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. During the 2021 fishery season, 320 crab (922 lb.) were harvested in winter commercial and 2,892 crab (5,784 lb) were harvested in the winter subsistence fishery. Summer commercial fishery opened in 2021, but 0 crab (0 lb) were harvested. In total, **3212** crab (**6,766** lb) were harvested during the 2021 season. This was below ABC of 0.35 million lb, and thus overfishing did not occur during the 2021 season.

3. Stock Biomass. Norton Sound red king crab is monitored not in biomass but in abundance. Abundance of the Norton Sound Red King Crab stock has been monitored by trawl surveys since 1976 by NOAA (1976-1991), NOAA NBS (2010-2019), and ADF&G (1996-2020). Historical survey abundance of the Norton Sound red king crab of carapace length greater than 63mm (CL > 63mm) ranged from 1.41 million to 5.9 million crab. In 2021 the survey abundance was 2.4 million crab (CV 0.6) by ADF&G trawl survey and 2.37 million crab (CV 0.43) by NOAA NBS trawl survey.

4. Recruitment. Recruitment is not monitored directly. It is inferred by the assessment model. The 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[a]	2.08	5.33				0.89	0.53, 0.40
2022[b]	2.15	4.79				0.96	0.58, 0.43

Notes:
MSST was calculated as $B_{MSY}/2$
OFL-ABC 2018-2020 are retained only
2019, 2020: Total catch equals retained catch. Discards catch was estimated only for summer commercial fishery, but summer commercial fishery did not occur.
2022 MSST, MMB, OFL, and ABC are CPT adopted after Jan 2022 CPT meeting
2022[a] model 21.0, 2022[b] model 21.5

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[a]	0.95	2.42				0.40	0.24, 0.18
2022[b]	0.98	2.17				0.44	0.26, 0.20

Conversion to Metric ton: 1 Metric ton (t) = 2.2046×1000 lb
2022[a] model 21.0, 2022[b] model 21.5

Biomass in millions of pounds

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	ABC Buffer	ABC
2018	4b	4.82	4.08	0.9	0.15	1980-2018	0.18	0.2	0.35
2019	4b	4.57	3.12	0.7	0.12	1980-2019	0.18	0.2	0.19
2020	4b	4.56	3.66	0.8	0.14	1980-2020	0.18	0.3	0.21
2021	4a	4.53	5.05	1.1	0.18	1980-2021	0.18	0.4	0.35
2022[a]	4a	4.17	5.33	1.3	0.18, 0.61	1980-2022	0.18, 0.61	0.4, 0.55	0.53, 0.40
2022[b]	4a	4.30	4.79	1.1	0.26, 0.59	1980-2022	0.26, 0.59	0.4, 0.55	0.58, 0.43

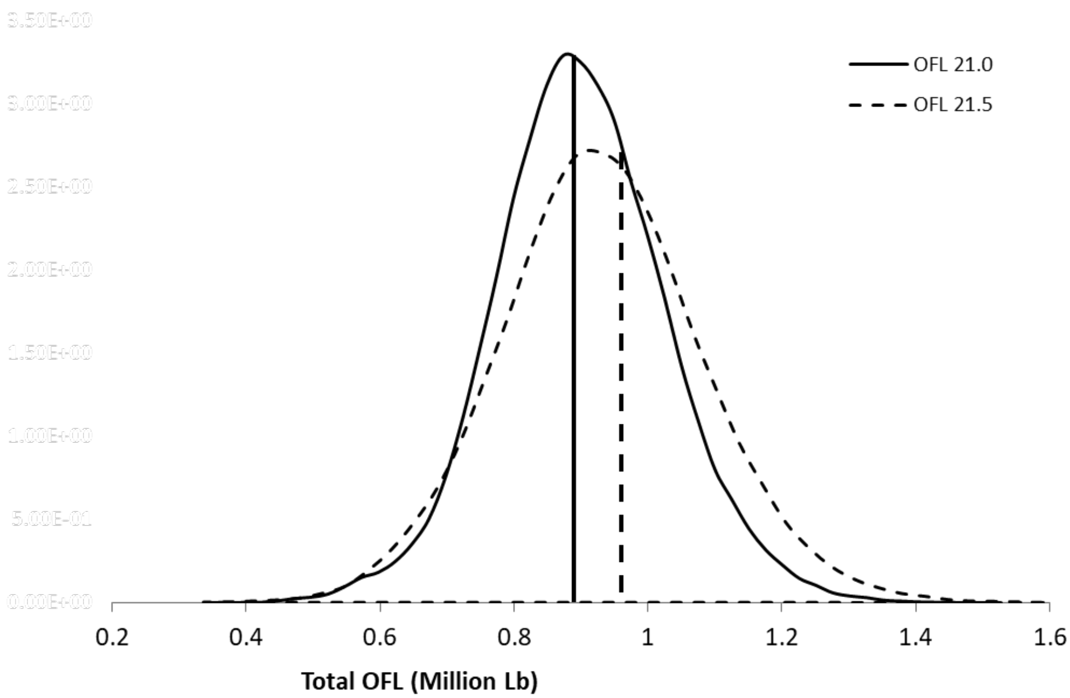
2022[a] model 21.0, 2022[b] model 21.5

Biomass in 1000t

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define	M	ABC Buffer	ABC

						BMSY			
2018	4b	2.07	1.85	0.9	0.15	1980-2018	0.18	0.2	0.16
2019	4b	2.06	1.41	0.7	0.12	1980-2019	0.18	0.2	0.09
2020	4b	2.07	1.66	0.8	0.14	1980-2020	0.18	0.3	0.09
2021	4a	2.05	2.29	1.1	0.18	1980-2021	0.18	0.4	0.16
2022[a]	4a	1.90	2.42	1.3	0.18, 0.61	1980-2022	0.18, 0.61	0.4, 0.55	0.24, 0.18
2022[b]	4a	1.95	2.17	1.1	0.26, 0.59	1980-2022	0.26, 0.59	0.4, 0.55	0.26, 0.20

6. Probability Density Function of the OFL and mcmc estimates of model 21.0 and 21.5.



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. Annual ABC buffer is determined by accounting for uncertainties in assessment and model results. **However, criteria for determining the mount of ABC buffer are undefined.** The SSC chose to use 90% OFL (10% Buffer) for the NARKC 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.

Year	ABC Buffer
2011-2014	10%
2015-2019	20%
2020	30%

2021	40%
2022	

8. A summary of the results of any rebuilding analysis

   NSRK is not overfished.

A. Summary of Major Changes in 2022 assessment model

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

   None. Summer commercial fishery opened but no crabs were harvested.

2. Changes to the input data.

   Input data update through 2021:

   Winter subsistence, winter and summer commercial crab fishery harvest.
   Trawl surveys: abundance, length-shell compositions: ADF&G, NOAA NBS 2021

   Standardized CPUE revision (See Appendix B)

3. Changes to the assessment methodology.

   Seven assessment models are compared in this report based on the recommendations by the CPT and SSC:

   a. Model 19.0e: with updated data,
   b. Model 21.0: Model 19.0e + St. CPUE with 3qs + 2 summer commercial retention probabilities,
   c. Model 21.1: Model 21.0 with M = 0.18 for all length size classes,
   d. Model 21.2: Model 19.0e + St. CPUE data updated with 3 q,
   e. Model 21.3: Model 19.0e + 2 summer commercial retention probabilities,
   f. Model 21.4: Model 21.0 with M estimated equally for all length size classes
   g. Model 21.5: Model 21.0 with M estimated for two length size classes (< 124mm, >123mm CL).

   These model scenarios focus on examination of *M* values and time blocks of fishery catchability and commercial retained probability.

4. Changes to the assessment results.

   Among the seven models, models 21.2 and 21.3 are incremental models between models 19.0e and 21.0 that corrects standardized summer commercial fishery CPUE and time blocks of retention probability based on re-evaluation of fishery history. Changes in standardized CPUE slightly increased overall abundance, MMB, and biomass but slightly decreased the projected 2022 MMB and OFL. Separating retention probability values before and after high grading reduced the retention probability of 94-104mm size class during the latter period, thus slightly improving model fit to summer commercial retention size proportions. Overall, the changes in model results are very minor for these two models. Model 21.1 with M = 0.18 for all size classes has the worst fit to the data among the seven models, followed by model 21.4. However, model 21.4 with a much higher estimated M fitted the data considerably better than the model 21.1. Model 21.5 had the best fit of data, slightly better than model 21.0. Both models have the same feature of M: two M values with one higher M value for crab over 123mm CL (M=0.18 & 0.62 for model 21.0 and M=0.26 & 0.59 for model 21.5). This suggests that the data are explained better by size-dependent M rather than a single M for all lengths.

Models 21.0 and 21.5 have similar estimates of molting probability and selectivity profiles. Both models, similar to the other models, also underestimated size-proportions of larger and oldshell crab from trawl survey and overestimated the proportions of oldshell crab from summer commercial fishery retained data. Model 21.5 has slightly higher estimated mean total abundance and recruits (3.4 and 1.4 million) than model 21.0 (3.1 and 1.2 million), but the estimated legal abundances and MMB were similar. Mohn's rho values from retrospective analyses are slightly smaller for model 21.5 (0.191) than for model 21.0 (0.209). Based on the model fits, we recommend model 21.0 or 21.5 for overfishing determination in 2022.

B. Response to SSC and CPT Comments

Following the request by SSC, CPT-SSC's requests/review (received in Jan 2021 and Oct 2021) 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 set to 0.18 from 0.3 of the initial assessment model. Since the inception of the crab

SAFE and adoption of NSRKC assessment model, the 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.

Authors reply:

Clutch fullness and confidence bounds are listed in Table 3. Figure is not provided as females are not used for the assessment model.

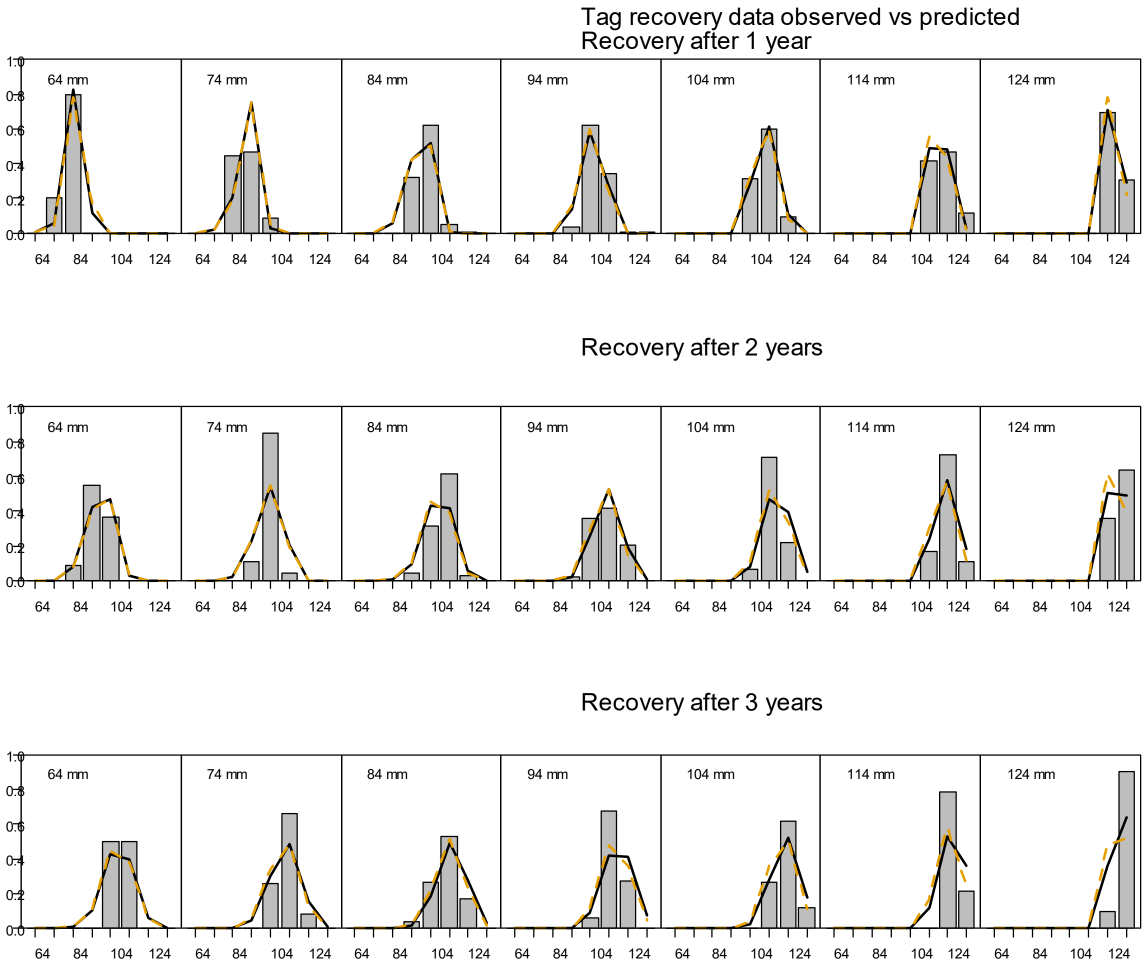
Growth

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.

Authors 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 dash red) generally matches. This suggest that transition size matrix derived from the tag-recovery data 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 look forward progress in the 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 affected very little 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 level	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, we evaluated following 3 methods of estimating discards.

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

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. CPT chose LNR2 discards observation method in 2021, 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 ADF&G 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.

Discards Estimate in the absence of observer survey

Bring forward methods to use historical data to estimate discard rates

Authors reply:

As noted in the above and Appendix C, discard estimation method of the NSRKC is an *ad hoc*. Given that the NSRKC observer survey is terminated, developing a method for estimating discards biomass is also an *ad hoc* and highly speculative.

Hear I present an intended method for estimating discards mortality biomass when observer data are available. This method can also be used for estimation of discards when the data are not available.

When an observer survey is conducted and observer discards and the size distribution are available, discards abundance and biomass can be estimated as follows:

1. Estimate the number of discarded crab (D_n) using the proportional method.

$$D_n = \frac{n_{dis}}{n_{ret}} N_{ret} = r_{dis} \cdot N_{ret}$$

where n_{ret} and n_{dis} are the number of retained and discarded crab in the observer survey, and N_{ret} is the number of retained crab from the commercial fisheries (tish ticket). r_{dis} is a discards-retained ratio.

2. Estimate biomass of discarded crab biomass (D_b)

$$D_b = D_n \sum_l p_{dis,l} \cdot wm_l = D_n \cdot w_{dis}$$

where $p_{dis,l}$ is the length (l) proportions of observed discarded crab, wm_l is the average weight of each length class (l). w_{dis} is a discard biomass unit per disgraced crab.

Combine the above two equations, discarded crab biomass is expressed as

$$D_b = r_{dis} \cdot w_{dis} \cdot N_{ret}$$

Applying discards mortality of 0.2, unretained catch biomass can be estimated as $0.2 \cdot D_b$, or $0.2 \cdot r_{dis} \cdot w_{dis} \cdot D_n$, $0.2 \cdot r_{dis} \cdot w_{dis}$ is a discard mortality biomass unit per retained crab (*Mort lb*).

During the 2012-2019 periods, discarded crab size proportions, r_{dis}, w_{dis}, and *Mort lb* are calculated as follows.

Size class	2012	2013	2014	2015	2016	2017	2018	2019	Average	Weight wm (lb)
34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.09
44	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.18
54	0.07	0.11	0.01	0.00	0.01	0.02	0.04	0.18	0.06	0.32
64	0.11	0.30	0.04	0.02	0.04	0.10	0.09	0.24	0.12	0.54
74	0.07	0.25	0.10	0.08	0.05	0.16	0.18	0.10	0.12	0.81
84	0.12	0.13	0.27	0.18	0.17	0.14	0.36	0.12	0.19	1.17
94	0.24	0.14	0.43	0.47	0.53	0.30	0.30	0.27	0.34	1.72
104	0.19	0.04	0.13	0.21	0.18	0.26	0.02	0.02	0.13	2.35
114	0.14	0.00	0.01	0.03	0.02	0.01	0.00	0.00	0.03	3.02
124	0.05	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	3.71
134	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.30
wdis	1.75	0.90	1.51	1.72	1.65	1.54	1.22	0.94	1.40	
r_{dia}	1.96	1.40	1.02	0.92	0.25	0.25	0.50	0.87	0.90	
$r_{dis} \cdot w_{dis}$	3.43	1.27	1.53	1.58	0.42	0.39	0.61	0.82	1.26	

Mort lb	0.786	0.254	0.306	0.316	0.084	0.078	0.122	0.164	0.252	

Mort lb ranged from 0.078 to 0.786, with the mean of 0.252. In the absence of observer data, unretained crab mortality can be estimated as $0.252N_{ret}$. However, this also indicates that applying the mean would overestimate unretained catch by 3.2 times (0.252/0.078) or underestimate it by 0.32 times (0.252/0.786).

Alternative methods:

Alternative 1.

An alternative method is using the trawl survey length proportion data as proxy for true length proportion. The model estimated trawl survey selectivity is 1.0 for all lengths, which indicates that trawl survey length composition equals NSRKC length proportion. Discards length proportion $p_{dis,l}$ can be estimated by multiplying model estimated fishery selectivity (S_l) and 1-retention probability ($S_{ret,l}$)

$$p_{dis,l} = p_{twl,l} \cdot S_l \cdot \left(1 - S_{ret.l}\right)$$

The discards-retained ratio (r_{dis}) is

$$r_{dis} = \frac{\sum_l p_{twl,l} \cdot S_l \cdot \left(1 - S_{ret,l}\right)}{\sum_l p_{twl,l} \cdot S_l \cdot S_{ret,l}}$$

The discard biomass unit (w_{dis}) is

$$w_{dis} = \frac{\sum_l p_{twl,l} \cdot S_l \cdot \left(1 - S_{ret,l}\right) \cdot wm_l}{\sum_l p_{twl,l} \cdot S_l \cdot \left(1 - S_{ret,l}\right)}$$

During the 2012 – 2019 periods, trawl survey occurred in 2014, 2017, 2018, and 2019. The table below shows trawl survey length proportion, and model estimated selectivity and retention probability from the 2021 assessment model.

Sizeclass	2014	2017	2018	2019	Selectivity (2021)	Retention (2021)	lb
34	0.01	0.11	0.02	0.00	0.00	0.00	0.09
44	0.00	0.02	0.33	0.00	0.01	0.00	0.18
54	0.01	0.01	0.42	0.02	0.04	0.00	0.32

64	0.01	0.06	0.08	0.13	0.12	0.00	0.54
74	0.07	0.12	0.05	0.47	0.33	0.00	0.81
84	0.14	0.11	0.02	0.26	0.64	0.00	1.17
94	0.25	0.06	0.02	0.04	0.86	0.07	1.72
104	0.27	0.09	0.01	0.02	0.96	0.88	2.35
114	0.14	0.13	0.01	0.01	0.99	1.00	3.02
124	0.06	0.23	0.01	0.02	1.00	1.00	3.71
134	0.02	0.07	0.02	0.03	1.00	1.00	4.30
w_{dis}	1.56	1.28	0.92	1.04			
r_{dia}	0.75	0.35	1.53	4.72			
$r_{dis} \cdot w_{dis}$	1.18	0.45	1.41	4.92			
Mort lb	0.236	0.090	0.282	0.984			
% Deviation	-22.9	+15.4	-56.7	+500			

Among the 4 years, the model estimated *Mort lb* multiplier ranged from 0.090 to 0.984. Compared those with observed, the model deviation ranged from -22% to +500%. The deviation was greater in 2018 and 2019.

Alternative 2.

The NSRKC assessment model estimates directly from the observed retained catch using the alternative model 1 approach except that the model uses predicted length composition. Use the adopted model (baseline model) with updated data to estimate discards biomass.

In all cases, the major difficulty is inferencing the amount and length composition of **unobserved crabs** that are highly variable and cannot be directly estimated from retained crab. Applying average Mort lb ignores the annual variations. Alternative models attempts to estimate annual variations with model estimated selectivity and retention probability; however, this also generate highly variable estimates.

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 ADF&G staff routinely ask reasons for additional permits, fishermen are NOT required to provide reason. Fishermen are not required to report 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.

Authors reply:

Jon Richar received an approval from his supervisor to work on a VAST model for the Norton Sound trawl surveys. We look forward to work with him when he is available.

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, exponent back to normal space (Appendix B, NPFMC 2013). For detailed description of the standardized CPUE calculation method and SD, please refer NPFMC (2013) for the original report and Appendix B for a brief data and model update.

III. NSRKC Assessment model

Data weighting

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.

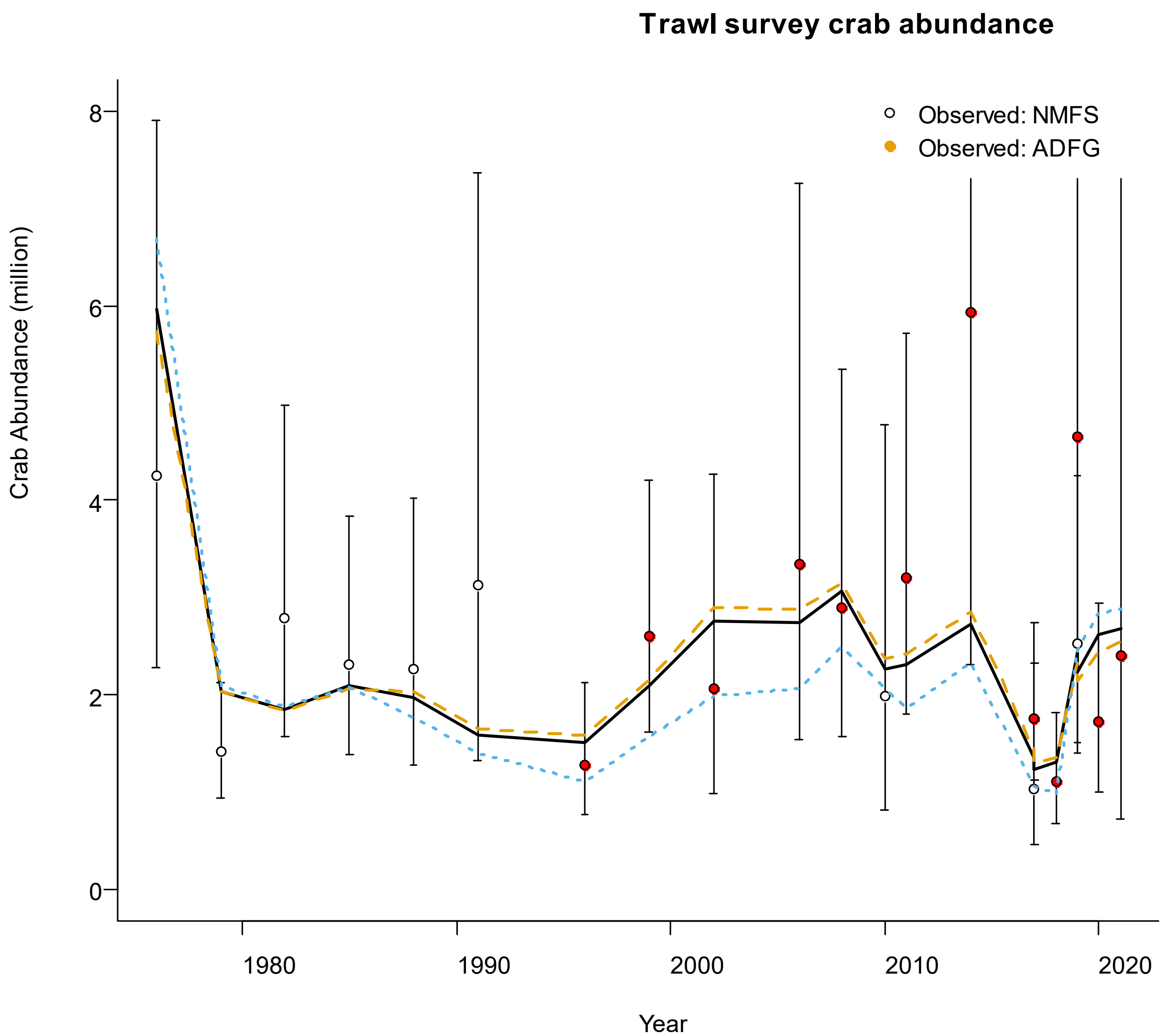


Figure: Model 21.0 default input sample size (20: trawl, 10: others) (black) vs. increased input sample size (200, 100) (blue dash line), and reduce input size (10, 5) (red dash line).

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.

Authors reply:

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

Variant of Model 21.0 with estimated natural mortality

Authors reply:

Models 21.4 and 21.5 estimates natural mortality.

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 ADF&G 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 to estimate the number of retained crab in Winter and summer commercial fishery prior of 2008. During this time, all legal sized crab was assumed to be retained. Since 2009 commercially retained crab size is CW > 5.0 and retention probability is estimated from the observer survey.

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. The plot is based on carapace length (CL>104mm) not carapace width (CW

>4.75 inch) that is the definition of legal crab. Legal crab biomass NOT used for calculation of the OFL. Thus, there is no meaning to plot the legal biomass time series by different proportion of legal crab.

The table below shows the proportion of legal vs. retained crab during the 2012-2019 observer survey, in response to request by the public.

Year		64	74	84	94	104	114	124	134
2012	Legal	0	0.01	0.02	0.22	0.9	1	1	1
	Retained	**0**	**0**	**0**	**0.05**	**0.46**	**0.63**	**0.64**	**0.85**
2013	Legal	0	0	0	0.44	0.98	1	1	1
	Retained	**0**	**0**	**0**	**0.14**	**0.86**	**0.99**	**1**	**1**
2014	Legal	0	0	0	0.22	0.91	1	1	1
	Retained	**0**	**0**	**0**	**0.04**	**0.74**	**0.97**	**0.99**	**1**
2015	Legal	0	0	0	0.38	0.98	1	1	1
	Retained	**0**	**0**	**0**	**0.11**	**0.74**	**0.91**	**0.94**	**0.89**
2016	Legal	0	0	0	0.46	1	1	1	1
	Retained	**0**	**0**	**0**	**0.13**	**0.89**	**0.99**	**1**	**1**
2017	Legal	0	0	0	0.12	0.91	1	1	1
	Retained	**0**	**0**	**0**	**0.02**	**0.75**	**0.99**	**1**	**1**
2018	Legal	0	0	0	0.16	0.95	0.99	1	1
	Retained	**0**	**0**	**0**	**0.14**	**0.92**	**0.99**	**1**	**0.99**
2019	Legal	0	0	0	0.18	0.93	1	1	1
	Retained	**0**	**0**	**0**	**0.15**	**0.93**	**1**	**1**	**1**

The proportion of legal sized crab retained from observer survey 2012-2019

Year	64	74	84	94	104	114	124	134
2012	0	0	0	0.23	0.51	0.63	0.64	0.85
2013	0	0	0	0.31	0.88	0.99	**1**	1
2014	0	0	0	0.19	0.82	0.97	0.99	1
2015	0	0	0	0.28	0.76	0.91	0.94	0.89
2016	0	0	0	0.28	0.89	0.99	1	1
2017	0	0	0	0.14	0.82	0.99	1	1
2018	0	0	0	0.87	0.98	1	1	0.99
2019	0	0	0	0.86	1	1	1	1

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.*

Authors 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 directly 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.

Authors 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 (NSRKC) is one of the northernmost red king crab populations that can support a commercial fishery (Powell et al. 1983). It is distributed throughout Norton Sound with a westward limit of 167-168° W. longitude, depths less than 30 m, and summer bottom temperatures above 4°C. The Norton Sound red king crab management area consists of two units: Norton Sound Section (Q3) and Kotzebue Section (Q4) (Menard et al. 2011). The Norton Sound Section (Q3) consists of all waters in Registration Area Q north of the latitude of Cape Romanzof, east of the International Dateline, and south of 66°N latitude (Figure 1). The Kotzebue Section (Q4) lies immediately north of the Norton Sound Section and includes Kotzebue Sound. Commercial fisheries have not occurred regularly in the Kotzebue Section. This report deals with the Norton Sound Section of the NSRKC management area.

3. Evidence of stock structure:

Based on variability at 15 SNP loci and in mtDNA sequences (COI, 665 bp), NSRK stock belongs to the Okhotsk Sea–Norton Sound–Aleutian Islands evolutionary lineage (SNPs, FCT = 0.054; mtDNA FCT = 0.222) (Grant and Chen 2012). However, this does not indicate that NSRKC is a single stock. The study indicates that the study was incapable of detecting possible evolutionary stock difference within NSRKC stock. No studies have investigated possible stock separation within Norton Sound management area (Figure 1).

4. Life history characteristics relevant to management:

Life history of NSRKC has not been well studied. One of the unique life-history traits of NSRKC 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 NSRKC have not been well studied. Based on the 1976-2021 trawl surveys, NSRKC 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. NSRKC are consistently abundant offshore of Nome.

NSRKC migrate between deep offshore and shallow inshore 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 Jan-March for female based on laboratory observation (Leah Zacher and Jennifer Gardner NOAA-AFSC personal comm). Trawl surveys show that crab distributions are patchy and dynamic.

5. Brief management history:

NSRKC 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 (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 fishery. In 2021 NSEDC stopped purchasing NSRKC.

<u>CDQ Fishery</u>

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

<u>Winter Commercial Fishery</u>

The winter commercial crab fishery is a small fishery using hand lines and pots through the nearshore ice. On average 10 permit holders harvested 2,500 crab during 1978-2009. From 2007 to 2015 the winter commercial catch increased from 3,000 crab to over 40,000 (Table 2). In 2015 the 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 with the 2016 season.

<u>Subsistence Fishery</u>

The 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 winter 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 NSRKC 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 the summer commercial fishery GHL was revised to (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 BOF passed the following regulations regarding the winter commercial fisheries:

   1) Revise GHL to include summer and winter commercial fisheries.
   2) Set GHL 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 below ABC retained that was derived from retained the OFL. Since 2021 the OFL and ABC of NSRKC is a total OFL that includes mortality of both retained and unretained crab. The historical management changes are summarized in the following table.

Year	Notable historical management changes
1976	The abundance survey started
1977	**Large vessel commercial fisheries began. Legal size was set to ≥ 5 inch CW**
1978	**Legal size was changed 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 was changed to ≥ 5 inch CW**
2012	The BOF adopted a revised GHL for summer fishery.
2016	Winter GHL for commercial fisheries was established and modified winter fishing season dates were implemented.
2020	The BOF closed summer commercial fishery E of 167 longitude
2021	NSEDC stopped purchasing NSRKC

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 (1993) or no crab was harvested (2020, 2021).

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 ADF&G summer trawl survey was conducted in 7/19 – 8/3 2021. Because of unfavorable weather condition, 39 out of usual 60 stations were surveyed. Total male crab abundance estimate (CL > 63mm) is 2,400,000 with a CV 0.60.

Norton Sound portion of the NOAA NBS trawl survey was conducted in 7/29 – 8/7 2021. Total male crab abundance estimate (CL > 63mm) is 2,370,000 with a CV 0.43.

2. Available survey, catch, and tagging data

Available NSRKC data consist of followings: trawl survey that informs abundance and size composition, catch that informs size composition and standardized CPUE that informs an index of abundance, and tag recovery that informs growth-transition.

Trawl survey

Trawl survey consists of 3 surveys: NMFS triennial survey: 1976-1992, ADF&G triennial-annual survey: 1996-2019, and NOAA biannual survey: 2010, 2017-2019.

NMFS triennial survey:

Norton Sound trawl survey was initiated by NMFS in 1976 to assess stock status of crab and ground fish in Norton Sound and Kotezbue Sound. The survey established 10 nautical mile (nm) grid survey stations throughout the entire Norton Sound and 15 nm grids outer Norton Sound area. The grid survey stations became the standard stations since 1976. Th survey was conducted from mid-late August to September-October, except for 1979. The survey used 83-112 Eastern Otter trawl gear, with tow distance of 1.3 – 1.7 nm (30 minutes tow). The survey was terminated in 1992.

ADF&G triennial -annual survey:

After the termination of the NMFS trawl survey, ADF&G began trawl survey in 1996 using the same survey stations, but smaller boat and survey coverage. The survey started as triennially but became annual survey in 2017. The survey usually occurs in late July – mid August, using 400 Eastern Otter trawl gear with tow distance of 1.0 nm. The survey used to have a re-tow protocol: when the first tow caught more than 7 red king crab, the station was re-towed. This protocol was dropped in 2012 in favor of more coverage.

NOAA biennial NBS survey:

NOAA NBS trawl survey started in 2010, and biennially since 2017. The survey occurs in late July-mid August, similar time as ADF&G survey. The survey has 20 nm grid using 83-112 Eastern Otter trawl gear, with tow distance of 1.3 – 2.5 nm (30 min tow).

Abundance estimation method

Methods of estimating abundance differed among the three surveys and throughout time periods. Abundance estimates have been revised many times.
Abundance and CV of the NMFS 1976-1991 surveys were provided by NOAA (Jon Richer NOAA p*ersonal communication*). The abundance was estimated by averaging catch CPUE (#/nm^2) of all stations (including survey stations out of Norton Sound) that was multiplied by standard Norton Sound Area (7600 nm^2) (i.e., N = 7600*mean CPUE). On the other hand, ADF&G survey abundance is calculated at each station CPUE*(100 mm^2) and summed across all surveyed stations (i.e., N = sum of 100*CPUEs) (Bell and Hamazaki 2019). Extent of the ADF&G survey coverage differed among years due to survey conditions, and survey abundance was not standardized. NOAA NBS survey abundance is estimated by the author with the data limited only Norton Sound survey area that overlaps ADF&G survey area (5841 nm^2).

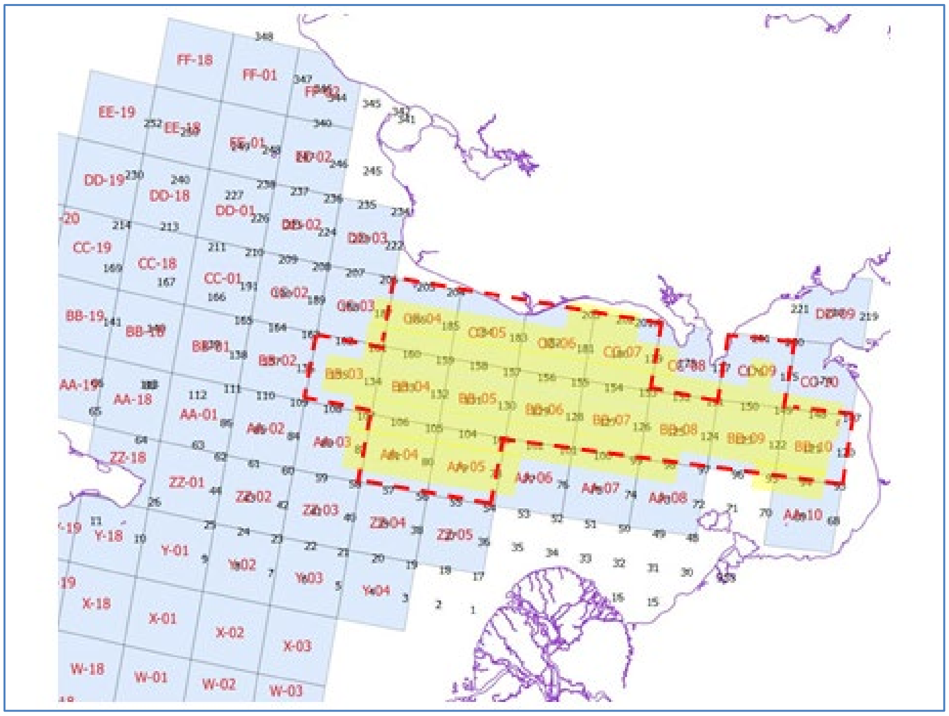


Figure ADF&G trawl survey coverage (yellow shade) and NOAA NBS trawl survey coverage where abundance estimates were made (red hashed line)

Catchability of NSRKC appears to differ between ADF&G and NMFS-NOAA NBS trawl surveys. ADF&G trawl survey abundance tend to be higher than NMFS-NOAA NBS trawl survey even though NMFS-NOAA NBS survey coverages are greater than ADF&G. The assessment model assumes (recommendation by CPT-SSC) that survey q of ADF&G trawl survey be 1.0, which resulted in q = 0.7-0.8 for NMFS and 0.7-0.96 for NOAA NBS survey.

Standardized CPUE

Standardized summer commercial fishery CPUE is included in the NSRKC assessment model as an index of NSRKC abundance that could supplement triennial trawl survey. CPUE standardization model was developed by Gretchen Bishop (ADF&G) (NPFMC 2013). Since then, the same model has been applied with updated data (Appendix C).

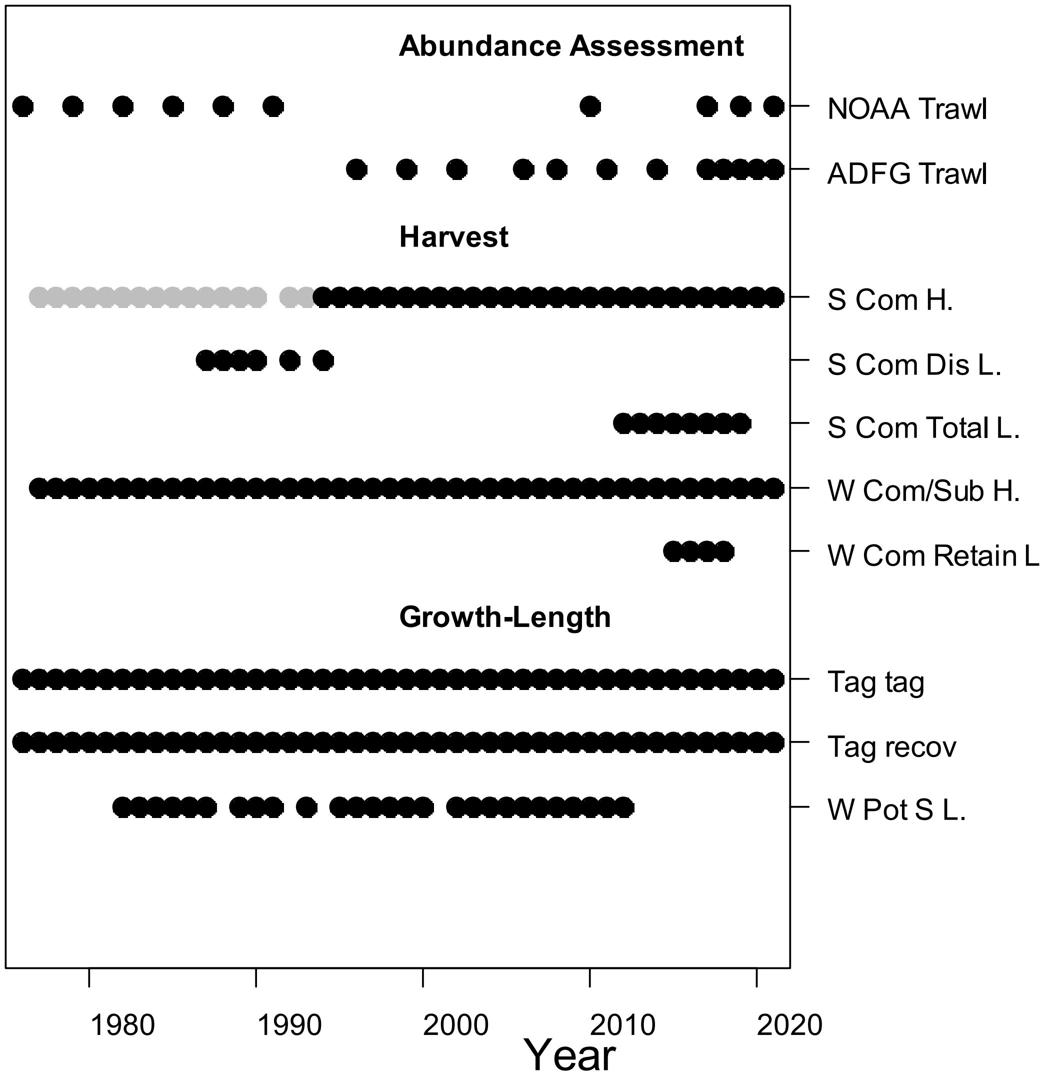
Tagging-recovery data

Norton Sound tagging study was initially conducted in 1980 as a part of mark-recapture abundance survey (Brannian 1987). The study was conducted in 1980-1982 and 1985. From 1986 to 2012 crabs were tagged during the winter pot survey. The winter surveys tagged more smaller (sublegal) crabs; however, very few were recovered. Tagging study was resumed in 2012-2015 for spring migration movement survey. In all the above studies, tagged crabs were recovered by commercial fisheries.

Length-Shell proportion data

Length-shell data have been collected in every research and harvest monitoring surveys. Of those, summer commercial harvest sampling, winter pot survey (terminated in 2012), and trawl survey have been consistent.

Time series of the data used for the NSRKC assessment model are summarized in the following figure and table.


Abundance Assessment
NOAA Trawl
ADFG Trawl
Harvest
S Com H.
S Com Dis L.
S Com Total L.
W Com/Sub H.
W Com Retain L.
Growth-Length
Tag tag
Tag recov
W Pot S L.
1980
1990
2000
2010
2020
Year

	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, Appendix B 4
Summer Com total catch	12-19	Length-shell comp	9
Summer Com Discards	87-90,92,94	Length-shell comp	8
Winter subsistence fishery	76-21	Total & Retained catch	2
Winter commercial fishery	78-21 15-18	Retained catch Retained Length-Shell	2 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	2005-2019	retained catch	Too few catches, ignored.
Winter Pot survey	87, 89-91,93,95-00,02-12	CPUE	CPUE data unreliable.
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. Norton Sound Fishery management area (Area Q3) extends to St. Lawrence Island and US-Russia border (Figure 1). In the absence of survey abundance extended to those area, it is questionable whether those bycatch mortalities be induced in the NSRKC population.

	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

Other miscellaneous data:

Tagging-recovery locations (2012-2019)

Satellite tag migration tracking (NOAA 2016, ADF&G 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:

Length data were aggregated by 10mm range, starting from 64-73mm. Crab length greater than 133mm were aggregated in >133 mm class.

Shell condition data were aggregated to from very new, new, old, very old, very very old to simple newshell and oldshell.

Tag-recovery data were aggregated regardless tagging years.

Data estimated outside the model:

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

Proportions of legal size crab, estimated from trawl survey and observer data. (Table 13)

Average weight of crab by length class (Table 13)

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, several alternative assumptions have been considered in the past.

   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. This modeling configuration resulted in estimating MMB twice higher than the default model (NPFMC 2017). The NOAA NBS surveys (2010, 2017, 2019) did not find high red king crab population in outer Norton Sound area. The large crab could also be near coastal area where commercial fishery is closed, and trawl survey is not conducted due to rocky bottom.

   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). However, the model fit is slightly worse than the default model. In Tier 4, a higher M also results in higher OFL.

   c. Higher natural mortality (M>0.18) for small and large crab having higher mortality than small crab.

      This model configuration had the best fit to data (NPFMC 2017). However, the CPT and SSC rejected the model.

   d. 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.

   e. 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, the overall model fit did not greatly 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 (NPFMC 2013). Additional variance was also included in standardize CPUE model cv (NPFMC 2014).

   In addition, time variant CPUE and trawl survey catchability (*q*) were included. Thr CPUE q has two values: 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 ADF&G trawl survey was assumed to be 1.0. Assuming the NMFS and NBS survey *q* to be 1.0 resulted in ADF&G trawl survey *q* greater than 1.0 (i.e. trawl survey overestimates abundance), even though ADF&G trawl survey area is generally smaller than NMFS and NBS survey areas.

   When M = 0.18 is assumed for all length classes, the model appears to ignore trawl survey data and assume low abundance. Survey *q* values for NMFS and NBS surveys increased to 1.65 and 1.28 respectively (Model 21.1). This indicates that survey the trawl surveys overestimated NSRKC abundance.

   This model fitting issue was also influenced by input sample sizes for size-shell compositions. Increasing the input sample size would also resulted in the model estimating lower abundance. Reducing the input sample sizes improved model fit to the trawl survey data but caused lower fit to size-shell composition data (NPFMC 2012, 2013, 2015). 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) The CPT and SSC suggested no model alternatives

2021 (NPFMC 2021) Included discards data. The CPT and SSC requested

1) Models that bridge from the Model 19.0e to 21.0
2) Model 21.0 with natural mortality estimated by model.

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 NSRKC. The detailed description of the model is in Appendix A.

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 assumes newshell crab as molted and oldshell crab as unmolted.

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.

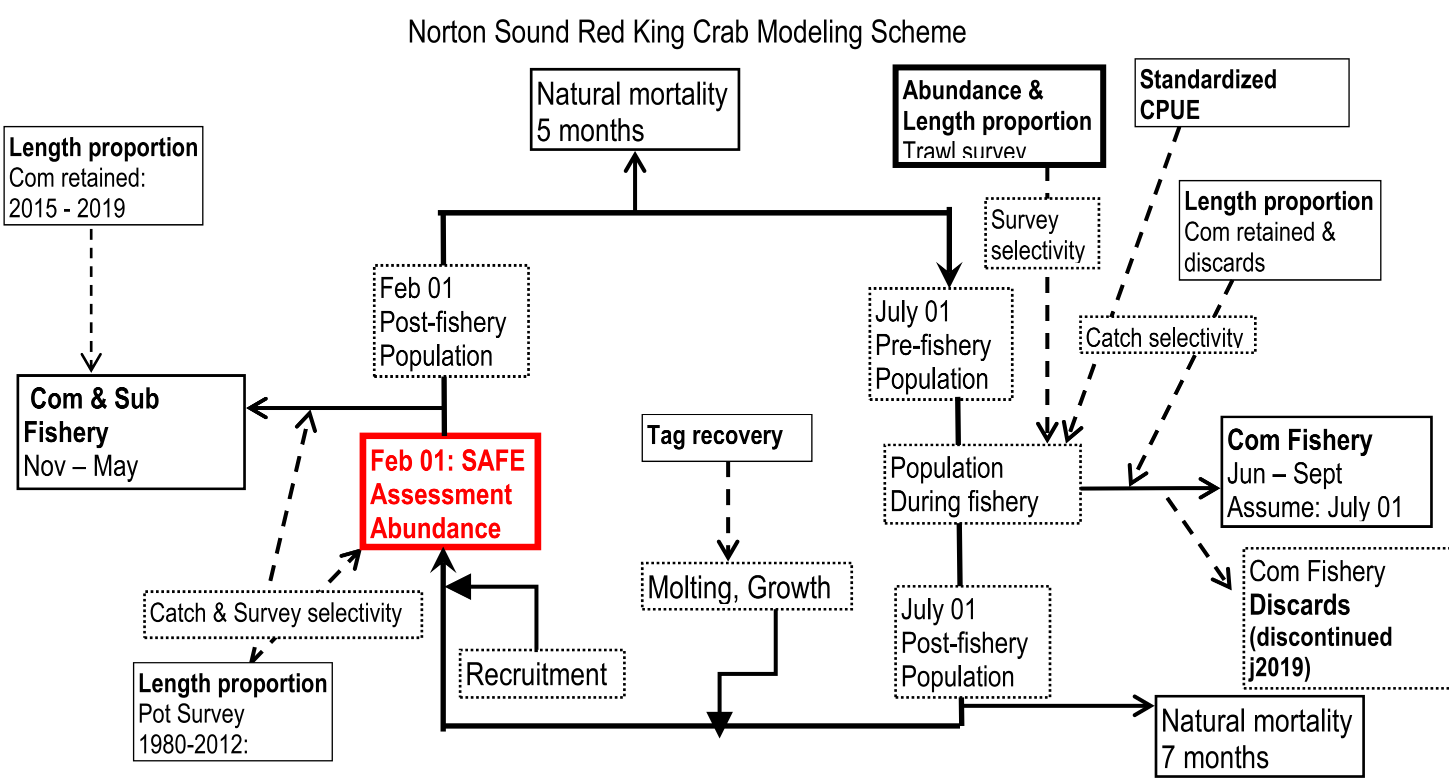


Figure: Norton Sound Red king crab model and data scheme. Bold type indicate data that were fitted to the model. Boxes in dotted line indicate model estimated parameters and quantities.

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) and summer (July 1st) fisheries**
- **Instantaneous molting and recruitment occur on July 1st**

- Critical model assumptions

NSRKC Crab Biology

1. Instantaneous annual natural mortality (*M*) is 0.18 and increase at the size greater than CL 123mm. *M* is constant over time.
2. Male crab size at maturity is 94mm CL.
3. Molting occurs in right after the summer fishery.
4. Recruitment occurs in fall at the same time of molting.

   In NSRKC assessment modeling, recruitment is not a function of mature males, but estimated model parameters entering to the immature length classes 64mm-93mm. In modeling, this adjustment is done at the same time of molting-growth.
5. Molting probability is an inverse logistic function. Molted crab become newshell and unmolted crab become oldshell crab.
6. Growth increment is a function of length, constant over time. Molted crab does not shrink.

NSRKC Survey

1. ADF&G trawl survey abundance has the same scale as the population (i.e. catchability q = 1.0). Abundances by historical NMFS (1976-1992) and NOAA NBS (2010-present) survey are biased low (i.e. q < 1.0).

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). The CPT and SSC recommended fixing the survey q of the ADF&G survey to 1.0.

2. 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 surveys 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, the SSC recommended that using only one selectivity.

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. The 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 fishery 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 a 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, the SSC recommended using only one selectivity.

3. 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.

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

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

6. 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.

Model data weighting

Survey data	Input 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

Recruitment SD: 0.5.

Discards CV: 0.3

"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 implied effective sample sizes vary greatly over time.

Changes of assumptions since last assessment:

None

3. Model Selection and Evaluation

a. Description of alternative model configurations.

For the 2021 final assessment, the CPT and SSC adopted model 19.0b (discard abundance estimated by the LNR2 method). For the 2022 draft assessment, we proposed model 21.0. For the 2022 final assessment, the CPT and SSC recommended following alternative models:

Model 19.0e: with updated data
Model 21.0: Model 19.0e+ St CPUE with 3qs + 2 summer commercial retention probabilities.
Model 21.1: Model 21.0 with M = 0.18 for all length size classes.
Model 21.2: Model 19.0e + St CPUE data updated with 3 qs.
Model 21.3: Model 19.0e+2 summer commercial retention probability
Model 21.4: Model 21.0 with M estimated equally for all length size classes
Model 21.5: Model 21.0 with M estimated for two length size classes (< 124mm, >123mm CL).

Models 21.2 and 21.3 are "bridging analyses" from model 19.0e to 21.0 requested by the CPT. Models 21.4 and 21.5 examine appropriateness of the *M*=0.18 assumptions. Model 21.4 assumes single *M* for all size classes, and model 21.5 assumes size dependent *M* same as the model 21.0

Model	Discards Est	St.CPUE Q	Retention probability	M	Parameters
19.0e	Prop	1	1	0.18+est (L)	
21.0	Prop	3	2	0.18+est (L)	+4
21.1	Prop	3	2	0.18	+3
21.2	Prop	1	2	0.18+est (L)	+2
21.3	Prop	3	1	0.18+est (L)	+2
21.4	Prop	3	2	Est	+4
21.5	Prop	3	2	Est (S,L)	+5

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

1. Revision of fishery time period and 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. In the 2019 model, the 3 periods were included as block effect of a single glm that was suggested by the CIE review. However, this was deemed to be incorrect.
3. Increase of summer and winter commercial retention probabilities from 1 model for each fishery to 2 model for each fishery, indicating changes in retention probability before and after high grading fishery. Model 19.0: indicating pre and post high grading in commercial fishery.
4. Models 21.2, 21.3 are intermediate transition from model 19.0e to 21.0, requested by the CPT and SSC.
5. Comparisons among Models 21.0, 21.1, 21.4, and 21.5 are proposed to examine the effects of *M* assumptions, requested by the SSC.

b. Evaluation of negative log-likelihood values.

Table L. Negative log likelihood for alternative models.

								Sept 2021	**Sept 2021**

Model	19.0e	21.0	21.1	21.2	21.3	21.4	21.5	21.0	21.1
Additional Parameters		+4	+3	+2	+2	+4	+5	+4	+3
Total	346.67	340.05	396.6	341.58	345.08	350.20	337.31	320.39	379.73
TSA	11.46	11.78	34.9	11.71	11.48	10.97	11.03	11.33	32.70
St.CPUE	-17.21	-23.57	-19.0	-23.73	-17.25	-24.19	-24.45	-36.35	-28.04
TLP	129.81	129.67	133.30	129.94	129.66	132.03	128.34	124.89	128.07
WLP	39.30	38.88	40.75	38.91	39.28	39.78	38.87	38.51	40.04
CLP	50.00	48.28	62.55	49.60	48.64	51.49	47.79	48.39	64.28
OBS	24.11	24.36	25.47	24.23	24.20	27.93	25.10	24.49	25.06
REC	2.77	2.77	2.56	2.77	2.78	2.14	2.59	2.81	2.54
WN	18.95	20.36	20.14	20.40	18.95	20.78	21.07	20.15	19.22
DIS	3.40	3.59	3.89	3.68	3.30	3.07	3.20	3.61	4.03
TAG	84.13	83.98	92.04	84.14	84.03	86.21	83.77	82.55	91.39
RMSE Trawl	0.35	0.35	0.56	0.35	0.35	0.33	0.34		
RMSE CPUE	0.45	0.40	0.43	0.39	0.46	0.39	0.40		
BMSY(mil.lb)	4.21	4.17	2.40	4.20	4.17	4.21	4.30	4.48	2.55
MMB 2022 (mil.lb)	5.17	5.33	4.90	5.17	5.35	4.70	4.79	5.22	4.85
Retainable Crab (mil.lb)	4.11	4.27	3.93	4.11	4.28	3.56	3.76		
Discards Crab (mil.lb)	1.22	1.24	1.03	1.21	1,24	1.11	1.12		
Total OFL(mil.lb)	0.92	0.89	0.64	0.89	0.88	1.12	0.96		
M	0.18 0.62	0.18 0.61	0.18	0.18 0.62	0.18 0.61	0.42	0.26 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

Models 21.2 and 21.3 are bridge analyses from model 19.0e to 21.0 that corrected standardized CPUE (Appendix C) and periods and types of retention probability based on re-evaluation of fishery history. Those updates are considered as data correction, and the bridge model were intended to show how those data corrections would change NSRKC population status. Changes in st.CPUE (19.0e vs. 21.2) increased overall abundance, MMB, and biomass (Figure 4, Table 14). This can also be manifested in decline of the NMFS survey q (q.1) from 0.805 (model 19.0e) to 0.772 (model 21.2) (Table 11). Simultaneously, the revised data also lowered projected 2022 MMB, which resulted in lower OFL (Table L). Separating retention probability before and after high grading (Model 21.0 vs. Model 21.2, Model 19.0e vs. Model 21.3) showed different retention probability patterns in which the latter period had lower retention probability of 94-104mm crab from 0.09 to 0.01 (Figure 3, Table 13). This also slightly improved model fit to summer commercial retention size proportion (CLP) (Table L). However, the dynamics of population and MMB for the two models were almost identical (Figure 4, 5).

Comparisons of models among 21.0, 21.4 and 21.5, center around exploration of alternative NSRKC life-history assumptions in the absence of studies verifying validity of natural mortality assumptions. Model 21.0 assumes M=0.18 and higher M for >123mm CL crab, whereas Model 21.4 assumes single M for all size classes and is estimated from the model. Model 21.5 allows the model to estimate two Ms for below and above 123mm CL. As expected, models 21.4 and 21.5 estimated higher M (Table L). Estimated M of model 21.4 was 0.42 that was 2.3 times higher than default M = 0.18. Estimated M of the model 21.5 was 0.26 for under 124mm CL and 0.59 for over 123mm CL. Those values were closer to the model 21.0 of 0.18 and 0.62 (Table L). Those suggest that the data are explained by size-dependent M rather than a single M for all lengths. The shapes of estimated molting probability, fishery selectivity, and retention probability also differed greatly among the models (Figure 3, Table 13). Model 21.4 estimated slightly lower molting probability for larger crab, asymptotic selectivity for trawl survey, and lower selectivity for small crab in winter pot, and summer commercial fisheries (Figure 3, Table 13). Molting probability and selectivity profiles of model 21.5 were closer to those of the model 21.0 (Figure 3, Table 13). Regarding to fit to trawl survey abundance and standardized CPUE, the models 21.4 and 21.5 were slightly better than 21.0 (Figure 7, 8, 16). RMSE of the models 21.4 and 21.5 were 0.01-0.02 point smaller than the model 21.0 (Table L). As for fit to size-shell data, estimating single M (models 21.1 and 21.4) showed lower fit to trawl and commercial catch shell-length compositions and tag-recovery size composition than size dependent M (models 21.0 and 21.5) (Table L). However, the differences among the models were visually very slight (Figures 8,9,10,11,12, and 13). For trawl survey data, all models underestimated size-proportion of larger and oldshell crab (Figure 9). For summer commercial retained data, all models overestimated the proportion of oldshell crab (Figure 8). Interestingly, model fit to total catch shell-size compositions appear to be better than fits to trawl and retained shell-size compositions (Figure 11).

Aside from the model fits, the great differences among models were estimates of abundance and MMB (Figure 4, 5). Model 21.4 had the highest mean abundance for total (4.1 million) and recruits (2.0 million), followed by model 21.5 (3.4 million and 1.4 million) and model 21.0 (3.1 million and 1.2 million). On the other hand, abundance of legal sized crab and MMB were similar among the 3 models (Figure 4, Table L). Among these three models, model 21.5 had the lowest negative log likelihood values, followed by model 21.0 (340.03) and model 21.4 (350.20) (Table L). This indicates that model 21.5 had the best model fit to the observed data, although difference of the fits among the models are small.

Retrospective analyses showed that Mohn's rho is the smallest for the model 21.4 (0.182), followed by model 21.5 (0.191) and model 18.0 (0.209) (Figure 17). Hurtado-Ferro et al. (2015) provided a guideline that Mohn's rho exceeding the range of (-0.15 to 0.2) for longer living species and (-0.22 to 0.30) for shorter living species should cause for concern. It is unknown whether NSRKC can be considered having a shorter or longer living. If it's considered longer living, model 21.0 should cause for concern.

Similar model fits among the 3 models (21.0, 21.4, 21.5) suggests that the observed data can be explained by several alternative life-history assumptions: high size independent mortality (model 21.4) size dependent mortality (models 21.0, and 21.5), or high migration of large crabs that explored previously (NPFMC 2017). For other NSRKC life-history traits that influence model fitting, such as time-invariant natural mortality, molt and recruitment timing, newshell-oldshell transition scheme (i.e., newshell crab = molted, oldshell crab = unmolted crab), only molt timing was confirmed outside the model.

Since inception of the model, the greatest discrepancies are overestimating the larger and oldshell crabs in trawl and summer commercial retained (Figures 8, 9). Some of those misfits could be due to uncertainties about shell conditions as well as selective discards of oldshell by fishermen.

Tag-recovery data (2012-2016) had 125 crabs that had no growth (+/- 3mm) in one year of liberty. Of those 100 crabs were released as newshell and 25 crabs were released as oldshell. If no growth is considered unmolted, all those crabs should be recaptured as oldshell. However, 29% of crabs released as newshell were recaptured as newshell crab and 48% of crabs released as oldshell were recaptured as newshell.

Table: The number of tagged NSRKC released and recovered in 1 year with no (+/- 3mm) changes in size (2012-2016)

Released\Recovered	Newshell	Oldshell
Newshell	29	71
Oldshell	12	13

Those crabs may be molted but did not grow, or did not molt but were incorrectly identified as newshell.

In the assessment model, retention probability is based on size; however, fishermen is more favor or retaining newshell than oldshell. Observer data showed that 21% of retained large crabs (> 110mm) were oldshell, whereas 51% of discarded large crabs were oldshell crab.

Table: Distribution of > 110mm CL crabs in observer survey

	Newshell	Oldshell
Retained	6037	1618
Discarded	361	381

For the final 2022 assessment model, the authors recommend model 21.0 or model 21.5. The major difference between the two models is whether to specify $M = 0.18$ of size classes under 124mm CL. Between the two models, model 21.5 is better in retrospective analyses.

F. Calculation of the OFL

1. Specification of the Tier level and stock status.

The NSRKC 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 SRKC 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 NSRKC, 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 : **Model 21.0: 4.17 million lb or 1.90 k t.**

Model 21.5: 4.30 million lb or 1.95 k t.

Predicted mature male biomass in 2022 on February 01

Mature male biomass: **Model 21.0: 5.33 million lb or 2.42 k t.**
Model 21.5: 4.79 million lb or 2.17 k t.

Since the projected MMB is above B_{MSY} proxy,

The NSRKS red status is Tier 4a,

And F_{OFL} for calculation of the OFL is $F_{OFL} = \gamma M$

2. Calculation formula of NSRKC OFL.

OFL of NSRKC is total OFL (OFL_T) that is a sum of the retained and unretained OFL (OFL_r, OFL_{nr}).

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

where

$$OFL_r = retained\_B \cdot F_{OFL} \text{ and } OFL_{nr} = unretained\_B \cdot F_{OFL} \cdot hm$$

retained_B is a biomass of crab subject to fisheries that is a sum of the products of crab abundance ($N_{w,l}$ + $O_{w,l}$), fishery selectivity ($S_{s,l}$), retention probability ($S_{r,l}$), and average weight lb (wm_l) by length class (l).

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

uretained_B is a biomass of crab subject to fisheries and is a sum of the products of crab abundance ($N_{w,l}$+ $O_{w,l}$), fishery selectivity ($S_{s,l}$), 1 minus retention probability ($S_{r,l}$), and average weight lb (wm_l) by length class (l).

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

hm is handling mortality of default 0.2

The NSRKC fishery consists of two distinct fisheries: winter and summer. The two fisheries are discontinuous with 5 months (0.42 year) between the two fisheries during which natural mortality occurs. To estimate the OFL for the two fisheries, the CPT in 2016 recommended the following formula that sum of winter and summer catch (*Hw*, *Hs*) equals to total OFL (OFL = *Hw*+*Hs*) and that winter catch is a fraction (p) of total OFL: $H_w = p\cdot$OFL, where ***p is predetermined fraction of*** the winter fishery to total fishery.

where

$$H_w = B_w(1-\exp(-x\cdot F_{OFL})),$$

$$H_s = B_s(1-\exp((1-x)\cdot F_{OFL})), \text{ and}$$

$$B_s = (B_w - Hw)e^{-0.42\cdot M}$$

B_w is the winter NSRKC biomass, B_s is the summer NSRKC biomass, and x is a fraction parameter,

Solving x of the above (see Appendix A for derivation), retained and unretained OFL is calculated as:

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

and

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

Because M of NSRKC is length-dependent, so that proper calculation of NSRKC OFL should account for length-dependent M as:

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

and

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

where M_l is a size specific natural mortality,

The SSC recommended the length-dependent M and F_{OFL} for calculation of NSRKC OFL, but reversed to applying length-independent F_{OFL} because of uncertainties about applying length-dependent F_{OFL} for Tire 4 stock, but more over to the fact that the length-dependent F_{OFL} increased the value of OFL greatly from the previous year (NPFMC 2017, 2018). In 2021 the SSC (2021 Oct) said that "The rationale that it may result in a higher OFL should not prevent exploring a higher value for M if that may be the best description of the dynamics." (Appendix D). We welcome the SSC's revised opinion on this issue and recommend length-dependent F_{OFL} for calculation of NSRKC OFL. This is a logical extension of the revised position should NSRKC assessment model estimates length-dependent M (e.g., model 21.5). Length-dependent F_{OFL} applied to NSRKC are 0.18 (CL < 124mm) and 0.61 (CL > 123mm) for model 21.0 and 0.26 (CL < 124mm) and 0.59 (CL > 123mm) for model 21.5.

3. Determination of NSRKC OFL for the 2022 fishery season.

Projected legal male biomass catchable to fishery and discards in 2022 are

Model 21.0: 4.27 and 1.24 million lb or 1.94 and 0.56 k t.

Model 21.5: 3.75 and 1.12 million lb or 1.70 and 0.51 k t.

With specified p = 0.16. Total OFL of NSRKC for 2022 fishery is

OFL =

Model 21.0: 0.89 million lb or 0.40 k t.

Model 21.5: 0.96 million lb or 0.44 k t.

G. Calculation of the ABC

1. Specification of the probability distribution of the OFL.

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 the 40% buffer, NSRKC ABC for the 2022 fishery is

ABC =

Model 21.0: 0.534 million lb or 0.24 k t.

Model 21.5: 0.576 million lb or 0.26 k t.

Taking further account of uncertainty of length-dependent *M* and F_{OFL}, the ABC buffer can be increased to 55% as:

ABC =

Model 21.0: 0.400 million lb or 0.18 k ton.

Model 21.5: 0.432 million lb or 0.20 k ton.

Incidentally, the 55% buffer of the model 21.0 corresponds to ABC 40% buffer, if OFL were calculated with default length-independent F_{OFL}. OFL of the model 21.0 with length-independent F_{OFL} is **0.67 million lb or 0.30 k t,** and ABC with 40% buffer is **0.402 million lb or 0.18 k t.**

H. Rebuilding Analyses

Not applicable

I. Data Gaps and Research Priorities

The major data gap of NSRKC is understandings of its 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 bring further insights about NSRKC biology and could be greatly significant in determination of management matrix such as ABC buffer.

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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] Open Access	CDQ	Number Harvest	Total Number (Open Access) Vessels	Permits	Landings	Total Pots Registered	Pulls	ST CPUE CPUE	SD	Season Length Days	Dates	Mid-day from July 1
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 NSRKC trawl survey abundance estimates (x 1000) (CL ≥ 64mm). NMFS and ADF&G trawl survey abundance estimate is based on 10×10 nm^2 grids, and NBS trawl survey is based on 20×20 nm^2 girds. Bold typed data are used for the assessment model.

				Abundance ≥64 mm		Female			
Year	Dates	Survey Agency	Survey method		CV	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	ADF&G	Pots	2092.3	N/A				
1981	6/28 - 7/14	ADF&G	Pots	2153.4	N/A				
1982	7/06 - 7/20	ADF&G	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	ADF&G	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	ADF&G	Trawl	**1283.0**	**0.25**	168	30.8	71.9	65.9-77.9
1999	7/28 - 8/07	ADF&G	Trawl	**2608.0**	**0.24**	81	4.7	80.4	76.0-84.7
2002	7/27 - 8/06	ADF&G	Trawl	**2056.0**	**0.36**	168	4.7	76.8	73.4-80.2
2006	7/25 - 8/08	ADF&G	Trawl	**3336.0**	**0.39**	194	3.6	67.3	63.2-71.5
2008	7/24 - 8/11	ADF&G	Trawl	**2894.2**	**0.31**	28	3.3	56.1	48.5-61.7
2010	7/27 - 8/09	NBS	Trawl	**1980.1**	**0.44**	116	0	70.2	63.8-78.5
2011	7/18 - 8/15	ADF&G	Trawl	**3209.3**	**0.29**	135	9.8	67.2	61.7-72.6
2014	7/18 - 7/30	ADF&G	Trawl	**5934.6**	**0.47**	60	0	60.4	54.3-66.6
2017	7/28 - 8/08	ADF&G	Trawl	**1762.1**	**0.22**	43	21.4	71.6	60.0-82.7
2017	8/18 - 8/29	NBS	Trawl	**1035.8**	**0.40**	58	0	80.0	72.5-87.5
2018	7/22 - 7/29	ADF&G	Trawl	**1108.9**	**0.25**	424	15.8	76.3	59.7-83.5
2019	7/17-7/29	ADF&G	Trawl	**4660.8**	**0.60**	386	47.8	50.6	43.1-56.4
2019	8/04-8/07	NBS	Trawl	**2532.4**	**0.26**	94	17.6	47.9	36.8-58.9
2020	7/31-8/14	ADF&G	Trawl	**1716.5**	**0.27**	186	4.5	66.2	61.6-70.8
2021	7/19-8/03	ADF&G	Trawl	**2400.0**	**0.60**	90	3.4	59.8	54.9-64.6
2021	7/29-8/07	NBS	Trawl	**2370.0**	**0.43**	138	2.6	61.1	58.8-63.4

Abundance of NMFS survey was estimated by NMFS, by multiplying the mean CPUE (# NRKC/nm^2) across all hauls (including re-tows) to a standard survey area (7600nm^2). Abundance of ADF&G and NBS survey was estimated by ADF&G by multiplying CPUE (# NRKC/nm^2) of each station to the grid represented by the station and summing across all surveyed station (ADF&G: 4700 – 5200nm^2. NBS 5841 nm^2).

%barren is calculated by dividing the number of mature females with no eggs by a total number of mature females.

Mean and 95% CI of %fullness is calculated among non-barren mature females. Clutch fullness of each non-barren females was assigned by fullness index that was converted to percentage in the table below.

Clutch fullness index of both NMFS-NBS and ADF&G were converted as follows

NMFS and NBS Code	NMFS and NBS Fullness	Assigned %	ADF&G code	ADF&G 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	ADF&G	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	ADF&G	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	ADF&G	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	ADF&G	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	ADF&G	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	ADF&G	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	ADF&G	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	ADF&G	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	ADF&G	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	ADF&G	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	ADF&G	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	ADF&G	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
2021	NMFS	82	0.05	0.16	0.21	0.16	0.10	0.02	0	0	0.01	0.05	0.11	0.06	0.06	0.01	0	0

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. Parameters with "log_" indicate log scaled parameters

Parameter	Parameter description	Lower	Upper
log_q_1	Commercial fishery catchability (1977-93)	-20.5	20
log_q2	Commercial fishery catchability (1994-2007)	-20.5	20
log_q3	Commercial fishery catchability (2008-2019)	-20.5	20
log_N_{76}	Initial abundance	2.0	15.0
R_0	Mean Recruit	2.0	12.0
log_σ_R^2	Recruit standard deviation	-40.0	40.0
$a_{1\text{-}7}$	Intimal length proportion	0	10.0
r_1	Proportion of length class 1 for recruit	0	10.0
log_α	Inverse logistic molting parameter	-5.0	-1.0
log_β	Inverse logistic molting parameter	1.0	5.5
log_ϕ_{st1}	Logistic trawl selectivity parameter	-5.0	1.0
log_ϕ_{wa}	Inverse logistic winter pot selectivity parameter	-5.0	1.0
log_ϕ_{wb}	Inverse logistic winter pot selectivity parameter	0.0	6.0
$Sw_{1,2}$	Winter pot selectivity of length class 1,2	0.1	1.0
log_ϕ_l	Logistic commercial catch selectivity parameter	-5.0	1.0
log_acr	Logistic summer commercial retention selectivity (1976-2007)	-5.0	1.0
log_bcr	Logistic summer commercial retention selectivity (1976-2007)	0.0	6.0
log_acr	Logistic summer commercial retention selectivity (2008-2019)	-5.0	1.0
log_bcr	Logistic summer commercial retention selectivity (2008-2019)	0.0	6.0
log_awr	Logistic winter commercial retention selectivity parameter	-5.0	1.0
log_bwr	Logistic winter commercial retention selectivity parameter	0.0	6.0
w^2_t	Additional variance for standard CPUE	0.0	6.0
ms	Natural mortality multipliers	0.5	5.0
q.1	Survey q for NMFS trawl 1976-91	0.1	1.0
q.2	Survey q for NMFS NBS trawl 2010,17,19	0.1	1.0
σ	Growth transition sigma	0.0	30.0
β_1	Growth transition mean	0.0	20.0
β_2	Growth transition increment	0.0	20.0

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

	Mosel 21,0		Model 18.0e		Model 21.2		Model 21.2	
name	Estimate	std.dev	Estimate	std.dev	Estimate	std.dev	Estimate	std.dev
log_q_1	-7.218	0.198	-6.866	0.117	-7.202	0.196	-6.866	0.117
log_q_2	-6.713	0.152			-6.700	0.151		
log_q_3	-6.770	0.147			-6.786	0.141		
log_N_{76}	9.137	0.139	9.086	0.122	9.134	0.138	9.084	0.122
R_0	6.413	0.081	6.414	0.080	6.413	0.081	6.412	0.080
a_1	0.976	4.459	1.054	4.469	0.973	4.460	1.060	4.469
a_2	1.672	4.193	1.779	4.202	1.685	4.191	1.768	4.204
a_3	3.454	3.931	3.524	3.943	3.461	3.930	3.519	3.945
a_4	3.977	3.909	4.008	3.921	3.977	3.908	4.010	3.923
a_5	4.250	3.900	4.268	3.913	4.248	3.899	4.271	3.914
a_6	3.508	3.929	3.520	3.941	3.506	3.928	3.522	3.943
a_7	2.066	4.195	2.065	4.208	2.066	4.194	2.065	4.210
r1	10.000	0.227	10.000	0.241	10.000	0.229	10.000	0.238
r2	9.616	0.281	9.613	0.293	9.615	0.283	9.615	0.291
log_a	-2.728	0.089	-2.726	0.089	-2.726	0.089	-2.727	0.089
log_b	4.834	0.015	4.833	0.015	4.834	0.015	4.833	0.015
log_ϕ_{st1}	-5.000	0.030	-5.000	0.032	-5.000	0.030	-5.000	0.032
log_ϕ_{wa}	-2.393	0.428	-2.394	0.430	-2.396	0.430	-2.390	0.429
log_ϕ_{wb}	4.776	0.066	4.776	0.067	4.776	0.067	4.777	0.066
Sw1	0.060	0.033	0.060	0.033	0.060	0.033	0.060	0.033
Sw2	0.424	0.144	0.425	0.145	0.424	0.145	0.425	0.144
Sw3	0.731	0.232	0.735	0.233	0.730	0.233	0.737	0.232
log_ϕ_l	-2.062	0.045	-2.070	0.039	-2.070	0.039	-2.064	0.043
log_ϕra1	-0.856	0.142	-0.792	0.123	-0.785	0.123	-0.870	0.143
log_ϕrb1	-0.490	0.283	4.647	0.007	4.648	0.007	-0.479	0.285
log_ϕra2	4.643	0.008					4.643	0.008
log_ϕrb2	4.656	0.013					4.655	0.013
log_ϕwra	-0.927	0.600	-0.925	0.604	-0.926	0.603	-0.923	0.607
log_ϕwrb	4.651	0.040	4.651	0.040	4.651	0.040	4.651	0.040
w^2_t	0.090	0.028	0.000	0.000	0.089	0.028	0.000	0.000
q.1	0.769	0.138	0.805	0.131	0.772	0.138	0.807	0.131
q.2	0.940	0.192	0.913	0.185	0.941	0.192	0.910	0.185
σ	3.818	0.209	3.819	0.208	3.814	0.209	3.822	0.208
β_1	11.776	0.697	11.795	0.695	11.773	0.695	11.801	0.697
β_2	7.819	0.171	7.812	0.171	7.821	0.171	7.810	0.171
ms78	3.453	0.272	3.386	0.266	3.461	0.272	3.377	0.265

	Model 21.0		Model 21.1		Model 21.4		Model 21.5	
name	Estimate	std.dev	Estimate	std.dev	Estimate	std.dev	Estimate	std.dev
log_q_1	-7.218	0.198	-6.410	0.148	-7.078	0.192	-7.239	0.197
log_q_2	-6.713	0.152	-6.177	0.158	-6.540	0.156	-6.664	0.153
log_q_3	-6.770	0.147	-6.238	0.153	-6.668	0.152	-6.753	0.146
log_N_{76}	9.137	0.139	8.452	0.040	9.495	0.165	9.328	0.162
R_0	6.413	0.081	5.813	0.044	7.083	0.159	6.652	0.129
a_1	0.976	4.459	1.553	4.369	2.554	4.590	1.246	4.494
a_2	1.672	4.193	2.276	4.095	2.871	4.386	1.937	4.231
a_3	3.454	3.931	4.013	3.827	4.415	4.146	3.686	3.974
a_4	3.977	3.909	4.477	3.802	4.735	4.127	4.153	3.953
a_5	4.250	3.900	4.668	3.793	4.874	4.118	4.389	3.944
a_6	3.508	3.929	3.771	3.828	3.949	4.149	3.607	3.973
a_7	2.066	4.195	1.905	4.159	2.070	4.427	2.070	4.240
r1	10.000	0.227	10.000	0.171	10.000	0.311	10.000	0.372
r2	9.616	0.281	9.576	0.236	9.523	0.356	9.654	0.406
log_a	-2.728	0.089	-2.779	0.096	-2.741	0.094	-2.722	0.089
log_b	4.834	0.015	4.832	0.017	4.816	0.016	4.827	0.015
log_ϕ_{st1}	-5.000	0.030	-5.000	0.011	-2.422	0.099	-5.000	0.078
log_ϕ_{wa}	-2.393	0.428	-2.059	0.332	-1.825	0.437	-2.275	0.453
log_ϕ_{wb}	4.776	0.066	4.807	0.034	4.866	0.027	4.817	0.049
Sw1	0.060	0.033	0.068	0.034	0.044	0.021	0.058	0.030
Sw2	0.424	0.144	0.504	0.129	0.357	0.084	0.406	0.115
Sw3	0.731	0.232	0.848	0.185	0.727	0.140	0.772	0.194
log_ϕ_l	-2.062	0.045	-2.038	0.046	-1.949	0.042	-2.024	0.045
log_ϕra1	-0.856	0.142	-0.871	0.142	-0.896	0.141	-0.866	0.142
log_ϕrb1	-0.490	0.283	-0.540	0.270	-0.459	0.286	-0.473	0.286
log_ϕra2	4.643	0.008	4.644	0.009	4.652	0.010	4.646	0.009
log_ϕrb2	4.656	0.013	4.663	0.011	4.655	0.014	4.655	0.013
log_ϕwra	-0.927	0.600	-1.113	0.472	-0.882	0.663	-0.897	0.660
log_ϕwrb	4.651	0.040	4.671	0.033	4.648	0.042	4.648	0.042
w^2_t	0.090	0.028	0.120	0.035	0.085	0.027	0.085	0.027
q,1	0.769	0.138	1.713	0.211	0.740	0.130	0.696	0.127
q,2	0.940	0.192	1.250	0.256	0.927	0.190	0.914	0.187
σ	3.818	0.209	3.967	0.194	3.796	0.205	3.790	0.209
β_1	11.776	0.697	12.775	0.702	12.670	0.723	12.021	0.706
β_2	7.819	0.171	7.454	0.170	7.595	0.17748	7.7681	0.1738
ms78	3.453	0.272					2.3206	0.3898
M					0.42	0.03	0.26	0.03

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	0.68	0.02	0.00	0.00	0.00
84 - 93			0.08	0.43	0.48	0.00	0.00	0.00
94 - 103				0.16	0.58	0.26	0.00	0.00
104 - 113					0.29	0.60	0.11	0.00
114 - 123						0.49	0.48	0.03
124 - 133							0.70	0.30
134+								1.00

Model 19.0e

Pre-molt	*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	0.68	0.02	0.00	0.00	0.00
84 - 93			0.08	0.43	0.48	0.00	0.00	0.00
94 - 103				0.16	0.58	0.26	0.00	0.00
104 - 113					0.29	0.60	0.10	0.00
114 - 123						0.49	0.48	0.03
124 - 133							0.71	0.29
134+								1.00

Model 21.1

Pre-molt	*Post-molt Length Class*							
	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
64 - 73	0.03	0.09	0.77	0.11	0.00	0.00	0.00	0.00
74 - 83		0.05	0.24	0.68	0.03	0.00	0.00	0.00
84 - 93			0.10	0.44	0.46	0.01	0.00	0.00
94 - 103				0.18	0.59	0.23	0.00	0.00
104 - 113					0.33	0.59	0.08	0.00
114 - 123						0.55	0.43	0.02
124 - 133							0.78	0.22
134+								1.00

Model 21.2

Pre-molt	*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	0.68	0.02	0.00	0.00	0.00
84 - 93			0.08	0.43	0.48	0.00	0.00	0.00
94 - 103				0.16	0.58	0.26	0.00	0.00
104 - 113					0.29	0.60	0.11	0.00
114 - 123						0.49	0.48	0.03
124 - 133							0.70	0.30
134+								1.00

Model 21.3

Pre-molt	*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	0.68	0.02	0.00	0.00	0.00
84 - 93			0.08	0.43	0.48	0.00	0.00	0.00
94 - 103				0.16	0.58	0.26	0.00	0.00
104 - 113					0.29	0.60	0.10	0.00
114 - 123						0.49	0.48	0.03
124 - 133							0.71	0.29
134+								1.00

Model 21.4

Pre-molt	*Post-molt Length Class*							
	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
64 – 73	0.03	0.08	0.79	0.10	0.00	0.00	0.00	0.00
74 - 83		0.05	0.21	0.71	0.03	0.00	0.00	0.00
84 - 93			0.10	0.41	0.49	0.01	0.00	0.00
94 - 103				0.18	0.57	0.25	0.00	0.00
104 - 113					0.33	0.58	0.09	0.00
114 - 123						0.54	0.44	0.02
124 - 133							0.76	0.24
134+								1.00

Model 21.5

Pre-molt	*Post-molt Length Class*							
	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
64 – 73	0.02	0.10	0.79	0.08	0.00	0.00	0.00	0.00
74 - 83		0.05	0.24	0.69	0.02	0.00	0.00	0.00
84 - 93			0.09	0.42	0.48	0.00	0.00	0.00
94 - 103				0.16	0.57	0.26	0.00	0.00
104 - 113					0.30	0.60	0.10	0.00
114 - 123						0.50	0.47	0.03
124 - 133							0.72	0.28
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

Molting Probability

	21.0	19.0e	21.1	21.2	21.3	21.4	21.5
64 - 73	0.98	0.98	0.97	0.98	0.98	0.97	0.98
74 - 83	0.96	0.96	0.95	0.96	0.96	0.95	0.95
84 - 93	0.92	0.92	0.91	0.92	0.92	0.90	0.92
94 - 103	0.86	0.86	0.84	0.86	0.85	0.83	0.85
104 - 113	0.75	0.75	0.74	0.75	0.75	0.72	0.74
114 - 123	0.62	0.61	0.61	0.62	0.61	0.58	0.60
124 - 133	0.45	0.45	0.45	0.45	0.45	0.42	0.44
134+	0.30	0.30	0.31	0.30	0.30	0.27	0.29

Trawl Selectivity

	21.0	19.0e	21.1	21.2	21.3	21.4	21.5
64 - 73	1.00	1.00	1.00	1.00	1.00	0.67	1.00
74 - 83	1.00	1.00	1.00	1.00	1.00	0.83	1.00
84 - 93	1.00	1.00	1.00	1.00	1.00	0.92	1.00
94 - 103	1.00	1.00	1.00	1.00	1.00	0.97	1.00
104 - 113	1.00	1.00	1.00	1.00	1.00	0.99	1.00
114 - 123	1.00	1.00	1.00	1.00	1.00	0.99	1.00
124 - 133	1.00	1.00	1.00	1.00	1.00	1.00	1.00
134+	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Winter Pot Selectivity

	21.0	19.0e	21.1	21.2	21.3	21.4	21.5
64 - 73	0.06	0.06	0.07	0.06	0.06	0.04	0.06
74 - 83	0.42	0.43	0.50	0.42	0.43	0.36	0.41
84 - 93	0.73	0.73	0.85	0.73	0.74	0.73	0.77
94 - 103	0.86	0.86	0.95	0.86	0.86	0.99	0.93
104 - 113	0.72	0.72	0.85	0.72	0.72	0.97	0.82
114 - 123	0.50	0.50	0.62	0.50	0.51	0.86	0.63
124 - 133	0.29	0.29	0.31	0.29	0.29	0.55	0.38
134+	0.14	0.14	0.11	0.14	0.14	0.20	0.18

Winter Pot retention probability

	21.0	19.0e	21.1	21.2	21.3	21.4	21.5
64 - 73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
74 - 83	0.00	0.00	0.00	0.00	0.00	0.00	0.00
84 - 93	0.00	0.00	0.00	0.00	0.00	0.00	0.00
94 - 103	0.08	0.08	0.06	0.08	0.08	0.08	0.08
104 - 113	0.82	0.82	0.64	0.82	0.82	0.85	0.84
114 - 123	1.00	1.00	0.98	1.00	1.00	1.00	1.00
124 - 133	1.00	1.00	1.00	1.00	1.00	1.00	1.00
134+	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Summer Commercial selectivity

	21.0	19.0e	21.1	21.2	21.3	21.4	21.5
64 - 73	0.12	0.13	0.10	0.13	0.12	0.04	0.09
74 - 83	0.33	0.34	0.29	0.34	0.33	0.16	0.26
84 - 93	0.63	0.64	0.60	0.65	0.64	0.45	0.57
94 - 103	0.86	0.86	0.84	0.87	0.86	0.77	0.84
104 - 113	0.96	0.96	0.95	0.96	0.96	0.93	0.95
114 - 123	0.99	0.99	0.99	0.99	0.99	0.98	0.99
124 - 133	1.00	1.00	1.00	1.00	1.00	1.00	1.00
134+	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Summer Commercial retention probability 1976-2007

	21.0	19.0e	21.1	21.2	21.3	21.4	21.5
64 - 73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
74 - 83	0.00	0.00	0.00	0.00	0.00	0.00	0.00
84 - 93	0.00	0.00	0.00	0.00	0.00	0.00	0.00
94 - 103	0.09	0.07	0.09	0.07	0.10	0.07	0.08
104 - 113	0.88	0.87	0.87	0.87	0.87	0.82	0.86
114 - 123	1.00	1.00	1.00	1.00	1.00	1.00	1.00
124 - 133	1.00	1.00	1.00	1.00	1.00	1.00	1.00
134+	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Summer Commercial retention probability 2008-2019

	21.0	19.0e	21.1	21.2	21.3	21.4	21.5
64 - 73	0.00		0.00		0.00	0.00	0.00
74 - 83	0.00		0.00		0.00	0.00	0.00
84 - 93	0.00		0.00		0.00	0.00	0.00
94 - 103	0.02		0.01		0.02	0.01	0.02
104 - 113	0.88		0.82		0.89	0.89	0.89
114 - 123	1.00		1.00		1.00	1.00	1.00
124 - 133	1.00		1.00		1.00	1.00	1.00
134+	1.00		1.00		1.00	1.00	1.00

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.

MMB

Year	Model 21.0	Model 19.0e	Model 21.1	Model 21.2	Model 21.3	Model 21.4	Model 21.5
1976	17.70	16.60	8.36	17.62	16.59	22.07	20.79
1977	19.39	18.37	9.97	19.32	18.34	21.57	21.80
1978	16.80	16.00	9.43	16.74	15.98	17.04	18.17
1979	11.83	11.29	6.93	11.78	11.28	11.41	12.51
1980	6.29	5.97	3.35	6.25	5.97	5.92	6.63
1981	4.13	4.01	2.25	4.09	4.01	4.03	4.35
1982	3.04	3.03	1.35	3.01	3.04	3.24	3.30
1983	3.85	3.81	1.83	3.83	3.80	4.21	4.20
1984	4.42	4.35	2.02	4.41	4.34	4.71	4.76
1985	4.92	4.81	2.13	4.91	4.79	5.12	5.28
1986	5.23	5.02	2.12	5.21	5.00	5.22	5.55
1987	5.19	4.89	1.95	5.17	4.88	5.00	5.44
1988	5.23	4.86	1.94	5.22	4.84	4.98	5.47
1989	5.09	4.71	1.96	5.08	4.69	4.79	5.28
1990	4.87	4.52	1.95	4.85	4.50	4.59	5.01
1991	4.60	4.33	1.96	4.58	4.31	4.37	4.72
1992	4.37	4.19	2.13	4.35	4.18	4.19	4.45
1993	4.02	3.95	2.16	4.01	3.93	3.87	4.06
1994	3.37	3.38	1.88	3.35	3.36	3.23	3.37
1995	2.78	2.85	1.60	2.77	2.84	2.69	2.77
1996	2.40	2.50	1.39	2.39	2.49	2.38	2.40
1997	2.43	2.55	1.44	2.42	2.54	2.44	2.43
1998	3.07	3.22	1.86	3.06	3.20	3.23	3.11
1999	4.01	4.20	2.40	4.01	4.17	4.18	4.08
2000	4.35	4.52	2.69	4.34	4.49	4.26	4.33
2001	4.03	4.16	2.51	4.03	4.14	3.82	3.96
2002	4.03	4.08	2.49	4.03	4.06	3.92	4.01
2003	4.36	4.32	2.65	4.36	4.30	4.36	4.39
2004	4.62	4.50	2.73	4.62	4.48	4.66	4.67
2005	4.47	4.31	2.60	4.48	4.29	4.47	4.52
2006	4.23	4.06	2.43	4.24	4.04	4.27	4.31
2007	4.32	4.17	2.45	4.34	4.16	4.51	4.46
2008	4.71	4.60	2.70	4.73	4.60	5.01	4.90
2009	5.07	4.99	2.86	5.09	4.99	5.39	5.28
2010	5.19	5.15	2.93	5.21	5.16	5.43	5.37
2011	4.79	4.78	2.72	4.81	4.79	4.83	4.91
2012	4.28	4.30	2.55	4.29	4.31	4.26	4.35
2013	4.05	4.09	2.46	4.05	4.11	4.16	4.14
2014	4.43	4.52	2.72	4.43	4.54	4.85	4.63
2015	4.95	5.10	3.11	4.96	5.11	5.39	5.17
2016	4.49	4.67	2.85	4.50	4.67	4.64	4.60
2017	3.63	3.80	2.42	3.64	3.81	3.53	3.62
2018	2.75	2.92	1.99	2.76	2.92	2.60	2.69
2019	2.32	2.47	1.90	2.33	2.47	2.22	2.24
2020	2.93	3.08	2.68	2.93	3.09	3.05	2.87
2021	4.38	4.54	4.07	4.37	4.56	4.37	4.21
2022	5.18	5.33	4.90	5.17	5.35	4.70	4.79

Legal abundance (> 103mm CL)

Year	Model 21.0	Model 19.0e	Model 21.1	Model 21.2	Model 21.3	Model 21.4	Model 21.5
1976	7.50	7.05	3.65	7.46	7.04	9.70	8.89
1977	7.18	6.82	3.76	7.15	6.81	8.21	8.12
1978	5.59	5.34	3.16	5.57	5.33	5.77	6.06
1979	3.73	3.57	2.18	3.71	3.57	3.65	3.96
1980	1.97	1.88	1.04	1.95	1.88	1.87	2.07
1981	1.36	1.35	0.74	1.35	1.35	1.37	1.44
1982	1.19	1.20	0.55	1.18	1.20	1.34	1.32
1983	1.57	1.54	0.76	1.56	1.54	1.79	1.73
1984	1.77	1.73	0.82	1.76	1.73	1.96	1.93
1985	1.93	1.88	0.84	1.92	1.87	2.10	2.11
1986	2.00	1.91	0.82	1.99	1.90	2.08	2.15
1987	1.94	1.82	0.73	1.94	1.81	1.96	2.07
1988	1.93	1.78	0.71	1.93	1.78	1.93	2.05
1989	1.84	1.70	0.70	1.84	1.69	1.81	1.94
1990	1.75	1.63	0.69	1.74	1.62	1.73	1.83
1991	1.64	1.55	0.69	1.63	1.55	1.63	1.71
1992	1.53	1.48	0.73	1.53	1.48	1.53	1.59
1993	1.40	1.39	0.73	1.40	1.38	1.40	1.43
1994	1.17	1.18	0.63	1.16	1.18	1.16	1.18
1995	0.97	1.00	0.54	0.97	1.00	0.98	0.98
1996	0.87	0.91	0.49	0.87	0.91	0.90	0.89
1997	0.93	0.97	0.54	0.93	0.97	0.97	0.95
1998	1.24	1.30	0.72	1.24	1.29	1.38	1.29
1999	1.60	1.67	0.91	1.60	1.66	1.73	1.65
2000	1.61	1.67	0.96	1.61	1.66	1.63	1.63
2001	1.45	1.49	0.86	1.45	1.48	1.44	1.45
2002	1.50	1.50	0.87	1.50	1.50	1.54	1.53
2003	1.68	1.65	0.96	1.68	1.64	1.76	1.73
2004	1.76	1.70	0.98	1.76	1.69	1.86	1.81
2005	1.64	1.58	0.90	1.65	1.57	1.72	1.70
2006	1.56	1.50	0.86	1.57	1.49	1.66	1.63
2007	1.66	1.60	0.92	1.67	1.60	1.83	1.75
2008	1.84	1.80	1.03	1.84	1.80	2.05	1.94
2009	1.97	1.94	1.10	1.97	1.95	2.19	2.09
2010	1.96	1.95	1.09	1.97	1.95	2.14	2.06
2011	1.73	1.73	0.97	1.74	1.74	1.81	1.80
2012	1.54	1.54	0.90	1.54	1.55	1.59	1.58
2013	1.52	1.54	0.91	1.52	1.55	1.65	1.59
2014	1.76	1.80	1.08	1.76	1.81	2.05	1.89
2015	1.94	2.00	1.21	1.94	2.00	2.20	2.06
2016	1.63	1.70	1.03	1.64	1.70	1.74	1.69
2017	1.24	1.30	0.82	1.25	1.30	1.23	1.25
2018	0.93	0.99	0.67	0.94	0.99	0.90	0.92
2019	0.83	0.87	0.67	0.83	0.88	0.81	0.81
2020	1.20	1.25	1.06	1.20	1.26	1.31	1.20
2021	1.82	1.87	1.62	1.81	1.88	1.85	1.76
2022	1.99	2.05	1.81	1.99	2.05	1.84	1.85

Table 15. Summary of catch (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.

Year	Summer Com	Winter Com	Winter Sub	Discards Winter Sub	Total
1977	0.52	0.000	0.000	0	0.520
1978	2.09	0.024	0.025	0.008	2.147
1979	2.93	0.001	0.000	0	2.931
1980	1.19	0.000	0.000	0	1.190
1981	1.38	0.000	0.001	0	1.381
1982	0.23	0.000	0.003	0.001	0.234
1983	0.37	0.001	0.021	0.006	0.398
1984	0.39	0.002	0.022	0.005	0.419
1985	0.43	0.003	0.017	0.002	0.452
1986	0.48	0.005	0.014	0.004	0.503
1987	0.33	0.003	0.012	0.002	0.347
1988	0.24	0.001	0.005	0.001	0.247
1989	0.25	0.000	0.012	0.002	0.264
1990	0.19	0.010	0.024	0.004	0.228
1991	0	0.010	0.015	0.002	0.027
1992	0.07	0.021	0.023	0.003	0.117
1993	0.33	0.005	0.002	0	0.337
1994	0.32	0.017	0.008	0.001	0.346
1995	0.32	0.022	0.011	0.002	0.355
1996	0.22	0.005	0.003	0.001	0.229
1997	0.09	0.000	0.001	0.001	0.092
1998	0.03	0.002	0.017	0.012	0.061
1999	0.02	0.007	0.015	0.003	0.045
2000	0.3	0.008	0.011	0.004	0.323
2001	0.28	0.003	0.001	0	0.284
2002	0.25	0.007	0.004	0.003	0.264
2003	0.26	0.017	0.008	0.005	0.290
2004	0.34	0.001	0.002	0.001	0.344
2005	0.4	0.006	0.008	0.003	0.417
2006	0.45	0.000	0.002	0.001	0.453
2007	0.31	0.008	0.021	0.011	0.350
2008	0.39	0.015	0.019	0.009	0.433
2009	0.4	0.012	0.010	0.002	0.424
2010	0.42	0.012	0.014	0.002	0.448
2011	0.4	0.009	0.013	0.003	0.425
2012	0.47	0.025	0.015	0.004	0.514
2013	0.35	0.061	0.015	0.014	0.440
2014	0.39	0.035	0.007	0.002	0.434
2015	0.40	0.099	0.019	0.005	0.523
2016	0.42	0.080	0.011	0.001	0.512
2017	0.41	0.078	0.012	0.001	0.501
2018	0.30	0.029	0.008	0.001	0.338
2019	0.08	0.032	0.003	0.001	0.116
2020	0	Conf.	0.001	0.000	Conf
2021	0	0.001	0.009	0.000	0.010

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

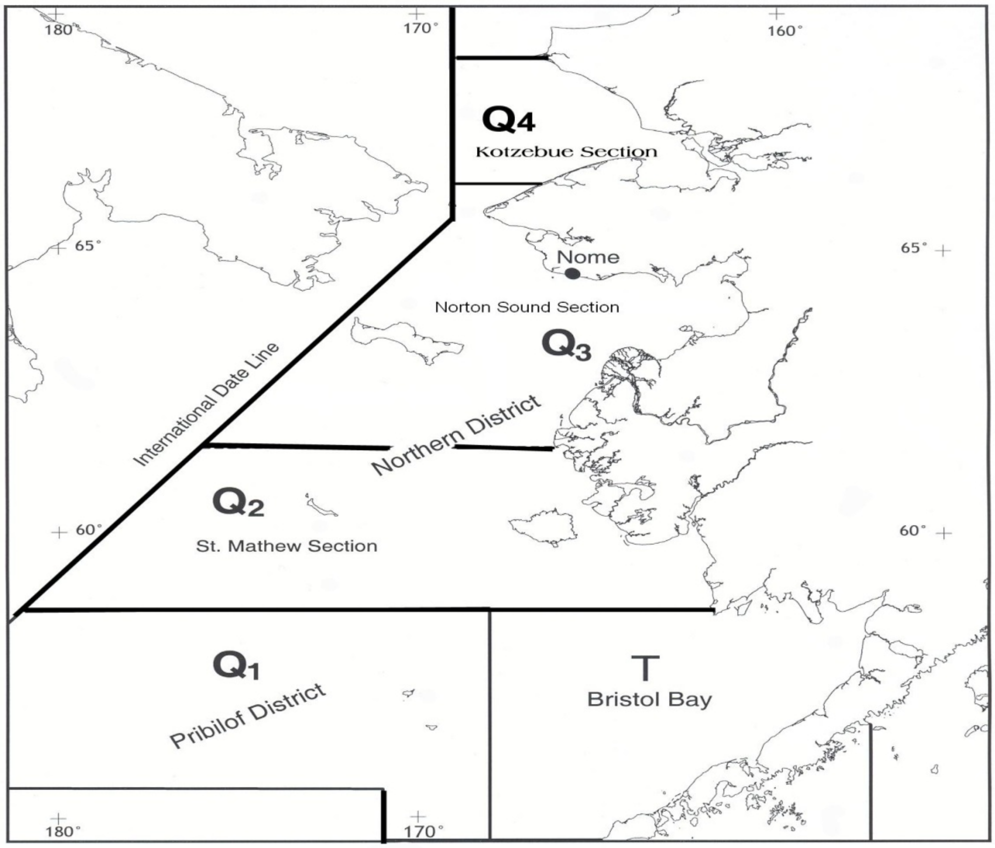

180°
170°
160°
Q4
Kotzebue Section
65°
65°
Nome
Norton Sound Section
Q3
International Date Line
Northern District
Q2
60°
60°
St. Mathew Section
Q1
Pribilof District
T
Bristol Bay
180°
170°

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.

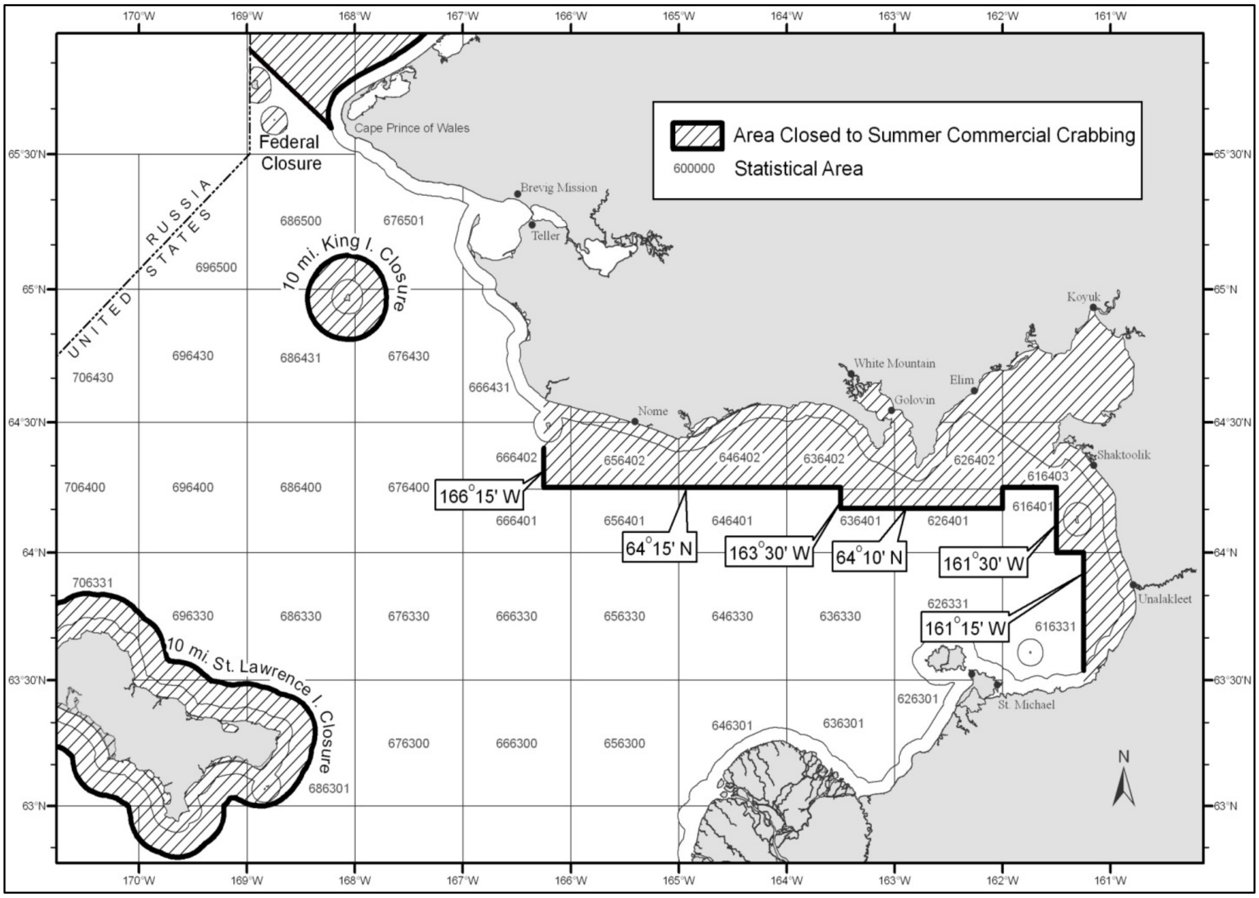
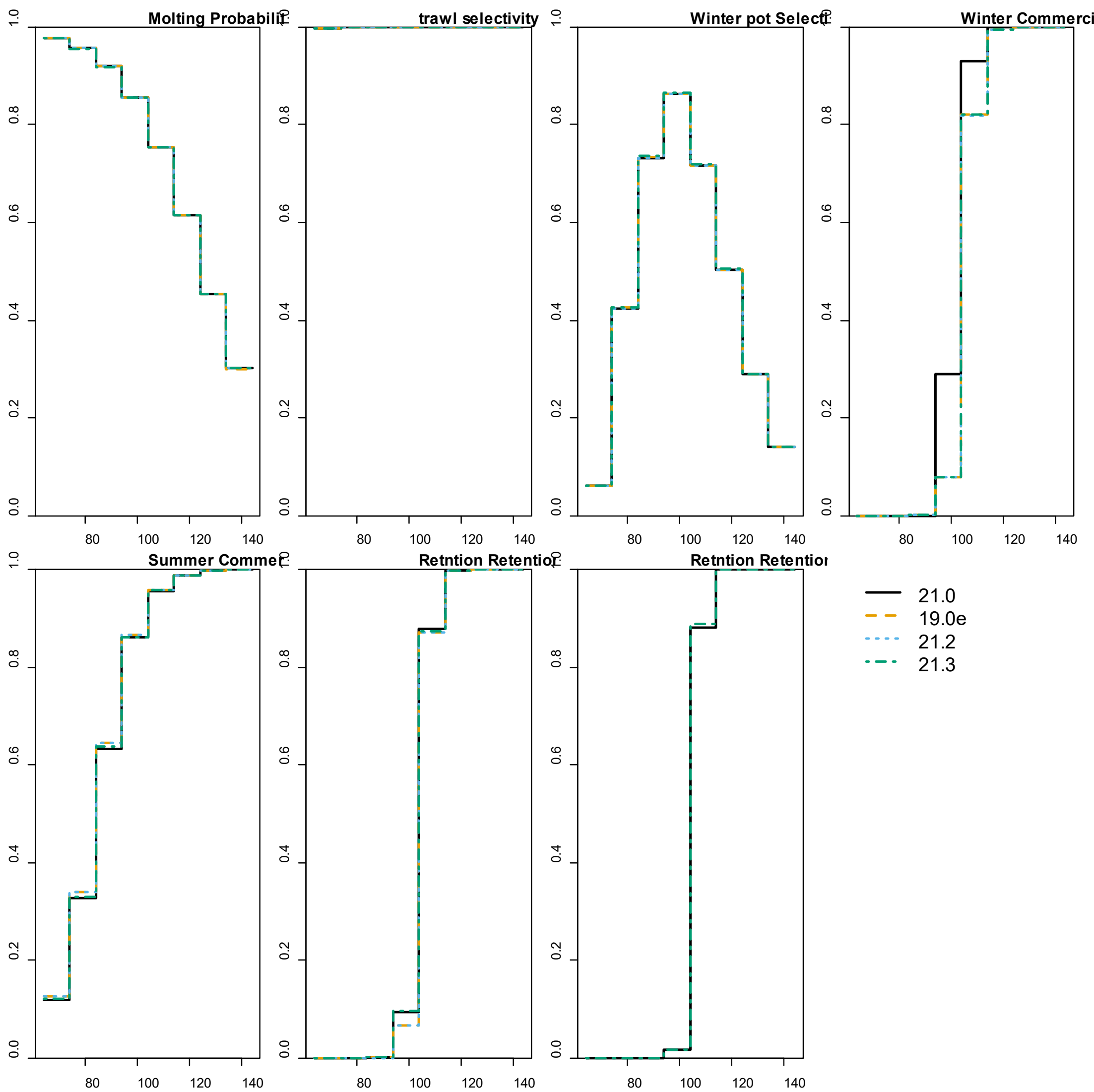


Figure 3. Model estimated annual molting probability, and selectivity for trawl survey, winter pot survey, summer commercial fishery, and summer and winter commercial retention. X-axis is carapace length (mm).



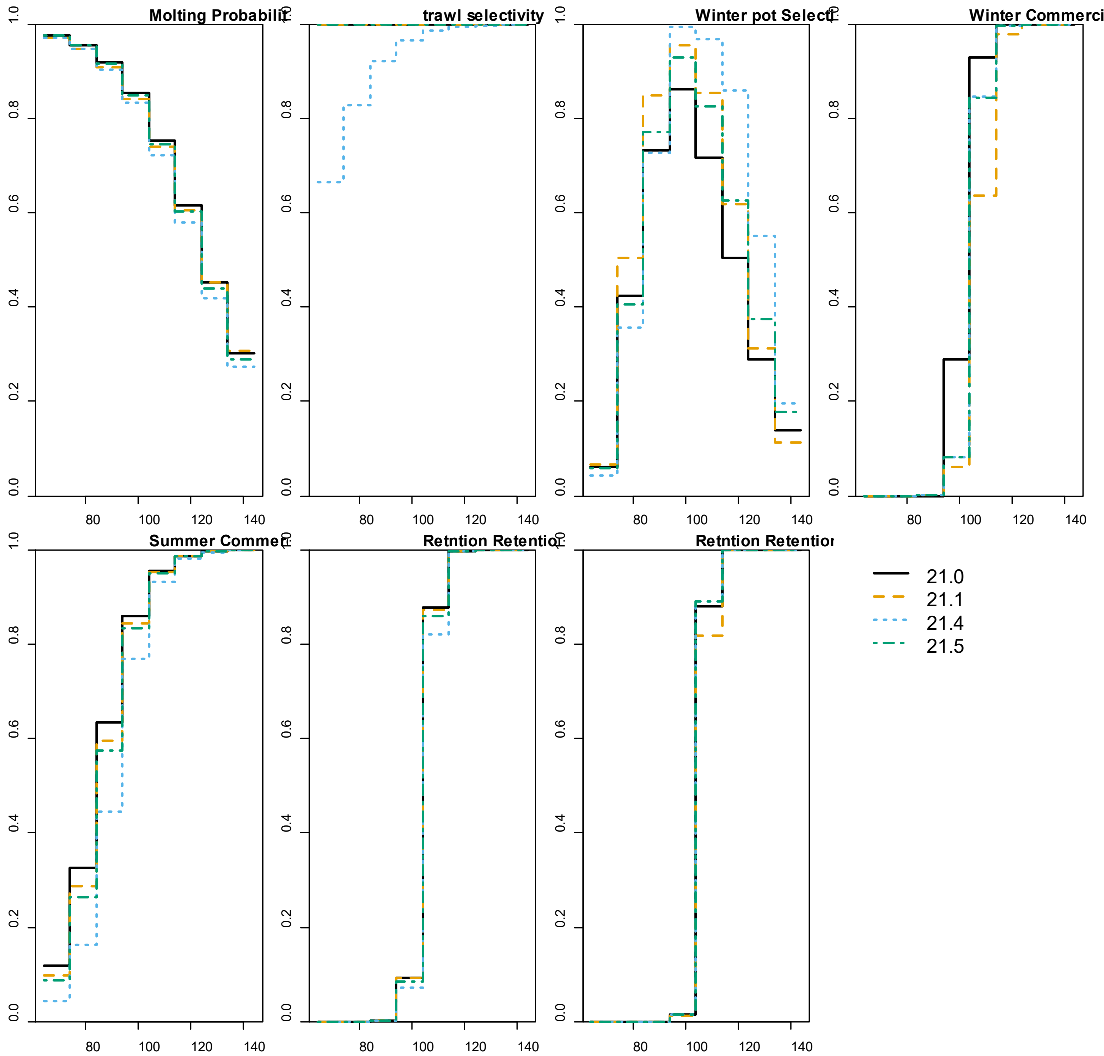
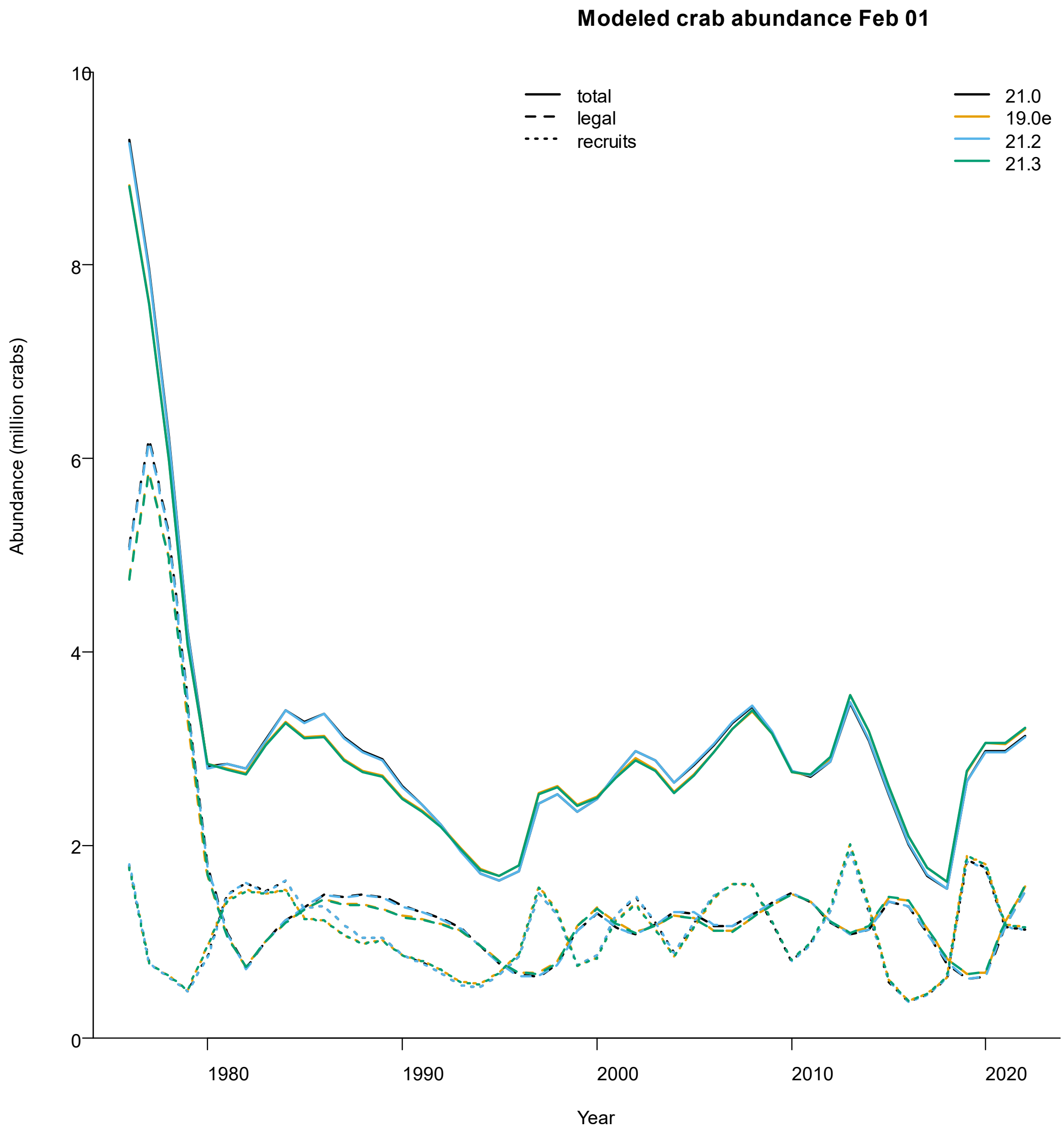
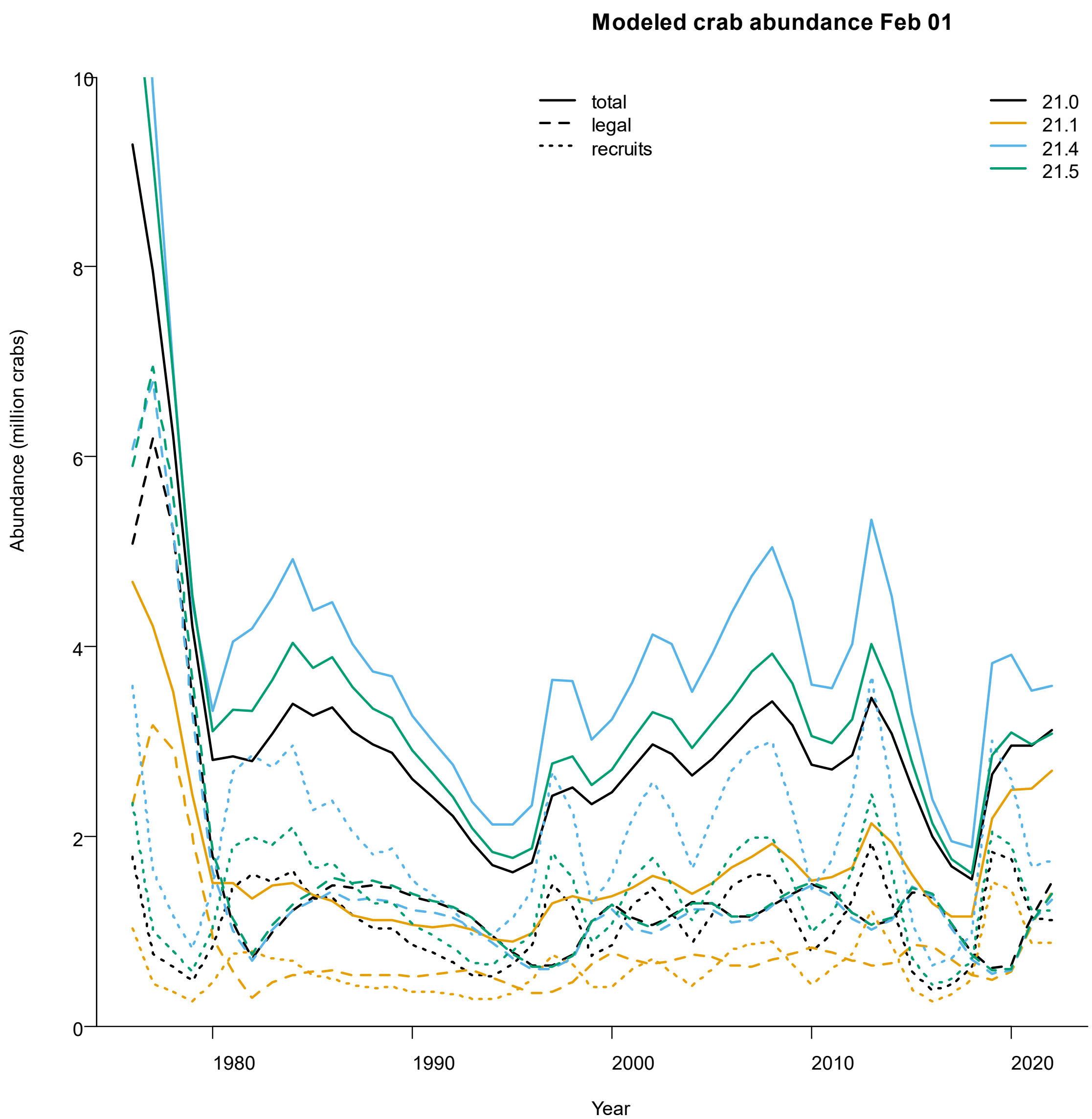

Molting Probabili
trawl selectivity
Winter pot Selecti
Winter Commercia
Summer Commer
Retntion Retentio
Retntion Retentior
21.0
21.1
21.4
21.5

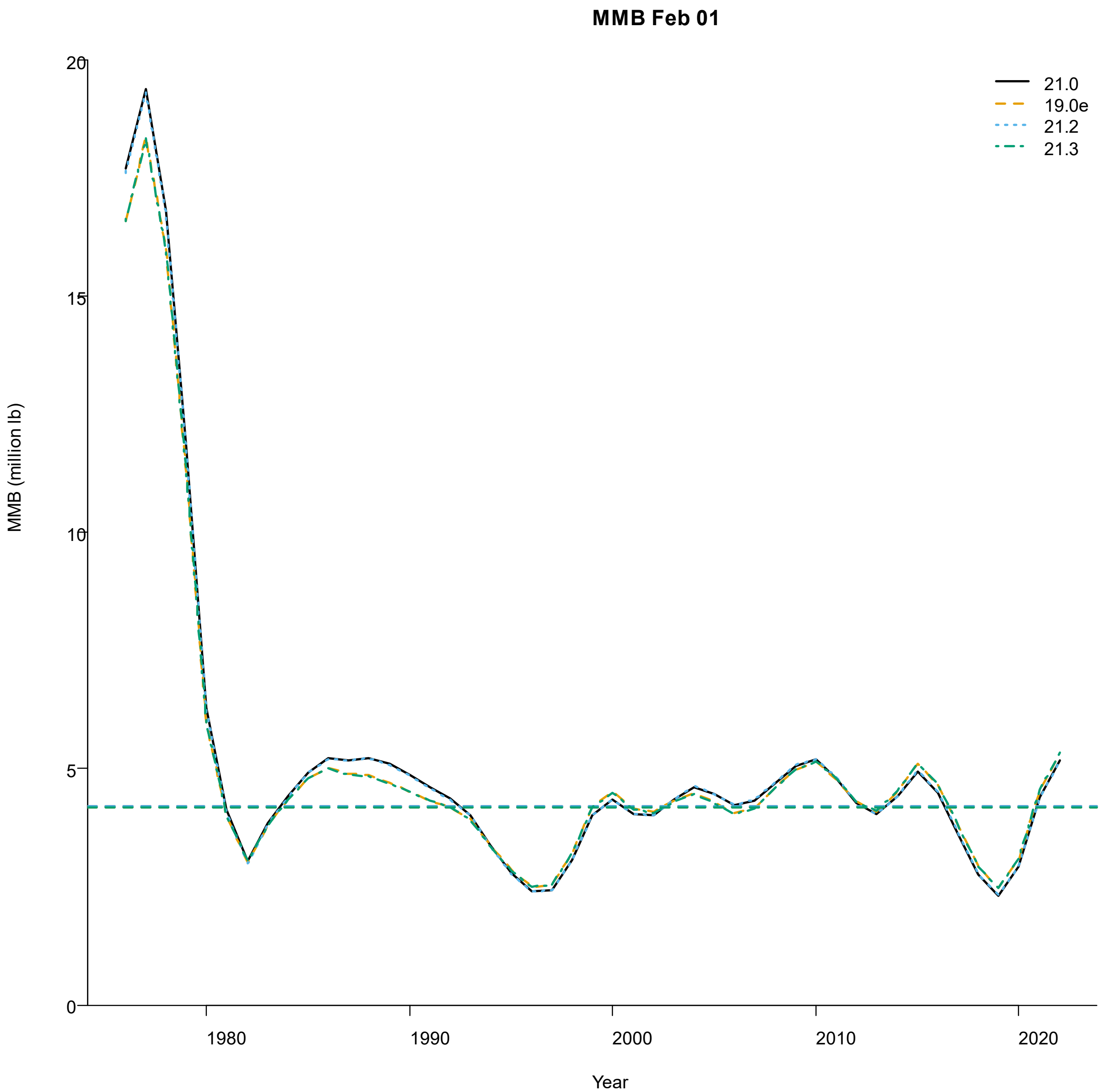
Figure 4. Model estimated abundances of total, legal (CL>104mm) and recruit (CL 64-94nn) males during1976-2021.

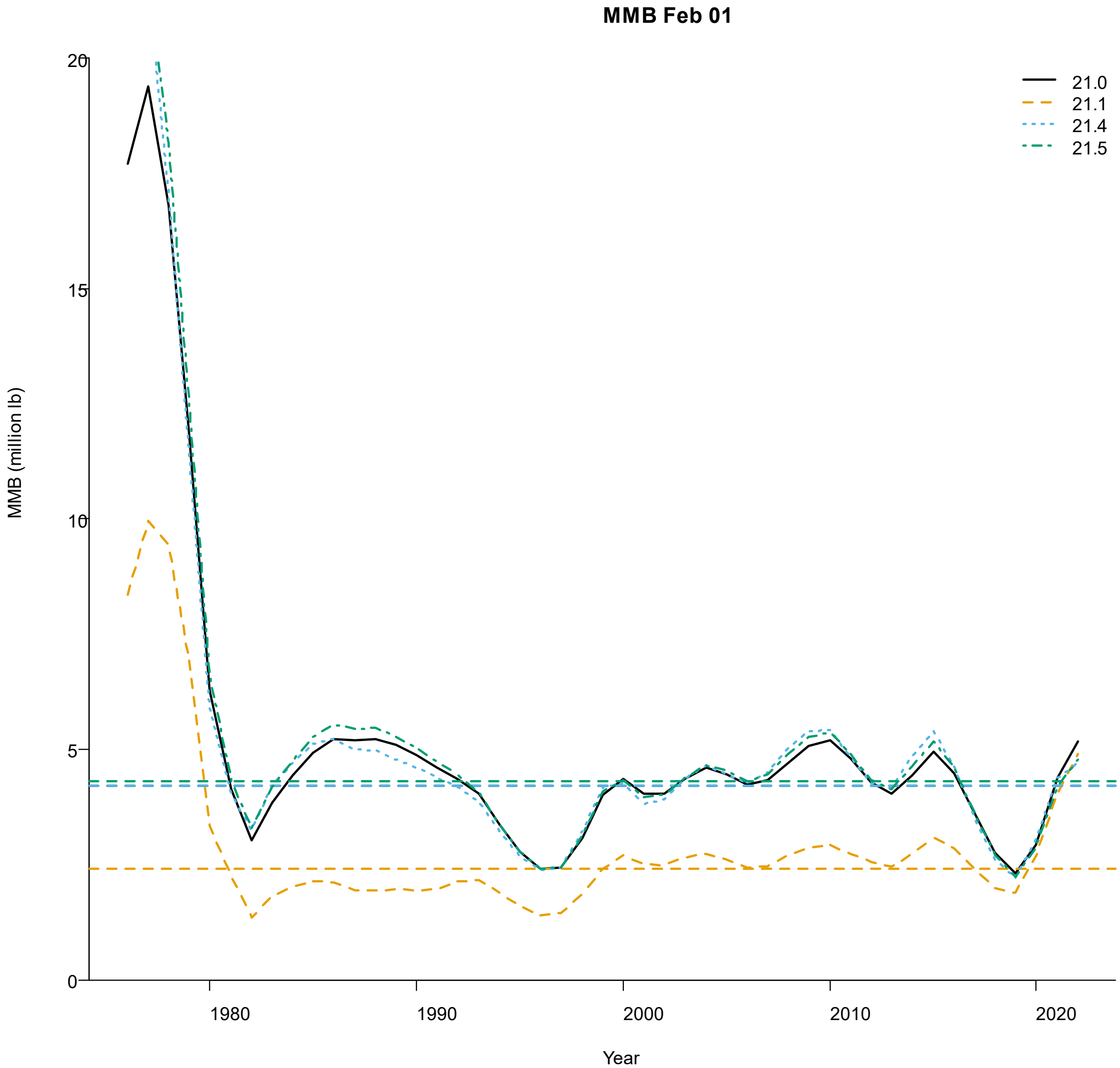




Modeled crab abundance Feb 01
total
legal
recruits
21.0
21.1
21.4
21.5
Abundance (million crabs)
0
2
4
6
8
10
1980
1990
2000
2010
2020
Year

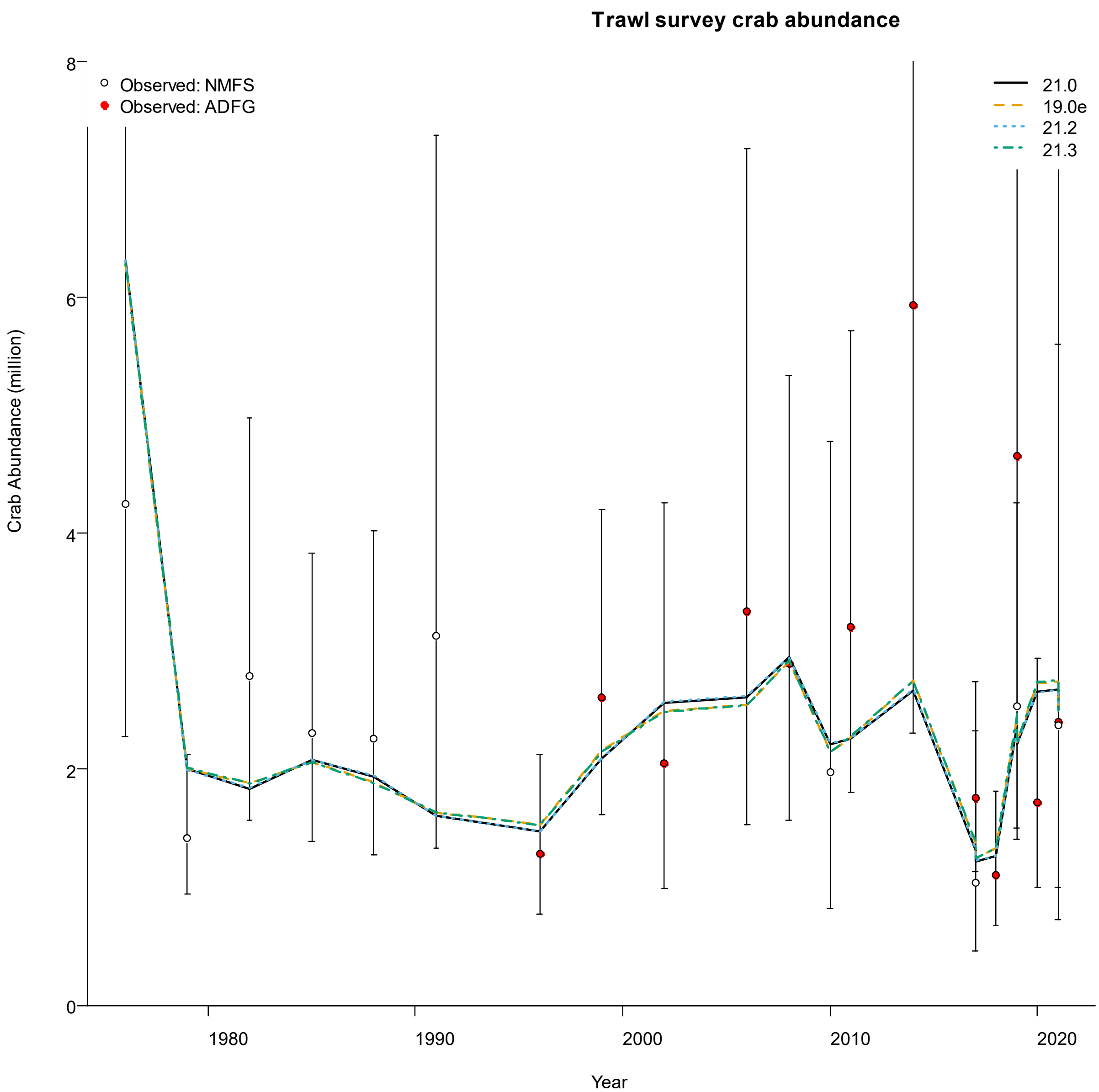
Figure 5. Estimated MMB during 1976-2022 (Model 21.0 solid black, Model 21.1 dash red). Horizontal line Bmsy (Average MMB of 1980-2022).





MMB Feb 01
20
15
10
5
0
MMB (million lb)
1980
1990
2000
2010
2020
Year
21.0
21.1
21.4
21.5

Figure 6. Observed (open circle) (White: NMFS, Red ADF&G) and model trawl survey male abundances with 95% lognormal Confidence Intervals (crab ≥ 64 mm CL).



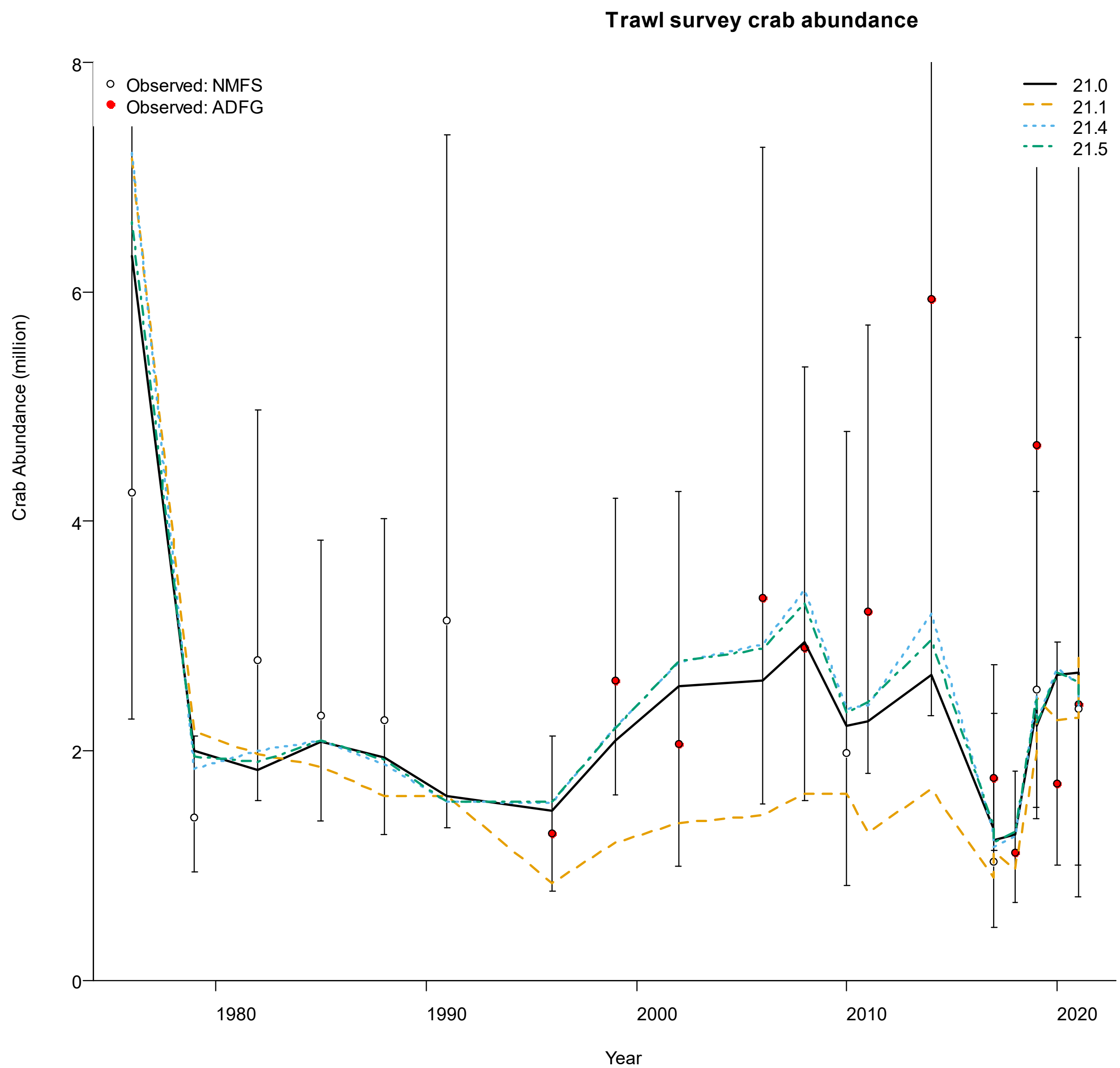

Trawl survey crab abundance
Observed: NMFS
Observed: ADFG
21.0
21.1
21.4
21.5
Crab Abundance (million)
0
2
4
6
8
1980
1990
2000
2010
2020
Year

Figure 7. 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

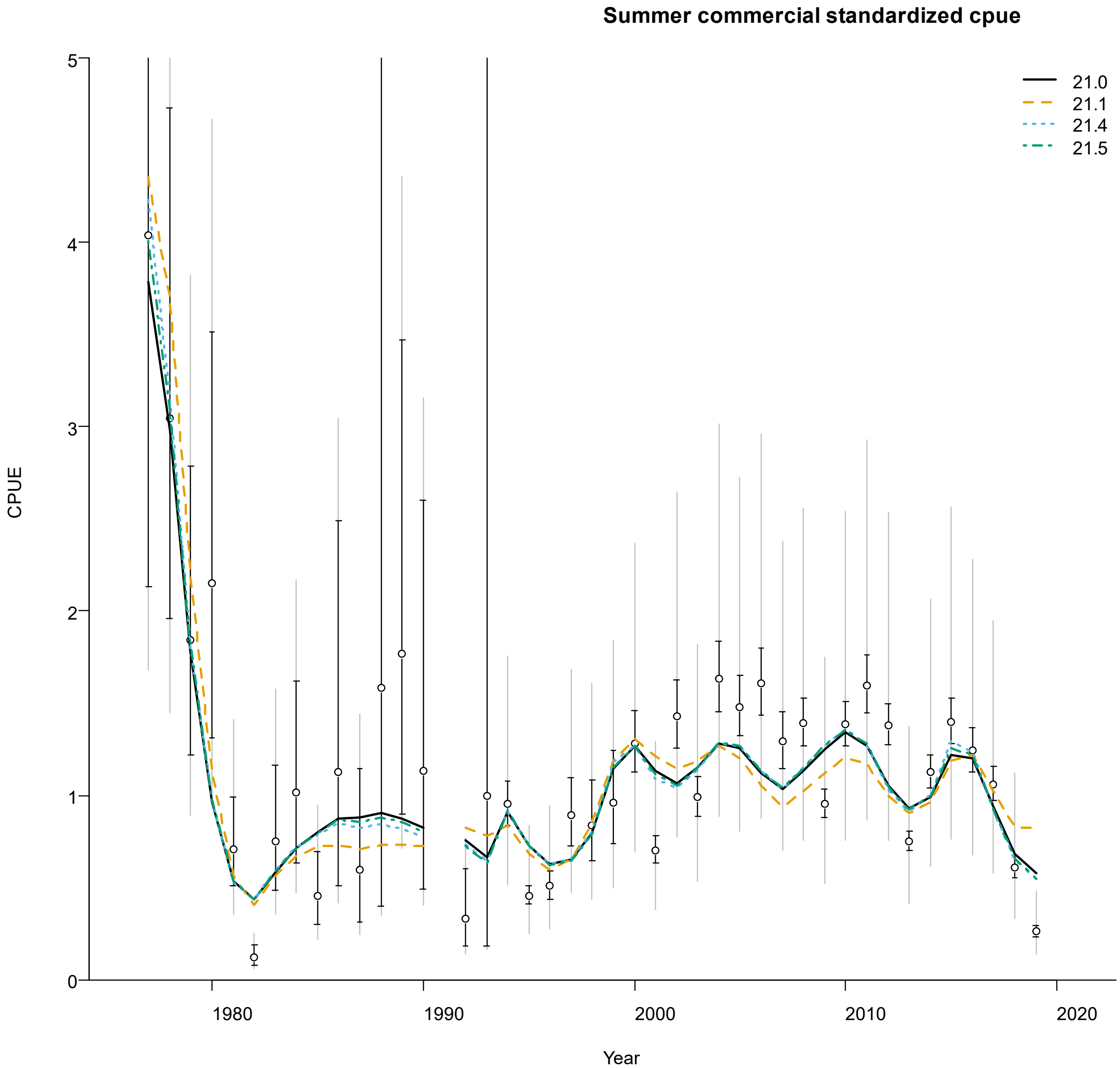
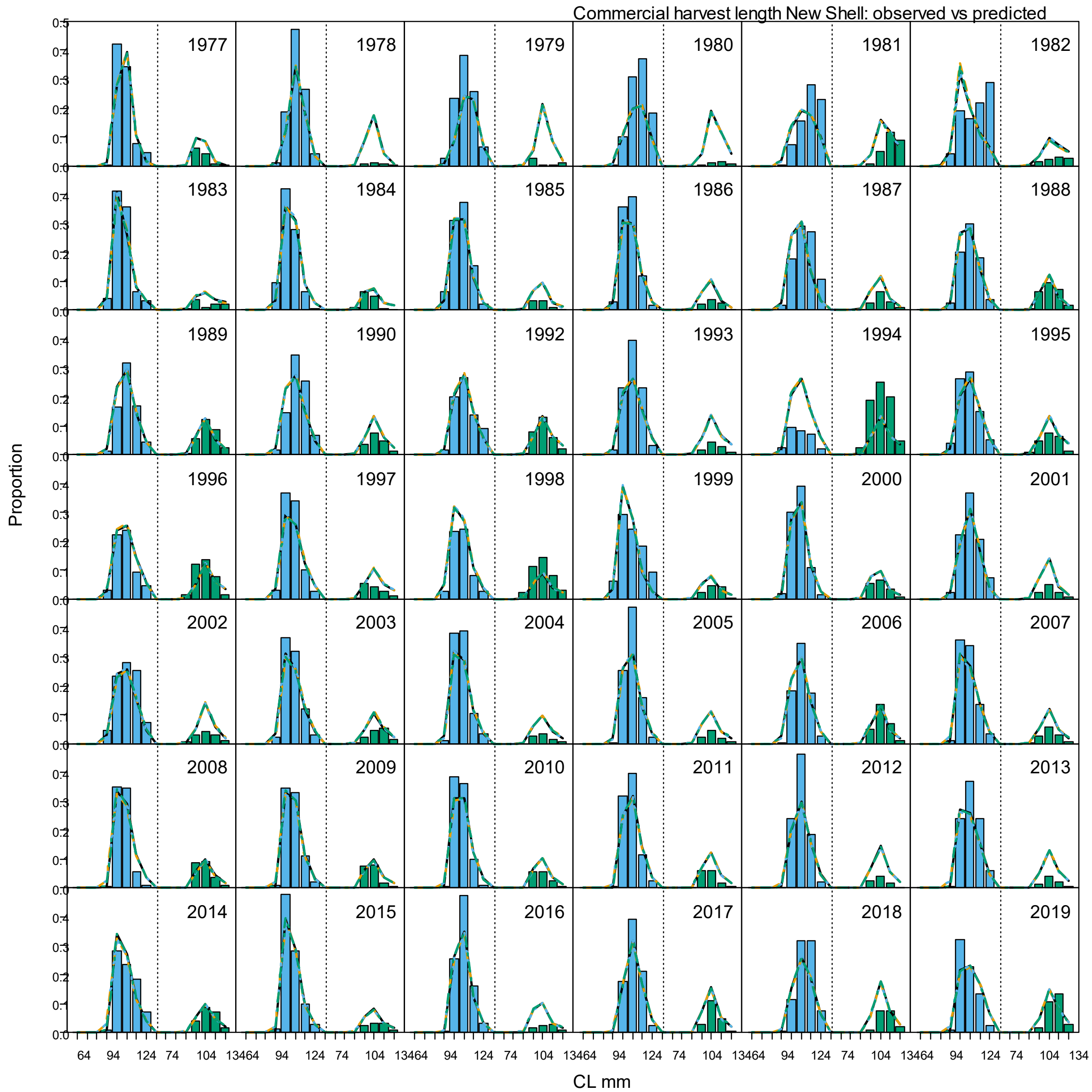


Figure 8. Predicted vs. observed (bar New Shell: blue, Old Shell: blue) length class proportions for the summer commercial harvest 1977-2019.

Model 21.0, 19.0e, 21.2, 21.3



Models 21.0, 21.1, 21.4, 21.5

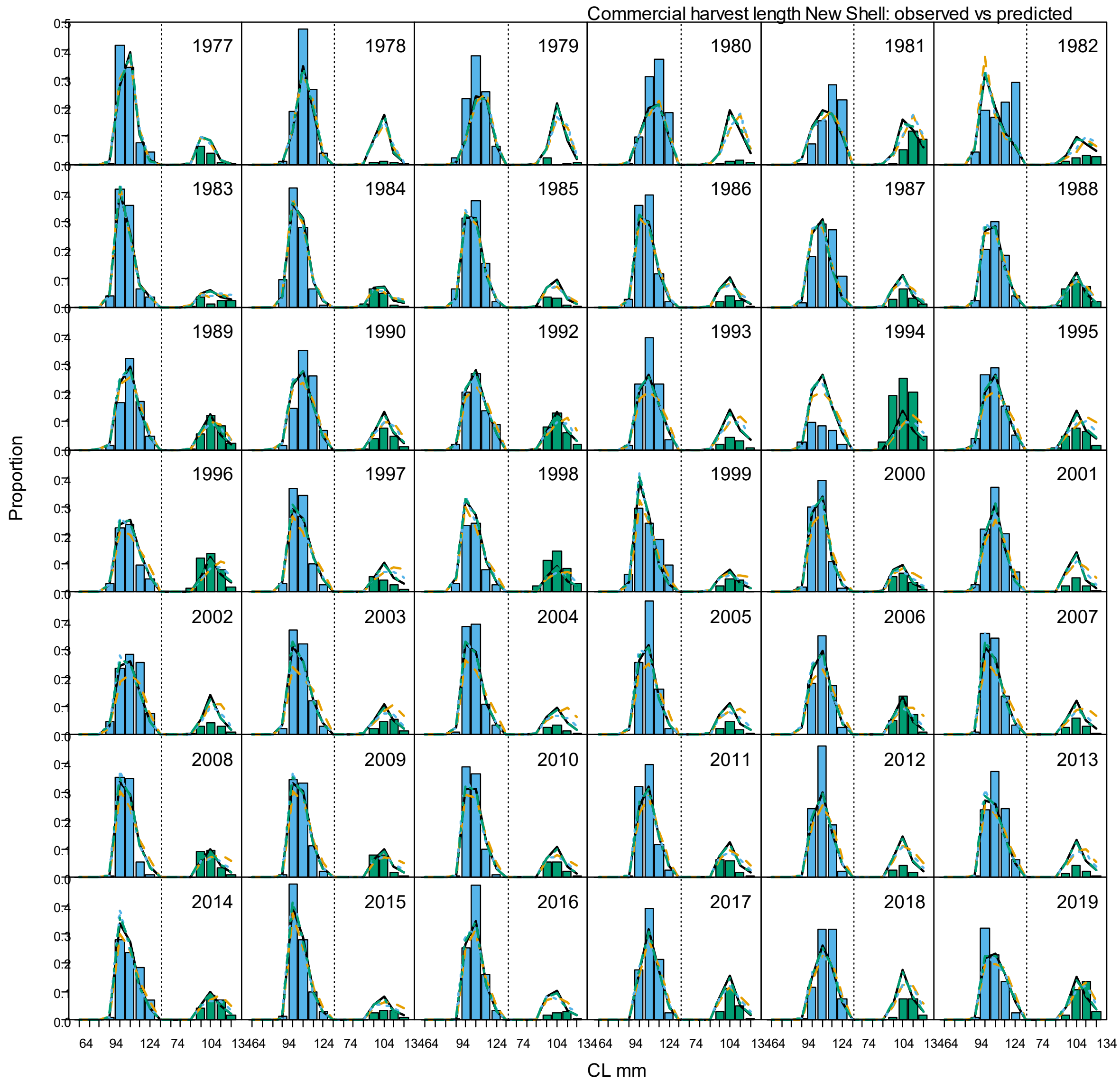
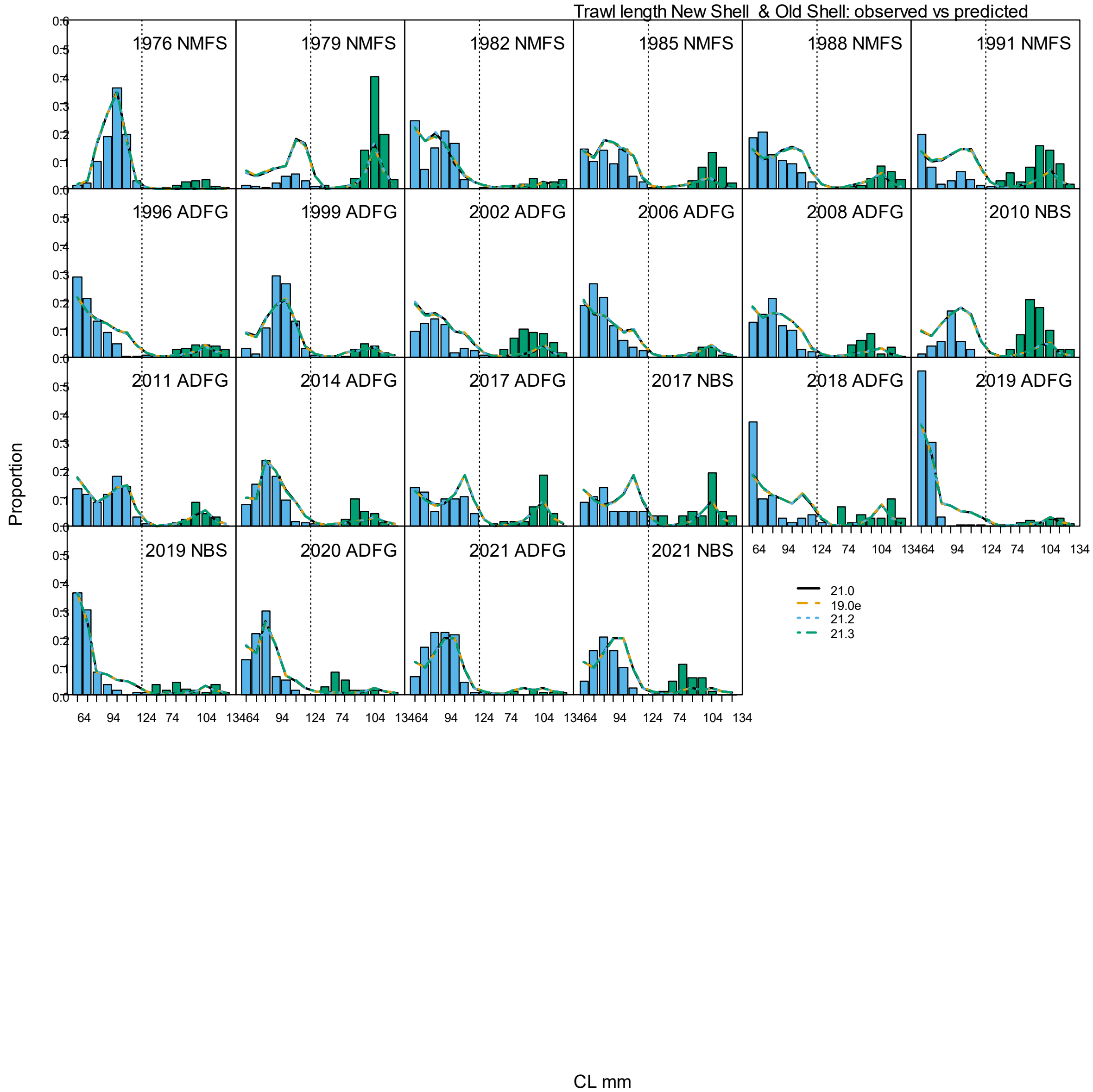


Figure 9. Predicted (line) vs. observed (bar New Shell: blue, Old Shell: blue) length class proportions for trawl survey 1976-2021.



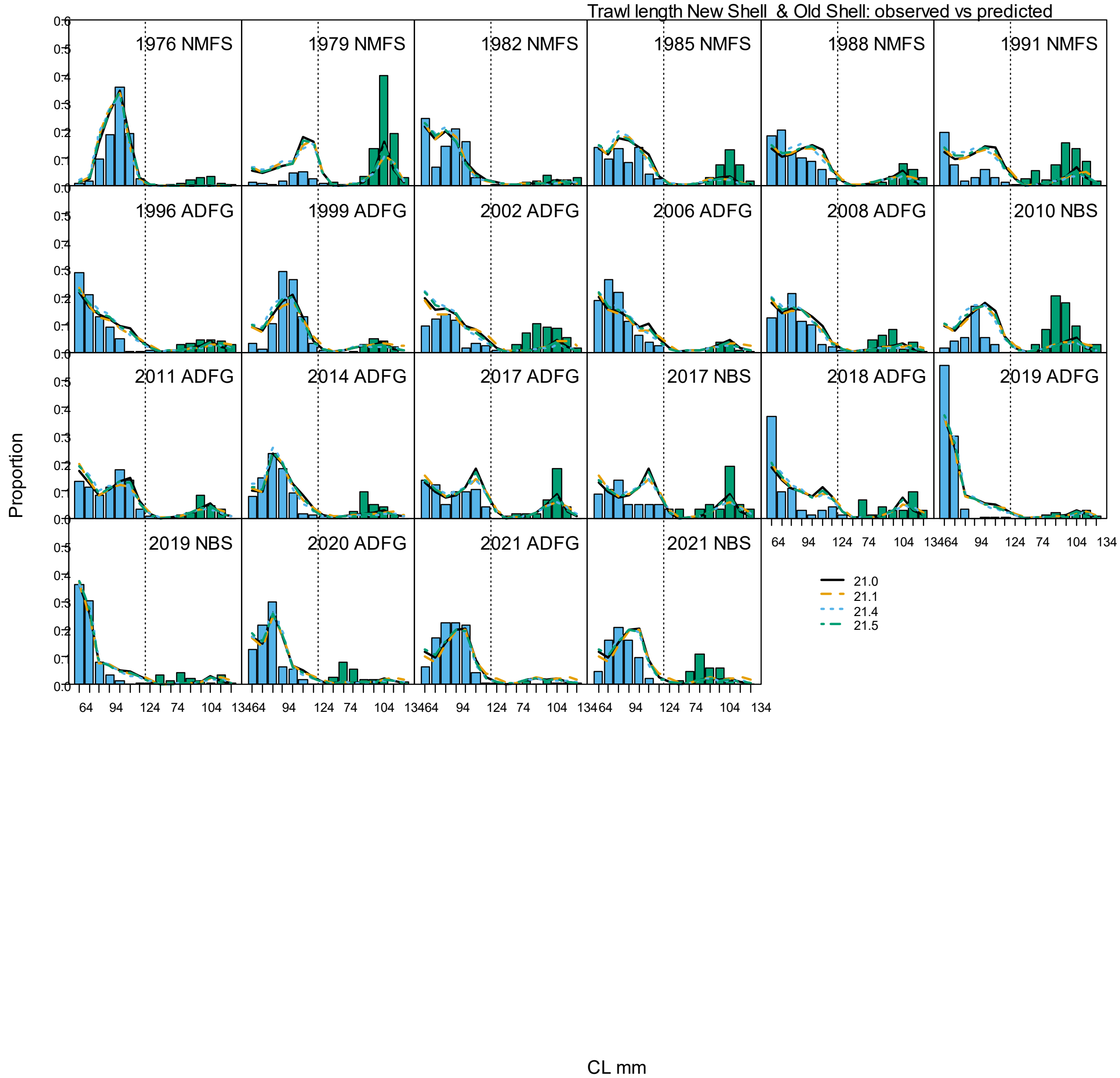
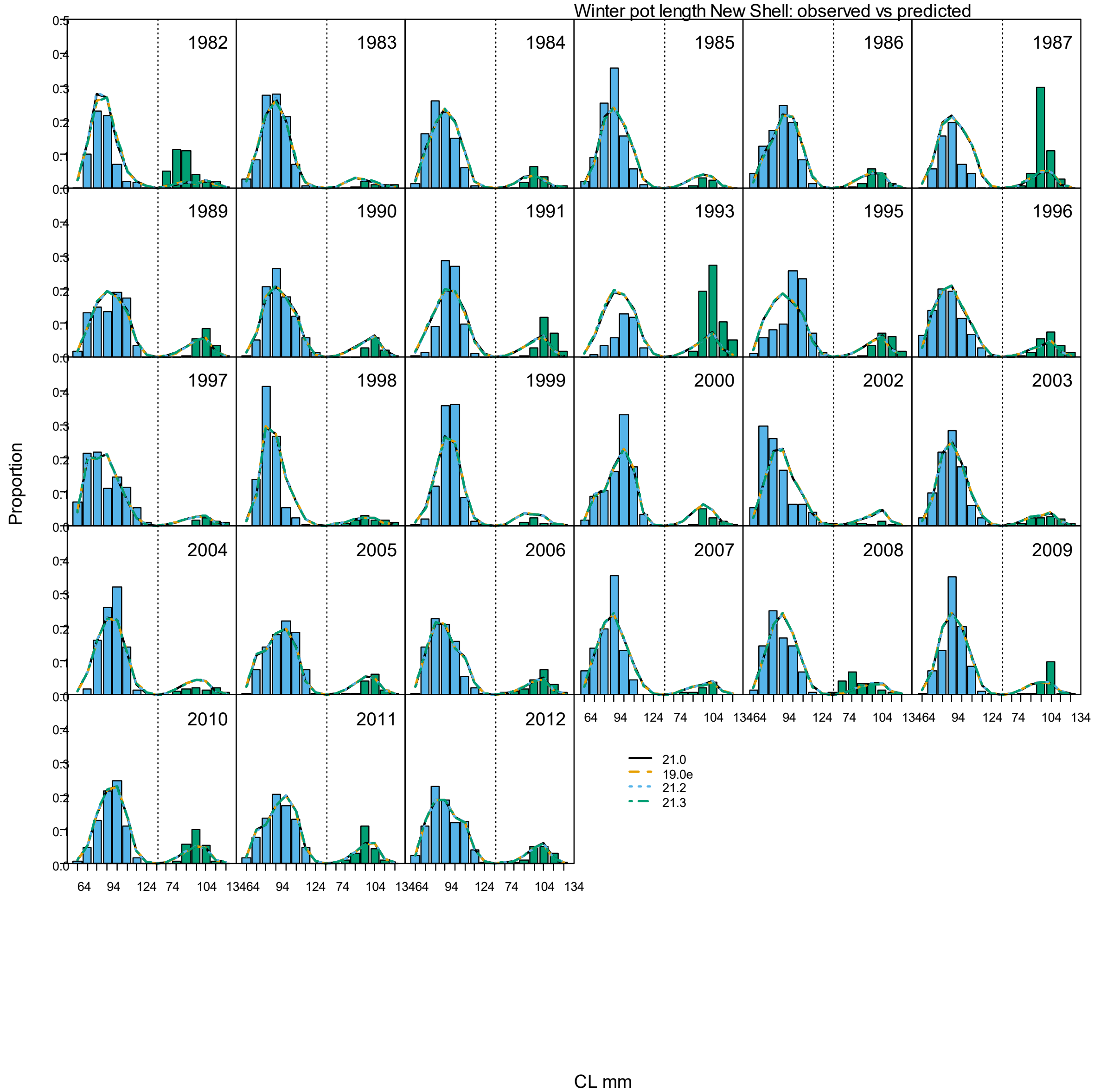

Trawl length New Shell & Old Shell: observed vs predicted
1976 NMFS
1979 NMFS
1982 NMFS
1985 NMFS
1988 NMFS
1991 NMFS
1996 ADFG
1999 ADFG
2002 ADFG
2006 ADFG
2008 ADFG
2010 NBS
2011 ADFG
2014 ADFG
2017 ADFG
2017 NBS
2018 ADFG
2019 ADFG
2019 NBS
2020 ADFG
2021 ADFG
2021 NBS
Proportion
CL mm
21.0
21.1
21.4
21.5

Figure 10 Predicted (line) vs. observed (bar New Shell: blue, Old Shell: blue) length class proportions for winter pot survey 1982-2012.



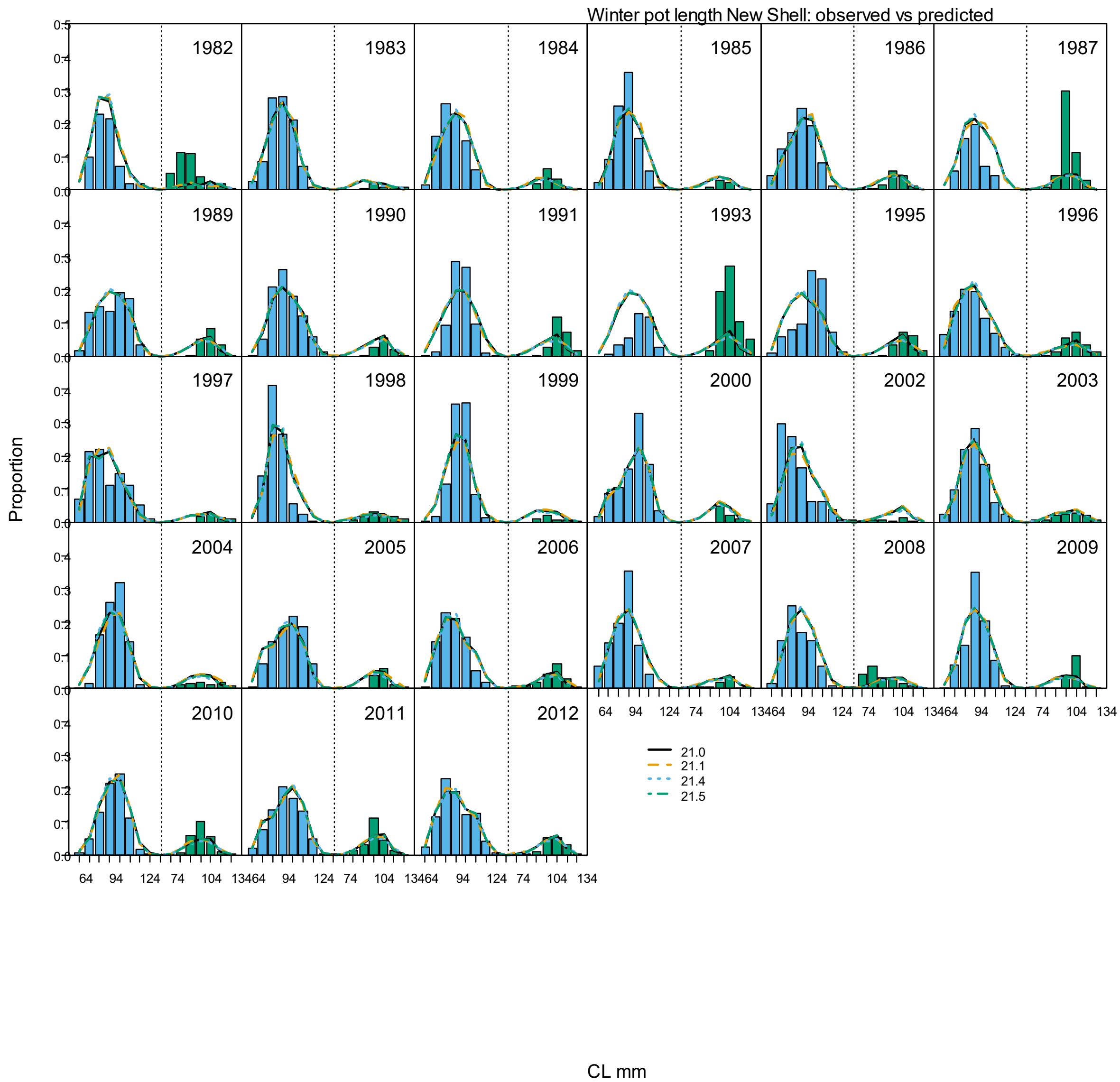
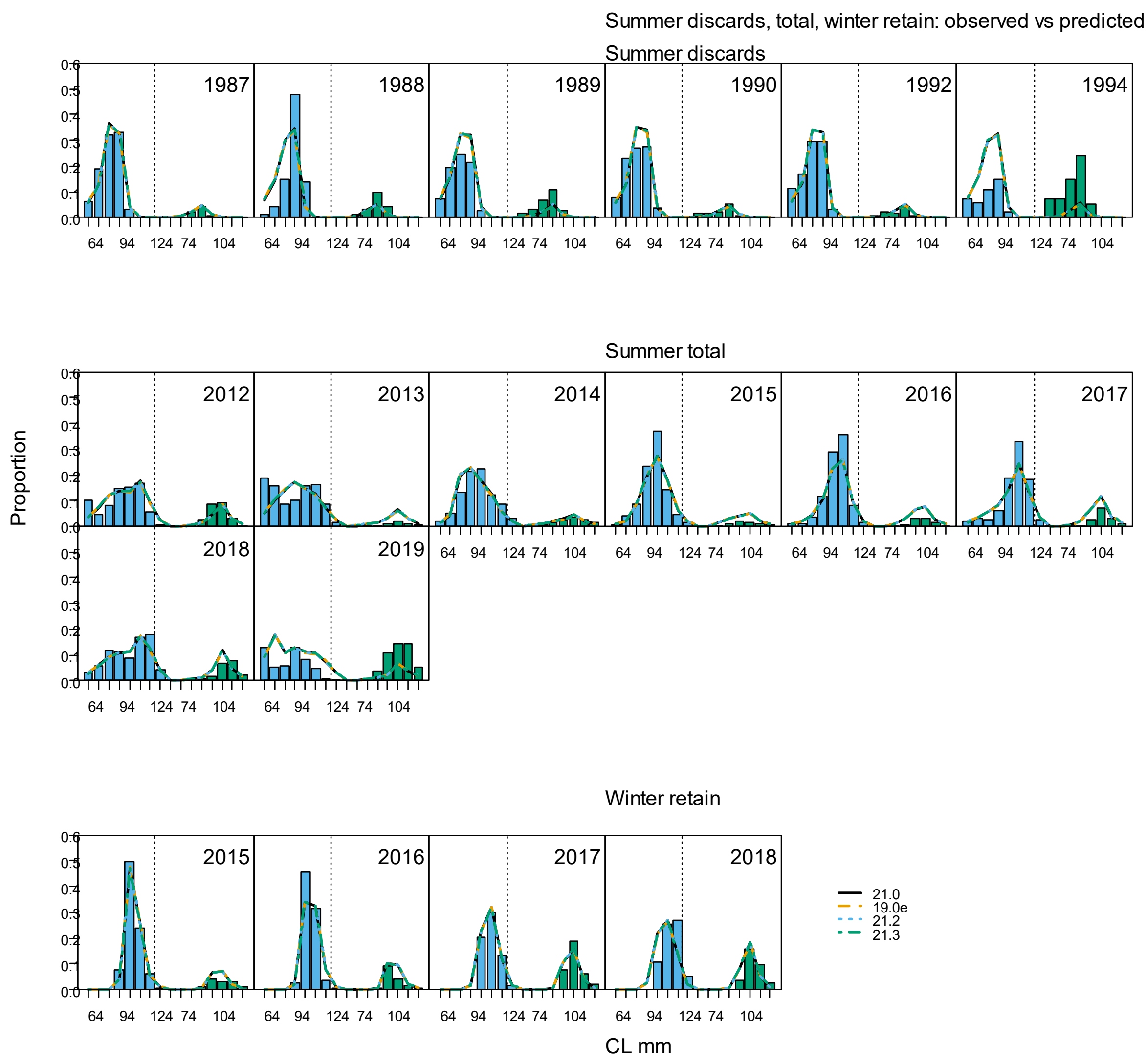
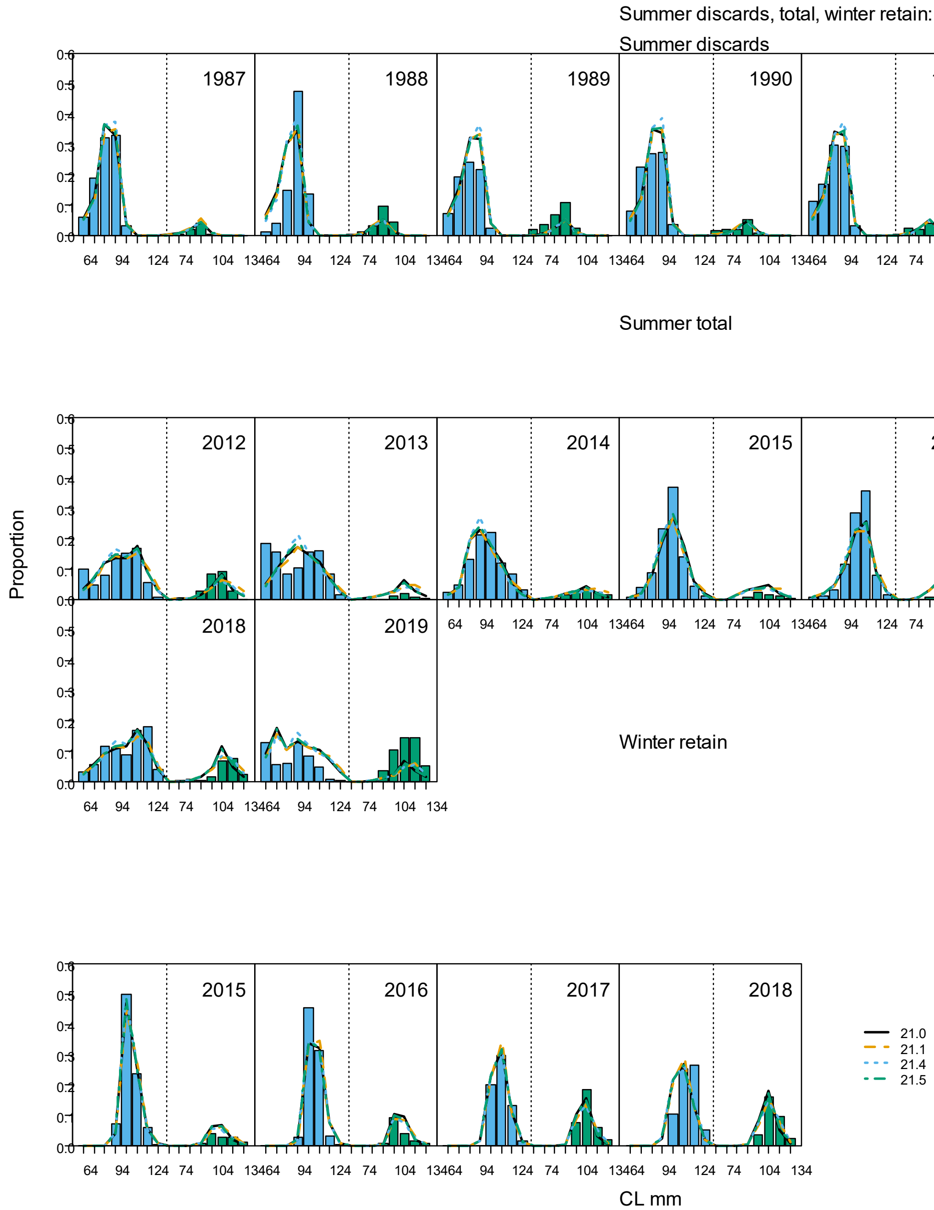

Winter pot length New Shell: observed vs predicted
Proportion
CL mm
21.0
21.1
21.4
21.5

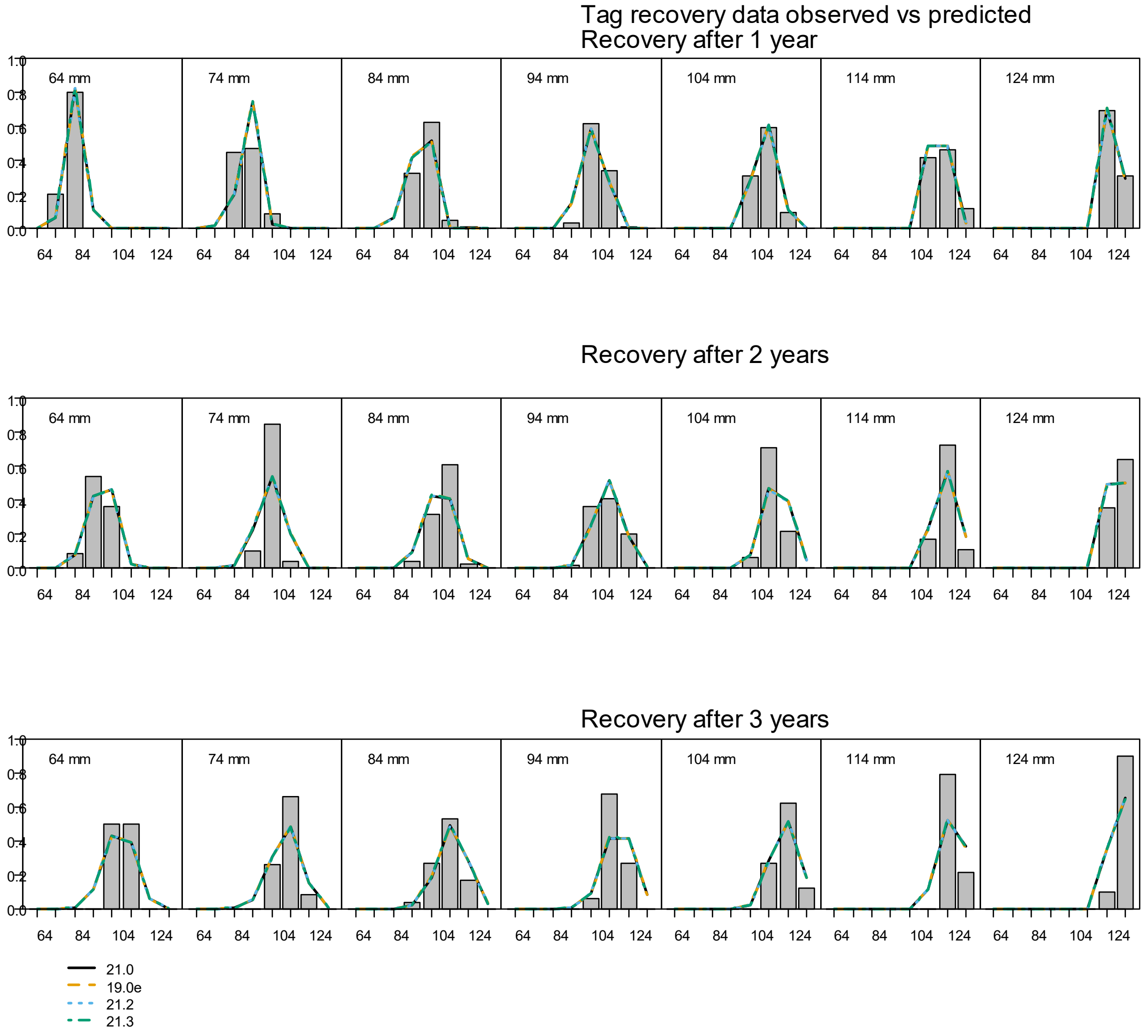
Figure 11. Predicted (line) vs. observed (bar New Shell: left blue, Old Shell: right green) length class proportions for summer commercial total and discards (1987-1994, 2012-2019) and winter commercial retained fishery 2015-2018

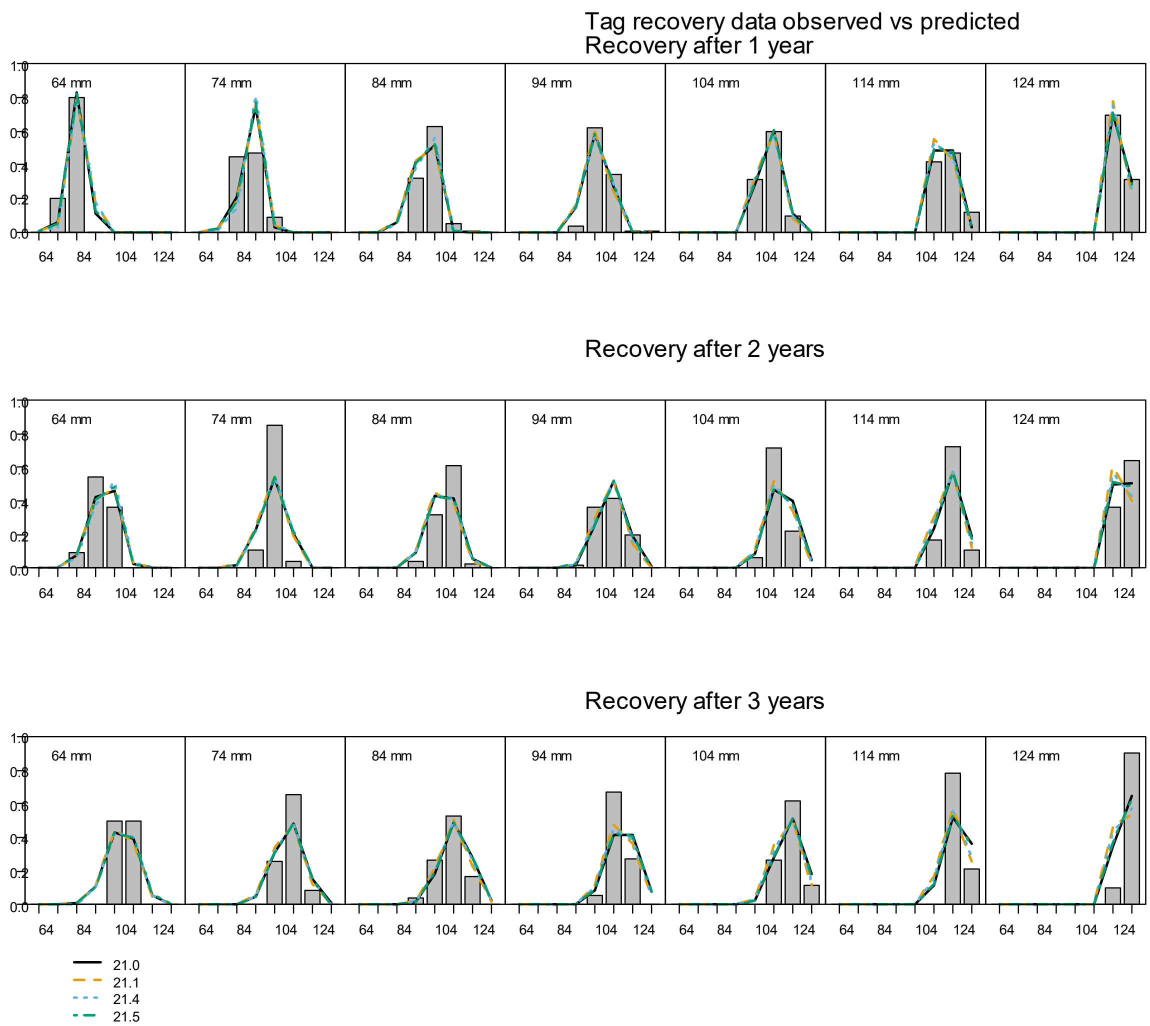




Summer discards, total, winter retain: observed vs predicted
Summer discards
1987
1988
1989
1990
1992
1994
Summer total
2012
2013
2014
2015
2016
2017
2018
2019
Winter retain
2015
2016
2017
2018
Proportion
CL mm
21.0
21.1
21.4
21.5

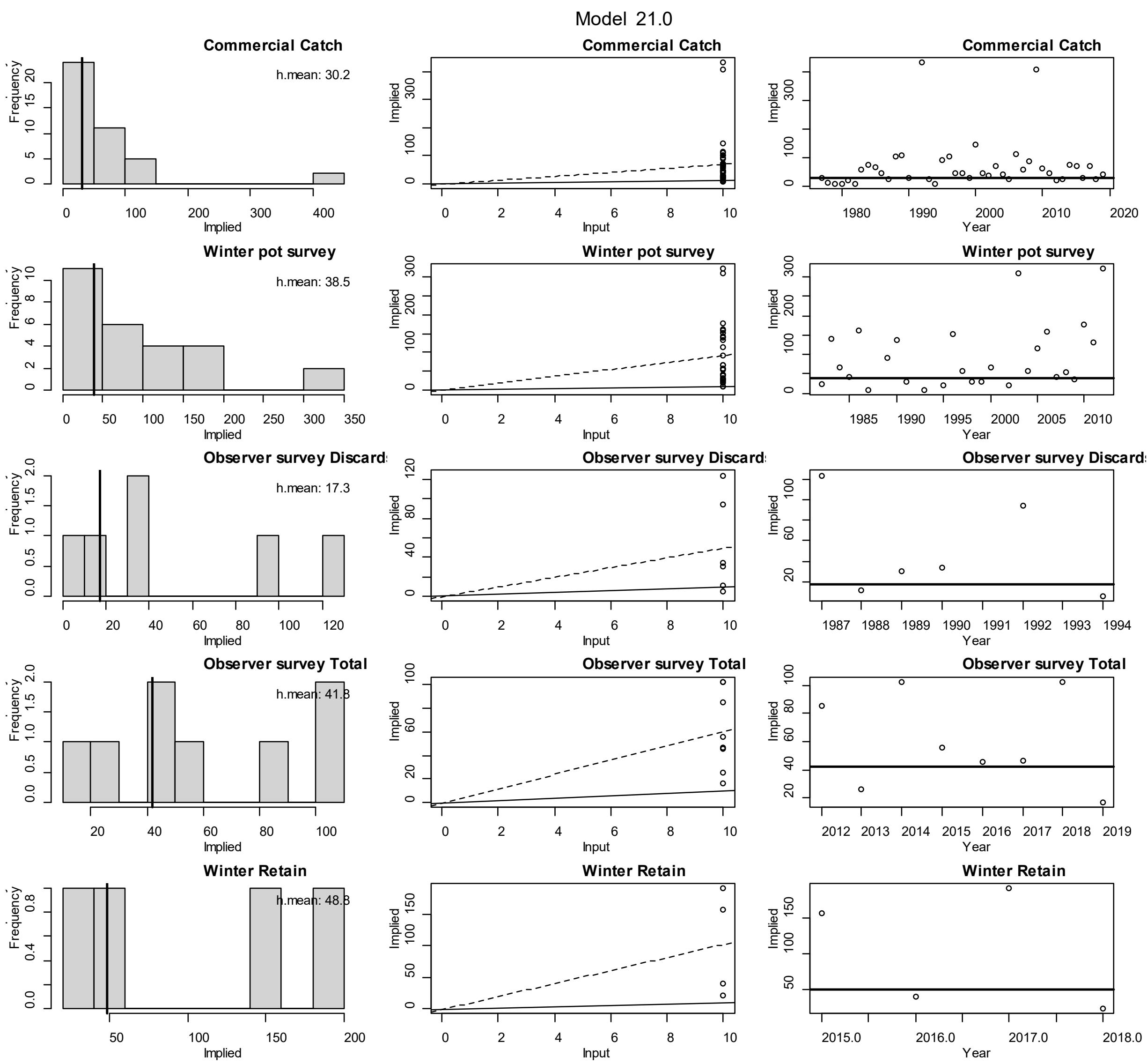
Figure 12. Predicted (line) vs. observed (bar) length class proportions for tag recovery data.

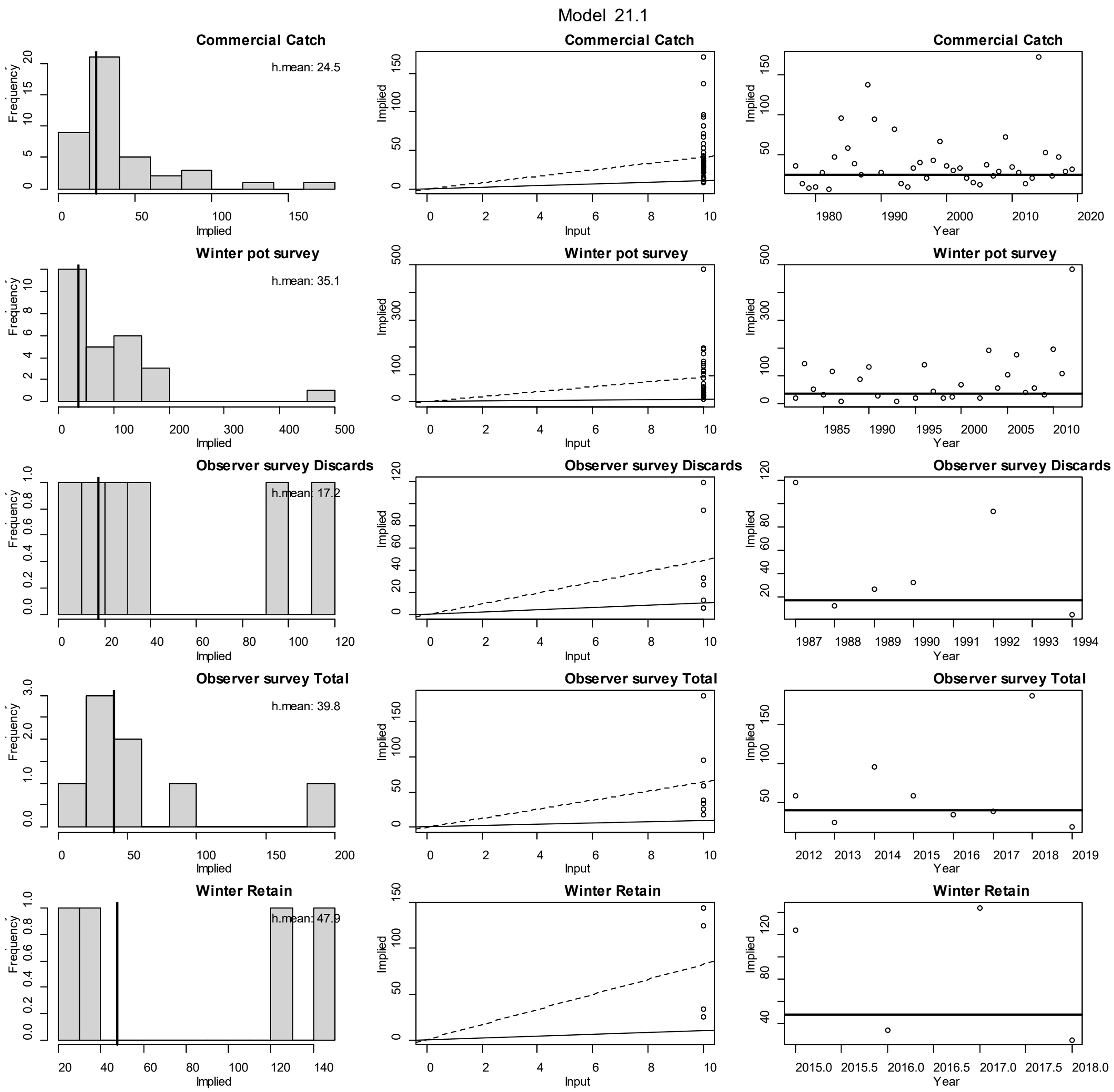


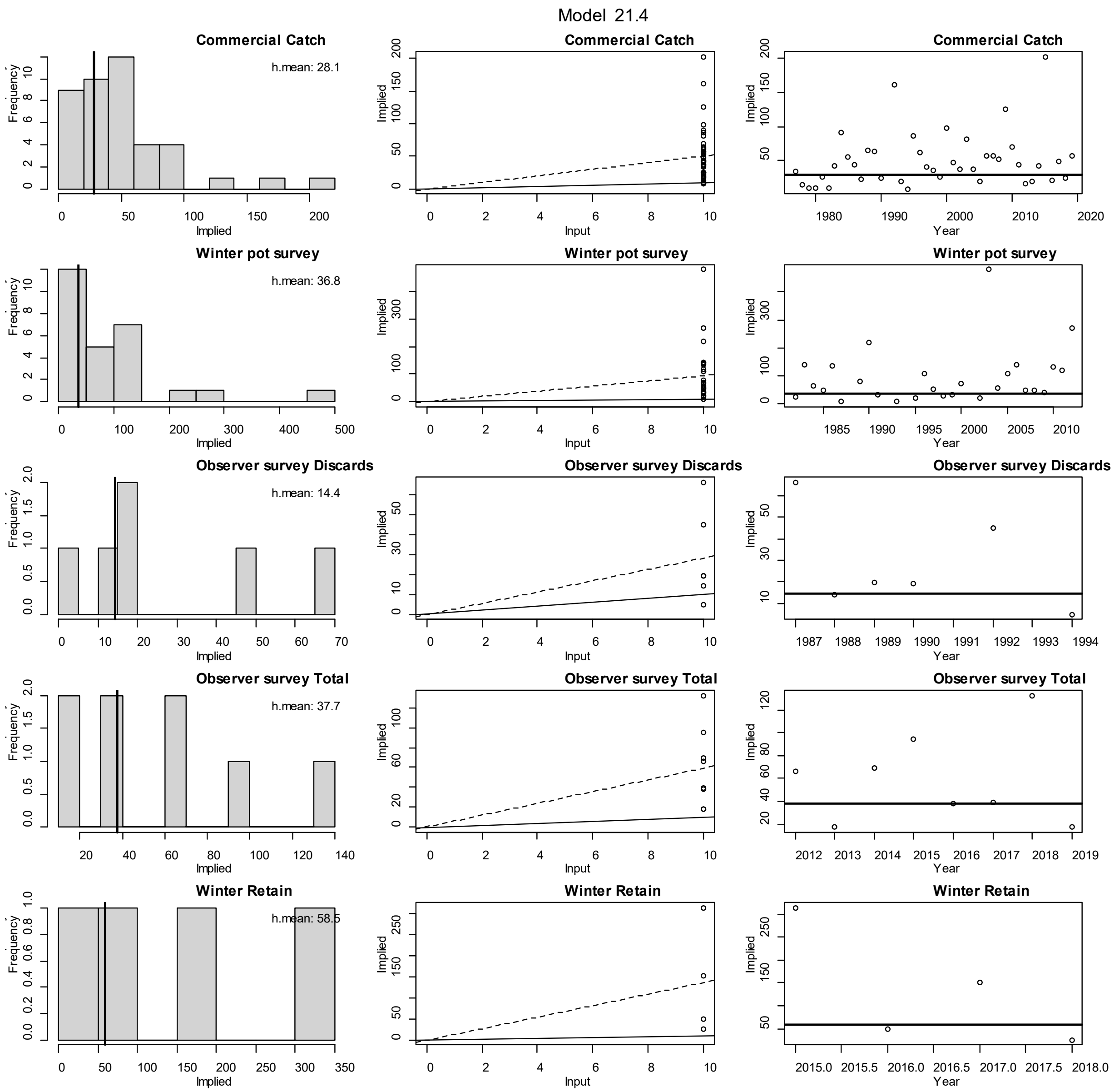


Tag recovery data observed vs predicted
Recovery after 1 year
Recovery after 2 years
Recovery after 3 years
64 mm
74 mm
84 mm
94 mm
104 mm
114 mm
124 mm
1.0
0.8
0.6
0.4
0.2
0.0
64
84
104
124
21.0
21.1
21.4
21.5

Figure 13. 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.




Model 21.1
Commercial Catch
h.mean: 24.5
Frequency
Implied
Input
Year
Winter pot survey
h.mean: 35.1
Observer survey Discards
h.mean: 17.2
Observer survey Total
h.mean: 39.8
Winter Retain
h.mean: 47.9


Model 21.4
Commercial Catch
h.mean: 28.1
Winter pot survey
h.mean: 36.8
Observer survey Discards
h.mean: 14.4
Observer survey Total
h.mean: 37.7
Winter Retain
h.mean: 58.5
Frequency
Implied
Input
Year

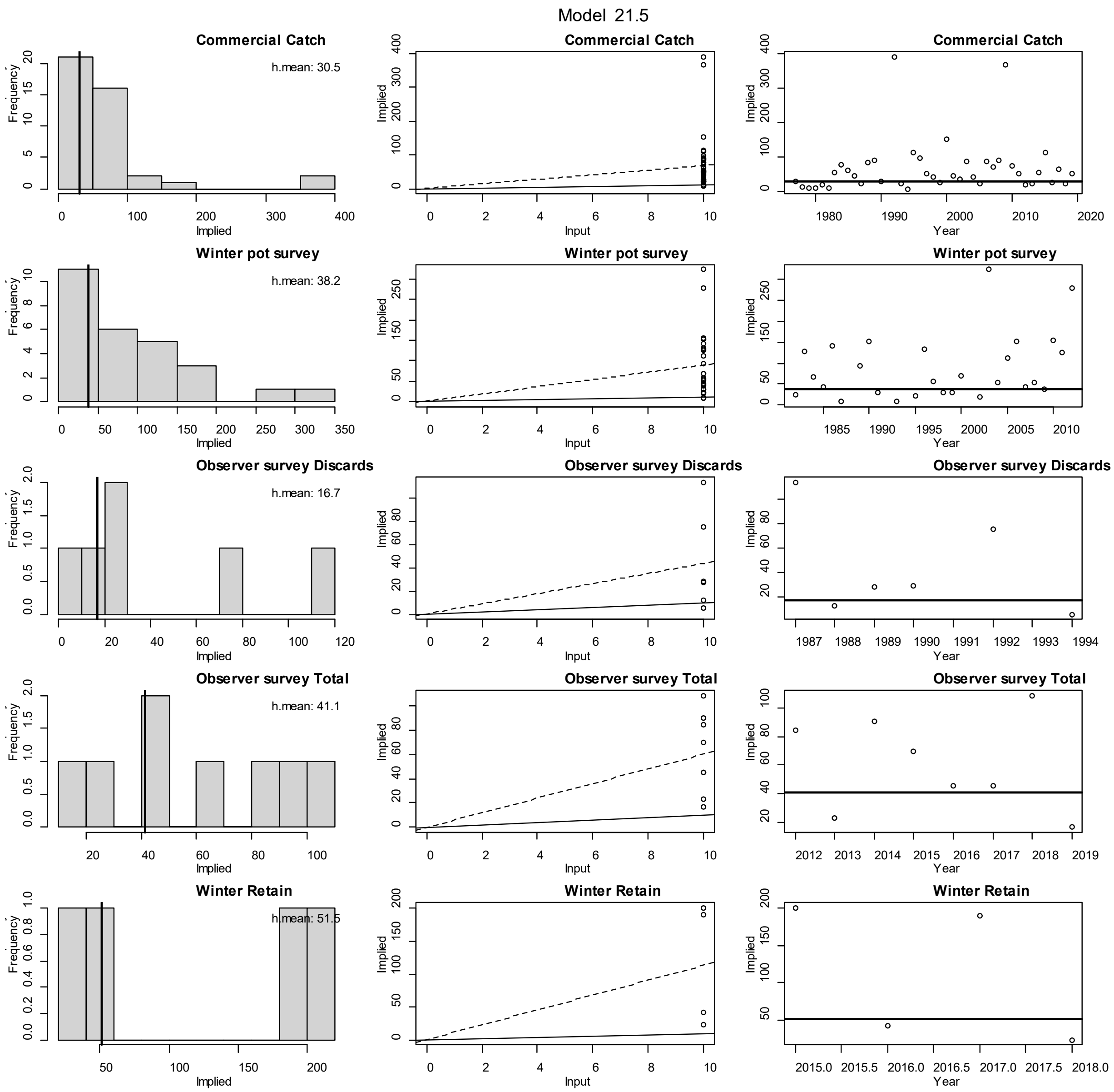
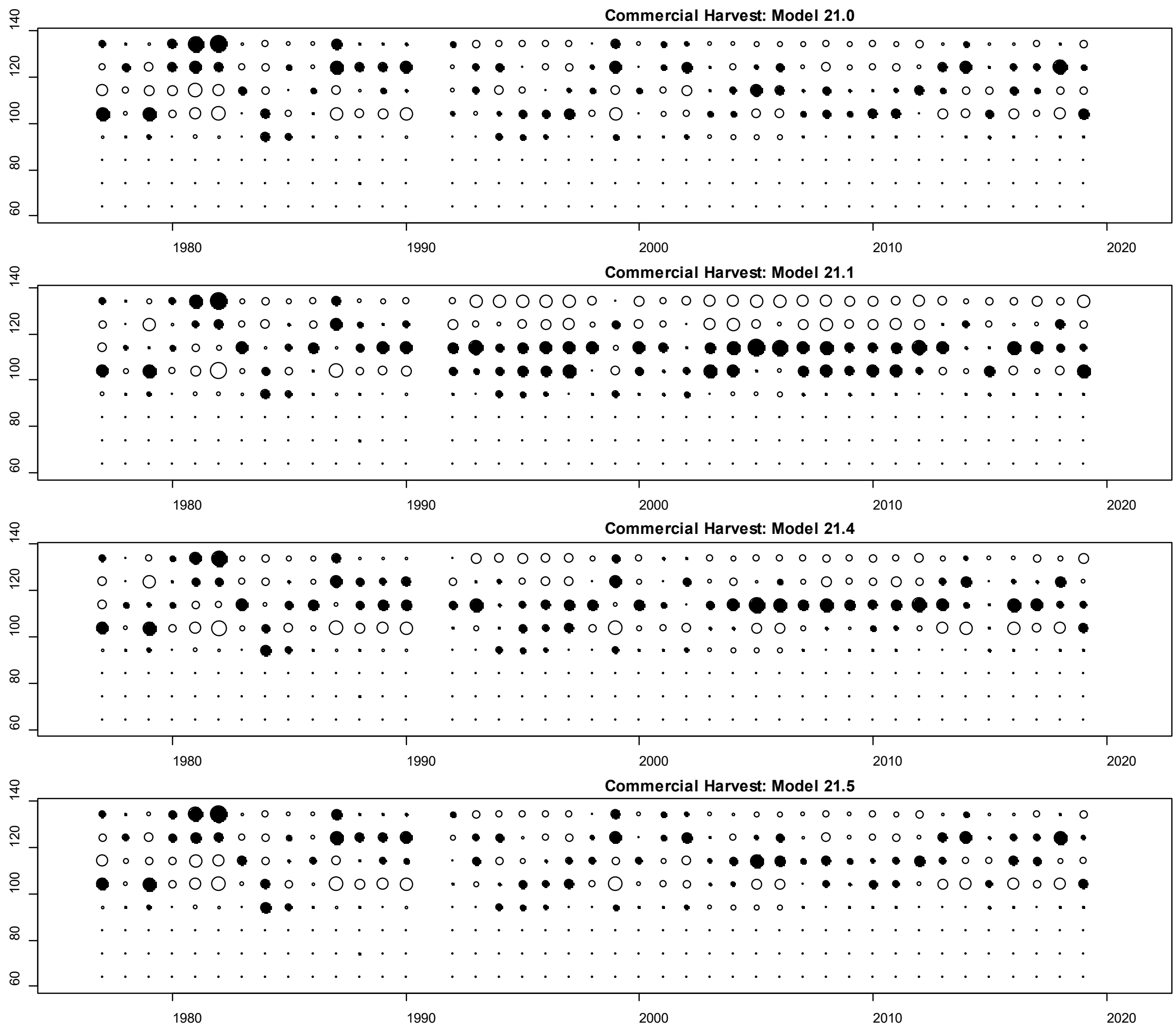
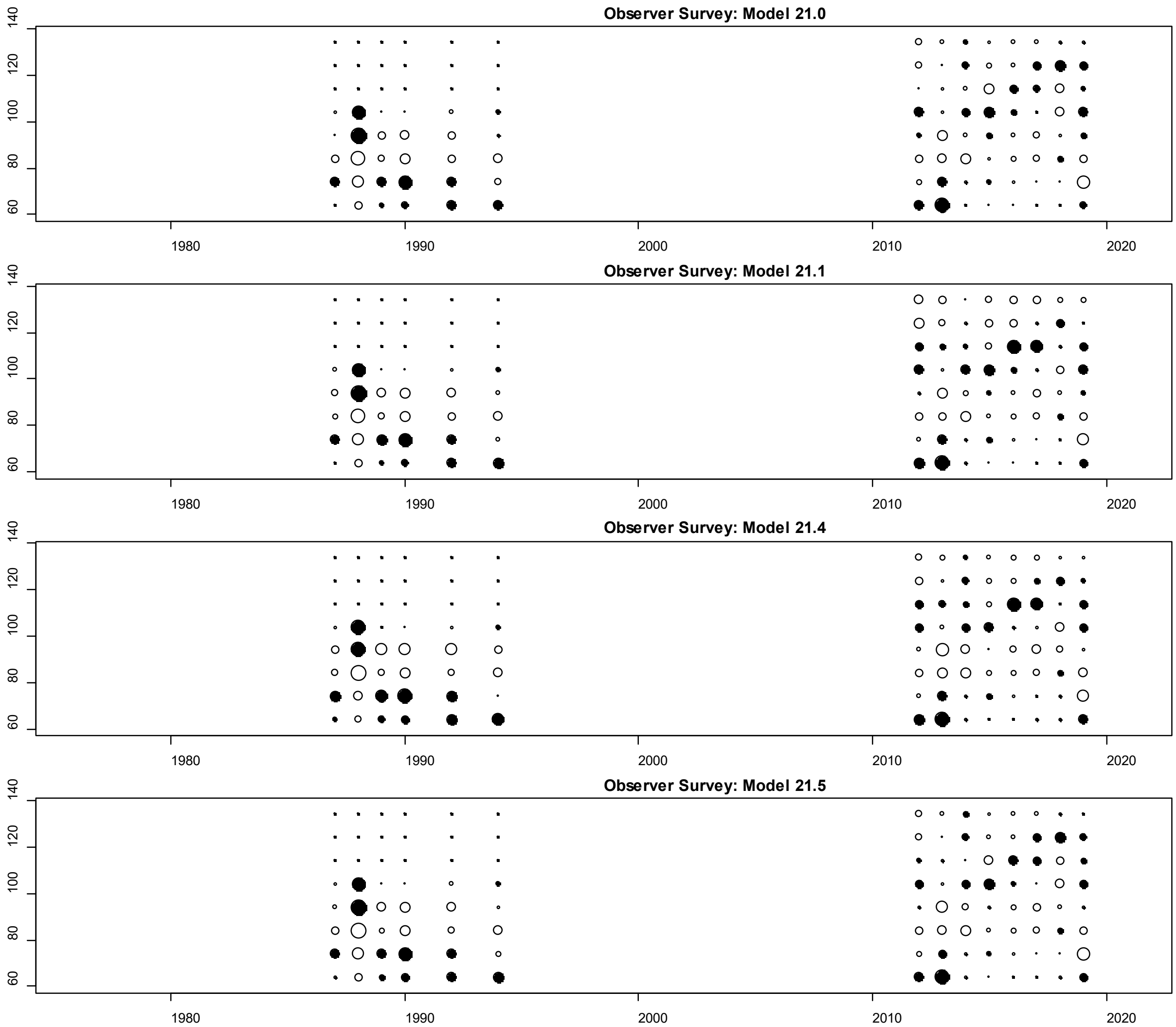
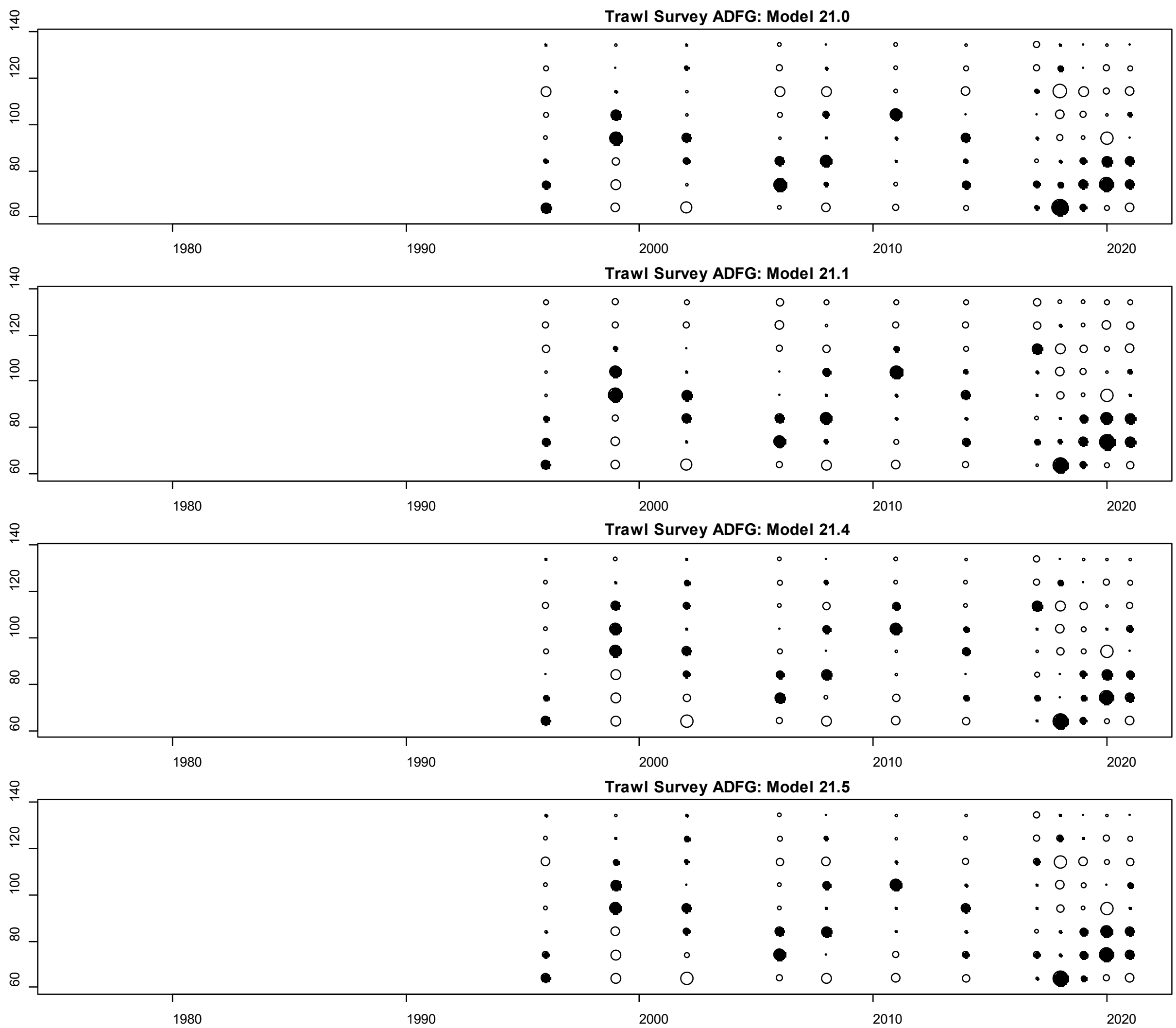
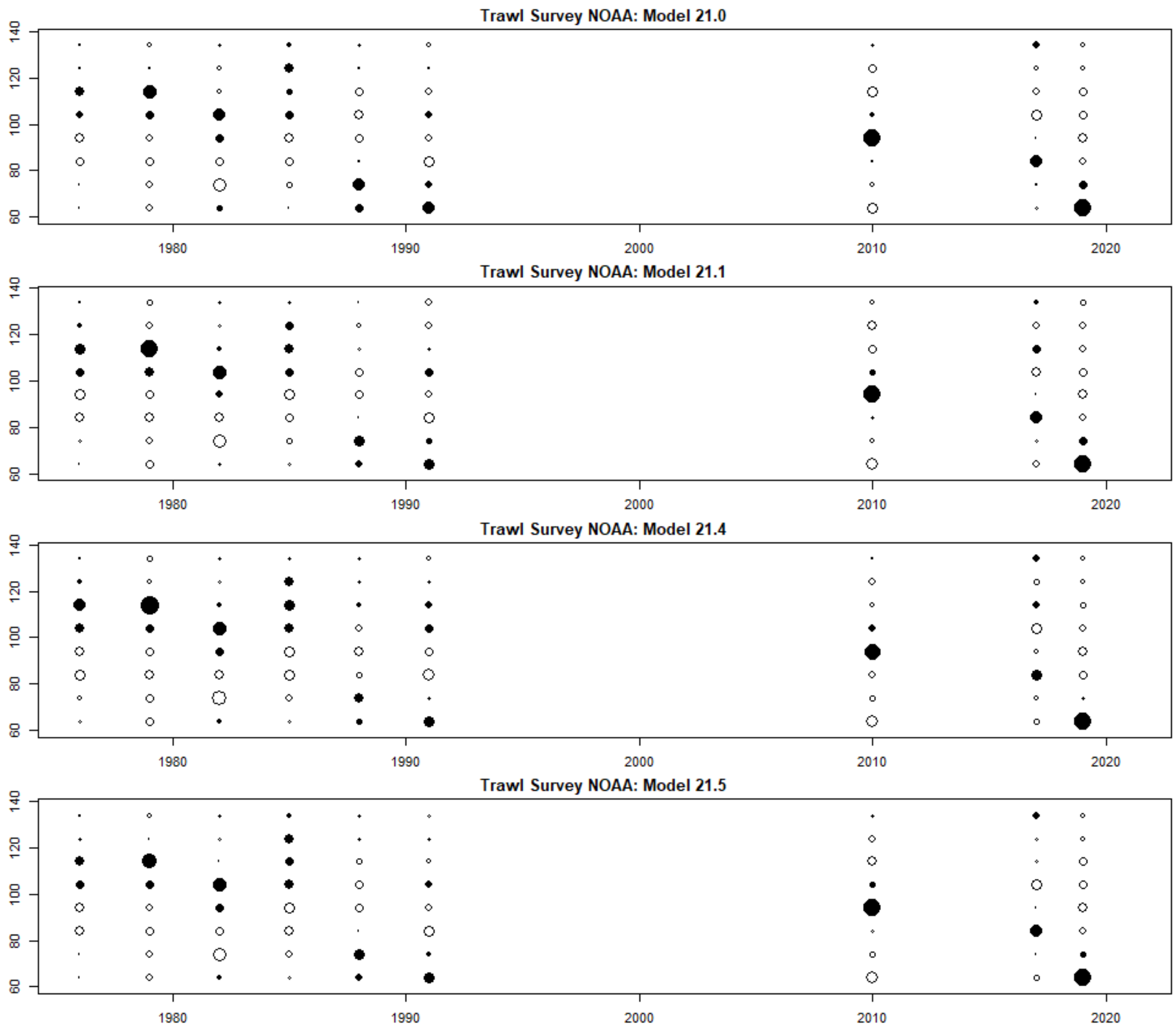

Model 21.5
Commercial Catch
h.mean: 30.5
Frequency
Implied
Input
Year
Winter pot survey
h.mean: 38.2
Observer survey Discards
h.mean: 16.7
Observer survey Total
h.mean: 41.1
Winter Retain
h.mean: 51.5

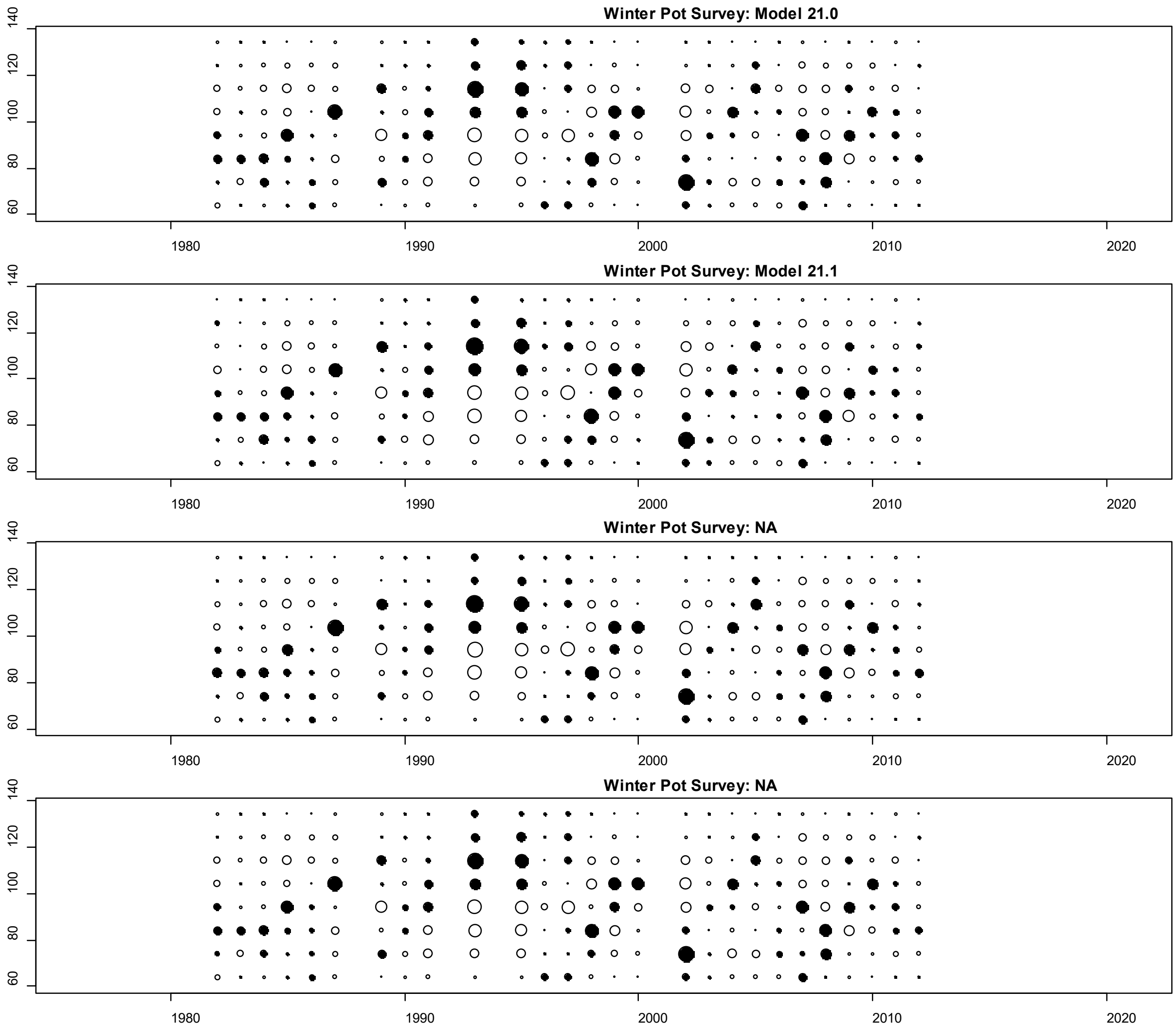
Figure 14. Bubble plots of predicted and observed length proportions.
Black circle indicates model underestimates than observed, and white circle indicates model overestimates than observed. Size of circle indicates degree of deviance (larger circle = larger deviance). In ideal model fit case, distribution of sizes and colors of circles should be random (i.e., no systematic model misfits).




Observer Survey: Model 21.0
Observer Survey: Model 21.1
Observer Survey: Model 21.4
Observer Survey: Model 21.5
60
80
100
120
140
1980
1990
2000
2010
2020


Trawl Survey ADFG: Model 21.0
Trawl Survey ADFG: Model 21.1
Trawl Survey ADFG: Model 21.4
Trawl Survey ADFG: Model 21.5
60
80
100
120
140
1980
1990
2000
2010
2020


Trawl Survey NOAA: Model 21.0
Trawl Survey NOAA: Model 21.1
Trawl Survey NOAA: Model 21.4
Trawl Survey NOAA: Model 21.5
60
80
100
120
140
1980
1990
2000
2010
2020


Winter Pot Survey: Model 21.0
Winter Pot Survey: Model 21.1
Winter Pot Survey: NA
Winter Pot Survey: NA
60
80
100
120
140
1980
1990
2000
2010
2020

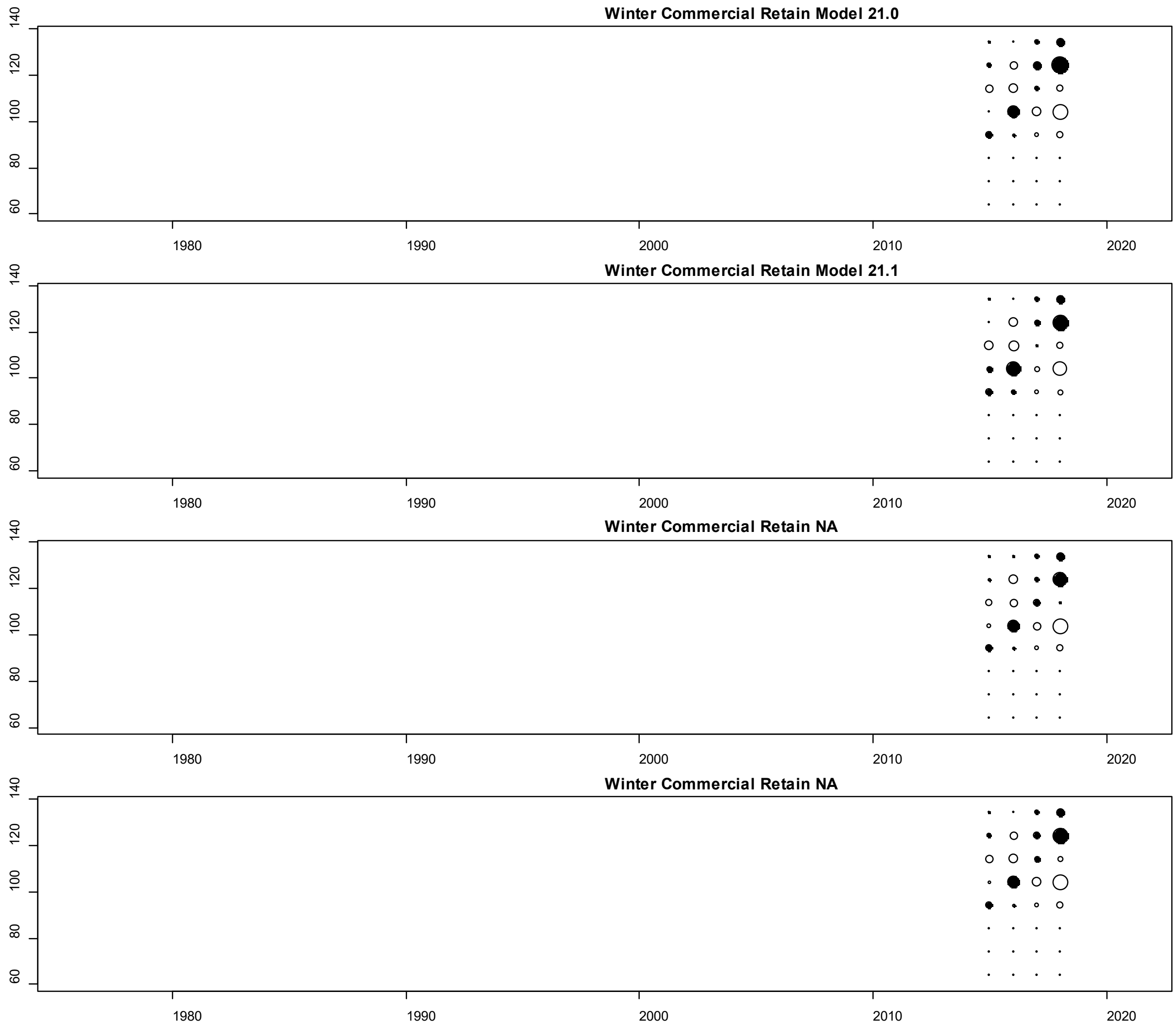
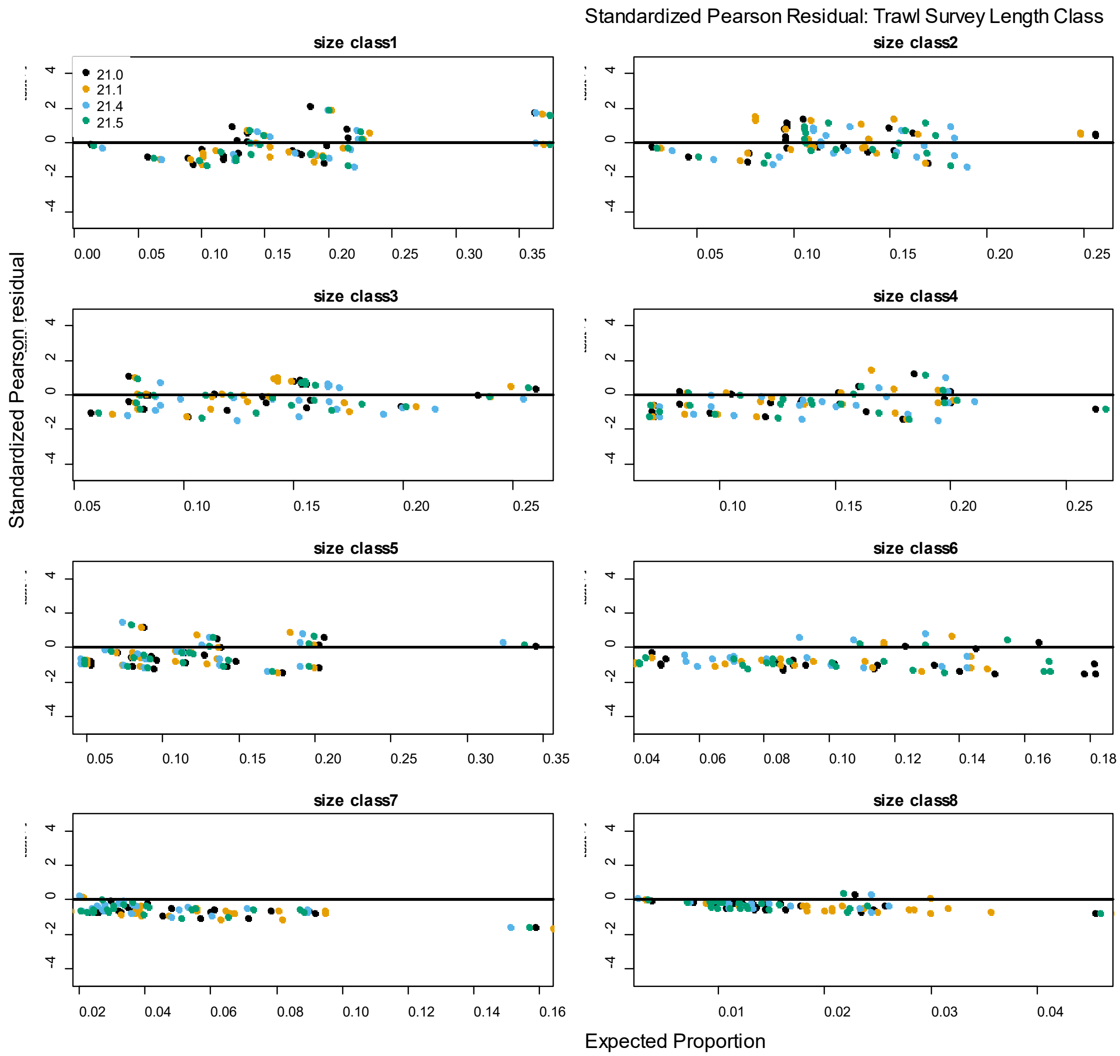
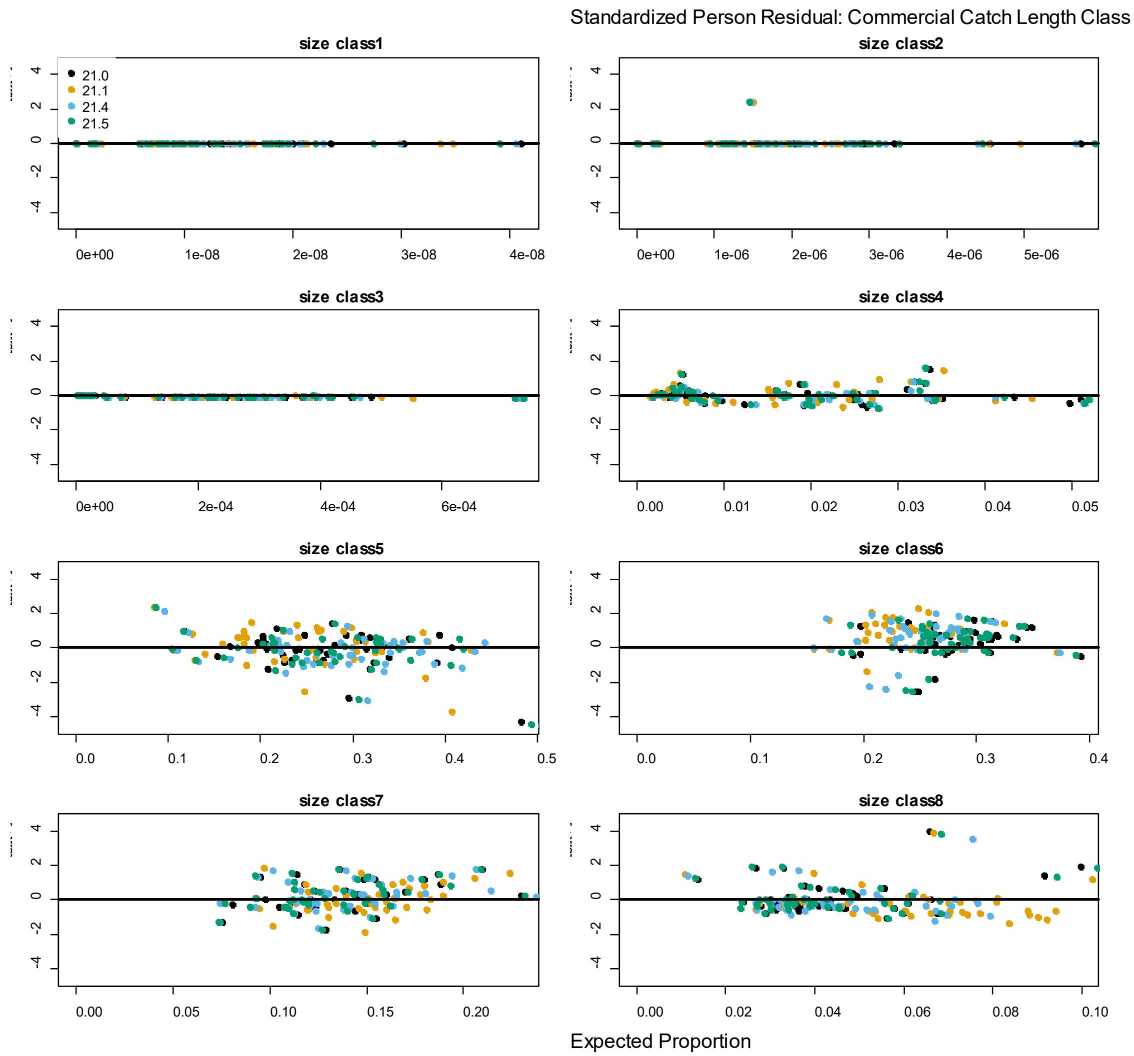
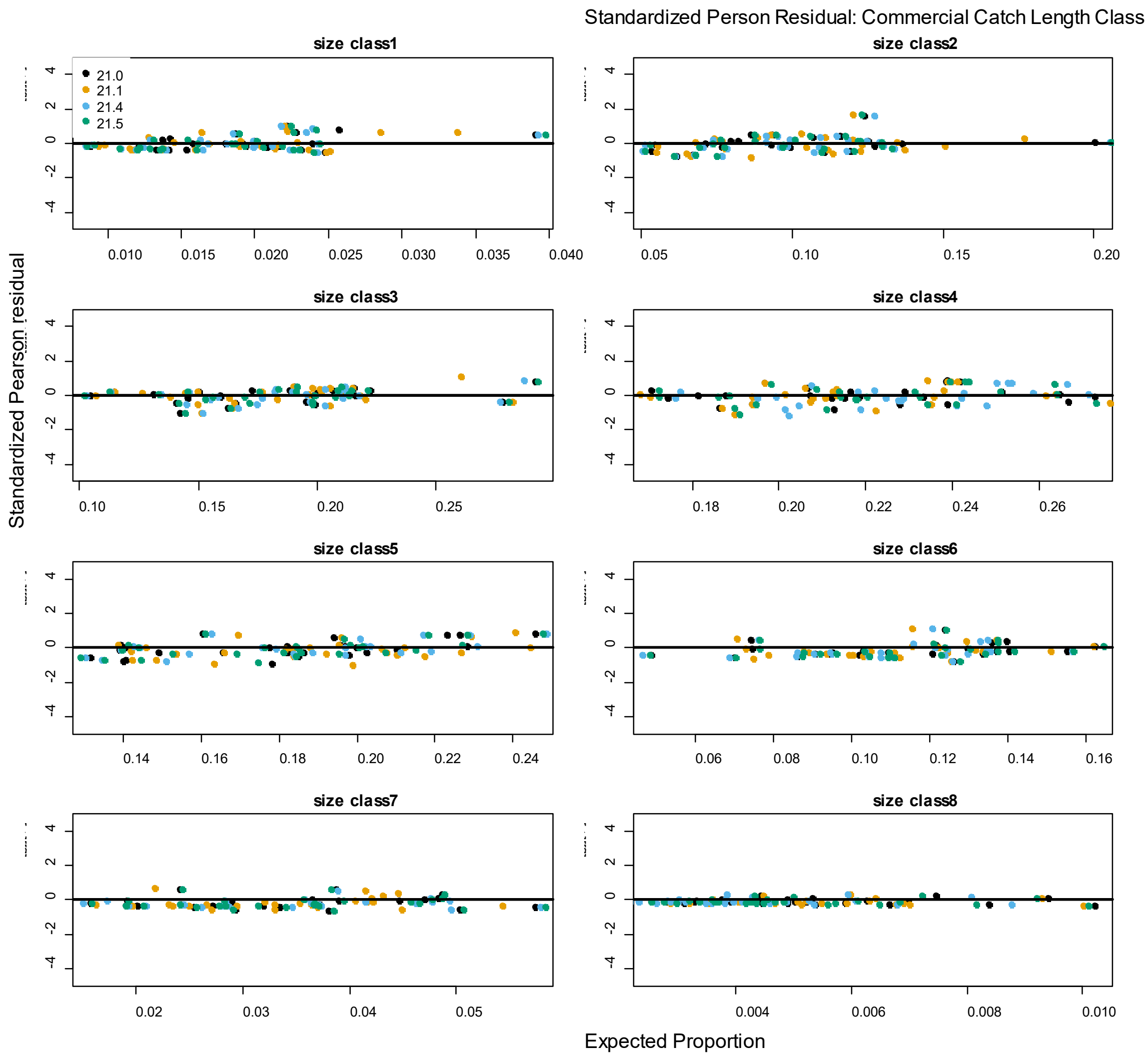
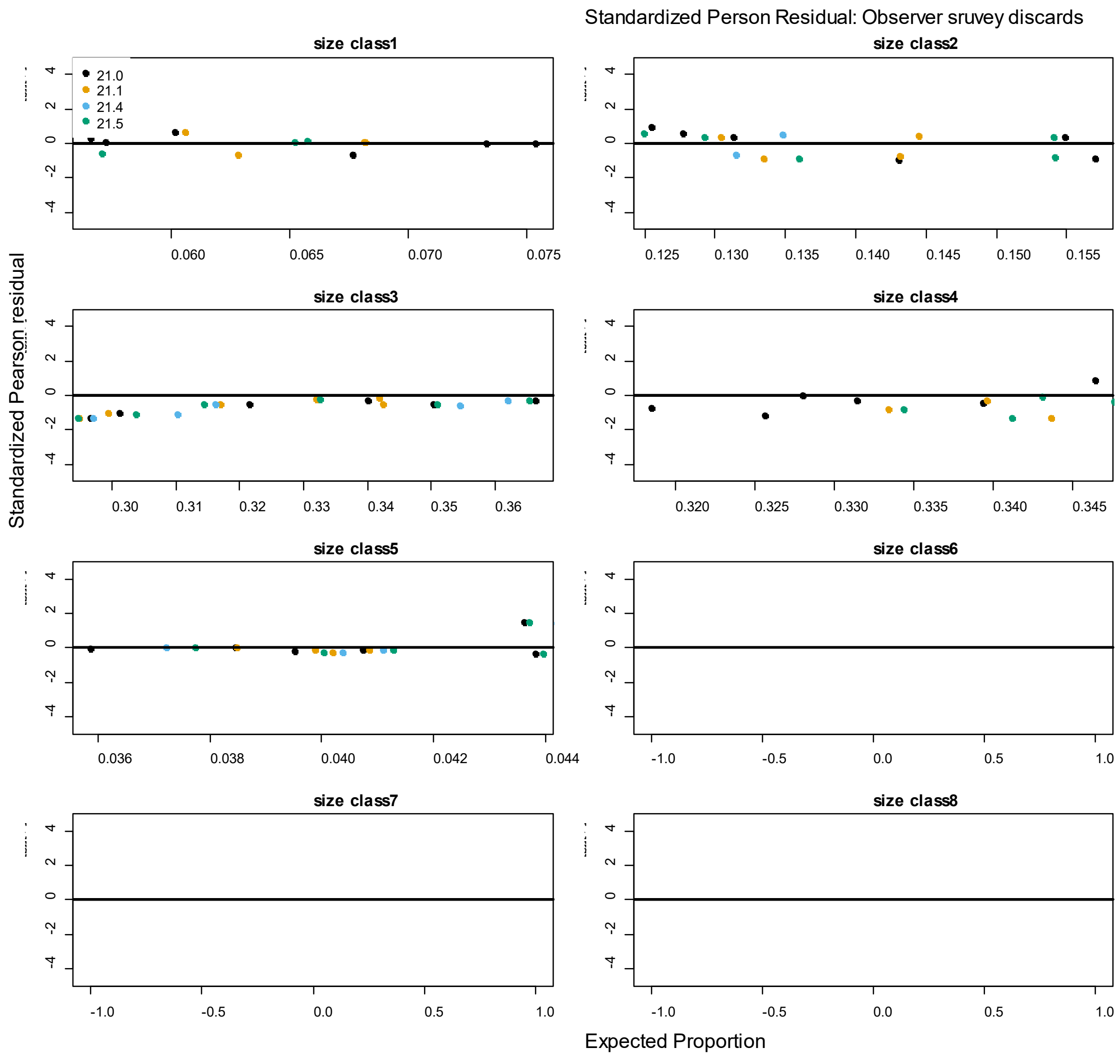

Winter Commercial Retain Model 21.0
Winter Commercial Retain Model 21.1
Winter Commercial Retain NA
Winter Commercial Retain NA
60
80
100
120
140
1980
1990
2000
2010
2020

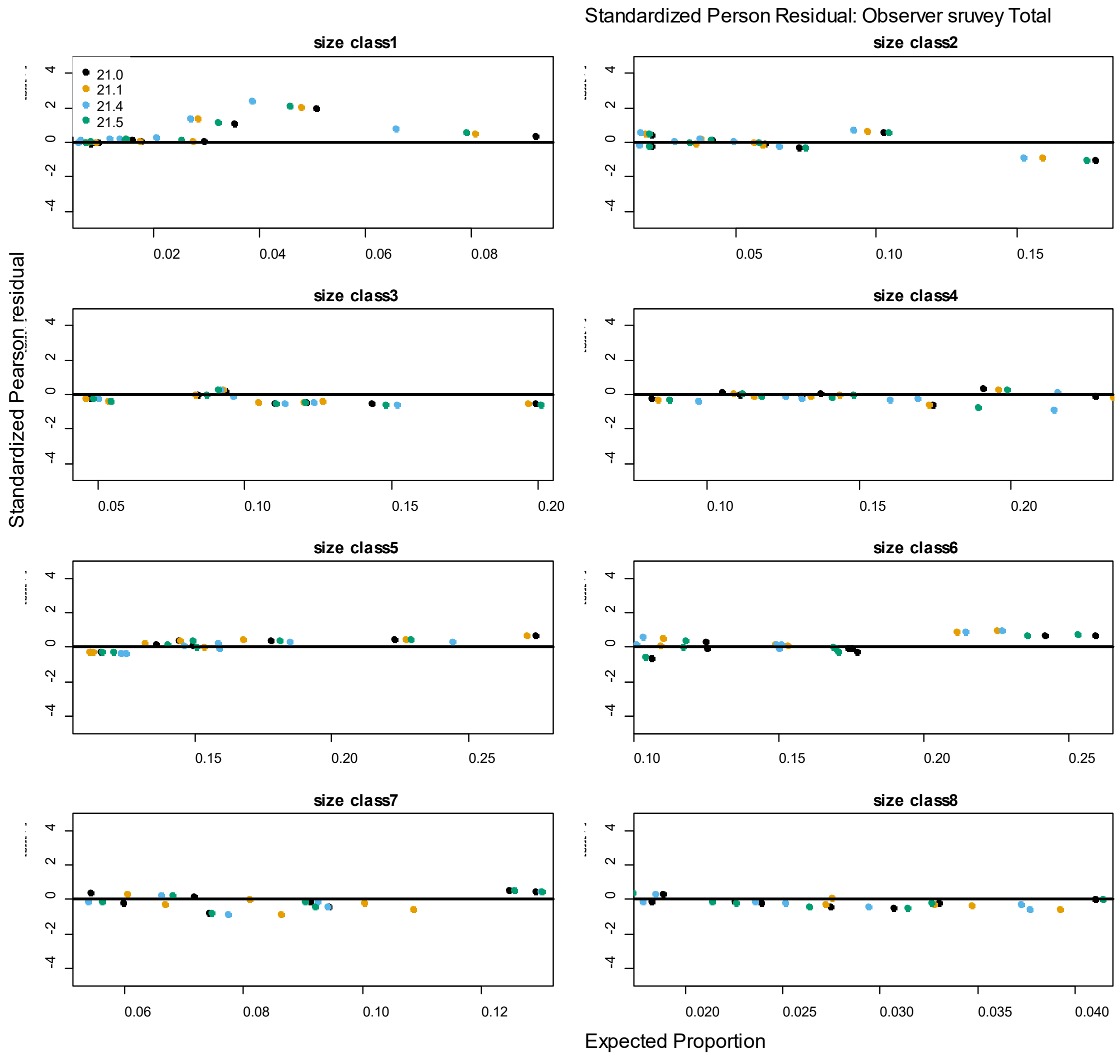
Figure 15. Standardized Pearson residual plot of trawl, summer commercial retain, winter survey, observer, length size classes 1-8.




Standardized Person Residual: Commercial Catch Length Class
size class1
size class2
size class3
size class4
size class5
size class6
size class7
size class8
21.0
21.1
21.4
21.5
Expected Proportion


Standardized Person Residual: Commercial Catch Length Class
Standardized Pearson residual
Expected Proportion
size class1
size class2
size class3
size class4
size class5
size class6
size class7
size class8
21.0
21.1
21.4
21.5


Standardized Person Residual: Observer sruvey discards
size class1
21.0
21.1
21.4
21.5
size class2
size class3
size class4
size class5
size class6
size class7
size class8
Standardized Pearson residual
Expected Proportion


Standardized Person Residual: Observer sruvey Total
size class1
size class2
size class3
size class4
size class5
size class6
size class7
size class8
21.0
21.1
21.4
21.5
Standardized Pearson residual
Expected Proportion

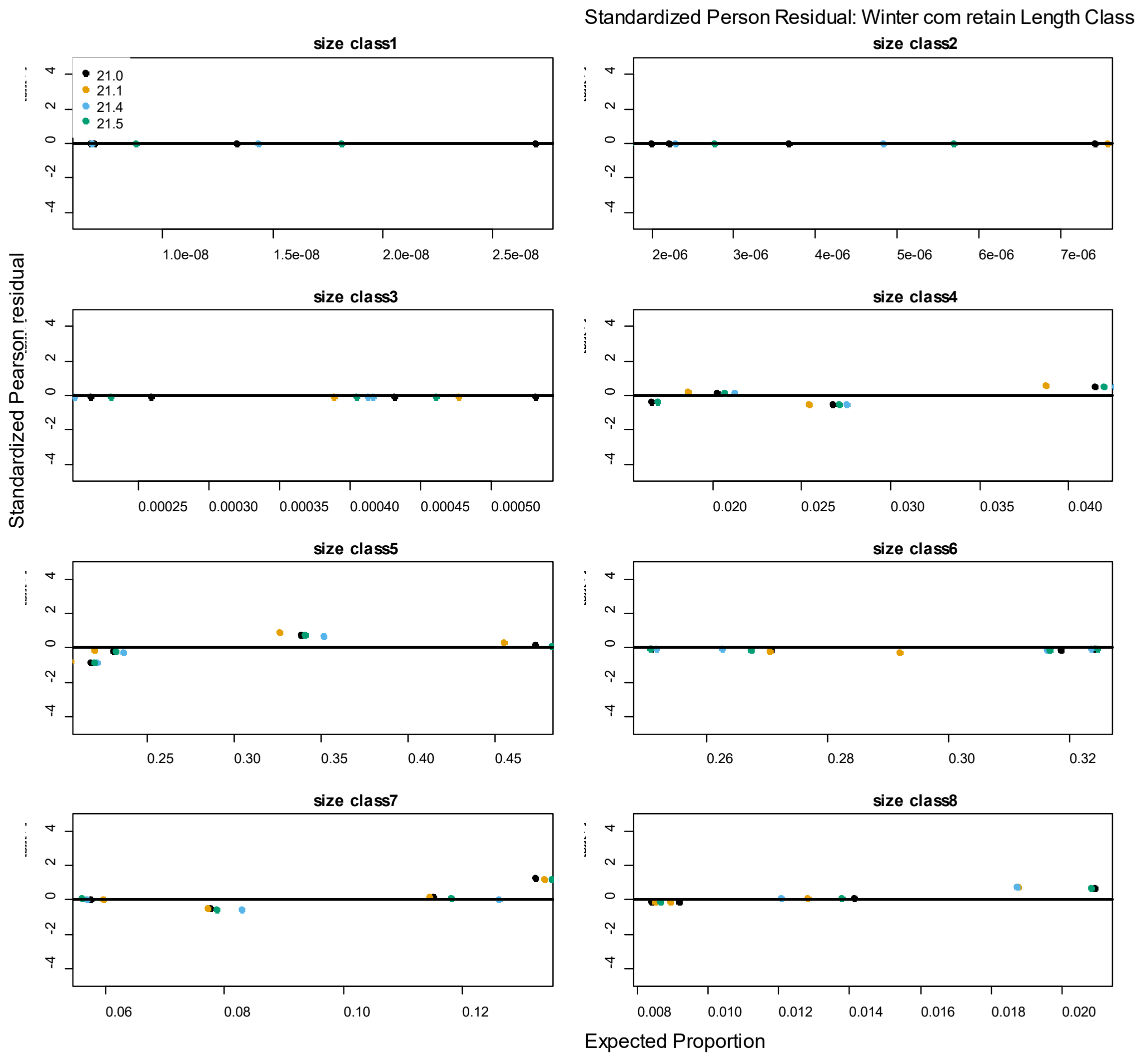
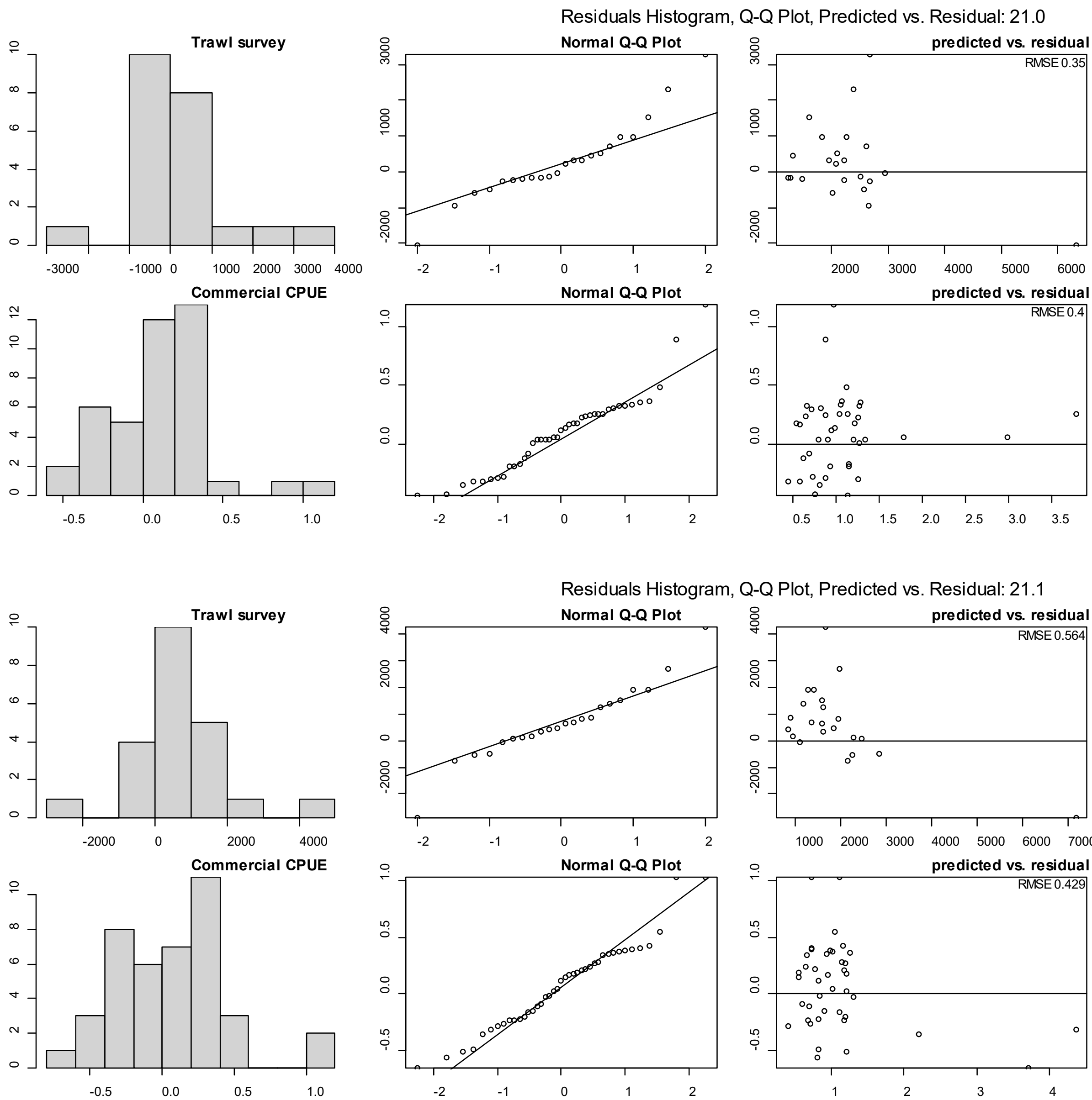
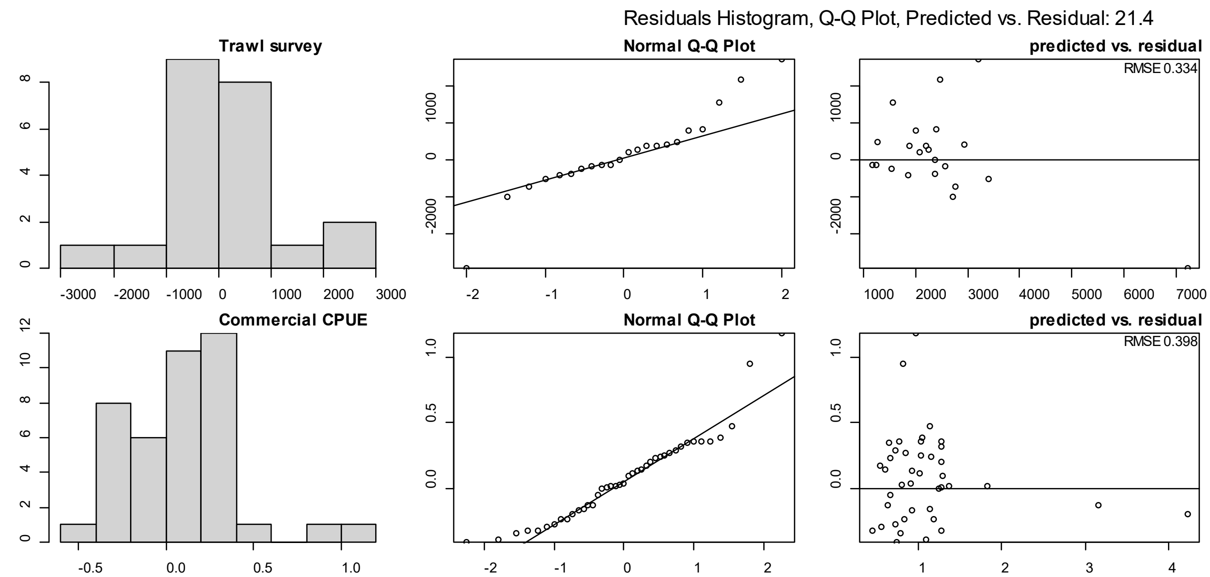

Standardized Person Residual: Winter com retain Length Class
size class1
size class2
size class3
size class4
size class5
size class6
size class7
size class8
21.0
21.1
21.4
21.5
Standardized Pearson residual
Expected Proportion

Figure 16. QQ Plot of Trawl survey and Commercial CPUE.




Residuals Histogram, Q-Q Plot, Predicted vs. Residual: 21.4
Trawl survey
Normal Q-Q Plot
predicted vs. residual
RMSE 0.334
Commercial CPUE
Normal Q-Q Plot
predicted vs. residual
RMSE 0.398

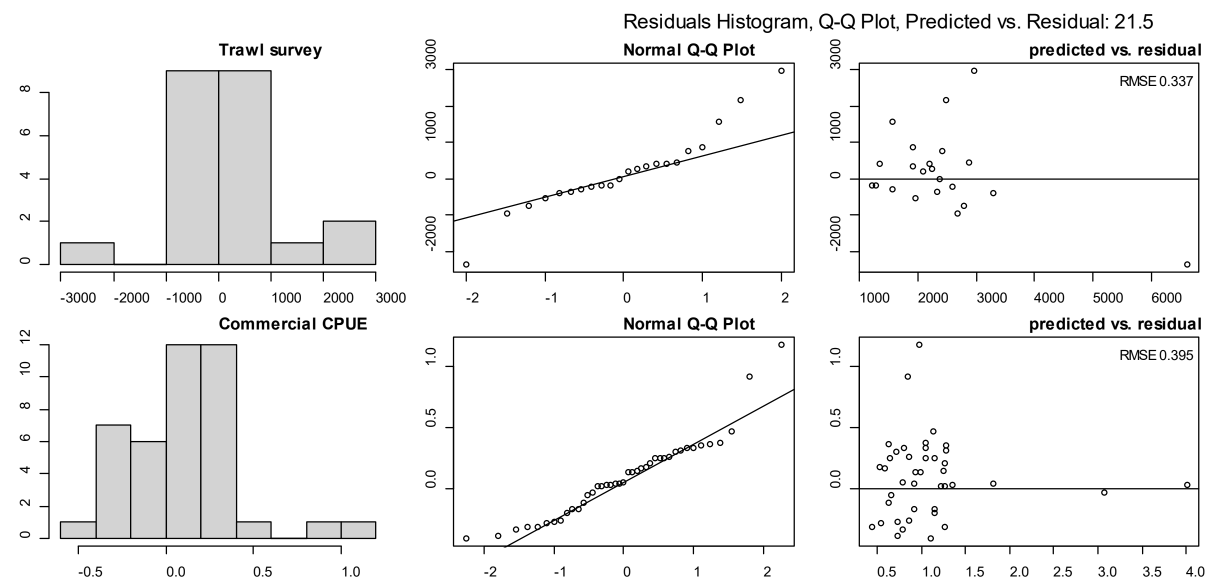
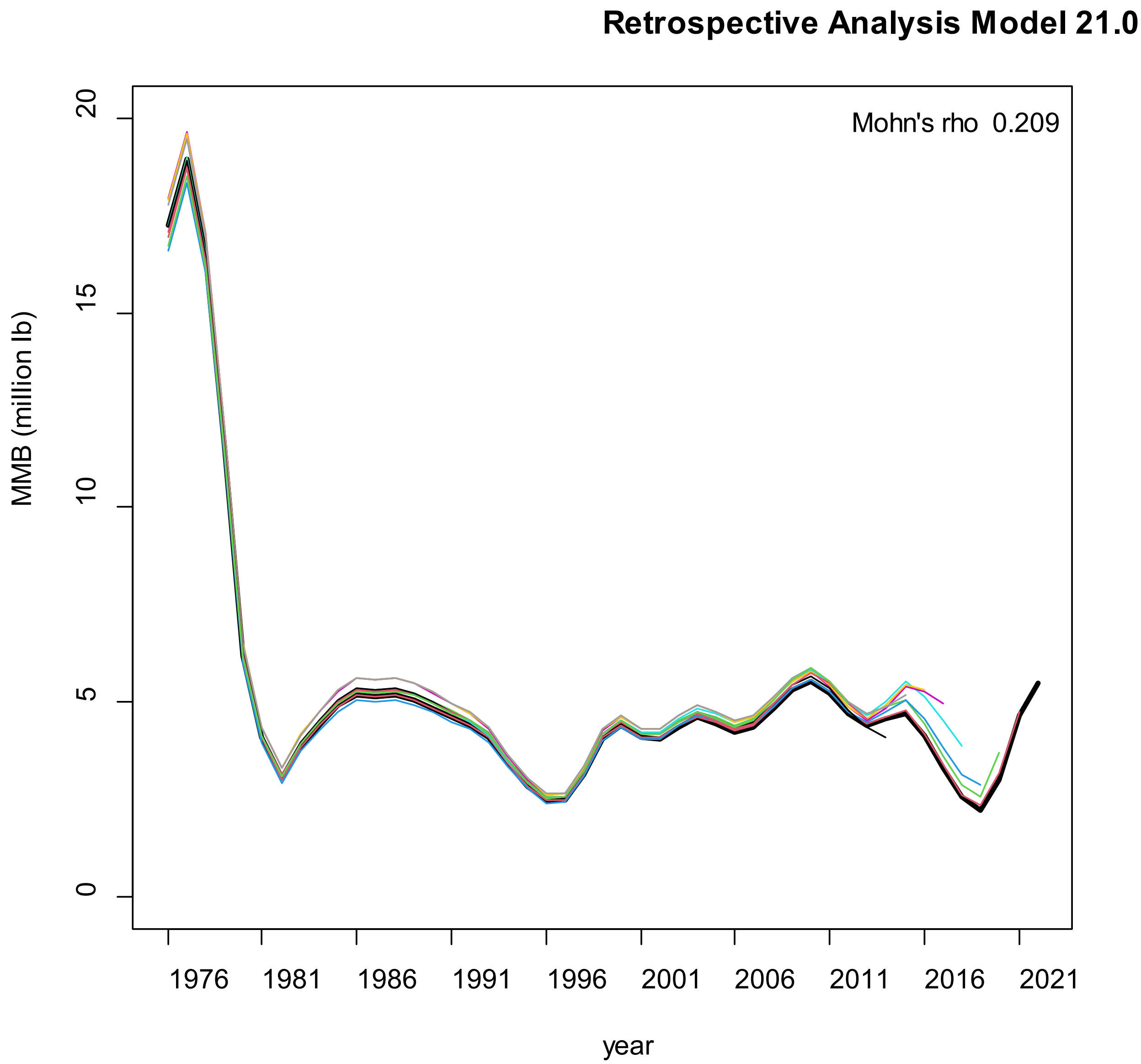
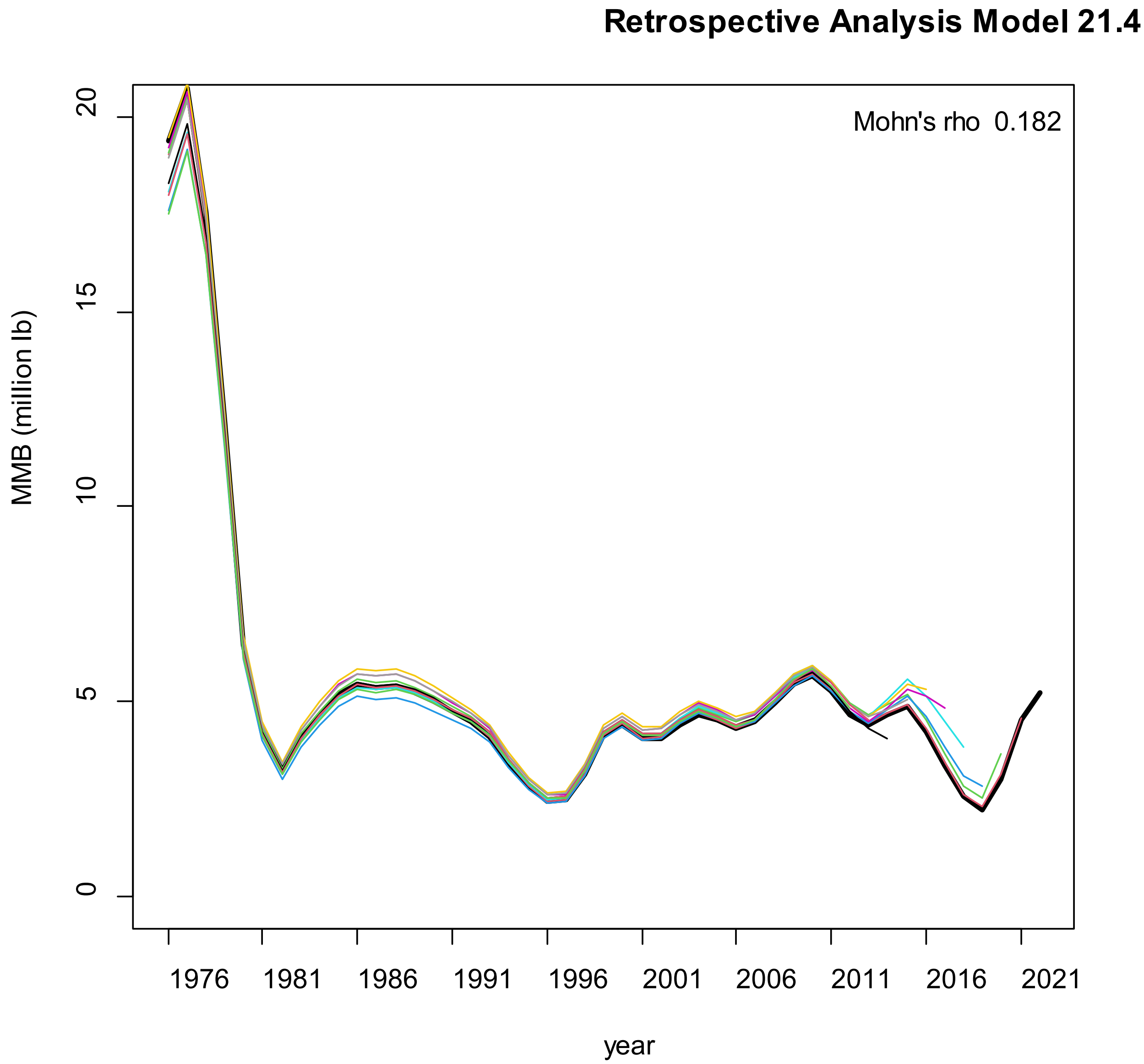
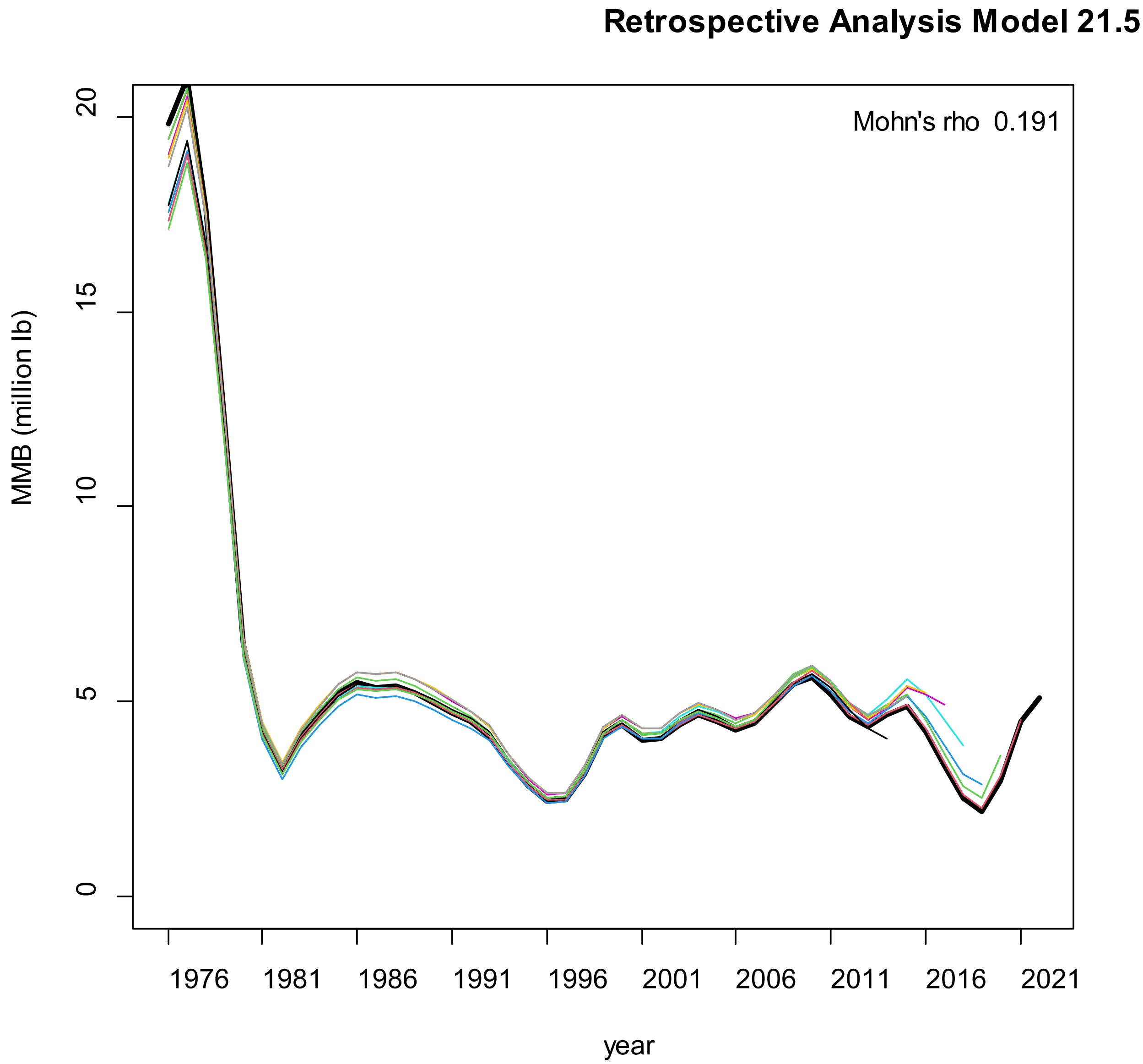

Residuals Histogram, Q-Q Plot, Predicted vs. Residual: 21.5
Trawl survey
Normal Q-Q Plot
predicted vs. residual
RMSE 0.337
Commercial CPUE
Normal Q-Q Plot
predicted vs. residual
RMSE 0.395

Figure 17. Retrospective Analyses of Norton Sound Red King Crab MMB from 2011 to 2022. Solid black line: 2022 assessment model results.




Retrospective Analysis Model 21.4
Mohn's rho 0.182
MMB (million lb)
0
5
10
15
20
1976
1981
1986
1991
1996
2001
2006
2011
2016
2021
year


Retrospective Analysis Model 21.5
Mohn's rho 0.191
MMB (million lb)
0
5
10
15
20
1976
1981
1986
1991
1996
2001
2006
2011
2016
2021
year