F_{OFL} = M$** (NPFMC 2010, 2013, 2017). Thus far, neither the CPT nor SSC recommended changing M for NSRKC stock.

Female clutch fullness

Future figures of clutch fullness should include confidence bounds.

Author reply:
Confidence bounds are now listed in Table.

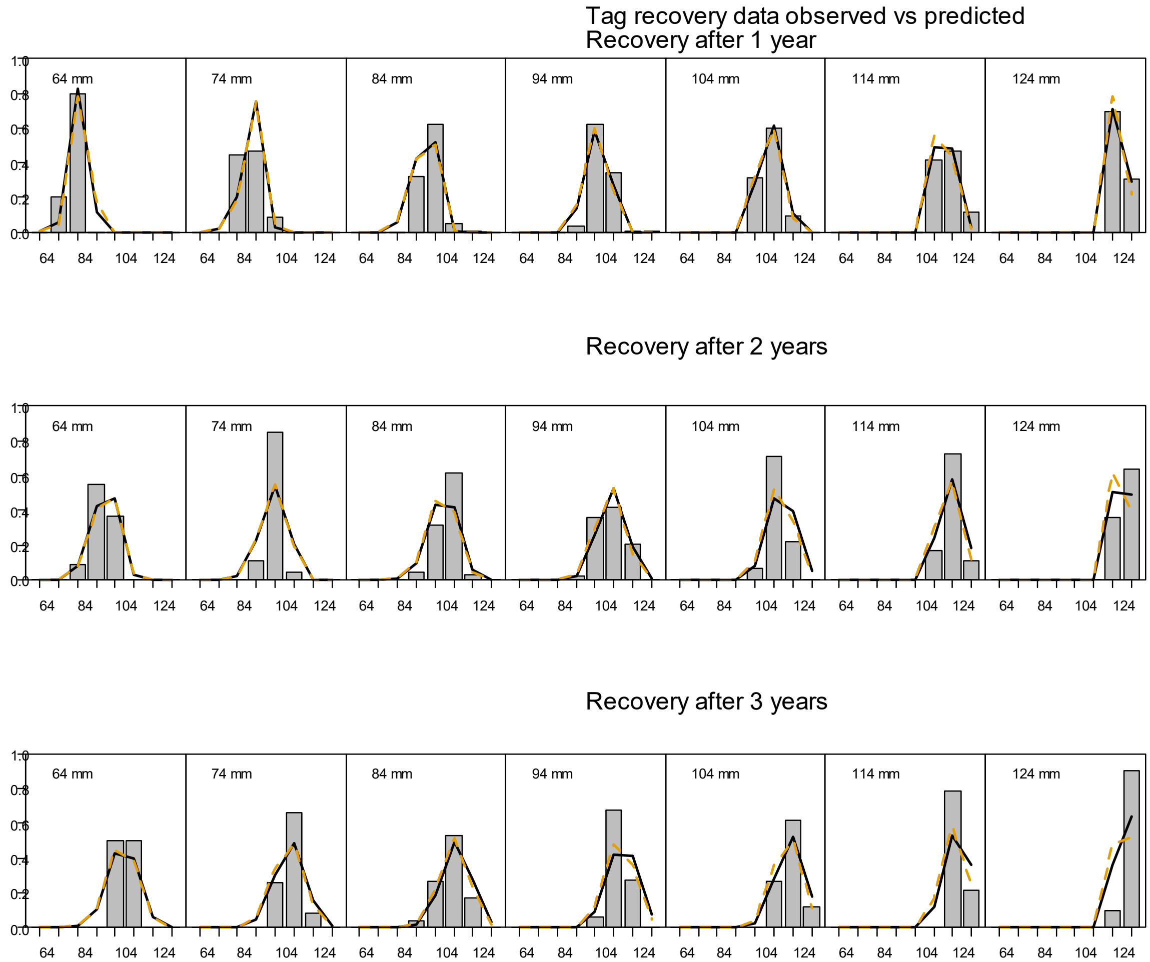
Growth

Revisit growth assumptions. Growth appears to be consistently overestimated in the assessment, producing too many large crab. The CPT looks forward to seeing the results from the laboratory studies on growth for NSRKC at the next meeting.

Author reply:

In 2020, 36 (14 male) NSRKC were sent to Kodiak NOAA laboratory. Average molting growth was 13.1mm for CL class 74-83mm and 12.8mm for CL class 84-93mm that was smaller than observed growth from tag recovery data (15mm for CL 74-83mm and 16mm for CL 84-93mm). However, the sample size was too small to evaluate statistical significance of the difference. To make more statistical comparison, > 30 crabs for each individual size classes needs to be captured and shipped to the lab.

As for overestimate of growth by the model, it should be reminded that the assessment model was not designed to fit observed growth increment, but to fit probability distributions of recaptured size classes based on the estimated transition matrix (Figure 13). Thus, the question should be not whether model estimated growth increments match to observed ones, but whether model estimated transition matrix predicted recaptured size proportion accurately.



The model fit between observed (bar) and predicted (Model 21.0 solid black, Model 21.1 dasj red) generally matches. This suggest that model is unlikely overproducing the larger crab. We also included Appendix H that describes how the tag recovery data were assembled.

Size at maturity

Investigations into size at maturity for this stock, referencing that of other red king crab stocks if useful.

Author reply:
As noted in previously (NPFMC 2018, 2019, 2020, 2021), size at maturity of Norton Sound male red king crab is highly uncertain. This is also true for other red king crab. First, maturity has two categories (biological and functional). Biological maturity indicate that male red king crab can biologically produce viable sperm, whereas functional maturity indicate that male red king crab is large enough to mate. The former can be determined using biological indicators, such as chela heights break point, whereas the latter is inferred by series of lab mating experiments. Few studies have been conducted to determine the size at functional maturity of male red king crab. The current NSRKC functional maturity size (>94mm) was inferred from Bristol Bay red king crab by incorporating the fact that Norton Sound red king crab is smaller. SSC suggested to investigate size at functional maturity of other stocks, such as of Barents Sea red king crab. However, it is unlikely that those metadata analyses would provide insights about size at maturity of Norton Sound red king crab because Norton Sound red king crab is the smallest among red king crab stocks. Authors were not able to find any other red king crab stocks that are comparable to the size of Norton Sound red king crab. We are looking for the progress in laboratory studies.

Although determining functional maturity size at maturity is important biologically, utility of this information for Tier 4 crab stock assessment is trivial. In Tier 4 stock assessment, size at maturity is used only for calculation of mature male biomass (MMB) and B_{MSY} (average MMB). Harvest control (F_{OFL}) is based on the ratio of projected MMB and B_{MSY} (projected MMB/B_{MSY}).

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

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

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 $\beta = 0.25$.

The MMB/B_{MSY} ratio is little affected by changes of maturity size, unless the ratio is very close to 1.0 (Tier 4a vs Tier 4b borderline). To illustrate this, we present 2022 assessment model results with various minimum size at maturity cutoff, as follows.

Table: Effects of Tier 4 level by changing different maturity size.

Maturity size	94mm (default)	74mm	84mm	104mm	114mm	124mm	>134mm
B_{MSY} mil. lb	4.88	5.21	4.92	3.76	2.71	1.33	0.39
MMB(2022) mil. lb	5.21	5.91	5.61	4.42	2.86	1.03	0.27
MMB/B_{MSY}	1.16	1.13	1.14	1.18	1.06	0.77	0.70

Tier 4 a b c	a	a	a	a	a	b	b
F_{OFL}	0.18	0.18	0.18	0.18	0.18	0.13	0.12

As illustrated in the above table, changing minimum maturity size has little effects on MMB/B_{MSY} ratio and Tier 4 level designation. OFL and ABC are based on retained and unretained catch by size applied by F_{OFL}.

However, this does not lessen biological importance of finding functional maturity size of NSRKC. The information would provide insights about productivity of the stock, as well as biological appropriateness of legal catch size.

II. NSRKC Assessment Surveys and Data

Discards Estimate

Further consider which of the methods to account for discards are most appropriate for NSRKC given probable future data availability. The CPT realizes that no method will be perfect, but an imperfect consideration of discards is better than ignoring them.

Authors reply:

As noted in Appendix C, the biggest issue of the NSRKC observer survey is that the surveyed samples are not representative.

Methods	Estimation logic	Assumption	Issue
LNR	Estimate total discards from sample discards CPUE	Accurate observed discards & CPUE	Observer may not know true discards.
Subtraction	Estimate total catch from sample total catch CPUE **and then subtract observed retained**	Accurate observed total catch & CPUE	Discards can be < 0, when total catch CPUE was underestimated.
Proportional	Estimate total discards from sample discard/retained ratio.	Accurate discards/retained ratio.	Discards/retained ratio may differ greatly.

The major issue regarding NSRKC observer survey is that the observed fishermen are the most experienced and having larger boat, and thus their catch CPUE is higher than other fishermen. In fact, their catch CPUE during the observed periods were also higher than their post-season retained catch CPUE as well as post-season CPUE of other unobserved fishermen (except for 2012).

Year	CPUEobs	$CPUE_{FT.obs}$	$CPUE_{FT.unobs}$
2012	13.53	16.05	16.57
2013	10.88	8.67	7.47
2014	12.50	12.80	11.87
2015	24.29	17.26	15.62
2016	25.37	17.36	15.30
2017	19.76	14.33	13.33
2018	14.05	10.19	10.09
2019	5.07	4.58	4.56

LNR2 and Subtraction2 methods are intended to correct those by applying CPUE ratio between observed and Unobserved fishermen.

In 2021, CPT chose LNR2 discards observation method, despite that author recommended not to use discards estimates of any methods at all.

Given that discard estimation is required, authors propose using the Proportional methods for simplicity of assumptions. In Norton Sound commercial crab fishery observer survey, the number and length of discarded crabs are accurate because the observer also work as deckhand. However, representativeness of observed CPUE is highly uncertain, even adjustment is applied. On the other hand, proportion of discards can be more representable across all fishermen. Norton Sound commercial crab fishery pot configurations (and escapement mechanism) are largely standardized. Their fishery is also limited in geographically. Although red king crab distribution is patchy and spatial segregation among size classes and sex are possible, it is unlikely that the size dependent spatial segregation is occurring within the fishery grounds. The proportional method is also consistent with the estimation discards by the assessment model. Thus, for 2022 assessment model, we used discards data based on the proportional method.

It should be noted that ADFG terminated observer survey program in 2021, so that discards and total catch (retained +discards x handling mortality) will not be estimated. This also implies that management performance of Norton Sound red king crab (total catch OFL-ABC) cannot be evaluated.

Pot loss

Reporting on pot loss, especially in regard to potential pot losses at the end of the season as noted in public testimony.

Authors reply:

Pot loss is inferred from “additional” pot permit requested by fishermen during the season (summer) and post-season self-reporting (winter commercial and subsistence). Although ADFG staff routinely ask reasons for additional permits, fishermen are NOT required to report their pot loss to ADF&G. Changes of regulations will be required to obtain accurate pot loss.

VAST

Explore having Jon Richar work on a VAST model for Norton Sound trawl surveys.

Author reply:
Jon Richar received an approval from his supervisor to work on a VAST model for Norton Sound trawl surveys. We look forward to his progress.

Standardized CPUE

Please explain how the SD was determined for the CPUE as it is the same from 2000 - 2019. Is this a fixed SD? If so shouldn't the CV be fixed rather than the SD?

Authors reply:

SD is a glm model estimate sigma of lognormal CPUE, exponented back to normal space (Appendix B, NPFMC 2013). For detailed description of the standardized CPUE calculation method and SD, pleased refer NPFMC (2013) and Appendix B.

III. NSRKC Assessment model

Continue exploration of data-weighting assumptions. Provide clarification and justification for the current data weighting scheme utilized in the model.

Authors reply:

Data-weighting is aimed to achieve a balance among various data sets. The current model data weighting schemes, although arbitrary were deemed appropriate by the CPT-SSC (NPFMC 2011,2012). As illustrated in the figure below, increasing weight of size composition data (input sample size: from minimum) would lower model fit to the trawl survey abundance data.

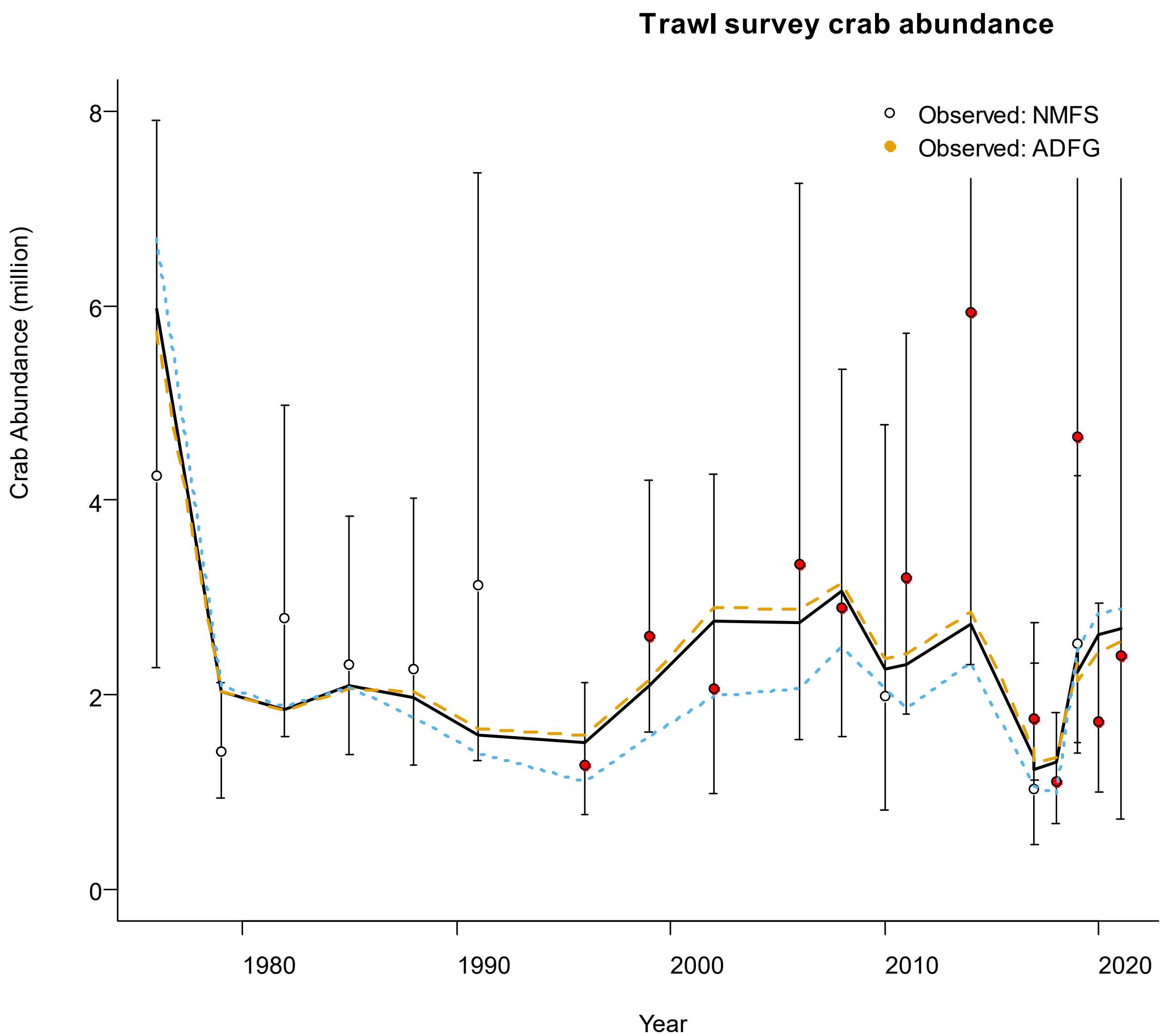


Figure: Model 21.0 default input sample size (20: trawl, 10: others) (black) vs. increased input sample size (200,100) (dash red), reduce input size (10,5) (dots blue).

Thus far, there is no objective criteria for determining the balance (i.e., how much a model should fit observed trawl abundance data vs. size composition data?). We have tried alternative weighting schemes (NPFMC 2019, 2020, 2021) and found current ones be appropriate. We welcome CPT and SSC's suggestions for alternative data weighting scheme.

In the Analytic approach, more descriptive text should be included in the sections describing the model and its assumptions, to reduce referring to Appendix A.

Part of Appendix A are now in model description sections.

Furthermore, a thorough description of the model selection and evaluation criteria, and most particularly, the results of the author's recommended models (and the base model, if they differ) is a basic requirement for a complete assessment document. A list of figures and tables is not an acceptable description of results.

Authors reply:

Implemented

IV. NSRKC Management

Legal sized crab

Explore and document the reasons for the changes in the relationship between carapace length and carapace width. Document which data sources are excluded or included and for what reason.

Authors reply:

In NSRKC, legal size is defined as carapace width greater than 4.75 inches that was conventionally equated as greater than 104mm carapace length. Since 1996 Alaska Department of Fish and Game has started noting legal size crab based on carapace width in trawl, commercial fishery observer, and other miscellaneous surveys to complement the carapace length measurement. Originally, the proportion was based solely from the trawl survey. As more data are collected from commercial observer surveys, recent proportions are based on more observer data.

Proportion of legal (CW>4.75inch) crab in Trawl survey

size class	64	74	84	94	104	114	124	134
1996	0.00	0.00	0.00	0.18	0.93	1.00	1.00	1.00
1999	0.00	0.00	0.00	0.40	0.98	0.98	1.00	1.00
2002	0.00	0.00	0.00	0.28	0.97	1.00	1.00	1.00
2006	0.00	0.00	0.00	0.18	1.00	1.00	1.00	1.00
2008	0.00	0.00	0.00	0.19	0.96	1.00	1.00	1.00
2011	0.00	0.00	0.00	0.24	0.99	1.00	1.00	1.00
2014	0.00	0.00	0.00	0.21	0.98	1.00	1.00	1.00
2017	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
2018	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
2019	0.00	0.00	0.00	0.33	1.00	1.00	1.00	1.00
2020	0.00	0.00	0.00	0.22	1.00	1.00	1.00	1.00

Total	**0.00**	**0.00**	**0.00**	**0.25**	**0.98**	**1.00**	**1.00**	**1.00**

Proportion of legal (CW>4.75inch) crab in Observer survey

size class	64	74	84	94	104	114	124	134
2012	0.00	0.01	0.02	0.22	0.90	1.00	1.00	1.00
2013	0.00	0.00	0.00	0.44	0.98	1.00	1.00	1.00
2014	0.00	0.00	0.00	0.22	0.91	1.00	1.00	1.00
2015	0.00	0.00	0.00	0.38	0.98	1.00	1.00	1.00
2016	0.00	0.00	0.00	0.46	1.00	1.00	1.00	1.00
2017	0.00	0.00	0.00	0.13	0.91	1.00	1.00	1.00
2018	0.00	0.00	0.00	0.16	0.95	0.99	1.00	1.00
2019	0.00	0.00	0.00	0.18	0.93	1.00	1.00	1.00
Total	**0.00**	**0.00**	**0.00**	**0.30**	**0.95**	**1.00**	**1.00**	**1.00**

The proportion of legal crab used in the assessment model is an average proportion based on observer survey data. In the assessment model, this proportion is used for estimation of retained crab in Winter commercial fishery prior of 2008. During this time, all legal sized crab was assumed to be retained. The legal crab proportion could also be used for calculation of OFL when fishermen changed to retain all legal sized crab due to changes in market preference and that retention probability in previous years are not applicable.

Plot the legal biomass over time using the different proportions of legal size crab to better understand the magnitude of the impact of the change.

Author reply:

Norton Sound red king assessment model is based on **abundance**. Time series of legal crab is plotted in Figure 4; however, this is based on size (CL>104mm) not observed legal proportion. Estimating legal size crab biomass as well as mature male biomass is calculated only at the time of OFL calculation. Thus, there is no meaning to plot the legal biomass time series by different proportion of legal crab.

OFL

The OFL should be specified based on total catch including retained catch and non-surviving discard. Specifying the OFL based on legal crab would result in higher OFLs than if based on retained crab. This would then translate to higher exploitation rates on the exploitable crab than the target rates and increased discard mortality on non-preferred size crab that must be sorted through to achieve the OFL.

Author reply:

Corrected. Note that observer survey was terminated in 2021. Thus, even though total OFL and ABC are specified, total catch (retained and discarded x discard mortality) will not be calculated.

LKTKS

The inclusion of local, traditional and subsistence knowledge (LKTKS) information in the assessment, an effort the SSC understands cannot be fully pursued until appropriate protocols are developed and pandemic conditions ease.

Author reply:

We look for the Taskforce's progress in Norton Sound red king crab case study writeup that is projected to be finished in April 2022.

C. Introduction

1. Species:

red king crab (*Paralithodes camtschaticus*) in Norton Sound, Alaska.

2. General Distribution:

Norton Sound red king crab is one of the northernmost red king crab populations that can support a commercial fishery (Powell et al. 1983). It is distributed throughout Norton Sound with a westward limit of 167-168° W. longitude, depths less than 30 m, and summer bottom temperatures above 4ºC. 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 1976-2021 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) ºC 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 within Norton Sound. 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) may stay offshore in the winter, based on findings that large crab are not found nearshore during spring offshore migration periods (Jenefer Bell, ADF&G, personal communication). Molting occurs in fall: late August – November for male and winter: Jan-March based on laboratory observation (Leah Zacher and Jennifer Gardner NOAA-AFSC personal comm). 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 NSRKC is harvested during the summer commercial fishery, whereas the winter commercial and subsistence fisheries occur nearshore through ice.

Summer Commercial Fishery

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 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. In 2005 and 2006, commercial buyers (NSEDC: Norton Sound Economic Development Corporation) accepted only legal crab of ≥ 5 inch CW. This preference became permanent since 2008.

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. In 2020 the Board of Fisheries closed Norton Sound area east of 167 degrees W. longitude for commercial summer crab fisheries. In 2021 NSEDC stopped purchasing Norton Sound red king crab,

CDQ Fishery

The Norton Sound and Lower Yukon CDQ groups divide the CDQ allocation. Only fishers designated by the Norton Sound and Lower Yukon CDQ groups are allowed to participate in this portion of the king crab fishery. Fishers are required to have a CDQ fishing permit from the Commercial Fisheries Entry Commission (CFEC) and register their vessel with the Alaska Department of Fish and Game (ADF&G) before begin fishing. Fishers operate under the authority of each CDQ group. CDQ harvest share is 7.5% of total projected harvest, which can be prosecuted in both summer and winter fisheries season.

Winter Commercial Fishery

The winter commercial crab fishery is a small fishery using hand lines and pots through the nearshore ice. On average 10 permit holders harvested 2,500 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 the 2017 season. The winter red king crab commercial fishing season was also set from January 15 to April 30, unless changed by an emergency order. The new regulation became in effect stating the 2016 season.

Subsistence Fishery

Winter subsistence fishery has a long history; however, harvest information is available only since the 1977/78 season. The majority of subsistence crab fishery occurs in winter using hand lines and pots through nearshore ice. Average annual winter subsistence harvest is 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. The summer subsistence fishery was not included in the assessment model.

Harvest of both commercial and subsistence winter fisheries is influenced largely by availability of stable ice condition. Low harvest can occur due to poor ice condition, regardless of crab abundance.

1. 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.

In practice, GHL is set to be under ABC retained that was derived from retained OFL.
Since 2021 OFL and ABC of Norton Sound red king crab total catch that include mortality of both retained and unretained crab.

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)
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.**
2008	**Commercially accepted legal crab size changed from ≥ 5 inch CW**
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.

2020	BOF closed summer commercial fishery E of 164 Latitude.
2021	NSEDC stopped purchasing Norton Sound red king crab.

2. 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.

D. Data

1. Summary of new information:

Winter commercial and subsistence fisheries:

The winter commercial fishery catch in 2021 was 320 crab (911 lb.). Subsistence retained crab catch was 2,892 and unretained was 1,763 crab or 38 % of total catch (Table 2).

Summer commercial fishery:

The summer commercial fishery opened on 6/25/2021 and closed on 9/03/2021. Total of 0 crab (0 lb.) were harvested (Table 1).

Standardized CPUE

Standardized CPUE for the years of 1993, 2020, 2021 were not calculated because commercial fishery did not occur.

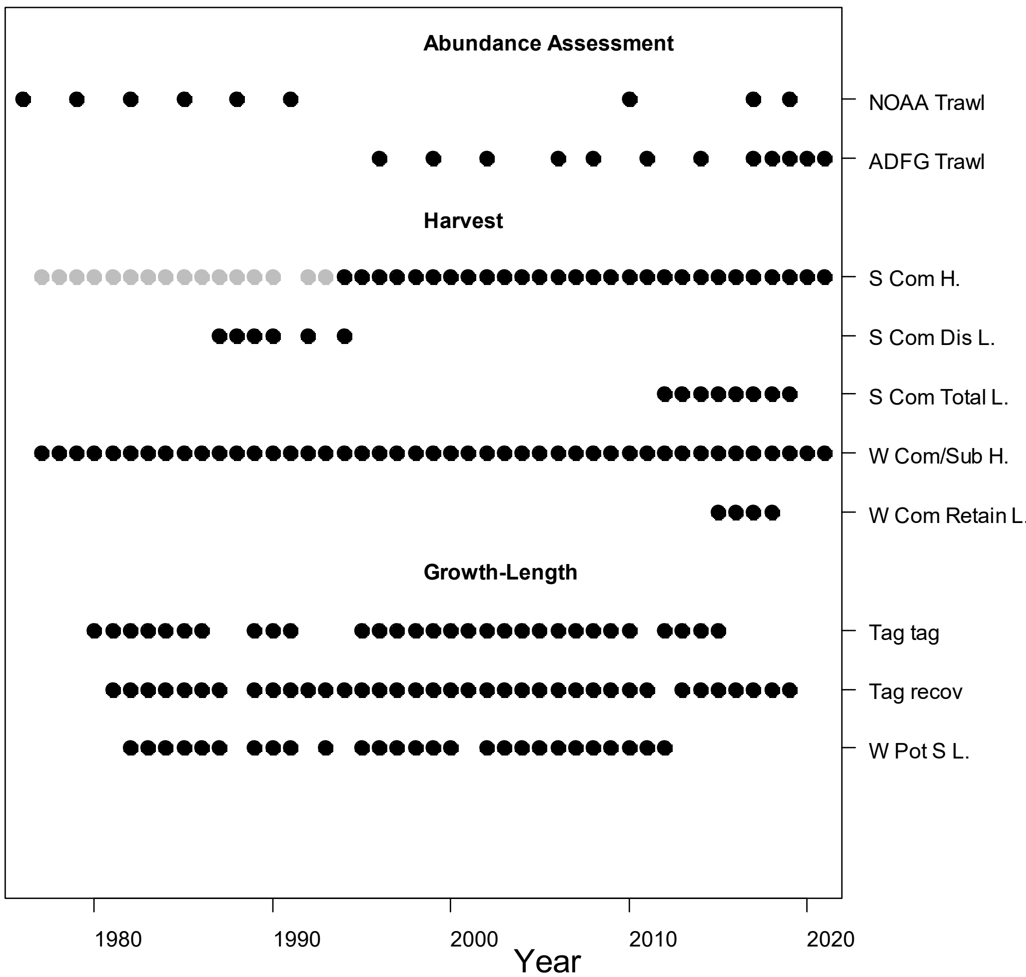
Recalculate standardized CPUE:
3 periods:
1977-1993: Large Scale commercial fishery
1994-2007: Small boat commercial fishery
2008-2019: Small boat commercial fishery with high grading.
NOTE: Time periods revised.

Discards
Estimates of discards is based on author preferred proportional method, instead of LNR2 method that CPT selected in 2020.

Summer Trawl Survey

Annual ADFG summer trawl survey was conducted in 7/19 – 8/3 2021. Because of unfavorable weather condition, 39 stations were surveyed. Total abundance estimates are 2,400,000 lb with CV 0.60.

2. Available survey, catch, and tagging data



3.

	Years	Data Types	Tables
Summer trawl survey	76,79,82,85,88,91,96, 99, 02,06,08,10,11,14,17-21	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	77-90,92-21	Retained catch Standardized CPUE, Length-shell comp	1 1 4

Summer Com total catch	12-21	Length-shell comp	9
Summer Com Discards	87-90,92,94, 12-19	Length-shell comp	8
Winter subsistence fishery	76-21	Total & Retained catch	2
Winter commercial fishery	78-21	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. In 2018 and 2019 fishery seasons, a total of 8 and 13 kg (mortality applied) of NSRKC were taken from the groundfish fisheries (CPT 2020). However, all of bycatch occurred in the west of 168.0 longitude where none of NSRKC survey has been conducted.

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

4. Other miscellaneous data:

   Satellite tag migration tracking (NOAA 2016, ADFG 2020-21)

   Spring offshore migration distance and direction (2012-2015)

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

   Growth increment, molting, and mating of captured crab (2021)

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 and issues:

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 model had following model mismatches:

1. Model projects higher abundance-proportions 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).

2. Poor model fit to trawl survey abundance. This was further exasperated when M = 0.18 for all length.

Those issues resulted in model overestimating projected abundance. Following describes historical model adjustments attempted.

1. Model projects higher abundance-proportions of large size class (> 123mm CL) of crab than observed.

   This issue has been solved by assuming (3-4 times) higher *M* for the large crab (i.e., *M* = 0.18 for length classes ≤ 123mm, and higher M for > 123mm) (NPFMC 2012, 2013, 2014, 2015, 2016, 2017, 2018). However, because this solution is biologically unusual, alternative assumptions have been considered.

   a. Large crabs move out of the survey and fishing area

      In modeling, this was dealt with by setting dome shaped survey and commercial catch selectivity. However, this resulted in model estimating MMB twice higher than default model. NBS surveys (2010, 2017, 2019) also did not find high red king crab population outer Norton Sound area.

   b. Higher natural mortality (*M*) than assumed *M* = 0.18

      Profile analyses and estimating *M* across all length classes resulted in higher *M* (0.3-0.45) than default *M*=0.18 (NPFMC 2013, 2017). In Tier 4, higher M also results in higher OFL.

c. Model overestimating molting and growth probability (transition matrix)

The transition matrix was estimated from outside to inside of the assessment model (NPFMC 2014). However, the estimated transition matrix was similar to that estimated outside of the model. Individual length specific molting probability estimates were also similar to default inverse logistic molting function (NPFMC 2016). Time variant molting function (random walk) process did not improve model fit.

d. Gradual size dependent natural mortality.

The default assessment model assumes abrupt M increase at size CL 124mm or greater. An alternative model suggested that *M* gradually increasing from size as low as CL 94mm; however, overall model fit did not improve from the default model (NPFMC 2017).

2. Poor model fit to trawl survey abundance, especially NMFS survey (1976-1992) data

In addition to triennial trawl survey, standardized summer commercial catch CPUE was included in the assessment model (2013). Additional variance was also included in standardize CPUE model cv (2014).
In addition, time variant CPUE and trawl survey *q* was included. CPUE q were pre and post 1993, reflecting changes in fishery practices. Trawl survey *q* was included for NMFS (1976-1992) and NBS (2010-2019), but trawl survey *q* for ADFG trawl survey was assumed to be 1.0. Assuming NMFS and NBS survey *q* to 1.0 resulted in estimating ADFG trawl survey *q* greater than 1.0 (i.e. trawl survey overestimates abundance).

When *M* = 0.18 is assumed for all length classes, the model appears to ignore all trawl survey data. Survey q for NMFS and NBS survey increased to 1.65 and 1.28 respectively (See figure

Further improving model fit, input sample size for size-shell composition was lowered (NPFMC 2012, 2013, 2015). However, this also resulted in lower fit to size-shell composition data. Alternative model weighting methods (e.g. Francis 2012) have been tried, but those did not improve model fit.

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)
4) Standardize commercial catch cpue and replace likelihood of commercial catch efforts to standardized commercial catch cpue with weight = 1.0.
5) Eliminate summer pot survey data from likelihood.
6) Estimate survey *q* of 1976-1991 NMFS survey with maximum of 1.0.
7) 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 2017) CPT-SSC suggested no model alternatives

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.

2020 (NPFMC 2020) CPT-SSC suggested no model alternatives
2021 (NPFMC 2021) Included discards data. CPT-SSC suggested no model alternatives

2. Model Description

a. Description of overall modeling approach:

The model is a male-only size structured model and based on **abundance** that combines multiple sources of surveys, fishery catches and discards, and mark-recovery data using a maximum likelihood modeling framework to estimate population dynamics under fisheries. The model is an extension of the length-based model developed by Zheng et al. (1998) for Norton Sound red king crab.

The model estimates abundances of male crab with CL ≥64 mm and with 10-mm length intervals (8 length classes, ≥134mm) because few crab measuring less than 64 mm CL were caught during surveys or fisheries. The model treats newshell and oldshell male crab separately but assumes they have the same molting probability, natural mortality, and fishery and survey selectivity.

One critical characteristic of the model is that the model does not estimate fishing mortality (*F*). Observed harvests were considered accurate and thus directly subtracted from the model estimated abundance.

The modeling scheme and data is described in the following figure.

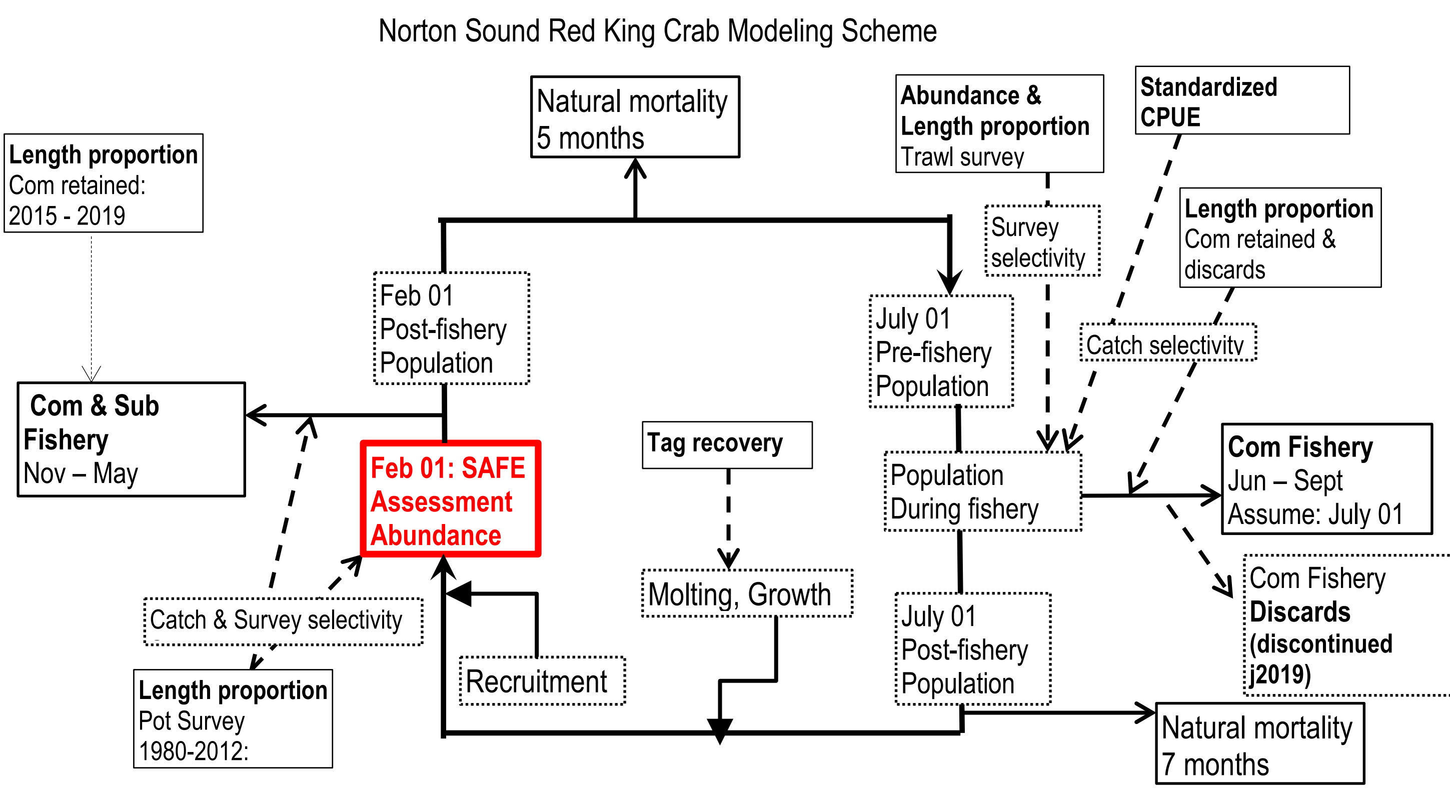


Figure: Norton Sound Red king crab model and data scheme. Bold type indicate data that were fitted to the model. Boxes in dotted line indicate model estimated parameters and quantities.

Natural mortality, M was set to 0.18 except for CL greater than 123mm that was estimated in the model.

Timeline of calendar events and crab modeling events:

- **Model year starts February 1st to January 31st of the following year.**
- **Initial Population Date: February 1st 1976, consisting only Newshell crab.**
- **Instantaneous fishing mortality: winter (February 1st) summer (July 1st) fishery**
- **Instantaneous molting and recruitment occur on July 1st**

- Critical model assumptions

NSRKC Crab Biology

3. Instantaneous annual natural mortality (*M*) is 0.18 and increase at the size greater than CL 123mm. *M* is constant over time.

4. Male crab size at maturity CL length 94mm.

5. Molting occurs in the right after the summer fishery.

6. Recruitment occurs in fall at the same time of molting.

   In NSRKC assessment modeling, recruitment is not a function of mature male, but *ad hoc* addition to the immature length classes 64mm- 93nnn to match the observed abundance and length composition following year. In modeling, this adjustment is done at the same time of molting-growth.

7. Molting probability is an inverse logistic function. Molted crab become newshell and unmolted crab become oldshell crab.

8. Growth increment is a function of length, constant over time. Molted crab does not shrink its size.

NSRKC Survey

1. Size selectivity is an asymptotic one parameter logistic function of 1.0 at the length class CL 134mm and the same across years and survey agencies.

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

This logistic function form was adopted during the crab workshop in 2005 as an way to reduce model parameters and parameter estimation stability.

Although the survey differ among NOAA (1976-1991), ADF&G (1996-present), and NOAA NBS (2010-2019) in terms of survey vessel and trawl net structure, selectivity of all surveys were assumed to be identical. Model fits separating and combining the surveys were examined in 2015; however, selectivity was essentially identical (1.0 across all size classes) (NPFMC 2015). For model parsimony, SSC recommended that using only one selectivity.

2. Trawl survey catchability is 1.0 for ADF&G (1996-present) survey, and < 1.0 (model estimate) for NOAA (1976-1992) and NOAA NBS (2010-present) survey.

   Lower survey q for NOAA survey was recommended in 2013 assessment (NPFMC 2013). Model estimated survey q for ADF&G trawl survey was greater than 1.0 (NPFMC 2013, 2019). CPT-SSC recommended to fix survey q to 1.0 for ADF&G survey.

3. Winter pot survey selectivity is a dome shaped function: a combination of a reverse logistic function of starting from length class CL 84mm and model estimate for CL < 84mm length classes. Selectivity is constant over time.

Winter pot survey selectivity is a dome shaped function: a combination of a reverse logistic function of starting from length class CL 84mm and model estimate for CL < 84mm length classes. Selectivity is constant over time.

$$S_{w,l} = \frac{1}{1+e^{\alpha(L-\beta)}}$$

This assumption is based on the fact that a low proportion of large crab are caught in the nearshore area where winter surveys occur. This does not necessarily imply that the crab pots are less selective to large crabs. Alternatively, this may imply that fewer large crab migrate into nearshore waters in winter.

NSRKC Fisheries

1. Fisheries occur twice on July 01 and Feb 01 and instantaneous.

2. Summer commercial fisheries size selectivity is an asymptotic one parameter logistic function of 1.0 at the length class CL 134mm. Selectivity is constant overtime.

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

This logistic function form was adopted during the crab workshop in 2005 as an way to reduce model parameters and parameter estimation stability. Although summer commercial fishery changed greatly among the periods (1977-1992, 1993-present) in terms of fishing vessel composition, 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 (NPFMC 2015). For model parsimony, SSC recommended using only one selectivity.

4. Winter commercial pot selectivity is the same as the selectivity of the winter pot survey.

   This assumption is based on the fact that the survey pot was similar to the one used for subsistence, and that many commercial fishermen are also catch for subsistence. However, by regulation winter commercial king crab pots can be any dimension (5AAC 34.925(d)) and recent popularity of winter commercial fishery may have deviated this assumption.

5. Winter subsistence fishery retains crab size greater than 94mm.

6. Subsistence fishery does not have retainable size limit, so that we assumed that it retains crab smaller than legal sized crab (~104mm CL)

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

   Discards mortality was specified by CPT. No empirical estimates are available.

Data quality

All size-shell composition data are collected accurately without systematic bias.

Annual retained catch is accurate without error.

In Norton Sound, almost all crabs are sold to NSEDC. This ensures accuracy of harvest.

Changes of assumptions since last assessment:

None

3. Model Selection and Evaluation

a. Description of alternative model configurations.

For 2021 final assessment, CPT-SSC adopted Model 19.0b (Discards data estimate by LNR2 method). For 2022 preliminary assessment, we prose Model 21.0 that is an update of the model Model 19.0e (Discards data estimated by Proportional method).

The updates are mostly due to changes in data inputs, which resulted in an increase of the number of parameters. The updates are:

1. Revision of fishery time periods. Revised the start year of high grading fishery period from 2005 to 2008, after review of management documents
2. Updates in standardized CPUE from a single model with 3 block periods (1977-1993, 1994-2007, 2008-2019) to 3 models for each period. This increased the model fishery q parameter from 1 to 3.
3. Increase of summer and winter commercial retention probabilities from 1 for each to 2 for each, indicating changes in retention probability before and after high grading fishery. Model 19.: indicating pre and post high grading in commercial fishery.

In addition, we included Model 21.1 that is Model 21.0 but assume M=0.18 for all size classes. The Model 21.1 is intended to illustrate rationales for increasing higher M for greater than 123mm length crabs

b. Evaluation of negative log-likelihood values.

	Jan 2021	Sept 2021	Sept 2021
Model	**19.0e**	**21.0**	**21.1**
Additional Parameters			-1
Total	325.55	320.39	379.73
TSA	11.03	11.33	32.70
St.CPUE	-24.23	-36.35	-28.04
TLP	122.28	124.89	128.07
WLP	38.48	38.51	40.04
CLP	49.21	48.39	64.28

OBS	24.37	24.49	25.06
REC	2.72	2.81	2.54
WN	17.81	20.15	19.22
DIS	1.01	3.61	4.03
TAG	82.77	82.55	91.39
BMSY(mil.lb)		4.48	2.55
MMB 2021 (mil.lb)		5.22	4.85
Retainable Crab (mil.lb)			
Discards Crab (mil.lb)			
OFL(mil.lb)			
M	0.18/0.59	0.18/0.62	0.18

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
DIS: Summer commercial discards abundance

4. Results

The 2022 assessment model results (Model 21.0) were similar to the 2021 model results (Model 19.0e). Between the two model results, likelihood components of no data changes (WLP, CLP, OBS, WN, DIS) were similar, except for WN. Trawl survey likelihood, even with additional one year of data did not change likelihood greatly. Likelihood of St.CPUE changed greatly between 2021 and 2022. This is due to changes in calculation of St.CPUE that largely reduced SE (Appendix B). This resulted in an increase of estimates of additional variance parameter from 0 to 0.04. Model fit to trawl survey abundance and standardized CPUE (Figure 7, 8, 21) appeared reasonable, except possibly for CPUE in 2019. This could be due to the model overestimating abundance, or that the commercial fishery in 2019 was exceptionally poor. In Norton Sound the area of the commercial fishery is limited in geography so that CPUE may not reflect abundance. Poor CPUE may indicate local depression (e.g. crabs did not move to fishery ground, or moved out of fishery ground before commercial fishery occurred).

Regarding model fit to trawl survey, the model estimates survey q of NMFS survey abundance to be 0.73 (1976-1992) and 0.93 (2010-2019), which indicates that NMFS surveys appear to underestimate NSRKC abundance. Those appear to be counter-intuitive since their survey coverage and expansion factors were greater than ADFG; but in fact NMFS survey estimates were lower than ADFG estimates when both surveys were operated (Table 3). Alternatively, ADFG trawl survey abundance can be overestimated. In fact, when NMFS survey q is assumed 1.0, ADFG survey q is estimated to be greater than 1.0.

Model estimated molting probability, selectivity, and retention probability appear to be reasonable (Figure 3). Trawl survey selectivity has been practically 1.0 across all sizes since inception of the assessment model, which resulted in estimates of logistic parameters hitting bounds. Although it is reasonable to fix trawl survey selectivity to 1.0, we intentionally kept this as logistic. Dome shaped winter pot selectivity not peaking 1.0 is not an issue for NSRKC assessment model. In the assessment model, selectivity is used to estimate size proportion, which is unaffected whether or not selectivity is standardized (Appendix A). The two retention probabilities for summer commercial fishery appear reasonable. The main difference is retention probability of the size class 94-103mm, in which the probability was lower for periods 2008-2019, reflecting the periods of high grading. Growth transition matrix and model fit to the tag recovery data appear to be reasonable. Lower model fit to size classes 64-73 and 74-84mm are partially due to low recovery sample size. Commercial fishery pots are not selective for those small sized crabs (Figure 3).

Overall, model fit to size composition (Figures 8-19) appear to be reasonable. As it has been pointed out, the model tends to overestimate the proportion of large crab in commercial harvest and trawl survey (Figure 15). The model also overestimated the proportions of oldshell crabs. This indicates overestimation of molting probability. Alternatively, it may indicate biased dock sampling (e.g., samplers tend to avoid picking up oldshell crabs from a torte), or commercial fishery not retaining oldshell crabs (e.g., shell condition specific retention probabilities). Furthermore, it is also possible that newshell crab does not necessarily indicate molted crab. For instance, Powell (1982) deduced that Norton Sound red king crab would molt in April because nearly all crab shells looked very new, just molted recently. But in fact, Norton Sound Red king crab molted in fall (late Sept-Nov) of previous year (Zacher NOAA). The assessment model assumes that unmolted crab becomes oldshell, but some newshell crabs may actually be unmolted ones.

The overestimation of large crabs in trawl survey (Figure 15) also indicates dome shaped size selectivity, as opposed to current model assumptions of logistic. In fact, the model choose reverse logistic selectivity when selectivity of each size class is estimated individually (NPFMC Year?). However, this results in a significant increase of crab abundance (i.e., model assumes existing of large crabs that are never observed.).

Poor model fit to winter commercial retained catch (Figure) is somewhat expected. The model assumes that winter commercial pot fisheries use smaller pots than are used for ADFG survey and are similar to the subsistence pot fishery. This assumption could have been reasonable when the winter commercial fishery was small and just extension of subsistence fishery. However, recent interests in winter commercial fisheries, winter commercial fishery gears may have been evolved.

As for model estimated abundance, NSRKC population appears to be relatively stable since mid-1980s after the initial decline from 1976-1979. Legal crab abundance and MMB is increasing since 2018 after the decline in mid-2010s, which was expected from large sublegal crab abundance in 2016-2018 and practically no fishery occurring in 2020 and 2021. Projected

MMB is above B_{MSY}, which indicates that Norton Sound red king crab is at Tier 4a status that is the same as 2021 assessment.

Comparisons of Model 21.0 and 21.1 illustrates issues assuming M=0.18 for all length classes. The most significantly, the model lowered historical trawl survey abundance and thus MMB by 40% (Figures 4,5,7). Moreover, Model 21.1 suggests that MMB increased more than 90% above the B_{MSY} in recent years. This is probably due to the model assuming ADFG survey q = 1.0. NMFS and NBS survey q were 1.64 and 1.28, indicating that the trawl surveys overestimated NSRKC abundance. Because ADFG survey abundance tend to be higher than NMFS and NBS survey, the model would estimate q > 1.0 for ADFG survey, which would have lessened the recent increase. Model 21.1 had poor fit to trawl survey. Lower st. CPUE values are due to greater additional variance (Model 21.0: 0.039 vs Model 21.1: 0.064). The Model 21.1 also had lower fit to all size composition data (Figures 9-13). Model 21.1 overestimated the proportion of large oldshell crabs in commercial retained and total catch (Figure 9, 12), which was more than the Model 21.0. Those justify the model assumption of higher *M* for large crabs (Model 21.0) that showed improved model fit to data than Model 21.1 of assuming *M*=0.18 for all sized crabs even though the latter model may be more biologically reasonable.

In summary, we recommend Model 21.0 be used for determination of OFL for the final SAFE in Jan 2022.

9. 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

The above sample sizes were arbitrary selected by examining model fit between abundance (trawl survey) data and model. Increasing input sample size generally resulted in decline of model fit totrawl survey abundance.

Weighting factor:

Recruitment SD: 0.5.

2. Tables of estimates.

   a. Model parameter estimates (Tables 11, 12, 13).
   b. Abundance and biomass time series (Table 14).
   c. Recruitment time series (Table 14).
   d. Time series of catch/biomass (Tables 15).

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 14).

   f. Plots of bubble and Pearson residuals (Figure 15- 20)

   f. RMSEs of trawl survey and standardized CPUE. QQ plots and histograms of residuals of trawl survey and standardized CPUE (Figure 21).

2. Retrospective analyses.

   To be completed in Jan 2022.

Hurtado-Ferro et al. (2015), provided guideline of Mohn's rho exceeding the range of (-0.15 to 0.2) for longer life-history and (-0.22 to 0.30) for shorter lived species, should cause for concern.

6. Uncertainty and sensitivity analyses.

F. Calculation of the OFL (To be completed in Jan 2022 final assessment model)

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 of M for the Norton Sound red king crab stock are uncertain.

At the Tier 4 level 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 1980-2022.

Estimated B_{MSY} proxy is: TBD million lb or TBD k ton.

Predicted mature male biomass in 2022 on February 01

Mature male biomass: TBD million lb. or TBD k ton

Since projected MMB is above B_{MSY} proxy,

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

Where F_{OFL} is calculated by

$$F_{OFL} = \gamma M$$

F_{OFL} of 0.18 for all length classes.

1. Calculation of OFL.

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

Retain_B is a biomass of legal crab subject to fisheries and is calculated as: projected abundance by length crab ($N_{w,l}$+ $O_{w,l}$)× fishery selectivity by length class ($S_{s,l}$) × retention probability of legal crab per length class ($S_{r,l}$) × average lb per length class (wm_l).

$$Retain\_B = \sum_l (N_{w,l,} + O_{w,l,}) S_{s,l} S_{r,l} wm_l$$

Unretained crab is defined as winter sublegal crab catchable to fishery

$$Unretain\_B = \sum_l (N_{w,l,} + O_{w,l,}) S_{s,l} (1 - S_{r,l}) wm_l$$

Determination of OFL

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:

$$B_s = B_w(1-\exp(-x\cdot F_{OFL}))e^{-0.42M}$$
$$OFL_r = (1-\exp(-(1-x)\cdot F_{OFL}))B_s$$

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

Where p is the proportion of winter crab harvest to total (winter + summer) harvest. We specified $p = 0.16$ that is average winter commercial harvest.

Solving x of the above (see Appendix A) , a revised retained OFL is

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

Accounting for difference in length specific natural mortality

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

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)

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

The total male OFL can be calculated as

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

However, because non-retained crabs are not evaluated, NSRKC OFL is limited to retained crab: OFL_r.

For calculation of the OFL_r 2021, we specified $p = 0.16$.

Projected legal male biomass catchable to fishery (Feb 01) in 2022 is: **TBD million lb or TBD k ton**

Retained OFL of Norton Sound Red King Crab for 2022 fishery is

OFL_r = TBD million lb. or TBD k ton

G. Calculation of the ABC

1. Specification of the probability distribution of the OFL.

Probability distribution of the OFL was derived using ADMB's 1 million MCMC.

ABC is calculated as (1-ABC buffer)·OFL

In 2015 ABC buffer of Norton Sound Red King Crab was set to 20%, which was increased to 30% in 2020 and to 40% in 2021.

Applying 40% buffer, Norton Sound Red King Crab retained ABC for 2021 fishery is

Not reported at this time.
ABC = TBD million lb. or TBD k ton

H. Rebuilding Analyses

Not applicable

I. Data Gaps and Research Priorities

The major data gap of Norton Sound red king crab is its overall biology, including natural mortality, size at maturity, spatial and temporal distribution and abundance, molting frequency and growth, as well as female abundance, fecundity, size at maturity, mating timing, spatial-temporal distribution and abundance. Specifically, the model assumes size dependent natural mortality (i.e. high natural mortality of > 123mm). Further missing is analyses of LK/TK and socio-economic impacts of NSRKC fisheries that could be highly significant in determination of management matrix such as ABC buffer.

Acknowledgments

We thank all CPT members for all review of the assessment model and suggestions for improvements and diagnoses.

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

Year	Guideline Harvest Level (lb) [b]	Commercial Harvest (lb) [a, b]		Number	Total Number (Open Access)			Total Pots		ST CPUE		Season Length		Mid-day from July
		Open Access	CDQ	Harvest	Vessels	Permits	Landings	Registered	Pulls	CPUE	SD	Days	Dates	
1977	[c]	517.787		195,877	7	7	13		5,457	3.29	0.68	60	[c]	0.049
1978	3,000.000	2,091.961		660,829	8	8	54		10,817	4.68	0.65	60	6/07-8/15	0.142
1979	3,000.000	2,931.672		970,962	34	34	76		34,773	2.87	0.64	16	7/15-7/31	0.088
1980	1,000.000	1,186.596		329,778	9	9	50		11,199	3.07	0.65	16	7/15-7/31	0.066
1981	2,500.000	1,379.014		376,313	36	36	108		33,745	0.86	0.64	38	7/15-8/22	0.096
1982	500.000	228.921		63,949	11	11	33		11,230	0.2	0.62	23	8/09-9/01	0.151
1983	300.000	368.032		132,205	23	23	26	3,583	11,195	0.9	0.65	3.8	8/01-8/05	0.096
\1984	400.000	387.427		139,759	8	8	21	1,245	9,706	1.59	0.65	13.6	8/01-8/15	0.110
1985	450.000	427.011		146,669	6	6	72	1,116	13,209	0.5	0.66	21.7	8/01-8/23	0.118
1986	420.000	479.463		162,438	3	3		578	4,284	1.74	0.7	13	8/01-8/25	0.153
1987	400.000	327.121		103,338	9	9		1,430	10,258	0.61	0.64	11	8/01-8/12	0.107
1988	200.000	236.688		76,148	2	2		360	2,350	2.36	0.86	9.9	8/01-8/11	0.110
1989	200.000	246.487		79,116	10	10		2,555	5,149	1.21	0.61	3	8/01-8/04	0.096
1990	200.000	192.831		59,132	4	4		1,388	3,172	1.08	0.68	4	8/01-8/05	0.099
1991	340.000			0	No Summer Fishery									
1992	340.000	74.029		24,902	27	27		2,635	5,746	0.17	0.6	2	8/01-8/03	0.093
1993	340.000	335.790		115,913	14	20	208	560	7,063	0.9	0.35	52	7/01-8/28	0.093
1994	340.000	327.858		108,824	34	52	407	1,360	11,729	0.81	0.34	31	7/01-7/31	0.044
1995	340.000	322.676		105,967	48	81	665	1,900	18,782	0.42	0.34	67	7/01-9/05	0.093
1996	340.000	224.231		74,752	41	50	264	1,640	10,453	0.51	0.34	57	7/01-9/03	0.101
1997	80.000	92.988		32,606	13	15	100	520	2,982	0.84	0.35	44	7/01-8/13	0.074
1998	80.000	29.684	0.00	10,661	8	11	50	360	1,639	0.79	0.36	65	7/01-9/03	0.110
1999	80.000	23.553	0.00	8,734	10	9	53	360	1,630	0.92	0.36	66	7/01-9/04	0.104
2000	336.000	297.654	14.87	111,728	15	22	201	560	6,345	1.24	0.34	91	7/01- 9/29	0.126
2001	303.000	288.199	0	98,321	30	37	319	1,200	11,918	0.64	0.34	97	7/01- 9/09	0.104
2002	248.000	244.376	15.226	86,666	32	49	201	1,120	6,491	1.23	0.34	77	6/15-9/03	0.060
2003	253.000	253.284	13.923	93,638	25	43	236	960	8,494	0.85	0.34	68	6/15-8/24	0.058
2004	326.500	314.472	26.274	120,289	26	39	227	1,120	8,066	1.27	0.34	51	6/15-8/08	0.033
2005	370.000	370.744	30.06	138,926	31	42	255	1,320	8,867	1.19	0.34	73	6/15-8/27	0.058
2006	454.000	419.191	32.557	150,358	28	40	249	1,120	8,867	1.31	0.34	68	6/15-8/22	0.052
2007	315.000	289.264	23.611	110,344	38	30	251	1,200	9,118	1.02	0.34	52	6/15-8/17	0.036
2008	412.000	364.235	30.9	143,337	23	30	248	920	8,721	1.32	0.34	73	6/23-9/03	0.079
2009	375.000	369.462	28.125	143,485	22	27	359	920	11,934	0.84	0.34	98	6/15-9/20	0.090
2010	400.000	387.304	30	149,822	23	32	286	1,040	9,698	1.22	0.34	58	6/28-8/24	0.074
2011	358.000	373.990	26.851	141,626	24	25	173	1,040	6,808	1.58	0.34	33	6/28-7/30	0.038
2012	465.450	441.080	34.91	161,113	40	29	312	1,200	10,041	1.29	0.34	72	6/29-9/08	0.093
2013	495.600	373.278	18.585	130,603	37	33	460	1,420	15,058	0.67	0.33	74	7/3-9/14	0.110
2014	382.800	360.860	28.148	129,657	52	33	309	1,560	10,127	1.12	0.34	52	6/25-8/15	0.052
2015	394.600	371.520	29.595	144,255	42	36	251	1,480	8,356	1.45	0.34	26	6/29-7/24	0.033
2016	517.200	416.576	3,583	138,997	36	37	220	1,520	8,009	1.27	0.34	25	6/27-7/21	0.025
2017	496,800	411,736	0	135,322	36	36	270	1,640	9,401	1.1	0.34	30	6/26-7/25	0.027
2018	319,400	298,396	0	89,613	34	34	256	1,400	8,797	0.64	0.34	35	6/24-7/29	0.030
2019	150,600	73,784	1,239	24,506	24	26	146	1,096	5,438	0.26	0.34	62	6/25-9/03	0.068
2020	170,000	0	0	0	0	0	0	0	0	NA	NA	0	6/25-9/03	NA
2021	290.000	0	0	0	0	0	0	0	0	NA	NA	0	6/15-9/03	NA

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

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

		Commercial			Subsistence				
Model Year	Year[a]	# of Fishers	# of Crab Harvested	Winter[b]	Permits Issued	Permits Returned	Permits Fished	Total Crab Caught[c]	Total Crab Retained[d]
1978	1978	37	**9,625**	1977/78	290	206	149	**NA**	**12,506**
1979	1979	1[f]	**221[f]**	1978/79	48	43	38	**NA**	**224**
1980	1980	1[f]	**22[f]**	1979/80	22	14	9	**NA**	**213**
1981	1981	0	**0**	1980/81	51	39	23	**NA**	**360**
1982	1982	1[f]	**17[f]**	1981/82	101	76	54	**NA**	**1,288**
1983	1983	5	**549**	1982/83	172	106	85	**NA**	**10,432**
1984	1984	8	**856**	1983/84	222	183	143	**15,923**	**11,220**
1985	1985	9	**1,168**	1984/85	203	166	132	**10,757**	**8,377**
1986	1985/86	5	**2,168**	1985/86	136	133	107	**10,751**	**7,052**
1987	1986/87	7	**1,040**	1986/87	138	134	98	**7,406**	**5,772**
1988	1987/88	10	**425**	1987/88	71	58	40	**3,573**	**2,724**
1989	1988/89	5	**403**	1988/89	139	115	94	**7,945**	**6,126**
1990	1989/90	13	**3,626**	1989/90	136	118	107	**16,635**	**12,152**
1991	1990/91	11	**3,800**	1990/91	119	104	79	**9,295**	**7,366**
1992	1991/92	13	**7,478**	1991/92	158	105	105	**15,051**	**11,736**
1993	1992/93	8	**1,788**	1992/93	88	79	37	**1,193**	**1,097**
1994	1993/94	25	**5,753**	1993/94	118	95	71	**4,894**	**4,113**
1995	1994/95	42	**7,538**	1994/95	166	131	97	**7,777**	**5,426**
1996	1995/96	9	**1,778**	1995/96	84	44	35	**2,936**	**1,679**
1997	1996/97	2[f]	**83[f]**	1996/97	38	22	13	**1,617**	**745**
1998	1997/98	5	**984**	1997/98	94	73	64	**20,327**	**8,622**
1999	1998/99	5	**2,714**	1998/99	95	80	71	**10,651**	**7,533**
2000	1999/00	10	**3,045**	1999/00	98	64	52	**9,816**	**5,723**
2001	2000/01	3	**1,098**	2000/01	50	27	12	**366**	**256**
2002	2001/02	11	**2,591**	2001/02	114	61	45	**5,119**	**2,177**
2003	2002/03	13	**6,853**	2002/03	107	70	61	**9,052**	**4,140**
2004	2003/04	2[f]	**522 [f]**	2003/04[g]	96	77	41	**1,775**	**1,181**
2005	2004/05	4	**2,091**	2004/05	170	98	58	**6,484**	**3,973**
2006	2005/06	1[f]	**75[f]**	2005/06	98	97	67	**2,083**	**1,239**
2007	2006/07	8	**3,313**	2006/07	129	127	116	**21,444**	**10,690**
2008	2007/08	9	**5,796**	2007/08	139	137	108	**18,621**	**9,485**
2009	2008/09	7	**4,951**	2008/09	105	105	70	**6,971**	**4,752**
2010	2009/10	10	**4,834**	2009/10	125	123	85	**9,004**	**7,044**
2011	2010/11	5	**3,365**	2010/11	148	148	95	**9,183**	**6,640**
2012	2011/12	35	**9,157**	2011/12	204	204	138	**11,341**	**7,311**
2013	2012/13	26	**22,639**	2012/13	149	148	104	**21,524**	**7,622**
2014	2013/14	21	**14,986**	2013/14	103	103	75	**5,421**	**3,252**
2015	2014/15	44	**41,062**	2014/15	155	153	107	**9,840**	**7,651**
2016	2015/16	25	**29,792**	2015/16	139	97	64	**6,468**	**5,340**
2017	2017	43	**26,008**	2017	163	163	109	**7,185**	**6,039**
2018	2018	28	**9,180**	2018	123	120	82	**5,767**	**4,424**
2019	2019	6	**1,050**	2019	101	101	60	**2,080**	**1,545**
2020	2020	1	**conf**	2020	79	79	50	**813**	**548**
2021	2021	5	**320**	2021	103	103	76	**4,655**	**2,892**

a Prior to 1985 the winter commercial fishery occurred from January 1 - April 30. As of March 1985, fishing may occur from November 15 - May 15.

b The winter subsistence fishery occurs during months of two calendar years (as early as December, through May).

c The number of crab actually caught, **including females**

d The number of crab retained is the number of crab caught and kept, **including females**

f Confidentiality was waived by the fishers.

h Prior to 2005, permits were only given out of the Nome ADF&G office. Starting with the 2004-5 season, permits were given out in Elim, Golovin, Shaktoolik, and White Mountain.

Table 3. Summary of triennial trawl survey Norton Sound male red king crab abundance estimates (x 1000) (CL ≥ 64mm) . Trawl survey abundance estimate is based on 10×10 nm^2 grid, except for 2010 and 2017 (20×20 nm^2). Bold typed data are used for the assessment model.

Year	Dates	Survey Agency	Survey method	Abundance ≥64 mm	CV	Female N	% barren	% clutch full	% clutch full 95% CI
1976	9/02 – 9/25	NMFS	Trawl	**4301.8**	**0.31**	181	2.5	66.7	62.4-71.0
1979	7/26 - 8/05	NMFS	Trawl	**1457.4**	**0.22**	42	25.0	79.9	64.8-94.8
1980	7/04 - 7/14	ADFG	Pots	2092.3	N/A				
1981	6/28 - 7/14	ADFG	Pots	2153.4	N/A				
1982	7/06 - 7/20	ADFG	Pots	1140.5	N/A				
1982	9/05 - 9/11	NMFS	Trawl	**3548.9**	**0.25**	269	0	84.3	81.5-87.2
1985	7/01 - 7/14	ADFG	Pots	2320.4	0.083				
1985	9/16 -10/01	NMFS	Trawl	**2424.9**	**0.26**	151	0	87.5	NA
1988	8/16 - 8/30	NMFS	Trawl	**2702.3**	**0.29**	219	1.0	80.7	77.3-84.2
1991	8/22- 8/30	NMFS	Trawl	**3132.5**	**0.43**	105	0	69.3	57.7-80.8
1996	8/07 - 8/18	ADFG	Trawl	**1283.0**	**0.25**	168	30.8	71.9	65.9-77.9
1999	7/28 - 8/07	ADFG	Trawl	**2608.0**	**0.24**	81	4.7	80.4	76.0-84.7
2002	7/27 - 8/06	ADFG	Trawl	**2056.0**	**0.36**	168	4.7	76.8	73.4-80.2
2006	7/25 - 8/08	ADFG	Trawl	**3336.0**	**0.39**	194	3.6	67.3	63.2-71.5
2008	7/24 - 8/11	ADFG	Trawl	**2894.2**	**0.31**	28	3.3	56.1	48.5-61.7
2010	7/27 - 8/09	NMFS	Trawl	**1980.1**	**0.44**	116	0	70.2	63.8-78.5
2011	7/18 - 8/15	ADFG	Trawl	**3209.3**	**0.29**	135	9.8	67.2	61.7-72.6
2014	7/18 - 7/30	ADFG	Trawl	**5934.6**	**0.47**	60	0	60.4	54.3-66.6
2017	7/28 - 8/08	ADFG	Trawl	**1762.1**	**0.22**	43	21.4	71.6	60.0-82.7
2017	8/18 - 8/29	NMFS	Trawl	**1035.8**	**0.40**	58	0	80.0	72.5-87.5
2018	7/22 - 7/29	ADFG	Trawl	**1108.9**	**0.25**	424	15.8	76.3	59.7-83.5
2019	7/17-7/29	ADFG	Trawl	**4660.8**	**0.60**	386	47.8	50.6	43.1-56.4
2019	8/04-8/07	NMFS	Trawl	**2532.4**	**0.26**	94	17.6	47.9	36.8-58.9
2020	7/31-8/14	ADFG	Trawl	**1716.5**	**0.27**	186	4.5	66.2	61.6-70.8
2021	7/19-8/03	ADFG	Trawl	**2400.0**	**0.60**	90	3.4	59.0	54.9-64.6

Abundance of NMFS survey (1976-1991) was estimated by NMFS, multiplying the mean CPUE (# NRKC/NM^2) across all hauls (including re-tows) to a standard survey area (7600NM^2).

In contrast, abundance of ADFG (1996-2019) and NMFS (2010,2017) survey were estimated by ADFG by multiplying CPUE (# NRKC/NM^2) of each station to an area represented by the station (~100NM^2) and summing across all surveyed station (ADFG: 4700 – 5200NM^2. NOAA 5841 NM^2).

%barren: # mature female with no eegs/# mature female

Clutch fullness index of both NOAA and ADFG were converted as follows

NOAA Code	NOAA Fullness	Assigned %	ADFG code	ADFG Fullness	Assigned %
2	0-1/8	6.25	3	1-29%	15
3	1/8-1/4	18.75	4	30-59%	45
4	1/4 – 1/2	27.5	5	60-89%	75
5	1/2 – 3/4	62.5	6	90-100%	95
6	3/4 – 1	87.5			
7	>1	100			

Table 4. Summer commercial retained catch length-shell compositions.

		New Shell								Old Shell							
Year	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1977	1549	0	0	0	0.00	0.42	0.34	0.08	0.05	0	0	0	0.00	0.06	0.04	0.01	0.00
1978	389	0	0	0	0.01	0.19	0.47	0.26	0.04	0	0	0	0.00	0.01	0.01	0.01	0.00
1979	1660	0	0	0	0.03	0.23	0.38	0.26	0.07	0	0	0	0.00	0.03	0.00	0.00	0.01
1980	1068	0	0	0	0.00	0.10	0.31	0.37	0.18	0	0	0	0.00	0.00	0.01	0.02	0.01
1981	1784	0	0	0	0.00	0.07	0.15	0.28	0.23	0	0	0	0.00	0.00	0.05	0.12	0.09
1982	1093	0	0	0	0.04	0.19	0.16	0.22	0.29	0	0	0	0.00	0.01	0.02	0.03	0.03
1983	802	0	0	0	0.04	0.41	0.36	0.06	0.03	0	0	0	0.00	0.04	0.01	0.02	0.02
1984	963	0	0	0	0.10	0.42	0.28	0.06	0.01	0	0	0	0.01	0.07	0.05	0.01	0.00
1985	2691	0	0	0.00	0.06	0.31	0.37	0.15	0.02	0	0	0	0.00	0.03	0.03	0.01	0.00
1986	1138	0	0	0	0.03	0.36	0.39	0.12	0.02	0	0	0	0.00	0.02	0.04	0.02	0.00
1987	1985	0	0	0	0.02	0.18	0.29	0.27	0.11	0	0	0	0.00	0.03	0.06	0.03	0.01
1988	1522	0	0.00	0	0.02	0.20	0.30	0.18	0.04	0	0	0	0.01	0.06	0.10	0.07	0.02
1989	2595	0	0	0	0.01	0.16	0.32	0.17	0.05	0	0	0	0.00	0.06	0.12	0.09	0.02
1990	1289	0	0	0	0.01	0.14	0.35	0.26	0.07	0	0	0	0.00	0.04	0.07	0.05	0.01
1991																	
1992	2566	0	0	0	0.02	0.20	0.27	0.14	0.09	0	0	0	0.00	0.08	0.13	0.06	0.02
1993	17804	0	0	0	0.01	0.23	0.39	0.23	0.03	0	0	0	0.00	0.02	0.04	0.03	0.01
1994	404	0	0	0	0.02	0.09	0.08	0.07	0.02	0	0	0	0.02	0.19	0.25	0.20	0.05
1995	1167	0	0	0	0.04	0.26	0.29	0.15	0.05	0	0	0	0.01	0.05	0.07	0.06	0.01
1996	787	0	0	0	0.03	0.22	0.24	0.09	0.05	0	0	0	0.01	0.12	0.14	0.08	0.02
1997	1198	0	0	0	0.03	0.37	0.34	0.10	0.03	0	0	0	0.00	0.06	0.04	0.03	0.01
1998	1055	0	0	0	0.03	0.23	0.24	0.08	0.03	0	0	0	0.02	0.11	0.14	0.08	0.03
1999	562	0	0	0	0.06	0.29	0.24	0.18	0.09	0	0	0	0.00	0.02	0.05	0.04	0.00
2000	17213	0	0	0	0.02	0.30	0.39	0.11	0.02	0	0	0	0.00	0.05	0.07	0.04	0.01
2001	20030	0	0	0	0.02	0.22	0.37	0.21	0.07	0	0	0	0.00	0.02	0.05	0.02	0.01
2002	5219	0	0	0	0.04	0.23	0.28	0.25	0.07	0	0	0	0.00	0.03	0.04	0.03	0.01
2003	5226	0	0	0	0.02	0.37	0.32	0.12	0.03	0	0	0	0.00	0.02	0.05	0.05	0.01
2004	9606	0	0	0	0.01	0.38	0.39	0.11	0.03	0	0	0	0.00	0.03	0.03	0.01	0.01
2005	5360	0	0	0	0.00	0.25	0.47	0.16	0.02	0	0	0	0.00	0.02	0.05	0.02	0.01
2006	6707	0	0	0	0.00	0.18	0.35	0.17	0.02	0	0	0	0.00	0.05	0.14	0.07	0.01
2007	6125	0	0	0	0.01	0.36	0.34	0.14	0.03	0	0	0	0.00	0.02	0.06	0.03	0.01
2008	5766	0	0	0	0.00	0.35	0.35	0.06	0.01	0	0	0	0.00	0.09	0.09	0.04	0.01
2009	6026	0	0	0	0.01	0.34	0.33	0.11	0.02	0	0	0	0.00	0.08	0.08	0.02	0.01
2010	5902	0	0	0	0.01	0.39	0.36	0.10	0.01	0	0	0	0.00	0.05	0.05	0.02	0.00
2011	2552	0	0	0	0.00	0.32	0.40	0.12	0.02	0	0	0	0.00	0.06	0.06	0.02	0.00
2012	5056	0	0	0	0.00	0.24	0.46	0.18	0.02	0	0	0	0.00	0.03	0.04	0.02	0.00
2013	6072	0	0	0	0.00	0.24	0.37	0.24	0.06	0	0	0	0.00	0.01	0.04	0.02	0.00
2014	4682	0	0	0	0.01	0.28	0.24	0.18	0.07	0	0	0	0.00	0.04	0.09	0.07	0.02
2015	4173	0	0	0	0.01	0.48	0.28	0.10	0.03	0	0	0	0.00	0.02	0.03	0.03	0.01
2016	1543	0	0	0	0.00	0.25	0.47	0.16	0.03	0	0	0	0.00	0.02	0.02	0.03	0.01
2017	3412	0	0	0	0.00	0.18	0.39	0.21	0.03	0	0	0	0.01	0.03	0.12	0.05	0.01
2018	2609	0	0	0	0.00	0.11	0.32	0.32	0.08	0	0	0	0	0.01	0.08	0.08	0.02
2019	1136	0	0	0	0.01	0.32	0.23	0.13	0.03	0	0	0	0	0.02	0.10	0.14	0.03

Table 5. Winter commercial catch length-shell compositions.

		New Shell								Old Shell							
Year	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
2015	576	0	0	0	0.07	0.50	024	0.06	0.01	0	0	0	0.01	0.04	0.03	0.03	0.01
2016	1016	0	0	0	0.03	0.45	0.31	0.03	0.00	0	0	0	0.01	0.09	0.04	0.02	0.01
2017	540	0	0	0	0.00	0.20	0.30	0.13	0.02	0	0	0	0.00	0.08	0.19	0.06	0.02
2018	401	0	0	0	0.00	0.11	0.25	0.27	0.05	0	0	0	0	0.04	0.16	0.10	0.02

Table 6. Summer Trawl Survey length-shell compositions.

			New Shell								Old Shell							
Year	Survey	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1976	NMFS	1326	0.01	0.02	0.10	0.19	0.34	0.18	0.02	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.01	0.01
1979	NMFS	220	0.01	0.01	0.00	0.02	0.05	0.05	0.03	0.01	0.01	0.00	0.01	0.04	0.14	0.40	0.19	0.03
1982	NMFS	327	0.22	0.07	0.16	0.23	0.17	0.03	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.02	0.03
1985	NMFS	350	0.11	0.11	0.19	0.17	0.16	0.06	0.01	0.00	0.00	0.00	0.00	0.02	0.05	0.08	0.05	0.01
1988	NMFS	366	0.16	0.19	0.12	0.13	0.11	0.06	0.03	0.00	0.00	0.00	0.01	0.01	0.03	0.07	0.05	0.03
1991	NMFS	340	0.18	0.08	0.02	0.03	0.06	0.03	0.01	0.01	0.03	0.06	0.02	0.08	0.16	0.14	0.09	0.02
1996	ADFG	269	0.29	0.21	0.13	0.09	0.05	0.00	0.00	0.01	0.00	0.00	0.03	0.03	0.04	0.04	0.04	0.03
1999	ADFG	283	0.03	0.01	0.10	0.29	0.26	0.13	0.03	0.01	0.00	0.00	0.00	0.03	0.05	0.04	0.02	0.00
2002	ADFG	244	0.09	0.12	0.14	0.11	0.02	0.03	0.02	0.01	0.01	0.03	0.07	0.10	0.09	0.09	0.05	0.02
2006	ADFG	373	0.18	0.26	0.21	0.11	0.06	0.04	0.02	0.00	0.00	0.00	0.00	0.02	0.04	0.04	0.01	0.00
2008	ADFG	275	0.12	0.15	0.21	0.11	0.10	0.03	0.02	0.01	0.00	0.01	0.04	0.06	0.08	0.01	0.04	0.00
2010	NMFS	69	0.01	0.04	0.06	0.17	0.06	0.03	0.00	0.00	0.00	0.03	0.09	0.20	0.19	0.07	0.03	0.01
2011	ADFG	315	0.13	0.11	0.09	0.11	0.18	0.14	0.03	0.01	0.00	0.00	0.01	0.02	0.09	0.04	0.03	0.00
2014	ADFG	387	0.08	0.15	0.24	0.18	0.09	0.02	0.01	0.01	0.00	0.00	0.03	0.10	0.05	0.04	0.01	0.00
2017	ADFG	116	0.14	0.12	0.05	0.09	0.10	0.04	0.00	0.00	0.01	0.02	0.02	0.02	0.07	0.18	0.04	0.00
2017	NMFS	58	0.09	0.10	0.14	0.05	0.05	0.05	0.05	0.03	0.03	0.00	0.03	0.05	0.03	0.19	0.05	0.03
2018	ADFG	73	0.37	0.10	0.11	0.03	0.01	0.03	0.04	0.01	0	0.07	0.01	0.04	0.03	0.03	0.10	0.03
2019	ADFG	307	0.55	0.30	0.03	0	0.00	0.00	0.00	0	0.00	0.00	0.01	0.02	0.01	0.02	0.03	0.01
2019	NMFS	135	0.36	0.30	0.08	0.04	0.01	0	0.01	0.01	0.04	0.01	0.04	0.02	0.01	0.01	0.04	0.01
2020	ADFG	111	0.13	0.22	0.30	0.06	0.05	0.01	0	0	0.03	0.08	0.05	0.02	0.02	0.02	0	0.01
2021	ADFG	158	0.06	0.17	0.22	0.22	0.22	0.04	0.01	0.01	0	0	0.01	0	0.02	0.01	0.01	0.01

Table 7. Winter pot survey length-shell compositions.

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

Table 8. Summer commercial 1987-1994 observer discards length-shell compositions.

		New Shell								Old Shell							
Year	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1987	1146	0.06	0.19	0.32	0.33	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.00	0.00	0.00	0.00
1988	722	0.01	0.04	0.15	0.48	0.14	0.00	0.00	0.00	0.00	0.01	0.03	0.10	0.04	0.00	0.00	0.00
1989	1000	0.07	0.19	0.24	0.22	0.03	0.00	0.00	0.00	0.02	0.03	0.07	0.11	0.03	0.00	0.00	0.00
1990	507	0.08	0.23	0.27	0.27	0.04	0.00	0.00	0.00	0.02	0.02	0.02	0.05	0.01	0.00	0.00	0.00
1992	580	0.11	0.17	0.30	0.29	0.03	0.00	0.00	0.00	0.01	0.02	0.02	0.04	0.01	0.00	0.00	0.00
1994	850	0.07	0.06	0.11	0.15	0.02	0.00	0.00	0.00	0.07	0.07	0.15	0.24	0.05	0.00	0.00	0.00

Table 9. Summer commercial observer total catch length-shell compositions.

		New Shell								Old Shell							
Year	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
2012	3055	0.10	0.05	0.08	0.15	0.15	0.17	0.06	0.01	0.00	0.00	0.00	0.03	0.08	0.09	0.03	0.00
2013	4762	0.19	0.16	0.09	0.10	0.16	0.16	0.09	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00
2014	3506	0.02	0.05	0.13	0.22	0.22	0.12	0.08	0.03	0.00	0.00	0.00	0.02	0.03	0.03	0.02	0.01
2015	1671	0.01	0.04	0.09	0.23	0.37	0.14	0.05	0.01	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.00
2016	2114	0.01	0.01	0.03	0.12	0.29	0.36	0.08	0.02	0.00	0.00	0.00	0.01	0.03	0.03	0.02	0.00
2017	2748	0.02	0.03	0.03	0.06	0.19	0.33	0.18	0.02	0.00	0.00	0.00	0.00	0.02	0.07	0.03	0.01
2018	1628	0.03	0.06	0.12	0.11	0.09	0.17	0.18	0.04	0.00	0.00	0.01	0.01	0.15	0.07	0.08	0.02
2019	236	0.13	0.06	0.06	0.13	0.08	0.05	0.01	0.01	0	0	0.00	0.04	0.11	0.14	0.14	0.05

Table 10. The observed proportion of tagged crab by each size class released and recovered after 1 -3 year of liberty 1980-2019 periods.

Year at liberty 1

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134	n
64-73	0	0.2	0.8	0	0	0	0	0	5
74-83		0	0.44	0.47	0.09	0	0	0	47
84-93			0	0.32	0.62	0.05	0.01	0	146
94-103				0.03	0.62	0.34	0.01	0.00	317
104-113					0.31	0.59	0.09	0	241
114-123						0.42	0.47	0.11	210
124-133							0.69	0.31	81
>134								1	26

Year at liberty 2

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134	n
64-73	0	0	0.09	0.55	0.36	0	0	0	11
74-83		0	0	0.11	0.85	0.04	0	0	113
84-93			0	0.04	0.32	0.61	0.03	0	114
94-103				0.02	0.36	0.41	0.20	0	94
104-113					0.06	0.71	0.22	0	108
114-123						0.17	0.72	0.11	65
124-133							0.36	0.64	25
>134								1	8

Year at liberty 3

	64-73	74-83	84-93	94-103	104-113	114-123	124-33	> 134	n
64-73	0	0	0	0	0.5	0.5	0	0	22
74-83	0	0	0	0	0.26	0.66	0.082	0	73
84-93	0	0	0	0.04	0.26	0.53	0.17	0	53
94-103	0	0	0	0	0.06	0.67	0.27	0	52
104-113	0	0	0	0	0	0.26	0.62	0.12	34
114-123	0	0	0	0	0	0	0.79	0.21	14
124-133	0	0	0	0	0	0	0.1	0.9	10
>134	0	0	0	0	0	0	0	1	1

Table 11. Summary of initial input parameter values and bounds for a length-based population model of Norton Sound red king crab Model 21.0. Parameters with "log_" indicate log scaled parameters

Parameter	Parameter description	Est	sd	Lower	Upper
log_q_1	Commercial fishery catchability (1977-93)	-7.038	0.171	-20.5	20
log_q2	Commercial fishery catchability (1994-2007)	-6.749	0.134	-20.5	20
log_q3	Commercial fishery catchability (2008-2019)	-6.785	0.132	-20.5	20
log_N_{76}	Initial abundance	9.117	0.109	2.0	15.0
R_0	Mean Recruit	6.454	0.080	2.0	12.0
log_σ_R^2	Recruit standard deviation			-40.0	40.0
a_{1-7}	Intimal length proportion			0	10.0
r_1	Proportion of length class 1 for recruit			0	10.0
log_α	Inverse logistic molting parameter	-2.697	0.089	-5.0	-1.0
log_β	Inverse logistic molting parameter	4.833	0.015	1.0	5.5
log_ϕ_{st1}	Logistic trawl selectivity parameter	-5.000*	0.033	-5.0	1.0
log_ϕ_{wa}	Inverse logistic winter pot selectivity parameter	-2.397	0.416	-5.0	1.0
log_ϕ_{wb}	Inverse logistic winter pot selectivity parameter	4.768	0.069	0.0	6.0
$Sw_{1,2}$	Winter pot selectivity of length class 1,2	0.059	0.033	0.1	1.0
		0.422	0.147		
log_ϕ_l	Logistic commercial catch selectivity parameter	-2.072	0.045	-5.0	1.0
log_acr	Logistic summer commercial retention selectivity (1976-2007)	-0.860	0.143	-5.0	1.0
log_bcr	Logistic summer commercial retention selectivity (1976-2007)	4.642	0.008	0.0	6.0
log_acr	Logistic summer commercial retention selectivity (2008-2019)	-0.484	0.285	-5.0	1.0
log_bcr	Logistic summer commercial retention selectivity (2008-2019)	4.656	0.013	0.0	6.0
log_awr	Logistic winter commercial retention selectivity parameter	-0.928	0.596	-5.0	1.0
log_bwr	Logistic winter commercial retention selectivity parameter	4.652	0.040	0.0	6.0
w^2_t	Additional variance for standard CPUE	0.039	0.013	0.0	6.0
ms	Natural mortality multipliers	3.420	0.263	0.5	5.0
q	Survey q for NMFS trawl 1976-91	0.727	0.127	0.1	1.0
q	Survey q for NMFS NBS trawl 2010,17,19	0.926	0.203	0.1	1.0
σ	Growth transition sigma	3.836	0.209	0.0	30.0
β_1	Growth transition mean	11.884	0.697	0.0	20.0
β_2	Growth transition increment	7.789	0.171	0.0	20.0

*: Parameter was unestimable because model estimated trawl survey selectivity was 1.0 across all size classes.

Table 12. Estimated molting probability incorporated transition matrix. Model 21.0

Pre-molt Length Class	Post-molt Length Class 64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
64 - 73	0.02	0.11	0.79	0.08	0.00	0.00	0.00	0.00
74 - 83		0.04	0.25	0.69	0.02	0.00	0.00	0.00
84 - 93			0.08	0.43	0.48	0.01	0.00	0.00
94 - 103				0.15	0.58	0.26	0.00	0.00
104 - 113					0.29	0.61	0.11	0.00
114 - 123						0.49	0.48	0.03
124 - 133							0.71	0.29
134+								1.00

Table 13. Estimated selectivity, mortality, molting probabilities, and proportions of legal crab by length class (mm CL) for Norton Sound male red king crab. Model 21.0

Length Class	Legal Proportion	Retention: Summer Com 1976-2007	Retention: Summer Com 2008-2019	Retention: Winter Com 2008-2019	Mean weight (lb)	Natural mortality (*M*)	Selectivity: Trawl	Selectivity: Winter Pot	Selectivity: Summer Fishery	Molting Probability
64 - 73	0.00	0.00	0.00	0.00	0.49	0.18	1.00	0.06	0.13	0.98
74 - 83	0.00	0.00	0.00	0.00	0.87	0.18	1.00	0.42	0.34	0.96
84 - 93	0.00	0.00	0.00	0.00	1.14	0.18	1.00	0.73	0.65	0.92
94 - 103	0.29	0.10	0.02	0.08	1.80	0.18	1.00	0.85	0.87	0.86
104 - 113	0.93	0.88	0.88	0.82	2.36	0.18	1.00	0.70	0.96	0.76
114 - 123	1.00	1.00	1.00	1.00	3.03	0.18	1.00	0.48	0.99	0.61
124 - 133	1.00	1.00	1.00	1.00	3.79	0.61	1.00	0.27	1.00	0.45
134+	1.00	1.00	1.00	1.00	4.43	0.61	1.00	0.13	1.00	0.30

Table 14. Annual abundance estimates (million crab) and mature male biomass (Feb 01) (MMB, million lb) for Norton Sound red king crab estimated by a length-based analysis. To be populated for Jan 2022 final draft.

Table 15. Summary of catch and estimated discards (million lb) for Norton Sound red king crab. Assumed average crab weight is 2.0 lb for winter subsistence catch and 1.0 lb for Winter subsistence discards. Summer and winter commercial discards were estimated from the model. (To be completed in 2022)

Year	Summer Com	Winter Com	Winter Sub	Modeled Discards Summer	Discards Winter Sub	Modeled Discards Winter Com	Total
1977	0.52	0.000	0.000		0		
1978	2.09	0.024	0.025		0.008		
1979	2.93	0.001	0.000		0		
1980	1.19	0.000	0.000		0		
1981	1.38	0.000	0.001		0		
1982	0.23	0.000	0.003		0.001		
1983	0.37	0.001	0.021		0.006		
1984	0.39	0.002	0.022		0.005		
1985	0.43	0.003	0.017		0.002		
1986	0.48	0.005	0.014		0.004		
1987	0.33	0.003	0.012		0.002		
1988	0.24	0.001	0.005		0.001		
1989	0.25	0.000	0.012		0.002		
1990	0.19	0.010	0.024		0.004		
1991	0	0.010	0.015		0.002		
1992	0.07	0.021	0.023		0.003		
1993	0.33	0.005	0.002		0		
1994	0.32	0.017	0.008		0.001		
1995	0.32	0.022	0.011		0.002		
1996	0.22	0.005	0.003		0.001		
1997	0.09	0.000	0.001		0.001		
1998	0.03	0.002	0.017		0.012		
1999	0.02	0.007	0.015		0.003		
2000	0.3	0.008	0.011		0.004		
2001	0.28	0.003	0.001		0		
2002	0.25	0.007	0.004		0.003		
2003	0.26	0.017	0.008		0.005		
2004	0.34	0.001	0.002		0.001		
2005	0.4	0.006	0.008		0.003		
2006	0.45	0.000	0.002		0.001		
2007	0.31	0.008	0.021		0.011		
2008	0.39	0.015	0.019		0.009		
2009	0.4	0.012	0.010		0.002		
2010	0.42	0.012	0.014		0.002		
2011	0.4	0.009	0.013		0.003		
2012	0.47	0.025	0.015		0.004		
2013	0.35	0.061	0.015		0.014		
2014	0.39	0.035	0.007		0.002		
2015	0.40	0.099	0.019		0.005		
2016	0.42	0.080	0.011		0.001		
2017	0.41	0.078	0.012		0.001		
2018	0.30	0.029	0.008		0.001		
2019	0.08	0.032	0.003		0.001		
2020	0	Conf.	0.001		0.000		
2021	0				0.000		

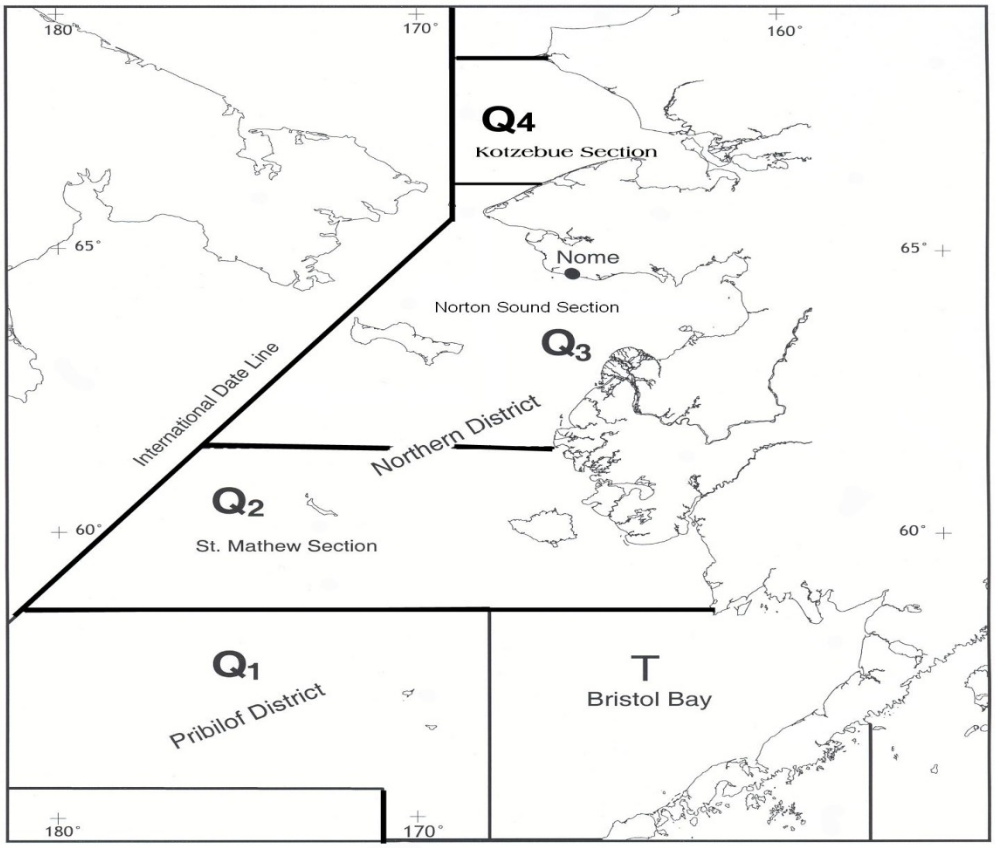


Figure 1. King crab fishing districts and sections of Statistical Area Q.

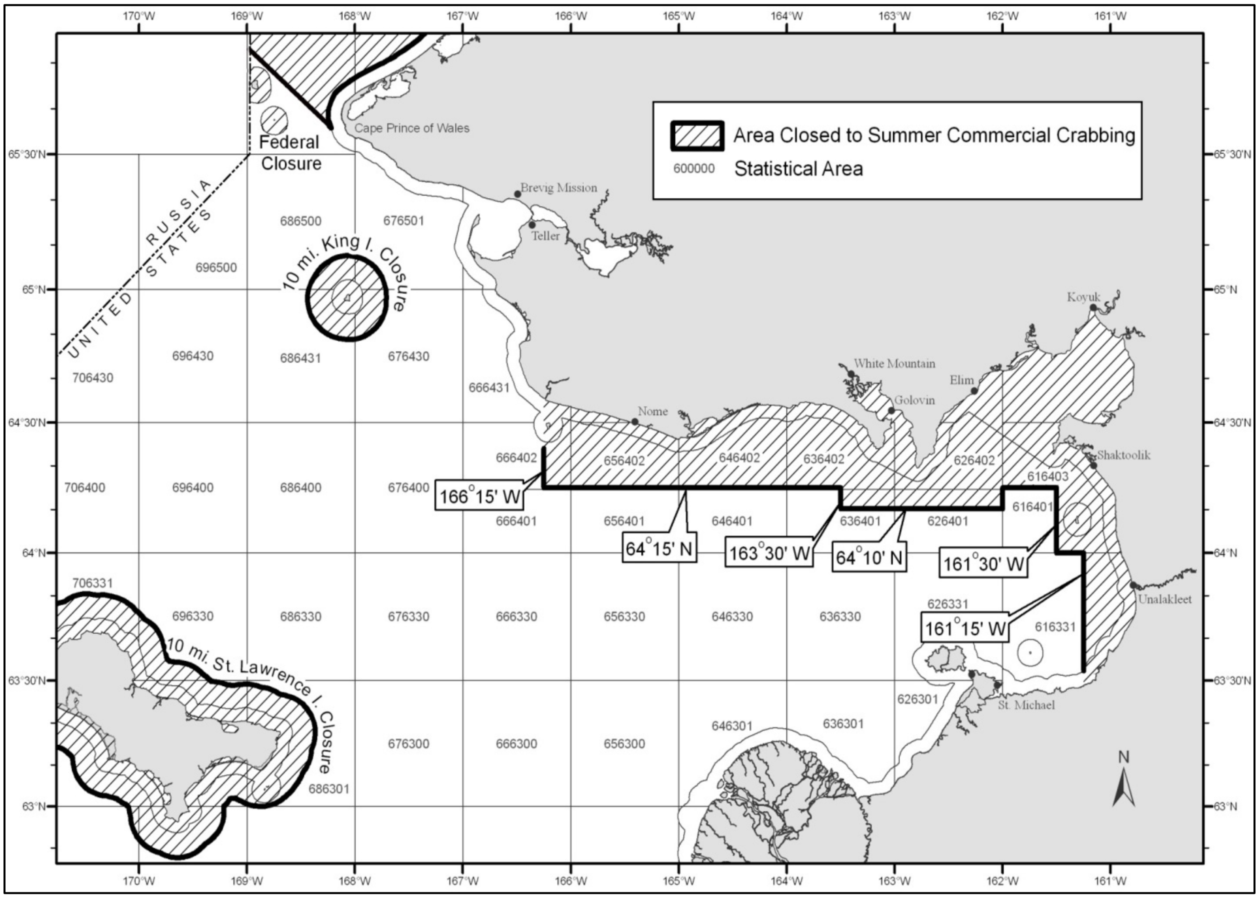


Figure 2. Closed water regulations in effect for the Norton Sound commercial crab fishery. Line around the coastline delineates the 3-mil state waters zone.

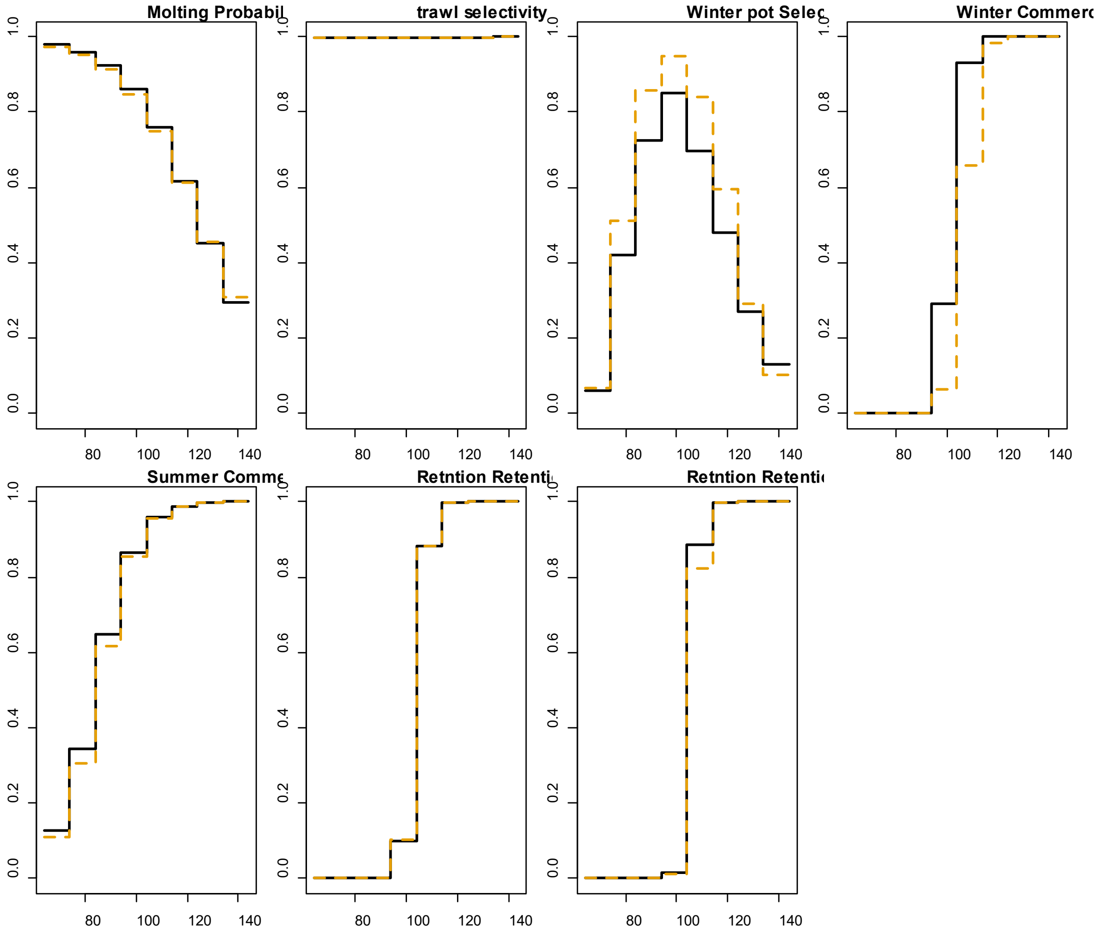


Figure 3. Model estimated (Model 21.0 solid line, Model 21.1 dash red) annual molting probability, and selectivity for trawl survey, winter pot survey, summer commercial fishery, and summer and winter commercial retention. X-axis is carapace length (mm).

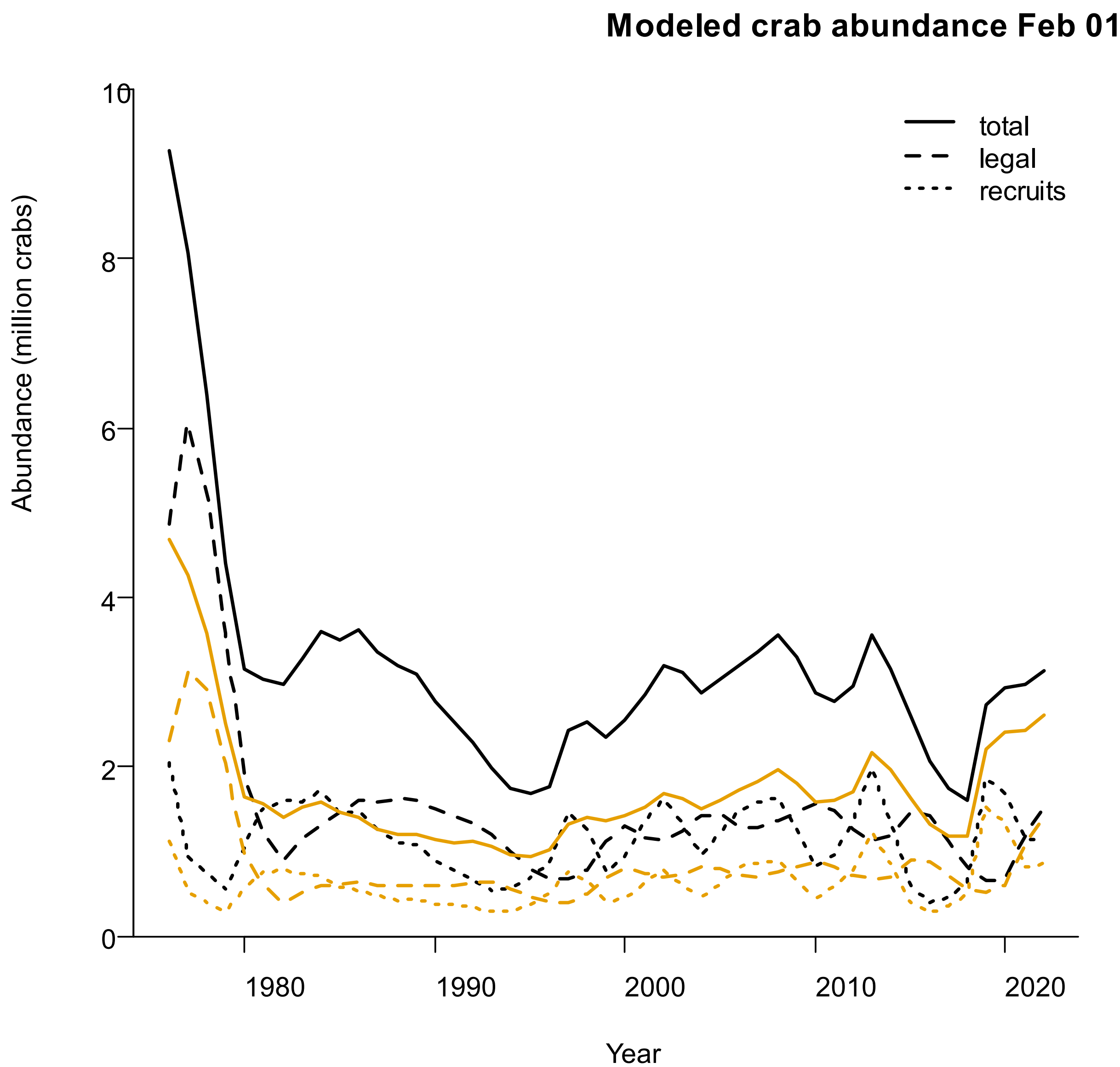


Figure 4. Model (Model 21.0 black, Model 21.1 red) estimated abundances of total, legal (CL>104mm) and recruit (CL 64-94nn) males during1976-2021.

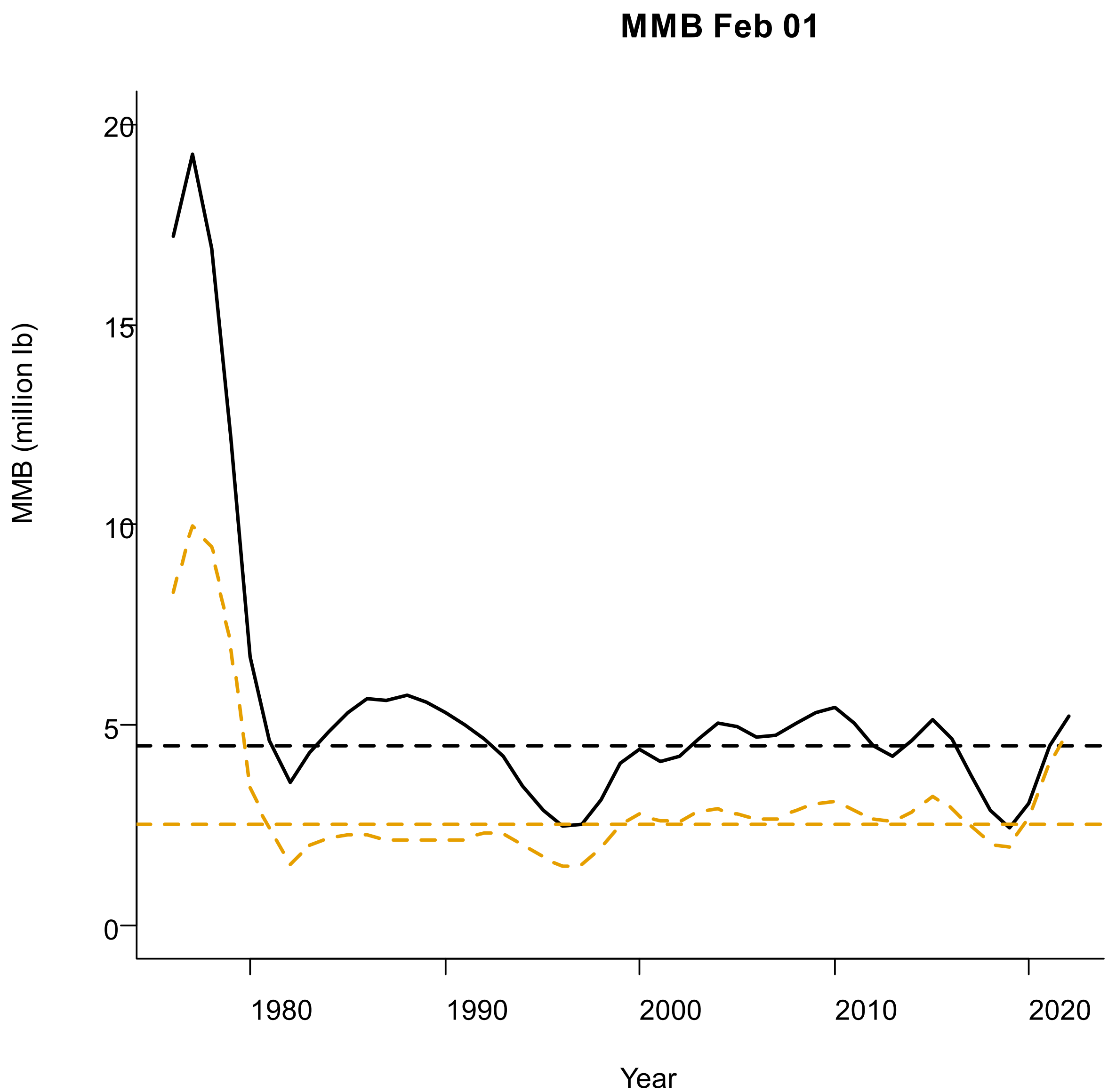


Figure 5. Estimated MMB during 1976-2022 (Model 21.0 solid black, Model 21.1 dash red). Horizontal line Bmsy (Average MMB of 1980-2022).

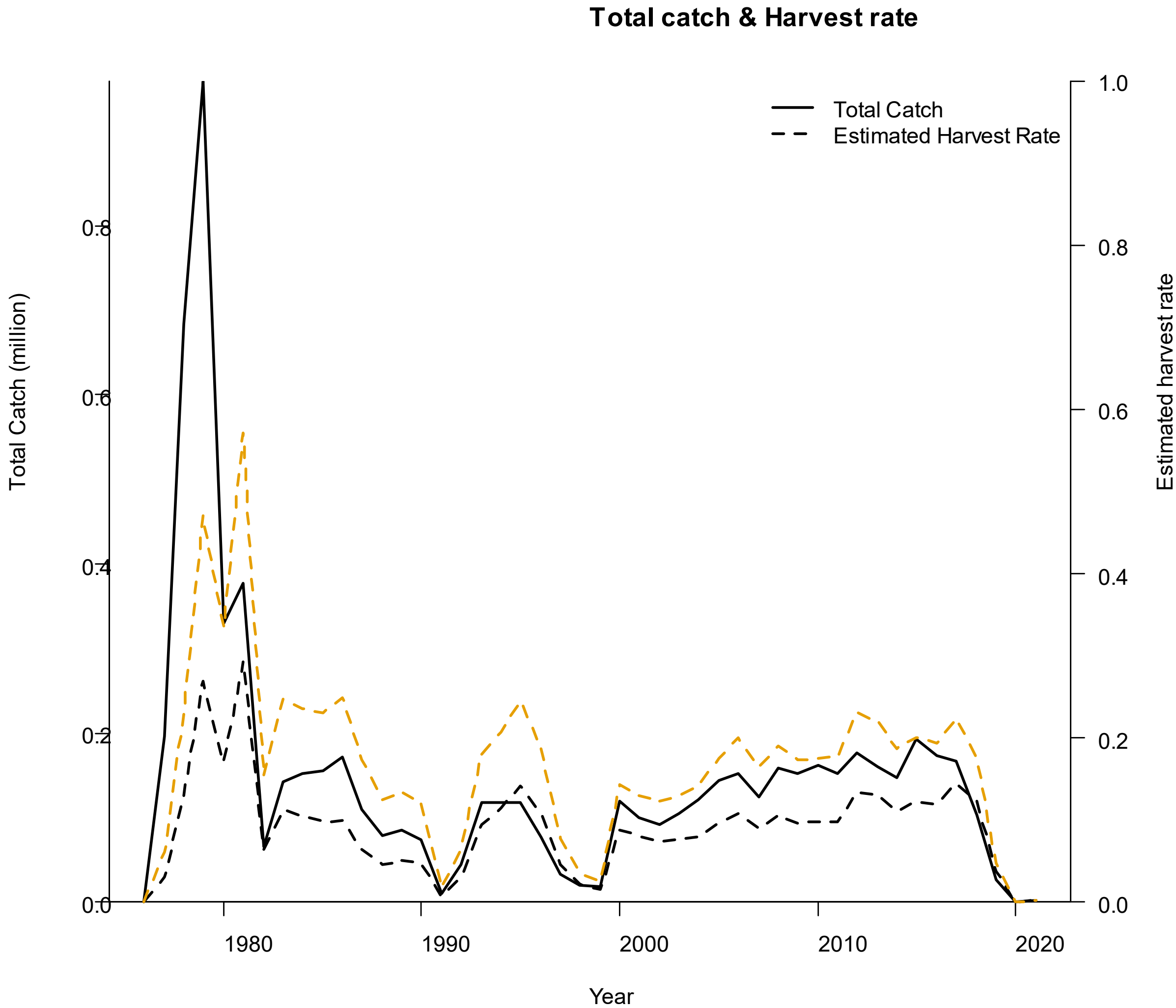


Figure 6. Commercial catch and estimated legal male harvest rate over time (Model 21.0 black dash, and Model 21.1 red dash).

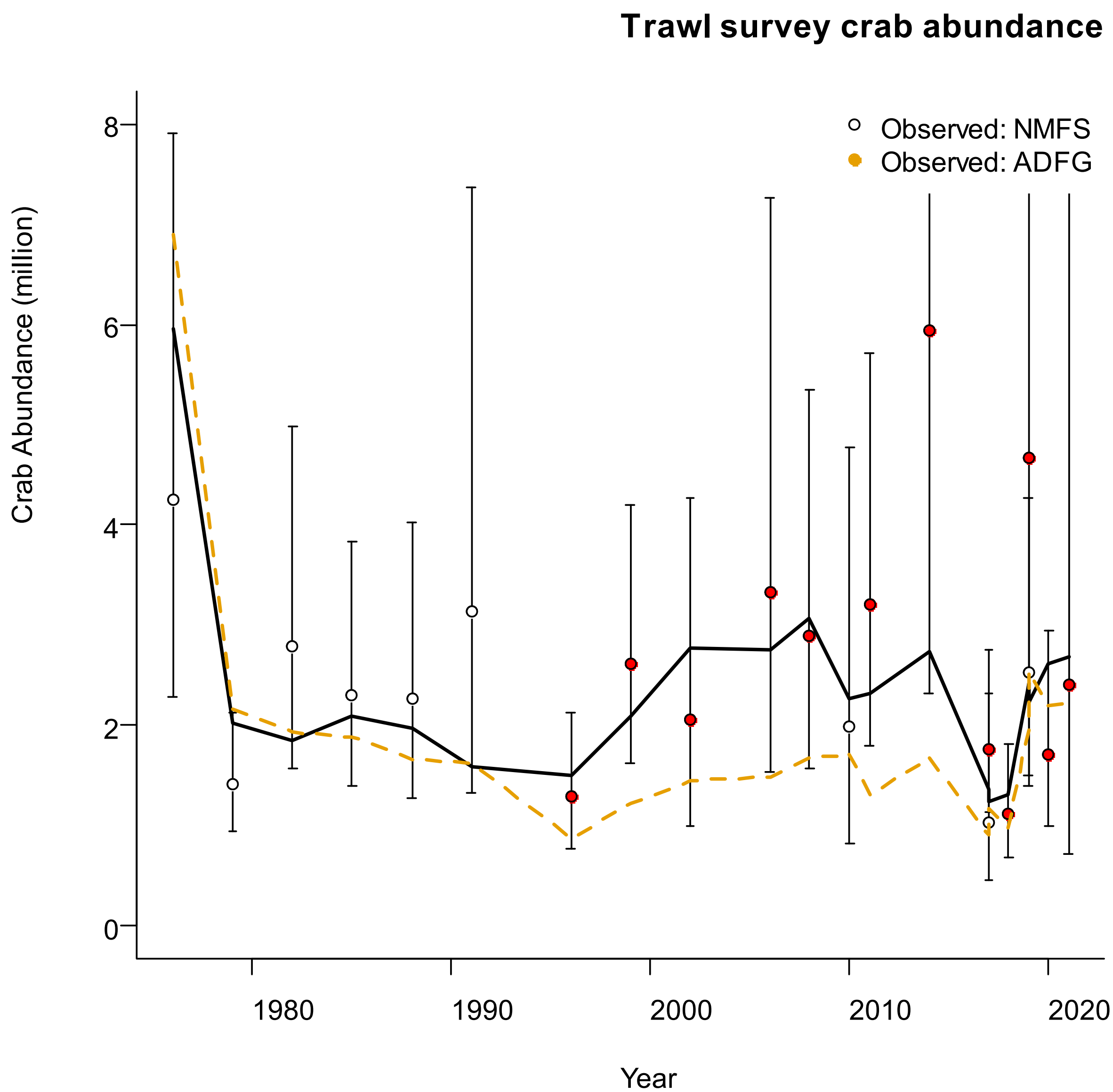


Figure 7. Observed (open circle) (White: NMFS, Red ADF&G) and model (Model 21.0 solid black, Model 21.1 dash red) trawl survey male abundances with 95% lognormal Confidence Intervals (crab ≥ 64 mm CL).

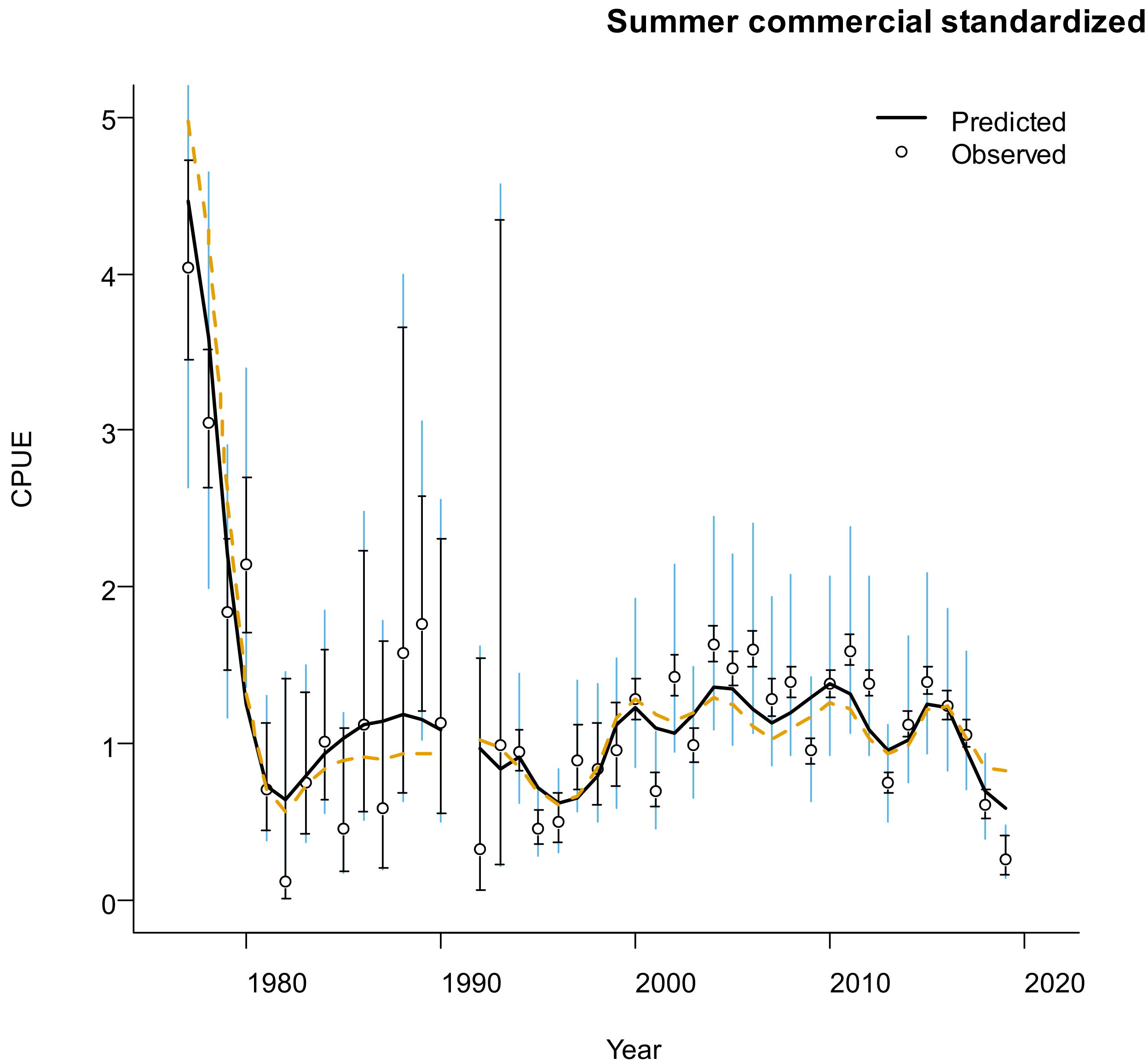


Figure 8. Observed (open circle) with 95% lognormal Confidence Intervals with additional variance (red), and model estimated (Model 21.0 line black, Model 21.1 dash red) standardized CPUE

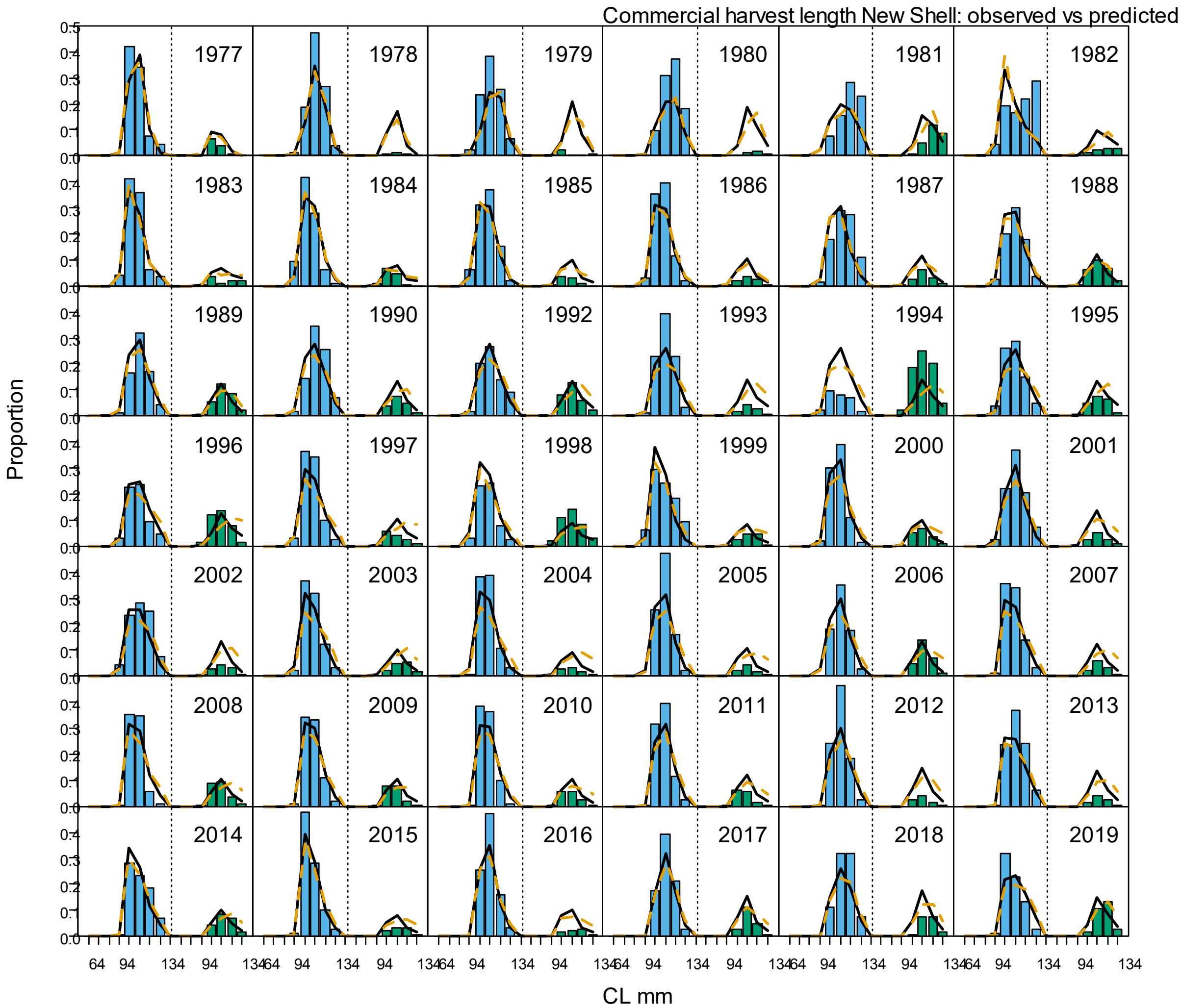


Figure 9. Predicted (Model 21.0 solid black, Model 21.1 dash red) vs. observed (bar New Shell: blue, Old Shell: blue) length class proportions for the summer commercial harvest 1977-2019.

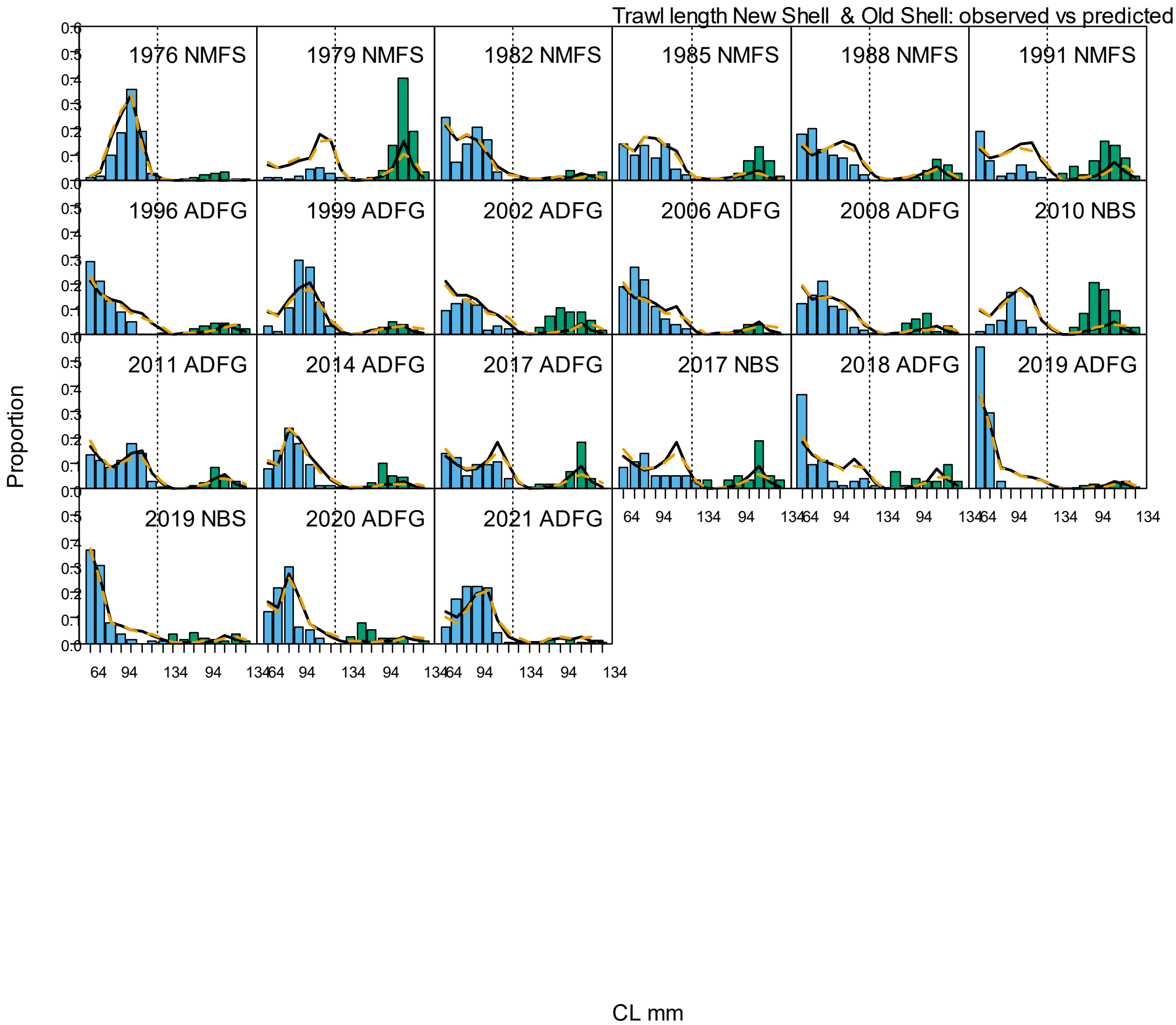


Figure 10. Predicted (Model 21.0 solid black, Model 21.1 dash red) vs. observed (bar New Shell: blue, Old Shell: blue) length class proportions for trawl survey 1976-2021.

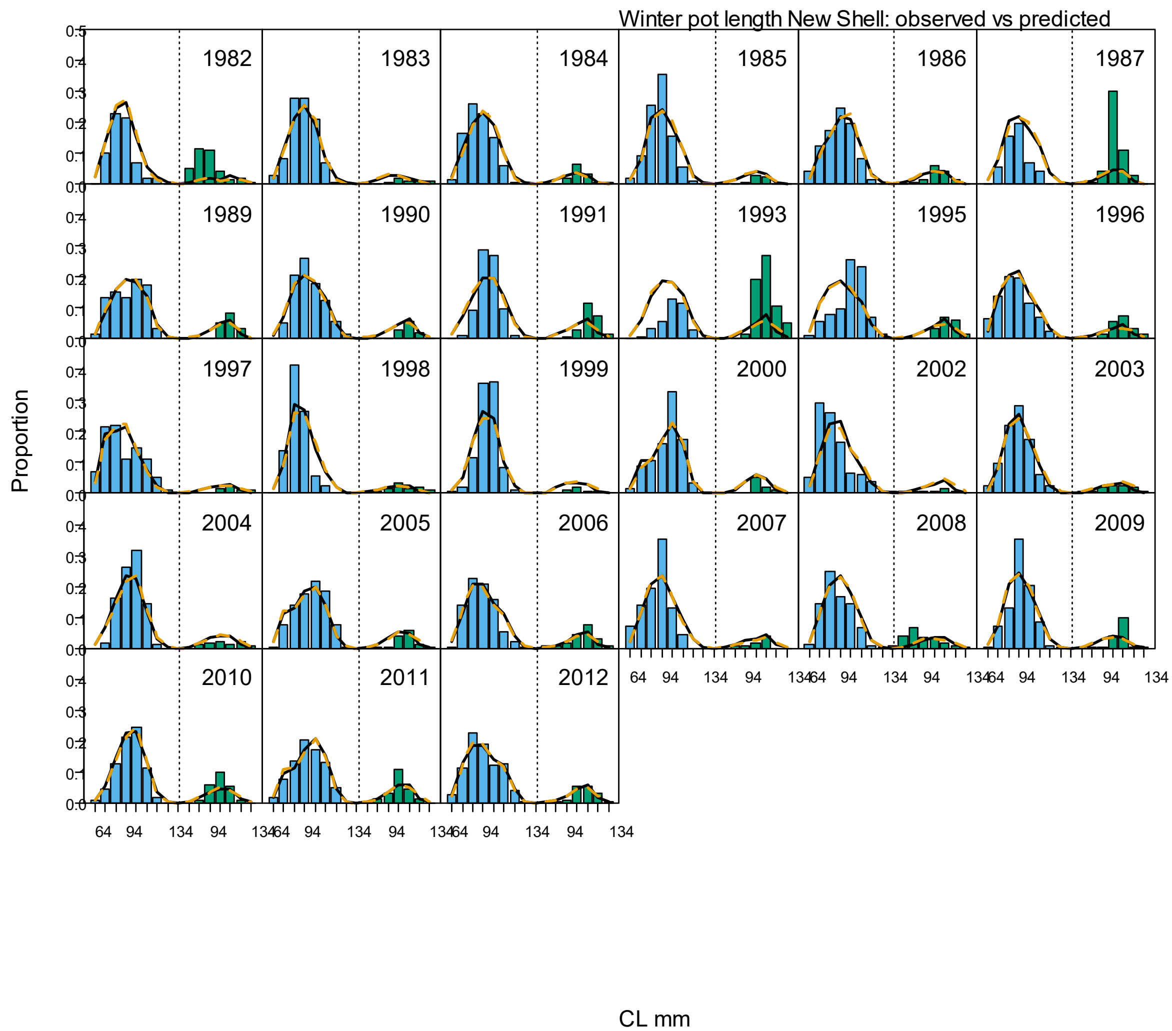


Figure 11 Predicted (Model 21.0 solid black, Model 21.1 dash red) vs. observed (bar New Shell: blue, Old Shell: blue) length class proportions for winter pot survey 1982-2012.

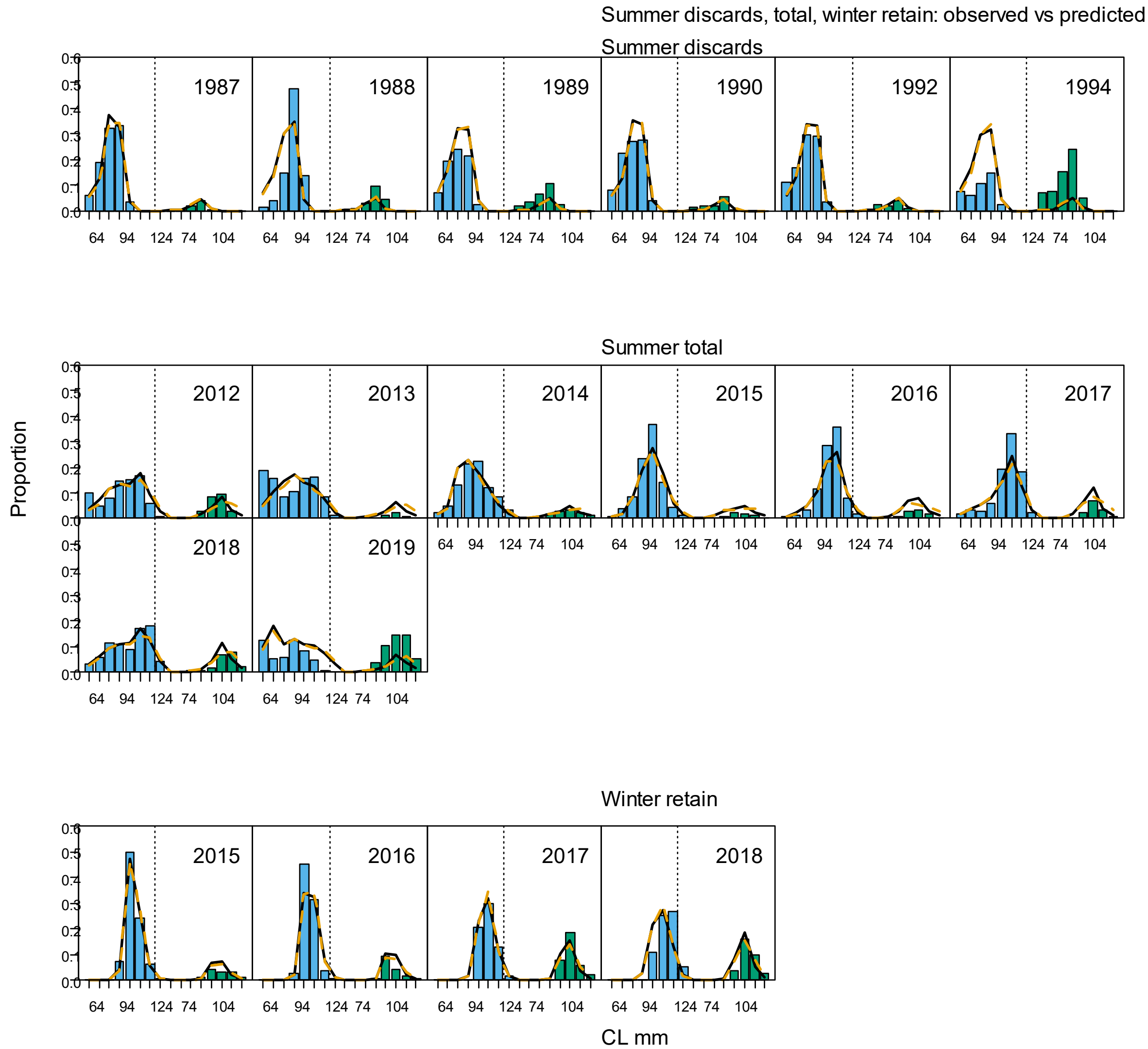


Figure 12. Predicted (Model 21.0 solid black, Model 21.1 dash red) vs. observed (bar New Shell: left blue, Old Shell: right green) length class proportions for summer commercial total and discards (1987-1994, 2012-2019) and winter commercial retained fishery 2015-2018

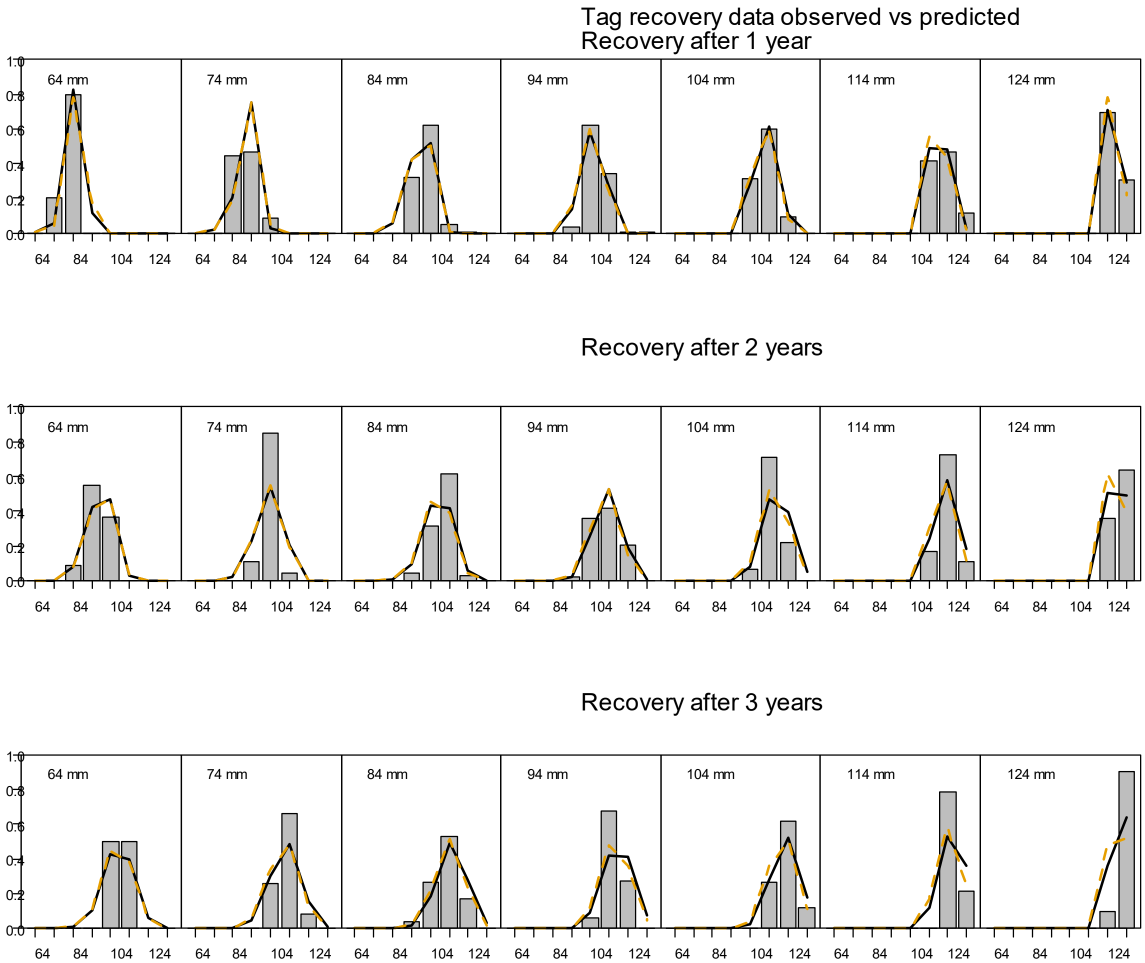
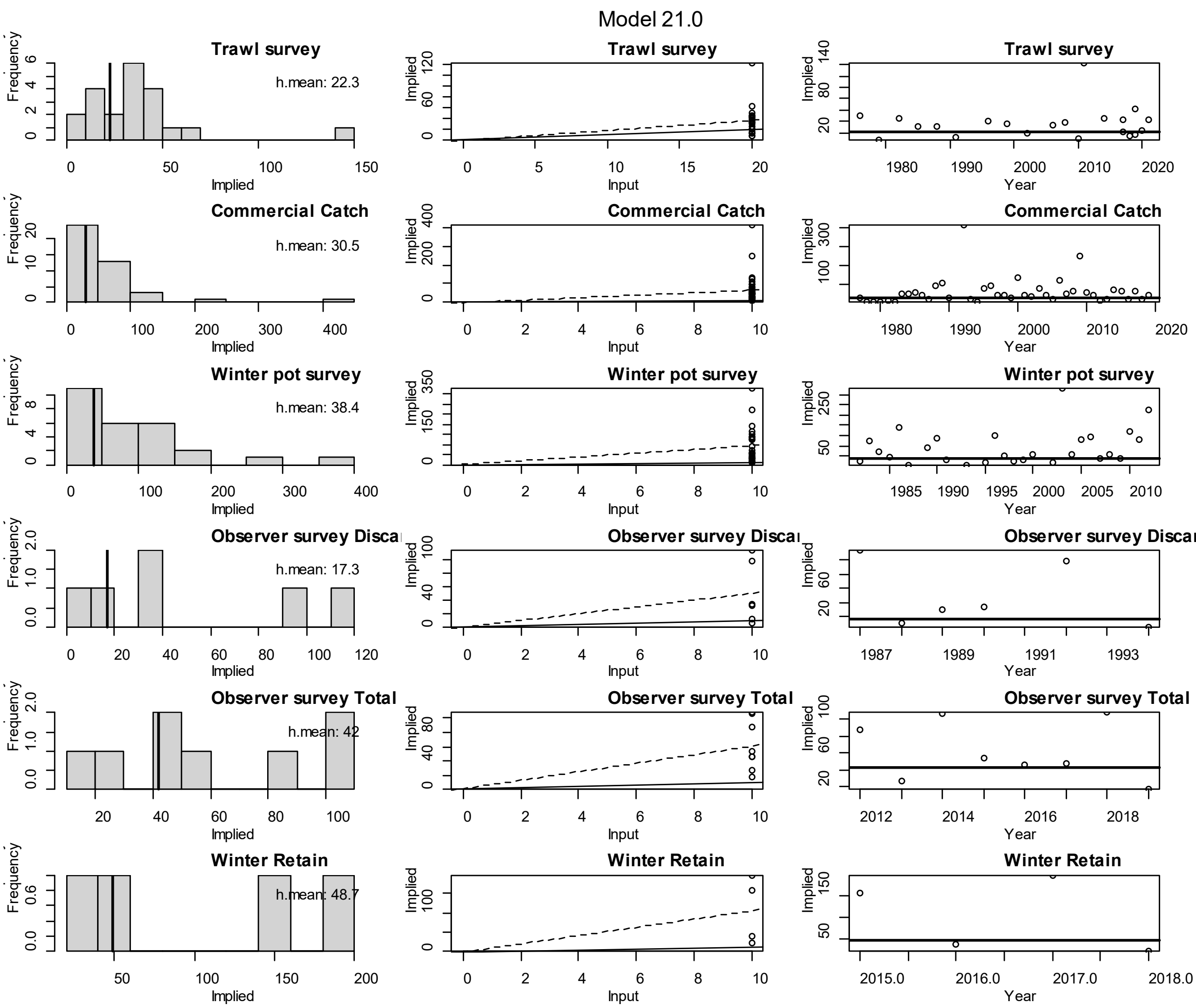


Figure 13. Predicted (Model 21.0 solid line, Model 21.1 dash red) vs. observed (bar) length class proportions for tag recovery data.


Model 21.0
Trawl survey
h.mean: 22.3
Commercial Catch
h.mean: 30.5
Winter pot survey
h.mean: 38.4
Observer survey Discar
h.mean: 17.3
Observer survey Total
h.mean: 42
Winter Retain
h.mean: 48.7
Frequency
Implied
Input
Year

Draft - Norton Sound Red King Crab Stock Assessment Sept 2021

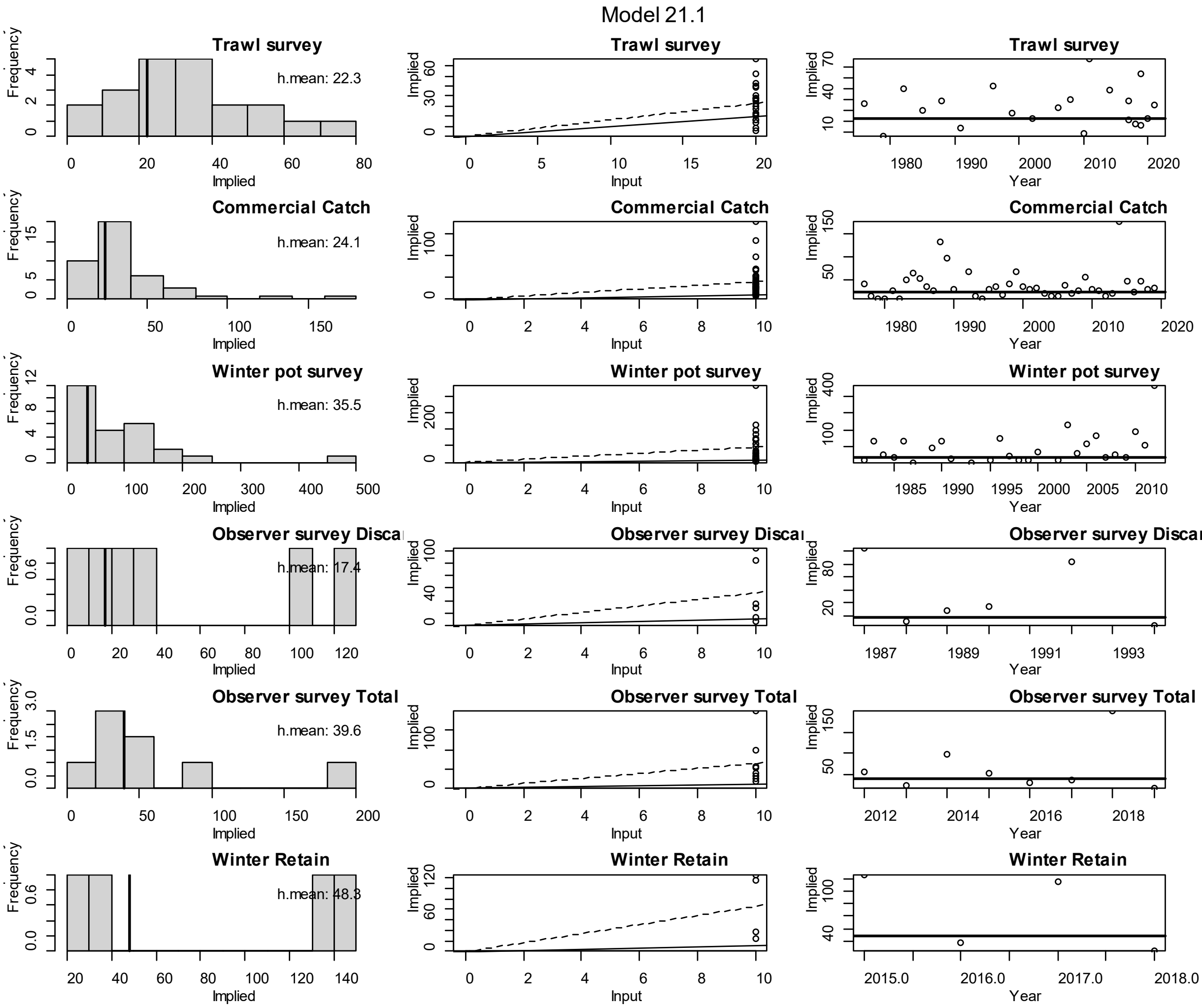
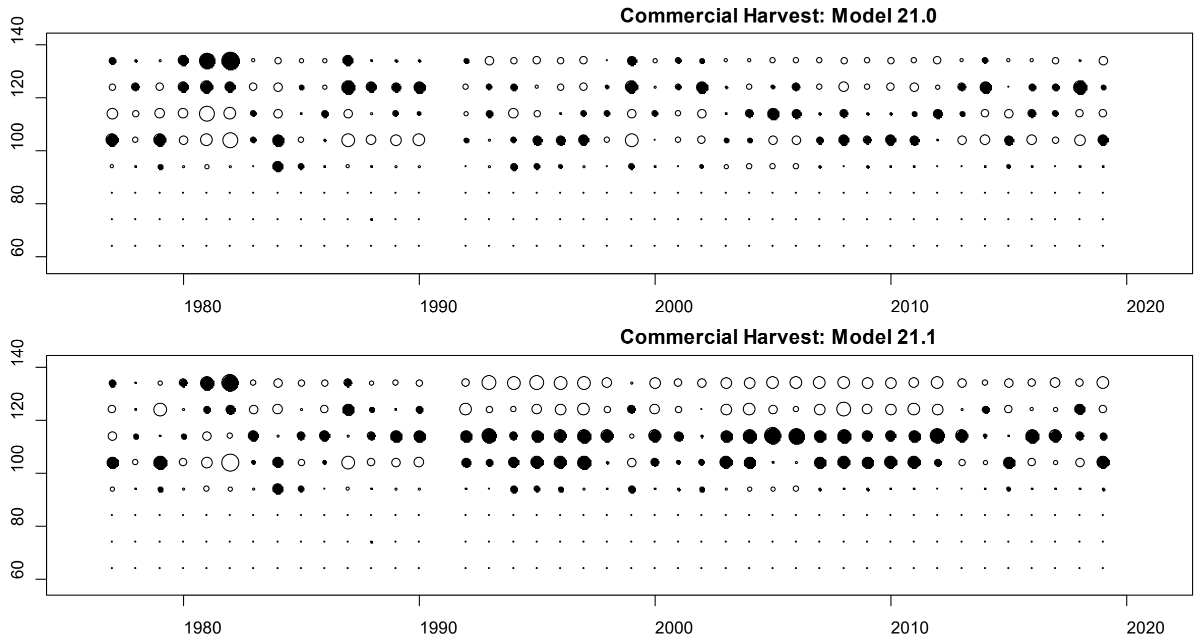
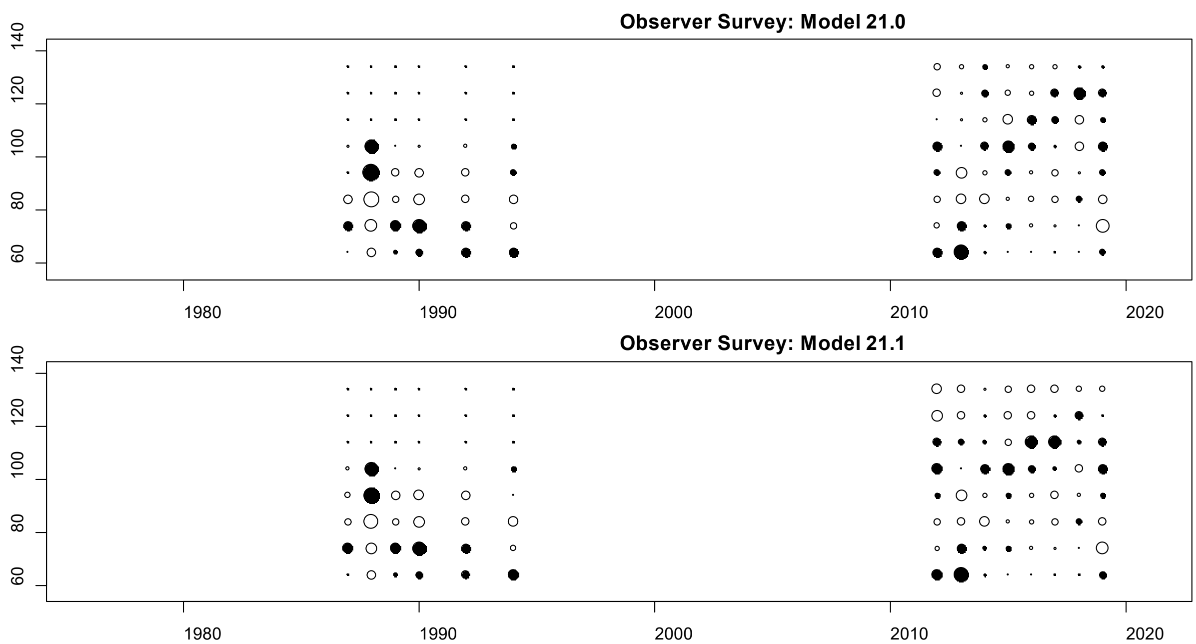
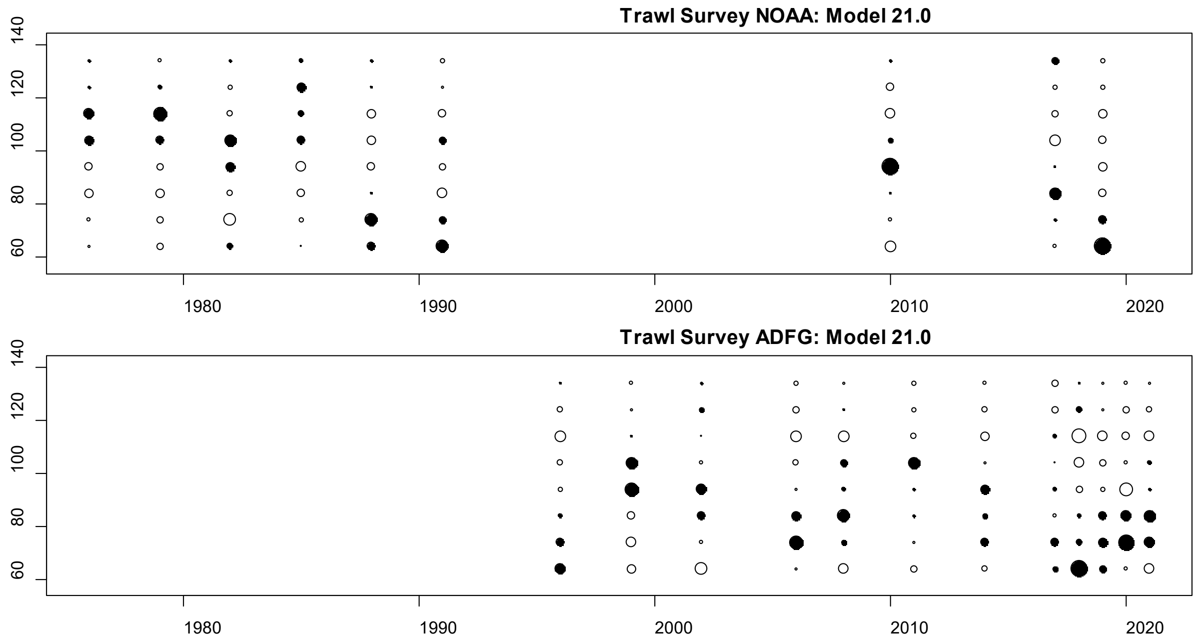


Figure 14. Input vs. model implied effective sample size. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the harmonic mean of implied sample size. Figures in the second column show input sample sizes (x-axis) vs. implied effective sample sizes (y-axis). Dashed line indicates the linear regression slope, and solid line is 1:1 line. Figures in the third column show years (x-axis) vs. implied effective sample sizes (y-axis). Horizontal solid line is the harmonic mean of implied sample size.


Commercial Harvest: Model 21.0
Commercial Harvest: Model 21.1
60
80
100
120
140
1980
1990
2000
2010
2020


Observer Survey: Model 21.0
Observer Survey: Model 21.1
60
80
100
120
140
1980
1990
2000
2010
2020


Trawl Survey NOAA: Model 21.0
60
80
100
120
140
1980
1990
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2020
Trawl Survey ADFG: Model 21.0
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1980
1990
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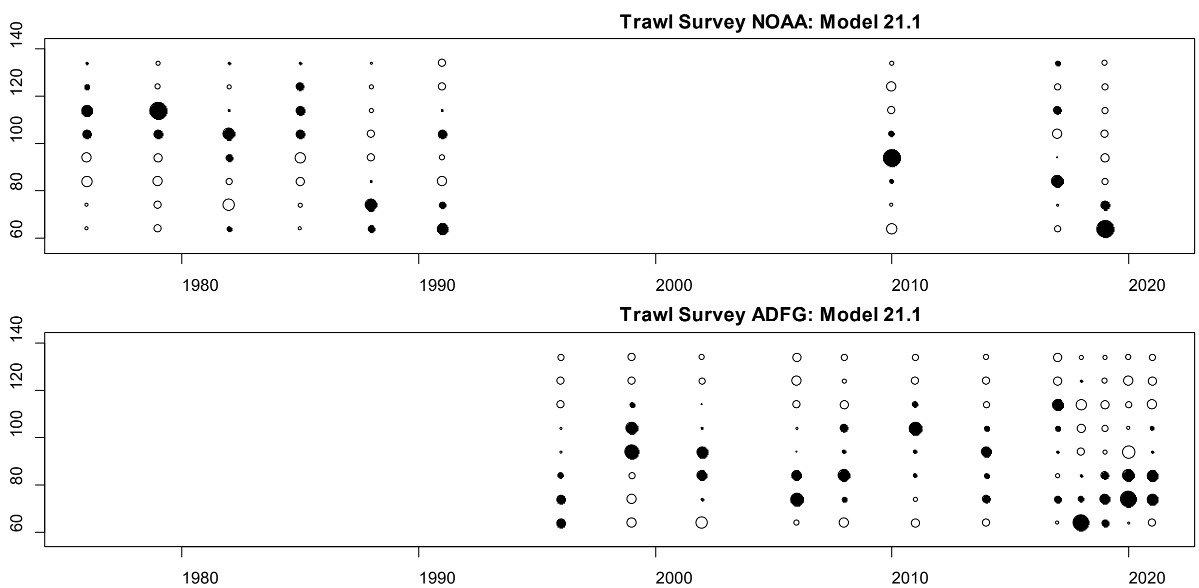
2010
2020


Trawl Survey NOAA: Model 21.1
60
80
100
120
140
1980
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2000
2010
2020
Trawl Survey ADFG: Model 21.1
60
80
100
120
140
1980
1990
2000
2010
2020

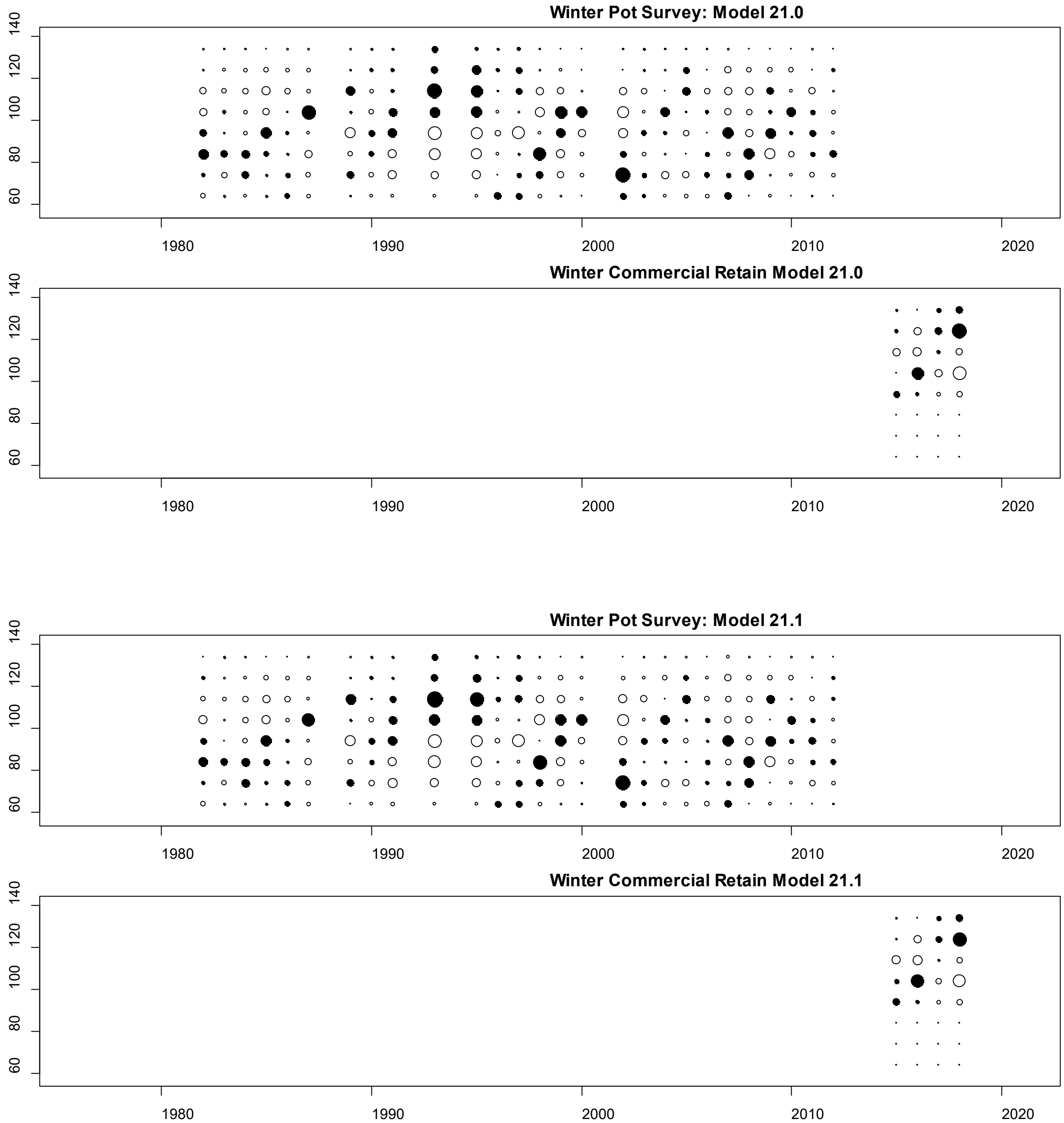


Figure 15. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white and black circles indicate model 21.0 and 21.1 overestimates and underestimate from observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

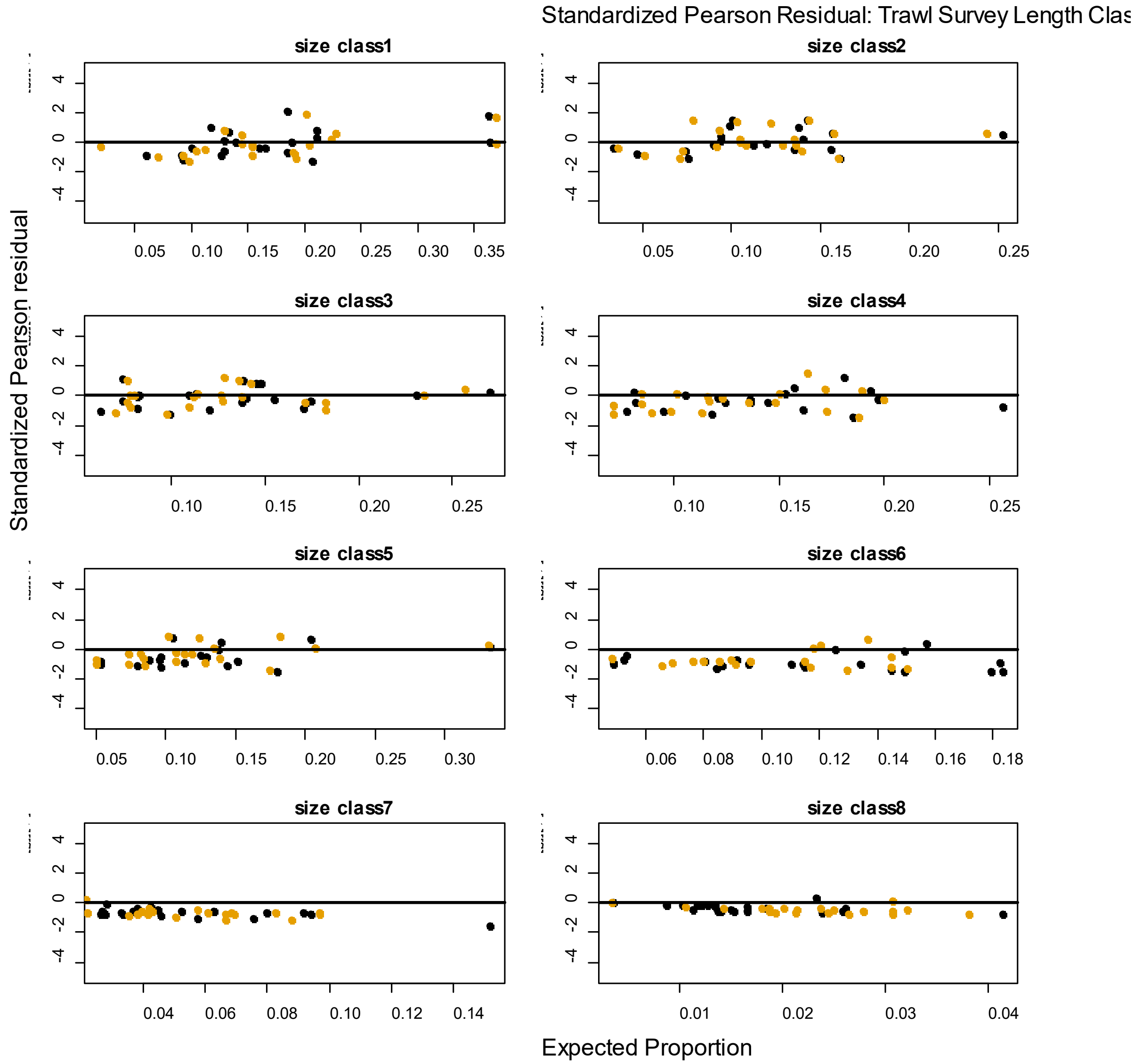


Figure 16. Standardized Pearson residual plot of Trawl survey length size classes 1-8. Model 21.0 (black) and Model 21.1 (red).

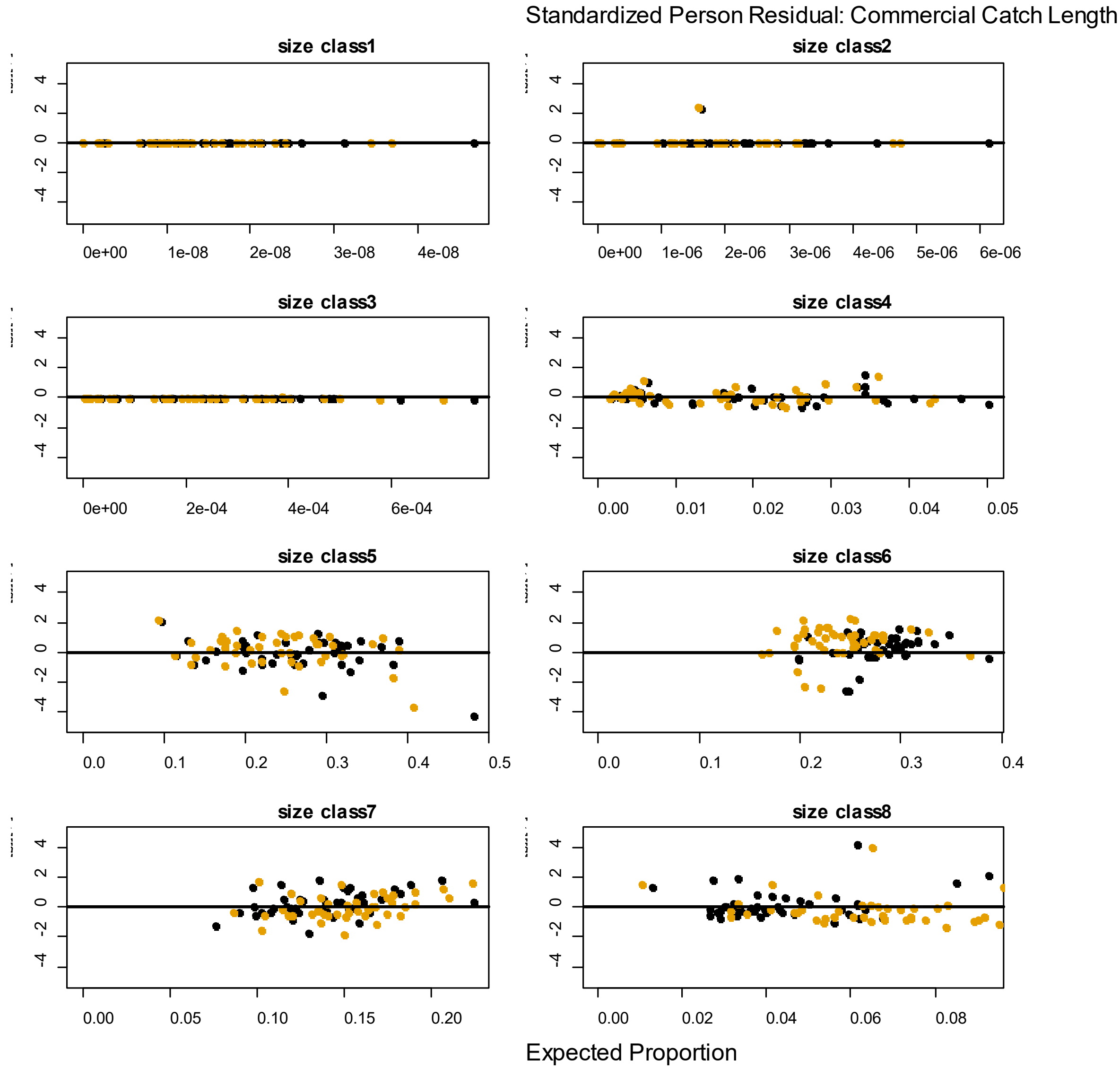


Figure 17. Standardized Pearson residual plot of Summer commercial retained length size classes 1-8. Model 21.0 black and Model 21.1 red.

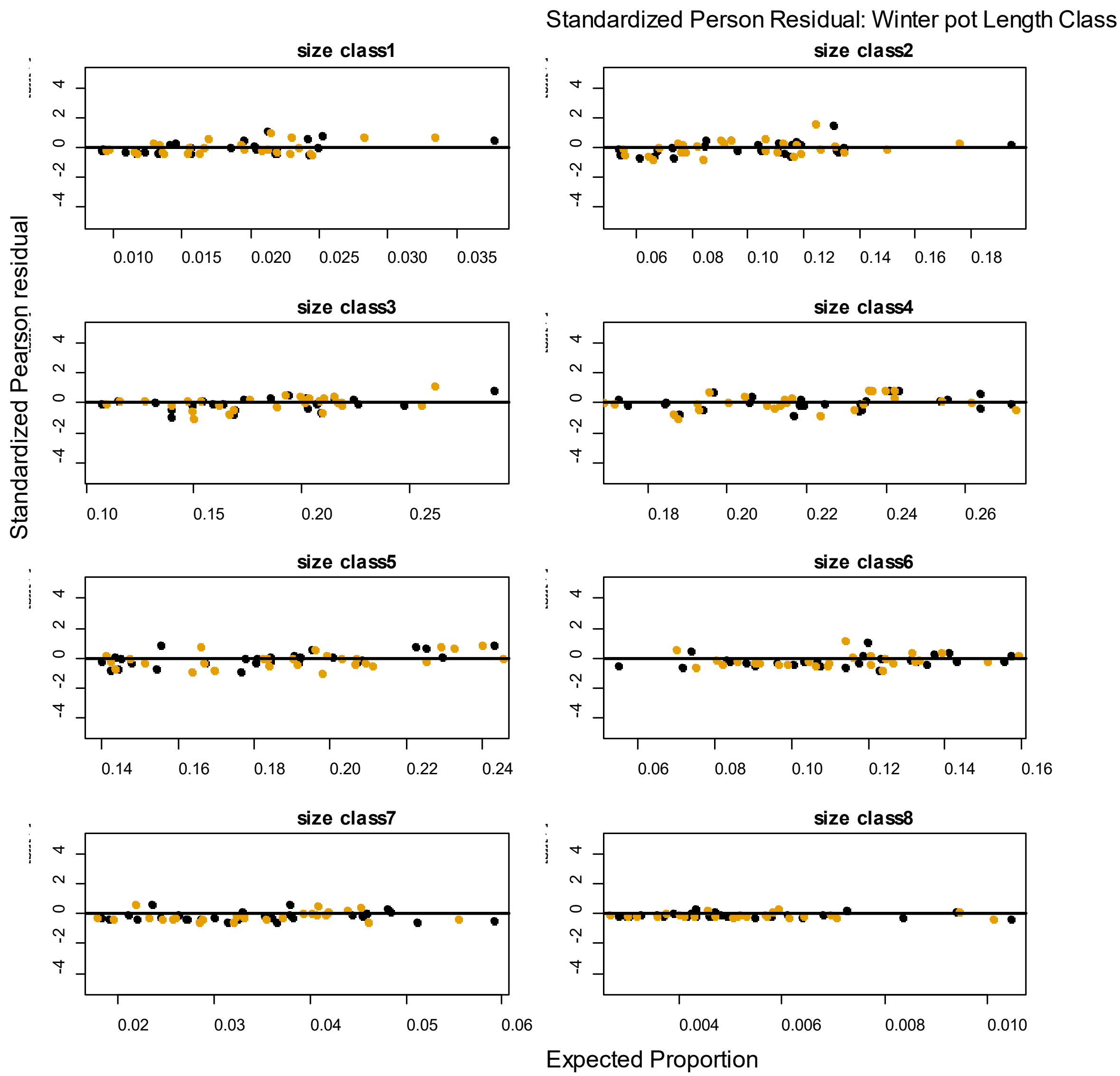
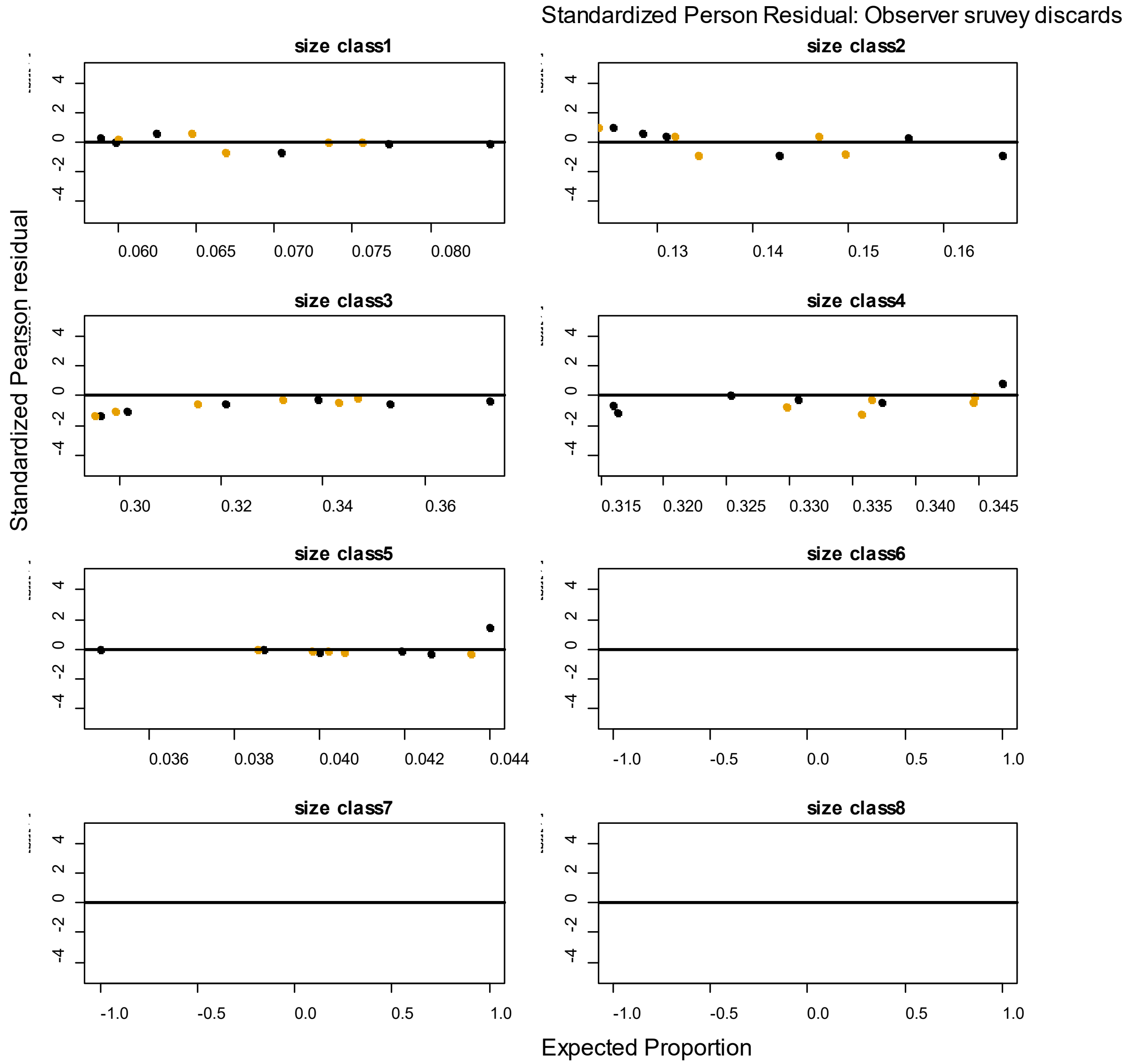


Figure 18. Standardized Pearson residual plot of Winter pot survey length size classes 1-8. Model 21.0 black and Model 21.1 red.


Standardized Person Residual: Observer sruvey discards
Standardized Pearson residual
Expected Proportion
size class1
size class2
size class3
size class4
size class5
size class6
size class7
size class8

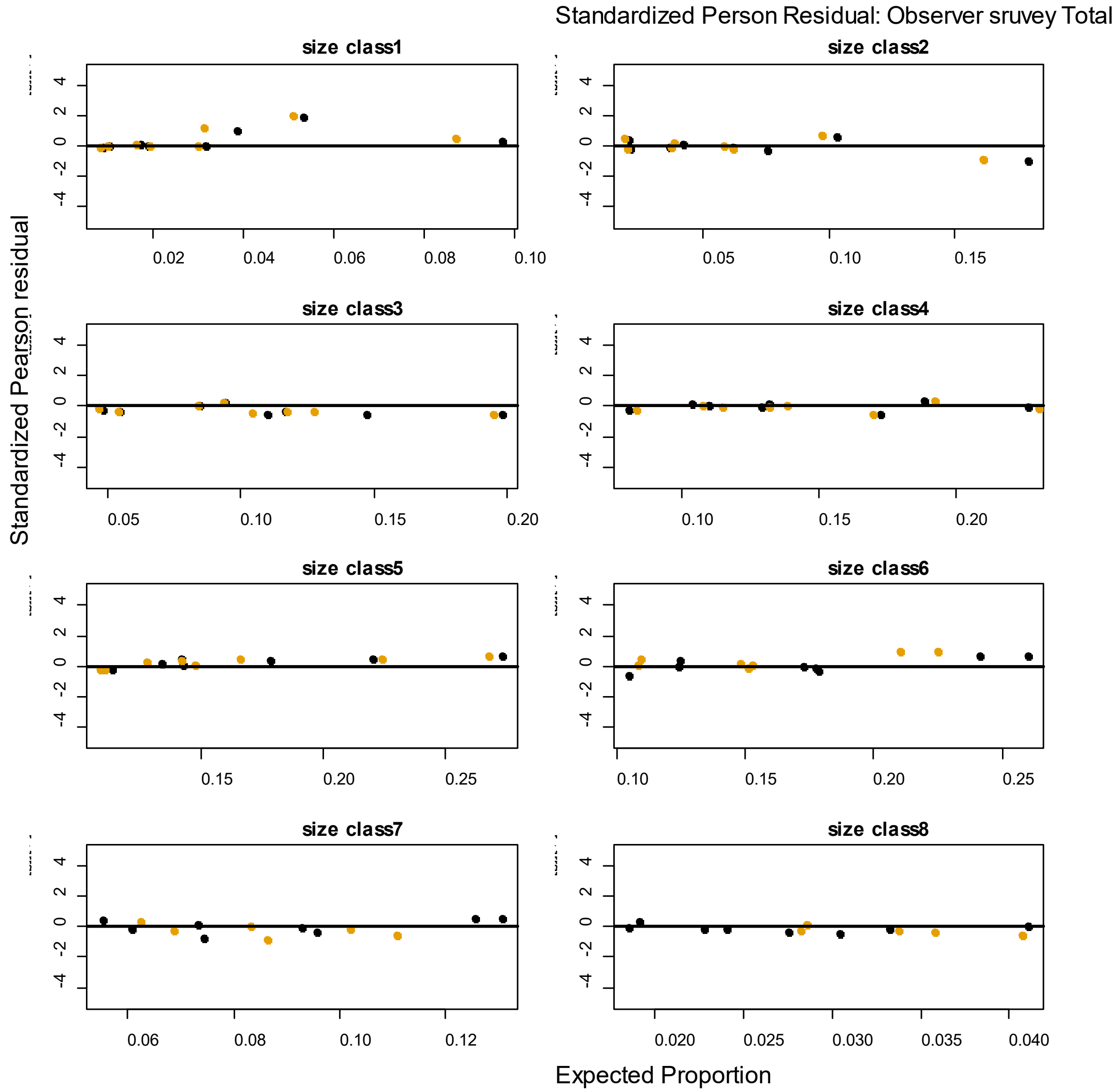


Figure 19. Standardized Pearson residual plot of Summer commercial observer total catch length size classes 1-8. Model 21.0 black and Model 21.1 red.

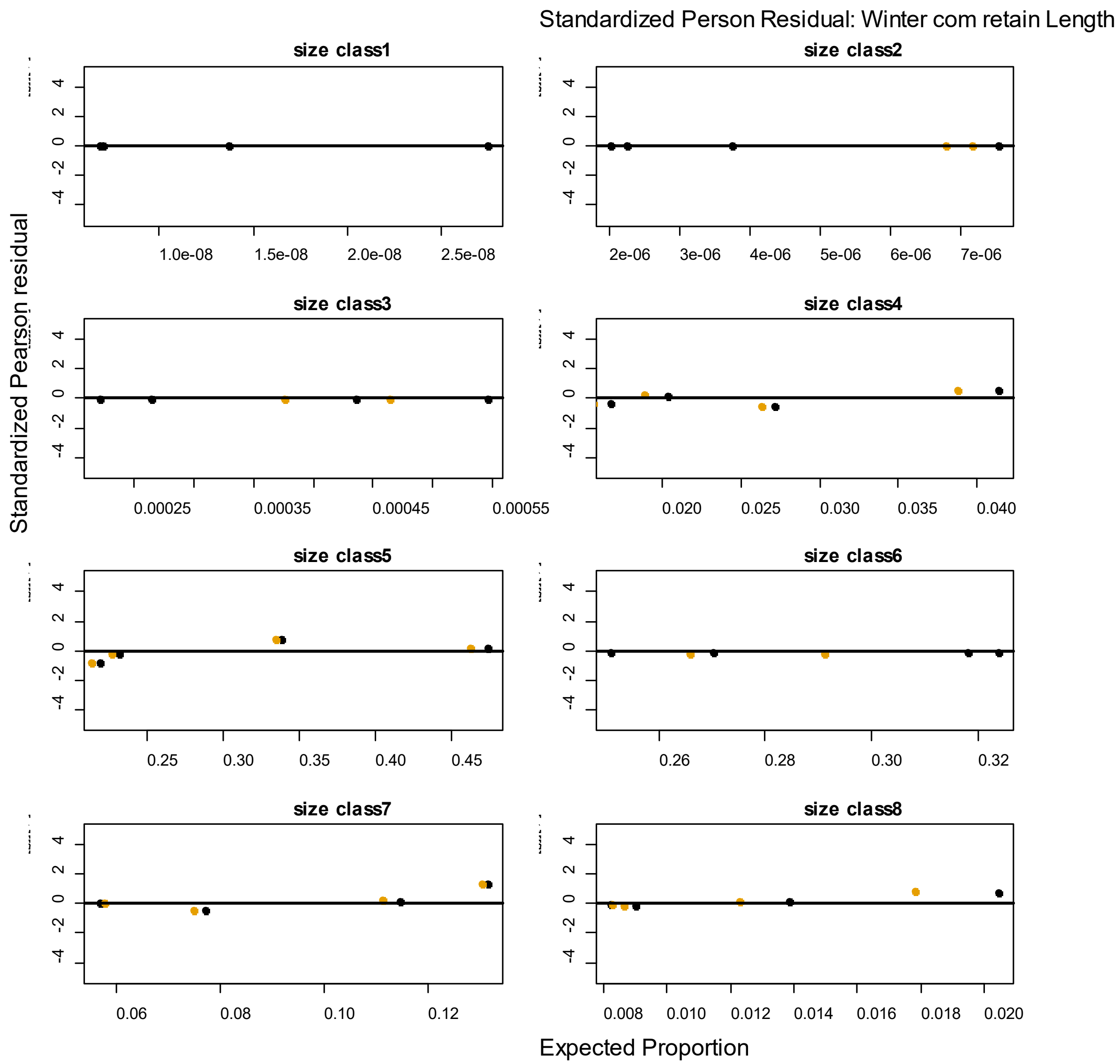
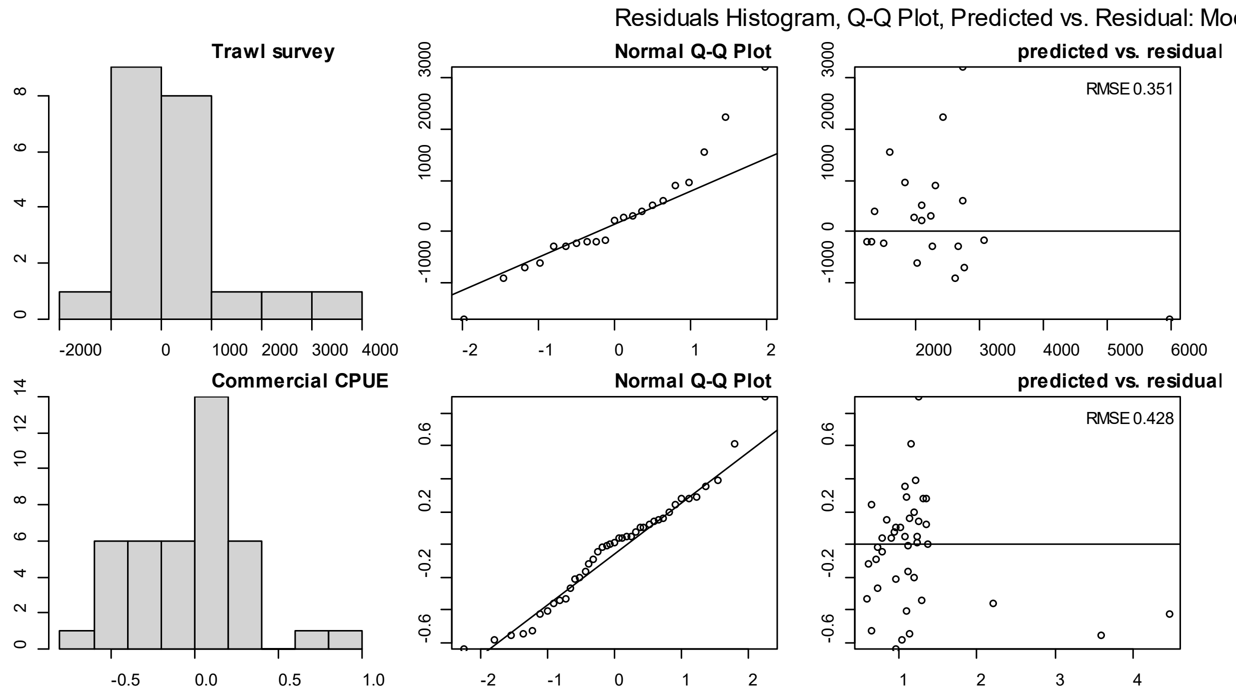


Figure 20. Standardized Pearson residual plot of Winter commercial retained length size classes 1-8. Model 21.0 black and Model 21.1 red.



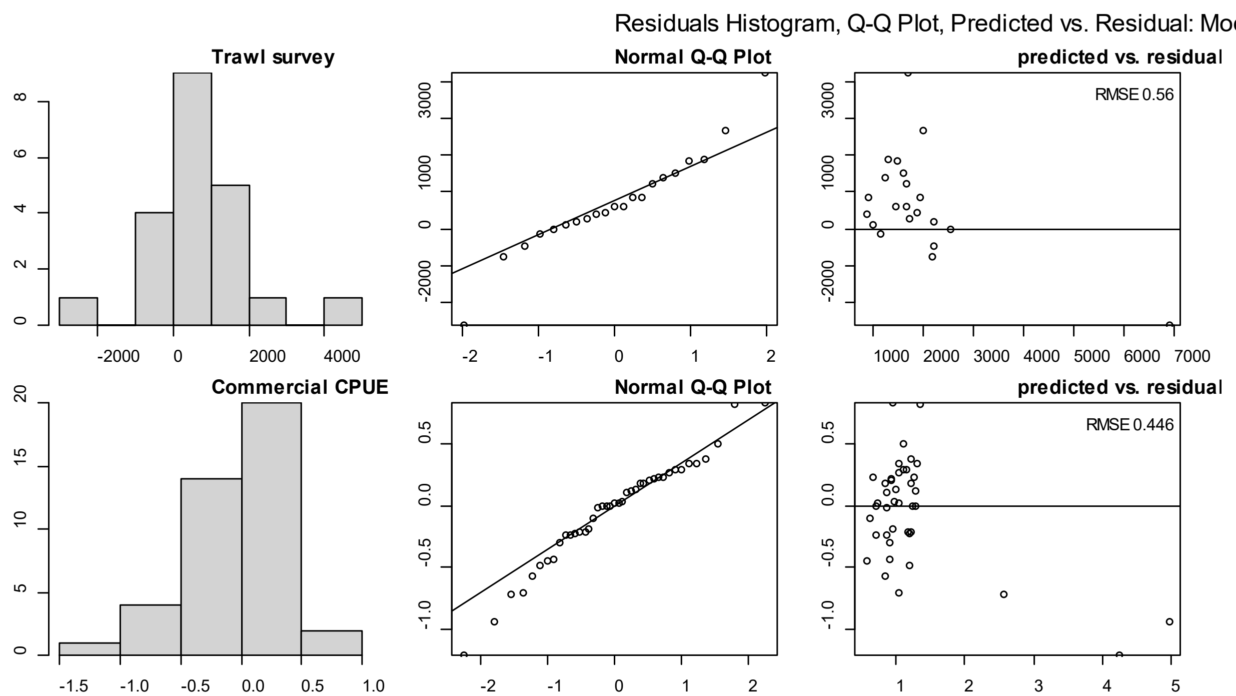


Figure 21. QQ Plot of Trawl survey and Commercial CPUE for Model 21.0 and Model 21.1

Place holder for Jan 2022
Figure 22. Retrospective Analyses of Norton Sound Red King Crab MMB from 2011 to 2022.

Solid black line: 2022 assessment model results.