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

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Executive Summary

1. Stock. Red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska.

2. Catches. This stock supports three important fisheries: summer commercial, winter commercial, and winter subsistence fisheries. Of those, the summer commercial fishery accounts for 85% of total harvest. The summer commercial fishery started in 1977. Catch peaked in the late 1970s with retained catch of over 2.9 million pounds. Since 1994, the Norton Sound Crab fishery operated as super exclusive. For the 2019 fishery season, Norton Sound Red King Crab harvest consisted of 1,050 crab (3,295 lb.) by winter commercial, 1,545 crab (3,100 lb) by winter subsistence, and 24,506 crab (75,023 lb) by summer commercial, totaling 27,099 crab (81,418 lb). Total harvests were below ABC of 0.19 million lb. The harvest decline was due to 1) late ice buildup preventing winter fisheries and 2) low catch CPUE and declined summer commercial fishery participation.

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

4. Recruitment. Model estimated recruitment was weak during the late 1970s and high during the early 1980s, with a slightly downward trend from 1983 to 1993. Estimated recruitment has been highly variable but on an increasing trend in recent years.

5. Management performance.

Status and catch specifications (million lb.)

Year	MSST	Biomass (MMB)	GHL	Retained Commercial Catch	Total Retained Catch	Retained OFL	Retained ABC
2016	2.26[A]	5.87	0.52	0.51	0.52	0.71[A]	0.57
2017	2.31[B]	5.14	0.50	0.49	0.50	0.67[B]	0.54
2018	2.41[C]	4.08	0.30	0.31	0.34	0.43[C]	0.35
2019	2.24[D]	3.12	0.15	0.08	0.08	0.24[D]	0.19
2020	2.28[E]	3.67	TBD	TBD	TBD	0.29[E]	0.22

Status and catch specifications (1000t)

Year	MSST	Biomass (MMB)	GHL	Retained Commercial Catch	Total Retained Catch	Retained OFL	Retained ABC
2016	1.03[A]	2.66	0.24	0.23	0.24	0.32[A]	0.26
2017	1.05[B]	2.33	0.23	0.22	0.24	0.30[B]	0.24
2018	1.09[C]	1.85	0.13	0.14	0.15	0.20[C]	0.16
2019	1.03[D]	1.41	0.07	0.04	0.04	0.11[D]	0.09
2020	1.04[E]	1.66	TBD	TBD	TBD	0.13[E]	0.10

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

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

Biomass in millions of pounds

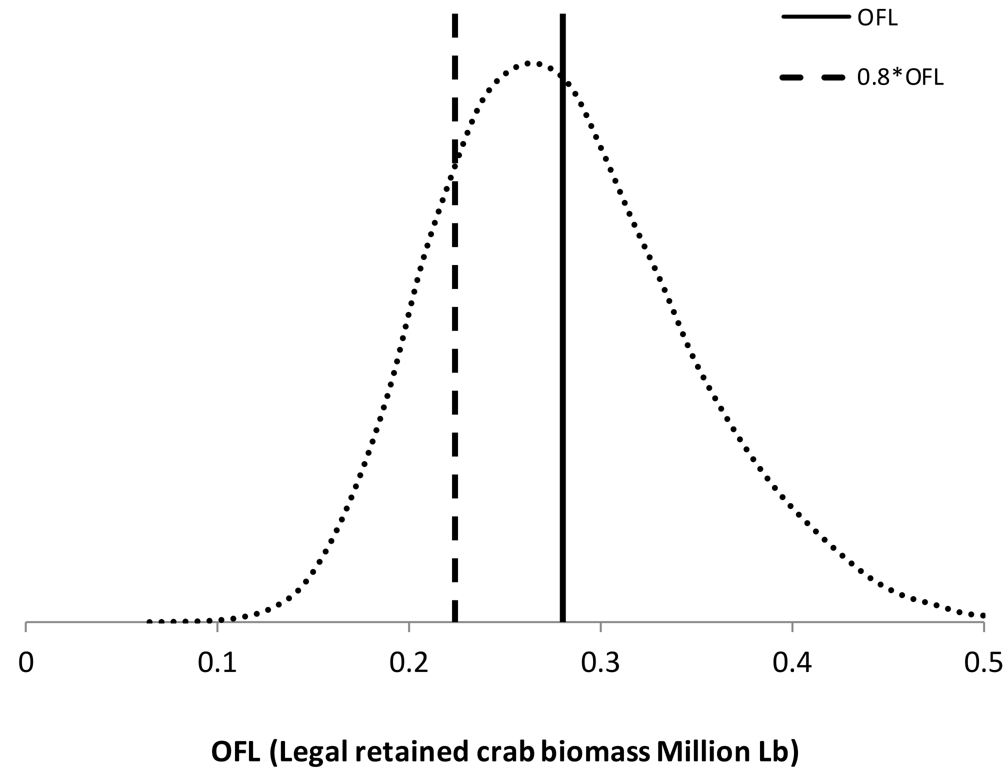
Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	Retained ABC
2016	4a	4.53	5.87	1.3	0.18	1980-2016	0.18	0.8	0.57
2017	4a	4.62	5.14	1.1	0.18	1980-2017	0.18	0.8	0.54
2018	4b	4.82	4.08	0.9	0.15	1980-2018	0.18	0.8	0.35
2019	4b	4.57	3.12	0.7	0.12	1980-2019	0.18	0.8	0.19
2020	4b	4.56	3.66	0.8	0.14	1980-2020	0.18	0.75	0.22

Biomass in 1000t

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define	M	1-Buffer	Retained ABC

						B_{MSY}			
2016	4a	2.06	2.66	1.3	0.18	1980-2016	0.18	0.8	0.26
2017	4a	2.10	2.33	1.1	0.18	1980-2017	0.18	0.8	0.24
2018	4b	2.07	1.85	0.9	0.15	1980-2018	0.18	0.8	0.16
2019	4b	2.06	1.41	0.7	0.12	1980-2019	0.18	0.8	0.09
2020	4b	2.07	1.66	0.8	0.14	1980-2020	0.18	0.75	0.10

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



7. The basis for the ABC recommendation

   For Tier 4 stocks, the default maximum ABC is based on P*=49% that is essentially identical to the OFL. Accounting for uncertainties in assessment and model results, the SSC chose to use 90% OFL (10% Buffer) for the Norton Sound red king crab stock from 2011 to 2014. In 2015, the buffer was increased to 20% (ABC = 80% OFL). In 2020, the buffer was increased to 25% (ABC = 75% OFL) over concern for low CPUE of 2018-2019.

8. A summary of the results of any rebuilding analysis

   N/A

A. *Summary of Major Changes in 2019*

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

   None

2. Changes to the input data

   a. Data update:

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

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

      iii. Tag recovery data 2019 (14 crab).

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

      ADFG and NMFS 2019

3. Changes to the assessment methodology:

   None

4. Changes to the assessment results.

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

B. *Response to SSC and CPT Comments*

Crab Plan Team – January 23-25, 2019

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

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

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

  Authors' reply:

  Alternative model: 19.1

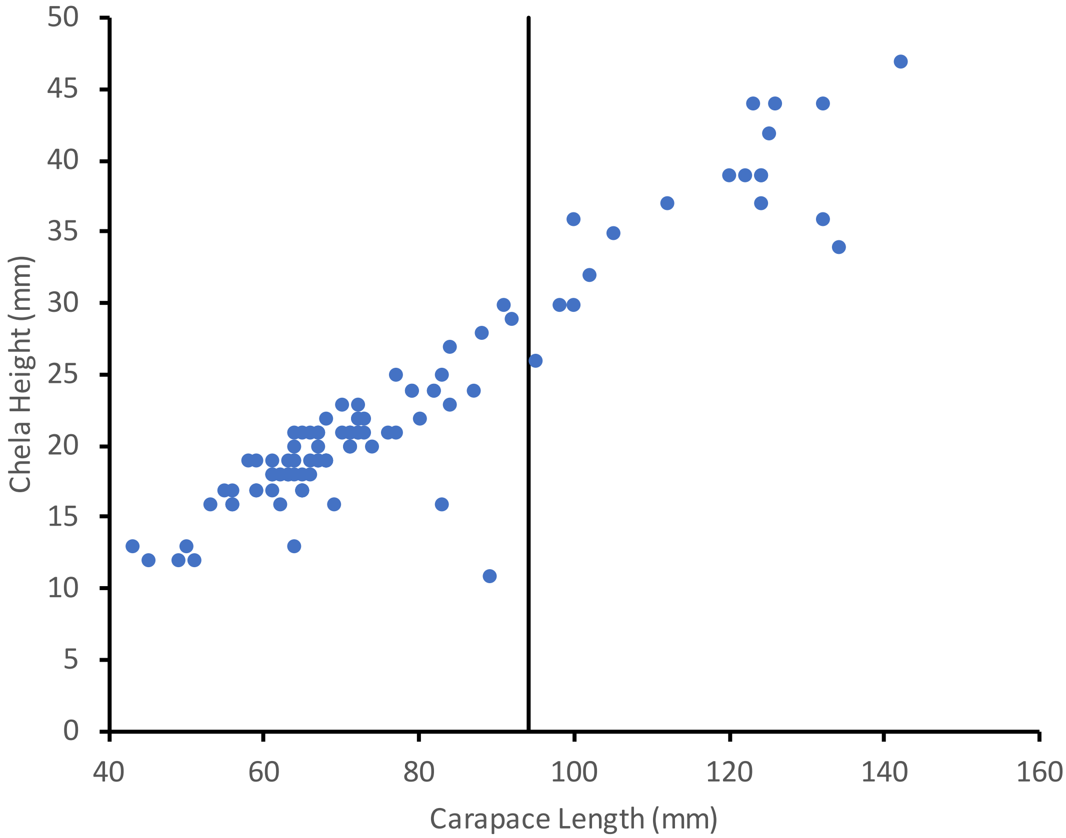
- Evaluate potential differences in survey Q between NOAA and ADFG bottom trawl surveys.

  Authors' reply: Alternative model 19.2 and 19.3

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

  Author's reply

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



SSC – February 4-6 2019

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

  Authors' reply:

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

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

  Authors' reply:

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

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

  Authors' reply: Alternative model 19.4 and 19.5

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

  Authors' reply: We believe that this task is more appropriate for NMFS.

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

  Author's reply:

  We are not familiar with those packages and spatial modeling, including intent of the comparison.

  It should also be noted that ADF&G and NMFS surveys are NOT "paired" (i.e., side-by-side survey). ADF&G and NMFS surveys differ in **survey protocols (e.g., tow distance), trawl gears, survey spatial extent and timing. Itis expected that the two surveys would differ in abundance and spatial distribution.** Changes of distribution and abundances between the two surveys may be due to different survey protocols, movement of crab.

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

  Author's reply:

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

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

  Author's reply:

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

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

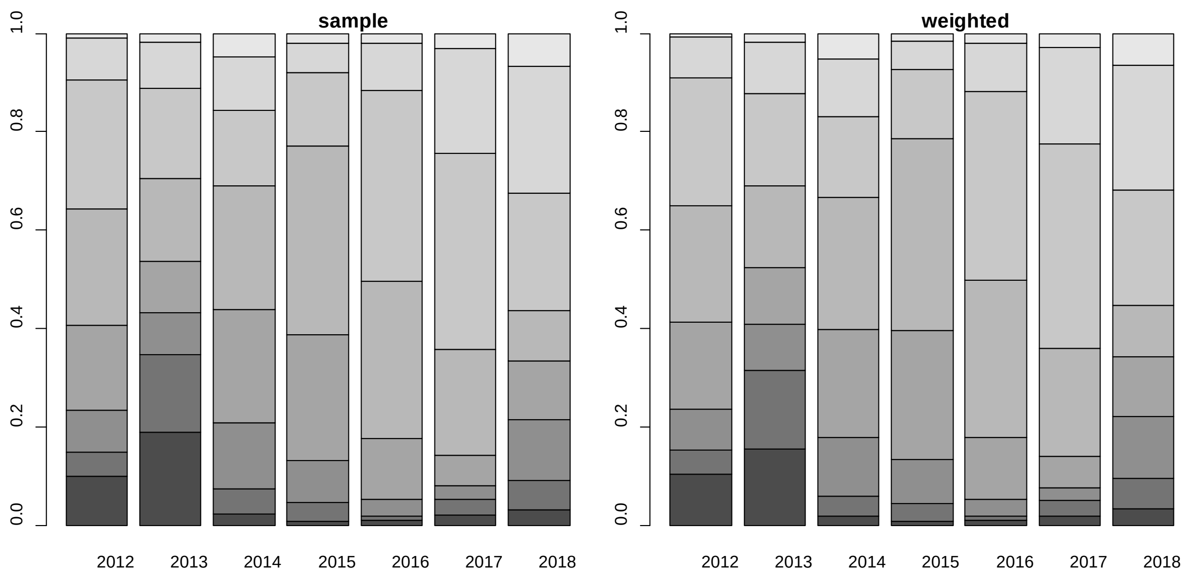
Authors' reply:

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

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

Authors' reply:

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



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

Authors' reply:

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

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

Authors' reply:

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

- Use revised Mohn's rho.

  Authors' reply:

  It was implemented for the final assessment. However, more fundamental note, CPT-SSC has not established standardized criterion for Mohn's rho (e.g., min-max rho value) for selection of the best alternative model, or an adjustment of predicted biomass or determination of OFL/ABC buffer (i.e., what to do when the Mohn's rho of the adopted model exceeded criteria?) The calculated Mohn.Rho of the CPT/SSC recommended model (19.0) based on retrospective analyses of past 4 years was 0.258. This exceeded, guideline range provided by Hurtado-Ferro et al. (2015), of -0.15 to 0.2 for longer lived and -0.22 to 0.30 for shorter lived species. If this is deemed concern, then the model may be rejected or other **Authors appreciate SSC's directive for potential application of revised Mohn's rho for improvement of the NSRKC assessment model.**

- Parameters r_1 and log-phi_{st1} hitting bounds.

  Authors' reply:

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

Crab Plan Team – April 29, 2019

- Draft assessment in GMACS will potentially be provided in September 2019.
  Authors' reply:

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

Crab Plan Team – Sept 16-20, 2019

SSC – Sept 30-Oct 2, 2019

- No additional requests.

C. Introduction

1. Species: red king crab (*Paralithodes camtschaticus*) in Norton Sound, Alaska.
2. General Distribution: Norton Sound red king crab is one of the northernmost red king crab populations that can support a commercial fishery (Powell et al. 1983). It is distributed throughout Norton Sound with a westward limit of 167-168^{o} W. longitude, depths less than 30 m, and summer bottom temperatures above 4^{o}C. The Norton Sound red king crab management area consists of two units: Norton Sound Section (Q3) and Kotzebue Section (Q4) (Menard et

al. 2011). The Norton Sound Section (Q3) consists of all waters in Registration Area Q north of the latitude of Cape Romanzof, east of the International Dateline, and south of 66°N latitude (Figure 1). The Kotzebue Section (Q4) lies immediately north of the Norton Sound Section and includes Kotzebue Sound. Commercial fisheries have not occurred regularly in the Kotzebue Section. This report deals with the Norton Sound Section of the Norton Sound red king crab management area.

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

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

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

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

   <u>Summer Commercial Fishery</u>

   A large-vessel summer commercial crab fishery started in 1977 in the Norton Sound Section (Table 1) and continued from 1977 through 1990. No summer commercial fishery occurred in 1991 because there were no staff to manage the fishery. In March 1993, the Alaska Board of Fisheries (BOF) limited participation in the fishery to small boats. Then on June 27, 1994, a super-exclusive designation went into effect for the fishery. This designation stated that a vessel registered for the Norton Sound crab fishery may not be used to take king crabs in any other registration areas during that registration year. A vessel moratorium was put into place before the 1996 season. This was intended to precede a license limitation program. In 1998, Community Development Quota (CDQ) groups were allocated a portion of the summer harvest; however, no CDQ harvest occurred until the 2000 season. On January 1, 2000 the North Pacific License Limitation Program (LLP) went into effect for the Norton Sound crab fishery. The program dictates that a vessel which exceeds 32 feet in length overall must hold a valid crab license issued under the LLP by the National Marine Fisheries Service. Changes in regulations and the location of buyers resulted in eastward movement of the harvest distribution in Norton Sound in the mid-1990s. In Norton Sound, a legal crab is defined as ≥ 4-3/4 inch carapace width (CW, Menard et al. 2011), which is approximately equivalent to ≥ 104 mm carapace length mm CL. Since 2005, commercial buyers (Norton Sound Economic Development Corporation) started accepting only legal crab of ≥ 5 inch CW. This may have increased discards; however, because discards have not been monitored until 2012, impact of this change on discards is unknown. This issue was also examined in assessment model selection, which showed no difference in estimates of selectivity functions before and after 2005 (NPFMC 2016).

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

CDQ Fishery

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

Winter Commercial Fishery

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

Subsistence Fishery

While the winter subsistence fishery has a long history, harvest information is available only since the 1977/78 season. The majority of the subsistence crab fishery harvest occurs using hand lines and pots through nearshore ice. Average annual winter subsistence harvest was 5,400 crab (1977-2010). Subsistence harvesters need to obtain a permit before fishing and record daily effort and catch. There are no size or sex specific harvest limits; however, the majority of retained catches are males of near legal size.

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

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

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

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

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

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

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

Year	Notable historical management changes
1976	The abundance survey started
1977	**Large vessel commercial fisheries began (Legal size ≥ 5 inch CW)**
1978	**Legal size changes to ≥ 4.75 inch CW**
1991	Fishery closed due to staff constraints
1994	Super exclusive designation went into effect. The end of large vessel commercial fishery operation.
1998	Community Development Quota (CDQ) allocation went into effect
1999	Guideline Harvest Level (GHL) went into effect
2000	North Pacific License Limitation Program (LLP) went into effect.
2002	Change in closed water boundaries (Figure 2)
2005	**Commercially accepted legal crab size changed from ≥ 5 inch CW**
2006	The Statistical area Q3 section expanded (Figure 1)
2008	Start date of the open access fishery changed from July 1 to after June 15 by emergency order. **Pot configuration requirement: at least 4 escape rings (>4.5 inch diameter) per pot located within one mesh of the bottom of the pot, or at least ½ of the vertical surface of a square pot or sloping side-wall surface of a conical or pyramid pot with mesh size > 6.5 inches.**
2012	The Board of Fisheries adopted a revised GHL for summer fishery.

2016	Winter GHL for commercial fisheries was established and modified winter fishing season dates were implemented.

7. Summary of the history of the $B_{MSY.}$

   NSRKC is a Tier 4 crab stock. Direct estimation of the B_{MSY} is not possible. The B_{MSY} proxy is calculated as mean model estimated mature male biomass (MMB) from 1980 to present. Choice of this period was based on a hypothesized shift in stock productivity a due to a climatic regime shift indexed by the Pacific Decadal Oscillation (PDO) in 1976-77. Stock status of the NSRKC was Tier 4a until 2013. In 2014 the stock fell to Tier 4b, but came back to Tier 4a for the 2015-2017 seasons. Since 2018 the stock has been under Tier 4b status.

D. Data

1. Summary of new information:

   Winter commercial and subsistence fisheries:

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

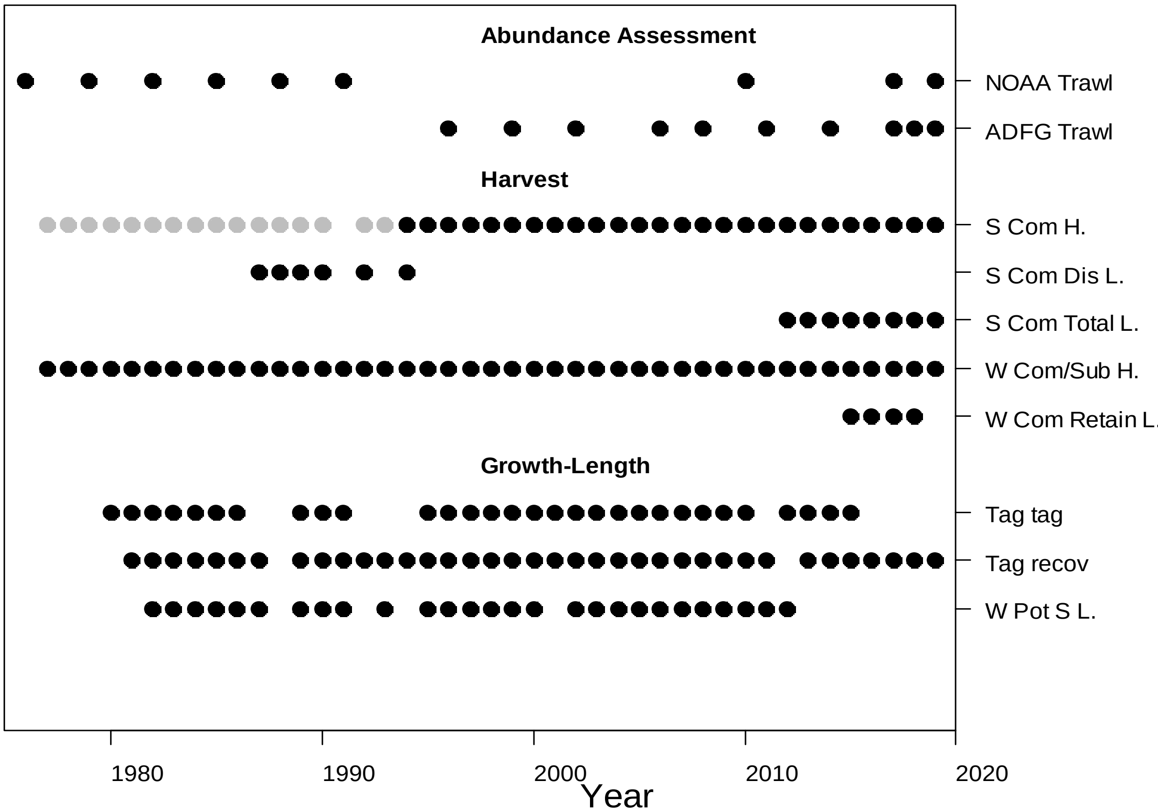
   Summer commercial fishery:

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

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

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

2. Available survey, catch, and tagging data



	Years	Data Types	Tables
Summer trawl survey	76,79,82,85,88,91,96, 99, 02,06,08,10,11,14,17, 18,19	Abundance Length-shell comp	3 6
Winter pot survey	81-87, 89-91,93,95-00,02-12	Length-shell comp	7
Summer commercial fishery	77-90,92-19	Retained catch Standardized CPUE, Length-shell comp	1 1 4
Summer Com total catch	12-19	Length-shell comp	9
Summer Com Discards	87-90,92,94	Length-shell comp	8
Winter subsistence fishery	76-19	Total & Retained catch	2
Winter commercial fishery	78-19	Retained catch	2
	15-18	Retained Length-Shell	5
Tag recovery	80-19	Recovered tagged crab	10

Data available but not used for assessment

Data	Years	Data Types	Reason for not used
Summer pot survey	80-82,85	Abundance Length proportion	Uncertainties on how estimates were made.
Summer preseason survey	95	Length proportion	Just one year of data
Summer subsistence fishery	2005-2013	retained catch	Too few catches compared to commercial
Winter Pot survey	87, 89-91,93,95-00,02-12	CPUE	CPUE data Not reliable due to ice conditions
Preseason Spring pot survey	2011-15	CPUE, Length proportion	Years of data too short
Postseason Fall pot survey	2013-15	CPUE, Length proportion	Years of data too short

Catches in other fisheries

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

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

3. Other miscellaneous data:

   Satellite tag migration tracking (NOAA 2016)

   Spring offshore migration distance and direction (2012-2015)

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

Data aggregated:

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

Data estimated outside the model:

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

E. Analytic Approach

1. History of the modeling approach.

The Norton Sound red king crab stock was assessed using a length-based synthesis model (Zheng et al. 1998). Since adoption of the model, the major challenge is a conflict between model projection and data, specifically the model projects higher abundance-proportion of large size class (> 123mm CL) of crab than observed. This problem was further exasperated when natural mortality *M* was set to 0.18 from previous *M* = 0.3 in 2011 (NPFMC 2011). This issue has been resolved by assuming (3-4 times) higher *M* for the length crabs (i.e., *M* = 0.18 for length classes ≤ 123mm, and higher M for > 123mm) (NPFMC 2012, 2013, 2014, 2015, 2016, 2017, 2018). Alternative assumptions have been explored, such as changing molting probability (i.e., crab matured quicker or delayed maturation), higher natural mortality, and dorm shaped selectivity (i.e., large crab are not caught, or moved out of fishery/survey grounds). However, those alternative assumptions did not produce better model fits. Model estimated length specific molting probability was similar to inverse logistic curve, and did not improve model fit (NPFMC 2016). Constant *M* across all length classes resulted in higher *M* (0.3-0.45) (NPFMC 2013, 2017). Dome shaped selectivity (i.e., assume large crab were not caught/not surveyed/moved out of survey and fishing area) increased MMB twice higher than other models. A model with gradual increase of *M* across length classes resulted in *M* increase staring at size 94mm. However, this did not improve overall model fit and was rejected for model consideration (NPFMC 2018). With addition of total catch length data in summer and retention length data in winter commercial fisheries, 2019 model specification examined estimation of retention curve for both summer and winter fishery, and evaluation of OFL under Tier 3 formula.

Historical Model configuration progression:

2011 (NPFMC 2011)
1). *M* =0.18.
2). *M* of the last length class = 0.288.
3). Include summer commercial discards mortality = 0.2.
4). Weight of fishing effort = 20.
5). The maximum effective sample size for commercial catch and winter surveys = 100.

2012 (NPFMC 2012)
1) *M* of the last length class = 3.6×*M*.
2) The maximum effective sample size for commercial catch and winter surveys = 50.
3) Weight of fishing effort = 50.

2013 (NPFMC 2013)
1) Standardize commercial catch cpue and replace likelihood of commercial catch efforts to standardized commercial catch cpue with weight = 1.0.
2) Eliminate summer pot survey data from likelihood.
3) Estimate survey *q* of 1976-1991 NMFS survey with maximum of 1.0.
4) The maximum effective sample size for commercial catch and winter surveys = 20

2014 (NPFMC 2014)
1) Modify functional form of selectivity and molting probability to improve parameter estimates (2 parameter logistic to 1 parameter logistic).
2) Include additional variance for the standardized cpue.
3) Include winter pot survey cpue (But was removed from the final model due to lack of fit).
4) Estimate growth transition matrix from tagged recovery data.

2015 (NPFMC 2015)
1) Winter pot survey selectivity is an inverse logistic, estimating selectivity of the smallest length group independently.

2) Reduce Weight of tag-recovery: W = 0.5.
3) Model parsimony: one trawl survey selectivity and one commercial pot selectivity.

2016 (NPFMC 2016)
1) Length range extended from 74mm – 124mm above to 64mm – 134mm above.
2) Estimate multiplier for the largest (> 123mm) length classes.

2017 (NPFMC 2017)
1) Change molting probability function from 1 to 2 parameter logistic. Assume molting probability not reaching 1 for the smallest length class.

2018 No model change requests
2019 (NPFMC 2019)
1) Fit total catch length composition and estimate retention probability for summer and winter commercial fishery.
2) Include winter commercial retained length data.

2. Model Description

a. Description of overall modeling approach:

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

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

b-f. See Appendix A.

g. Critical assumptions of the model:

i. Male crab mature at CL length 94mm.

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

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

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

iv. Trawl survey selectivity is a logistic function with 1.0 for length classes 7-8. Selectivity is constant over time.

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

This assumption is based on the fact that a low proportion of large crab are caught in the nearshore area where winter surveys occur. Causes of this pattern may be that (1) fewer large crab migrate into nearshore waters in winter or (2) large crab are fished out by winter fisheries where the survey occurs (i.e., local depletion). Recent studies suggest that the first explanation is more likely than the second (Jenefer Bell, ADFG, personal communication).

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

vii. Summer trawl survey selectivity is an asymptotic logistic function of 1.0 at the length of CL 134mm. While the survey changed greatly between NOAA (1976-1991) and ADF&G (1996-present) in terms of survey vessel and trawl net structure, selectivity of both periods was assumed to be identical. Model fits separating and combining the two surveys were examined in 2015. No differences between the two models were observed (NPFMC 2015) and for model parsimony the two were combined.

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

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

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

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

xii. A summer fishing season for the directed fishery is short. All summer commercial harvests occur at the day when 50% of harvest occurred.

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

xiv. Annual retained catch is measured without error.

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

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

h. Changes of assumptions since last assessment:

None.

3. Model Selection and Evaluation

a. Description of alternative model configurations.

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

In September 2019 draft assessment, we examined alternative models of
Model 19.0: Baseline: Model 18.2b

Model 19.1: Model 19.0 + Tag recovery data just for 1 year

Model 19.2: Model 19.0 + NOAA trawl survey Q =1.0, Est: ADFG survey Q

Model 19.3: Model 19.0 + Est survey Qs NOAA and ADFG

Model 19.4: Model 19.0 + Est *M* equal for all lengths + Dome shape selectivity for trawl and summer commercial (max sel 94-103 for trawl, 104-113 for com)

Model 19.5: Model 19.0 + Est *M* equal for all lengths + Dome shape selectivity for trawl and summer commercial (max sel 104-113 for trawl, 114-123 for com)

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

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

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

TSA: Trawl Survey Abundance
St. CPUE: Summer commercial catch standardized CPUE
TLP: Trawl survey length composition:
WLP: Winter pot survey length composition
CLP: Summer commercial retention catch length composition
REC: Recruitment deviation
OBS: Summer commercial catch observer discards (Baseline) or total catch (Alternative models) length composition
TAG: Tagging recovery data composition
WN: Winter Commercial length-shell composition

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

Search for balance:

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

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

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

4. **Results**

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

"Implied" effective sample sizes were calculated as

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

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

Maximum sample sizes for length proportions:

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

Weighting factor:

Recruitment SD: 0.5.

2. Tables of estimates.
   a. Model parameter estimates (Tables 11, 12).
   b. Abundance and biomass time series (Table 13).
   c. Recruitment time series (Table 13).
   d. Time series of catch/biomass (Tables 14).
3. Graphs of estimates.
   a. Molting probability and trawl/pot selectivity (Figure 3).
   b. Estimated male abundances (recruits, legal, and total) (Figure 4).

c. Estimated mature male biomass (Figure 5).

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

4. Evaluation of the fit to the data.

a. Fits to observed and model predicted catches.

Not applicable. Catch is assumed to be measured without error.

b. Model fits to survey numbers.

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

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

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

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

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

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

5. Retrospective analyses (Figure 18).

Retrospective analyses was limited to past 4 years because winter commercial length data that was used to estimate retention curve was limited to 4 years of data.

Year	Predicted MMB (x1000)	Hindcast MMB	Mohn.Rho
2019	3038.92	2826.42	0.2935
2018	3951.35	3190.10	0.4161
2017	5662.02	4762.69	0.2386
2016	6160.35	5164.06	0.0822

Revised Mohn.Rho 0.258

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

6. Uncertainty and sensitivity analyses.

F. Calculation of the OFL

1. Specification of the Tier level and stock status.

The Norton Sound red king crab stock is placed in Tier 4. It is not possible to estimate the spawner-recruit relationship, but some abundance and harvest estimates are available to build a computer simulation model that captures the essential population dynamics. Tier 4 stocks are assumed to have reliable estimates of current survey biomass and instantaneous M; however, the estimates for the Norton Sound red king crab stock are uncertain.

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

Level	Criteria	F_{OFL}
a	$B/B_{MSY^{prox}} > 1$	$F_{OFL} = \gamma M$
b	$\beta < B/B_{MSY^{prox}} \leq 1$	$F_{OFL} = \gamma M (B/B_{MSY^{prox}} - \alpha)/(1-\alpha)$
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 $\beta = 0.25$.

For Norton Sound red king crab, MMB is defined as the biomass of males > 94 mm CL on February 01 (Appendix A). B_{MSY} proxy is

B_{MSY} proxy = average model estimated MMB from 1980-2020.

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

Predicted mature male biomass in 2020 on February 01

Mature male biomass: 3.664 (SE 0.452) million lb. or 2.07 (SE 0.305) k ton

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

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

Where F_{OFL} is calculated by

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

F_{OFL} of 0.141 for all length classes.

1. Calculation of OFL.

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

Legal_B is a biomass of legal crab subject to fisheries and is calculated as: projected abundance by length crab × fishery selectivity by length class × proportion of legal crab per length class × average lb per length class.

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

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

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

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

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

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

Solving x of the above, a revised retained OFL is

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

Accounting for difference in length specific natural mortality

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

Unretained OFL (OFL_{ur}) is a sub-legal crab biomass catchable to the summer commercial pot fishery calculated as: projected legal abundance (Feb 1st) × commercial pot selectivity × proportion of sub-legal crab per length class × average lb per length class × handling mortality (hm =0.2)

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

The total male OFL is

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

For calculation of the OFL 2020, we specified p = 0.16.

Legal male biomass catchable to fishery (Feb 01): 2.428 (SE 0.30) million lb or 1.101 k ton
OFL_r = 0.287 million lb. or 0.104 k ton

G. *Calculation of the ABC*

1. Specification of the probability distribution of the OFL.

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

In 2015 of ABC buffer of Norton Sound Red King Crab was set to 20%, and ABC is calculated as (1-ABC buffer)·OFL

In 2020, CPT recommended the buffer to 25% due to declined CPUE.

Retained ABC for legal male crab is 75% of OFL

ABC = 0.215 million lb. or 0.098 k ton

H. *Rebuilding Analyses*

Not applicable

I. *Data Gaps and Research Priorities*

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

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Tables

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.

	Guideline Harvest	Commercial Harvest (lb) [a, b]			Total Number (Open Access)			Total Pots		ST CPUE		Season Length		Mid-day
Year	Level (lb) [b]	Open Access	CDQ	**Number Harvest**	Vessels	Permits	Landings	Registered	Pulls	**CPUE**	**SD**	Days	Dates	**from July**
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**

[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					
					Permits			Total Crab	
Model Year	Year[a]	# of Fishers	# of Crab Harvested	Winter[b]	Issued	Returned	Fished	Caught[c]	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**

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; some may have been returned.
d The number of crab retained is the number of crab caught and kept.
f Confidentiality was waived by the fishers.
h Prior to 2005, permits were only given out of the Nome ADF&G office. Starting with the 2004-5 season, permits were given out in Elim, Golovin, Shaktoolik, and White Mountain.

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

				Survey coverage			Abundance ≥64 mm	
Year	Dates	Survey Agency	Survey method	Total surveyed hauls	Stations w/ NSRKC	n mile^2 expaned		CV
1976	9/02 – 9/25	NMFS	Trawl	117	61	7600	**4301.8**	**0.31**
1979	7/26 - 8/05	NMFS	Trawl	115	33	7600	**1457.4**	**0.22**
1980	7/04 - 7/14	ADFG	Pots				2092.3	N/A
1981	6/28 - 7/14	ADFG	Pots				2153.4	N/A
1982	7/06 - 7/20	ADFG	Pots				1140.5	N/A
1982	9/05 - 9/11	NMFS	Trawl	57	46	7600	**3548.9**	**0.25**
1985	7/01 - 7/14	ADFG	Pots				2320.4	0.083
1985	9/16 -10/01	NMFS	Trawl	78	58	7600	**2424.9**	**0.26**
1988	8/16 - 8/30	NMFS	Trawl	82	45	7600	**2702.3**	**0.29**
1991	8/22 - 8/30	NMFS	Trawl	51	38	7600	**4049.1**	**0.40**
1996	8/07 - 8/18	ADFG	Trawl	50	30	4938	**1283.0**	**0.25**
1999	7/28 - 8/07	ADFG	Trawl	52	31	5221	**2608.0**	**0.24**
2002	7/27 - 8/06	ADFG	Trawl	57	37	5621	**2056.0**	**0.36**
2006	7/25 - 8/08	ADFG	Trawl	114	45	6000	**3336.0**	**0.39**
2008	7/24 - 8/11	ADFG	Trawl	86	44	7330	**2894.2**	**0.31**
2010[a]	7/27 - 8/09	NMFS	Trawl	16	14	5841	**1980.1**	**0.44**
2011	7/18 - 8/15	ADFG	Trawl	65	34	6447	**3209.3**	**0.29**
2014	7/18 - 7/30	ADFG	Trawl	47	34	4700	**5934.6**	**0.47**
2017	7/28 - 8/08	ADFG	Trawl	60	41	6000	**1762.1**	**0.22**
2017	8/18 - 8/29	NMFS	Trawl	16	8	5841	**1035.8**	**0.40**
2018	7/22 - 7/29	ADFG	Trawl	60	34	6000	**1108.9**	**0.25**
2019	7/17-7/29	ADFG	Trawl	52	27	5221	**4660.8**	**0.60**
2019	8/04-8/07	NMFS	Trawl	16	10	5841	**2532.4**	**0.30**

Abundance of NMFS survey (1976-1991) was estimated by NMFS, multiplying the mean CPUE (# NRKC/NM^2) across all hauls (including re-tows) to a standard survey area (7600NM^2).
In contrast, abundance of ADFG (1996-2019) and NMFS (2010,2017) survey were estimated by ADFG by multiplying CPUE (# NRKC/NM^2) of each station to an area represented by the station (~100NM^2) and summing across all surveyed station (ADFG: 4700 – 5200NM^2. NOAA 5841 NM^2).

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

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

Table 5. Winter commercial catch length-shell compositions.

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

Table 6. Summer Trawl Survey length-shell compositions.

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

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 number of tagged data released and recovered after 1 year (Y1) – 3 year (Y3) during 1980-1992 and 1993-2019 periods.

Release Length Class	Recap Length Class	1980-1992					1993-2019					
		Y1	Y2	Y3	Y4	Y5	Y1	Y2	Y3	Y4	Y5	Y6
64 – 73	64 – 73											
64 – 73	74 - 83	1										
64 – 73	84 - 93	1	1				3					
64 – 73	94 - 103							5				
64 – 73	104 – 113				1			4	11	3	1	1
64 – 73	114 – 123				1				11	5	1	
64 – 73	124 – 133									1		1
64 – 73	134+										2	
74 - 83	74 - 83											
74 - 83	84 - 93						21					
74 - 83	94 - 103						22	12				
74 - 83	104 – 113		2				4	94	19	4	1	
74 - 83	114 – 123			2		2		5	46	17	2	1
74 - 83	124 – 133								6	11	3	2
74 - 83	134+									1		
84 - 93	84 - 93											
84 - 93	94 - 103	5					42	5	2			
84 - 93	104 – 113	10	2		1		81	34	14	1		
84 - 93	114 – 123		1	1	1		7	69	27	9	3	
84 - 93	124 – 133				1	1	1	3	9	12	4	
84 - 93	134+									2	1	
94 - 103	94 - 103	3	1	1			7	2				
94 - 103	104 – 113	31	1	3			165	33	2			
94 - 103	114 – 123	26		1	1		82	38	32	3		
94 - 103	124 – 133	2						19	13	5	1	
94 - 103	134+					1	1			1	1	1
104 – 113	104 – 113	16					59	7				
104 – 113	114 – 123	34	13				109	64	9	3	1	
104 – 113	124 – 133	7	6	3	1		15	18	18	9	1	
104 – 113	134+				1				4	1	1	1
114 – 123	114 – 123	16	2				72	9				
114 – 123	124 – 133	26	9	1			72	38	10	1	1	
114 – 123	134+	5	1		1		19	6	3	4		
124 – 133	124 – 133	15					41	9	1			
124 – 133	134+	10	4	2			15	12	7	1		
134+	134+	15	6	1			11	2				

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	Est	sd	Lower	Upper
$log\_q_{1,2}$	Commercial fishery catchability (1977-92, 1993-2017)	-6.768	0.110	-20.5	20
log_N_{76}	Initial abundance	9.113	0.108	2.0	15.0
R_0	Mean Recruit	6.462	0.081	2.0	12.0
$log\_\sigma_R^2$	Recruit standard deviation			-40.0	40.0
a_{1-7}	Intimal length proportion			0	10.0
r_1	Proportion of length class 1 for recruit			0	10.0
log_α	Inverse logistic molting parameter	-2.682	0.089	-5.0	-1.0
log_β	Inverse logistic molting parameter	4.831	0.015	1.0	5.5
log_ϕ_{st1}	Logistic trawl selectivity parameter	-5.000	0.048	-5.0	1.0
log_ϕ_{wa}	Inverse logistic winter pot selectivity parameter	-2.220	0.269	-5.0	1.0
log_ϕ_{wb}	Inverse logistic winter pot selectivity parameter	4.795	0.029	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	-2.067	0.052	-5.0	1.0
log_acr	Logistic summer commercial retention selectivity parameter	-0.787	0.129	-5.0	1.0
log_bcr	Logistic summer commercial retention selectivity parameter	4.646	0.008	0.0	6.0
log_awr	Logistic winter commercial retention selectivity parameter	-0.954	0.536	-5.0	1.0
log_bwr	Logistic winter commercial retention selectivity parameter	4.656	0.037	0.0	6.0
w^2_t	Additional variance for standard CPUE	0.000	0.000	0.0	6.0
ms	Natural mortality multipliers	3.226	0.252	0.5	5.0
q	Survey q for NMFS trawl 1976-91	0.710	0.114	0.1	1.0
σ	Growth transition sigma	3.853	0.209	0.0	30.0
β_1	Growth transition mean	12.196	0.704	0.0	20.0
β_2	Growth transition increment	7.713	0.173	0.0	20.0

Table 12. Estimated molting probability incorporated transition matrix.

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	0.10	0.79	0.09	0.00	0.00	0.00	0.00
74 - 83		0.04	0.24	0.70	0.03	0.00	0.00	0.00
84 - 93			0.08	0.43	0.49	0.01	0.00	0.00
94 - 103				0.15	0.58	0.26	0.00	0.00
104 - 113					0.29	0.61	0.10	0.00
114 - 123						0.50	0.47	0.03
124 - 133							0.72	0.28
134+								1.00

Table 13. 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.

	Abundance			Legal (≥ 104mm)		MMB
Year	Recruits (<94mm)	Total	Mature (≥ 94mm)	Abundance	Biomass	Biomass
1976	2.61	9.07	6.46	4.14	11.03	15.39
1977	1.07	7.97	6.90	5.43	15.54	18.35
1978	0.77	6.41	5.64	5.01	15.51	16.74
1979	0.55	4.50	3.95	3.58	11.72	12.42
1980	1.10	3.33	2.23	1.99	6.68	7.13
1981	1.59	3.25	1.66	1.31	4.43	5.07
1982	1.69	3.21	1.52	0.99	3.07	4.04
1983	1.66	3.51	1.85	1.23	3.63	4.78
1984	1.71	3.76	2.05	1.43	4.17	5.34
1985	1.38	3.59	2.20	1.57	4.63	5.81
1986	1.34	3.58	2.23	1.67	4.99	6.05
1987	1.15	3.28	2.13	1.62	4.94	5.89
1988	1.06	3.13	2.07	1.60	4.93	5.80
1989	1.10	3.05	1.95	1.54	4.79	5.57
1990	0.92	2.78	1.86	1.45	4.54	5.32
1991	0.82	2.58	1.76	1.39	4.36	5.06
1992	0.72	2.38	1.66	1.33	4.21	4.83
1993	0.58	2.10	1.52	1.23	3.93	4.47
1994	0.55	1.84	1.29	1.05	3.35	3.79
1995	0.65	1.73	1.08	0.87	2.77	3.17
1996	0.85	1.81	0.96	0.73	2.30	2.73
1997	1.52	2.51	1.00	0.70	2.16	2.71
1998	1.30	2.61	1.31	0.82	2.43	3.34
1999	0.75	2.42	1.66	1.15	3.32	4.29
2000	0.81	2.49	1.67	1.32	3.94	4.61
2001	1.17	2.66	1.49	1.19	3.69	4.26
2002	1.35	2.85	1.50	1.10	3.43	4.18
2003	1.11	2.74	1.64	1.15	3.50	4.40
2004	0.83	2.52	1.69	1.24	3.73	4.56
2005	1.13	2.70	1.57	1.22	3.72	4.37
2006	1.45	2.94	1.50	1.11	3.41	4.14
2007	1.60	3.21	1.61	1.10	3.33	4.26
2008	1.63	3.45	1.82	1.24	3.66	4.73
2009	1.28	3.27	1.98	1.38	4.05	5.18
2010	0.85	2.87	2.02	1.50	4.44	5.42
2011	0.92	2.75	1.83	1.45	4.42	5.12
2012	1.17	2.79	1.62	1.27	3.97	4.61
2013	1.98	3.52	1.54	1.13	3.50	4.26
2014	1.40	3.17	1.77	1.13	3.41	4.59
2015	0.67	2.67	2.00	1.41	4.08	5.19
2016	0.48	2.20	1.72	1.39	4.16	4.79
2017	0.55	1.91	1.36	1.15	3.61	4.01
2018	0.74	1.83	1.08	0.88	2.84	3.21
2019	2.31	3.32	1.00	0.75	2.38	2.85

Table 14. Summary of catch and estimated discards (million lb) for Norton Sound red king crab. Assumed average crab weight is 2.0 lb for winter subsistence catch and 1.0 lb for Winter subsistence discards. Summer and winter commercial discards were estimated from the model.

Year	Summer Com	Winter Com	Winter Sub	Modeled Discards Summer	Discards Winter Sub	Modeled Discards Winter Com	Total	Catch/ MMB
1977	0.52	0.000	0.000	0.022	0	0.000	0.542	0.035
1978	2.09	0.024	0.025	0.040	0.008	0.001	2.188	0.141
1979	2.93	0.001	0.000	0.049	0	0.000	2.98	0.254
1980	1.19	0.000	0.000	0.024	0	0.000	1.214	0.182
1981	1.38	0.000	0.001	0.067	0	0.000	1.448	0.327
1982	0.23	0.000	0.003	0.020	0.001	0.000	0.254	0.083
1983	0.37	0.001	0.021	0.036	0.006	0.000	0.434	0.119
1984	0.39	0.002	0.022	0.033	0.005	0.000	0.452	0.108
1985	0.43	0.003	0.017	0.032	0.002	0.000	0.484	0.105
1986	0.48	0.005	0.014	0.028	0.004	0.001	0.532	0.107
1987	0.33	0.003	0.012	0.018	0.002	0.000	0.365	0.074
1988	0.24	0.001	0.005	0.012	0.001	0.000	0.259	0.053
1989	0.25	0.000	0.012	0.012	0.002	0.000	0.276	0.058
1990	0.19	0.010	0.024	0.009	0.004	0.001	0.238	0.052
1991	0	0.010	0.015	0.000	0.002	0.001	0.028	0.006
1992	0.07	0.021	0.023	0.003	0.003	0.002	0.122	0.029
1993	0.33	0.005	0.002	0.014	0	0.000	0.351	0.089
1994	0.32	0.017	0.008	0.013	0.001	0.001	0.36	0.108
1995	0.32	0.022	0.011	0.015	0.002	0.002	0.372	0.134
1996	0.22	0.005	0.003	0.014	0.001	0.001	0.244	0.106
1997	0.09	0.000	0.001	0.009	0.001	0.000	0.101	0.047
1998	0.03	0.002	0.017	0.004	0.012	0.001	0.066	0.027
1999	0.02	0.007	0.015	0.002	0.003	0.001	0.048	0.014
2000	0.3	0.008	0.011	0.015	0.004	0.001	0.339	0.086
2001	0.28	0.003	0.001	0.015	0	0.000	0.299	0.081
2002	0.25	0.007	0.004	0.019	0.003	0.001	0.284	0.083
2003	0.26	0.017	0.008	0.021	0.005	0.002	0.313	0.090
2004	0.34	0.001	0.002	0.022	0.001	0.000	0.366	0.098
2005	0.4	0.006	0.008	0.022	0.003	0.001	0.44	0.118
2006	0.45	0.000	0.002	0.032	0.001	0.000	0.485	0.142
2007	0.31	0.008	0.021	0.029	0.011	0.001	0.38	0.114
2008	0.39	0.015	0.019	0.037	0.009	0.002	0.472	0.129
2009	0.4	0.012	0.010	0.033	0.002	0.002	0.459	0.113
2010	0.42	0.012	0.014	0.026	0.002	0.001	0.475	0.107
2011	0.4	0.009	0.013	0.019	0.003	0.001	0.445	0.101
2012	0.47	0.025	0.015	0.026	0.004	0.002	0.542	0.137
2013	0.35	0.061	0.015	0.031	0.014	0.009	0.48	0.137
2014	0.39	0.035	0.007	0.042	0.002	0.007	0.483	0.142
2015	0.40	0.099	0.019	0.028	0.005	0.010	0.561	0.138
2016	0.42	0.080	0.011	0.016	0.001	0.005	0.533	0.128
2017	0.41	0.078	0.012	0.013	0.001	0.004	0.518	0.143
2018	0.30	0.029	0.008	0.012	0.001	0.002	0.352	0.124
2019	0.08	0.032	0.003	0.006	0.001	0.006	0.128	0.054

Figures

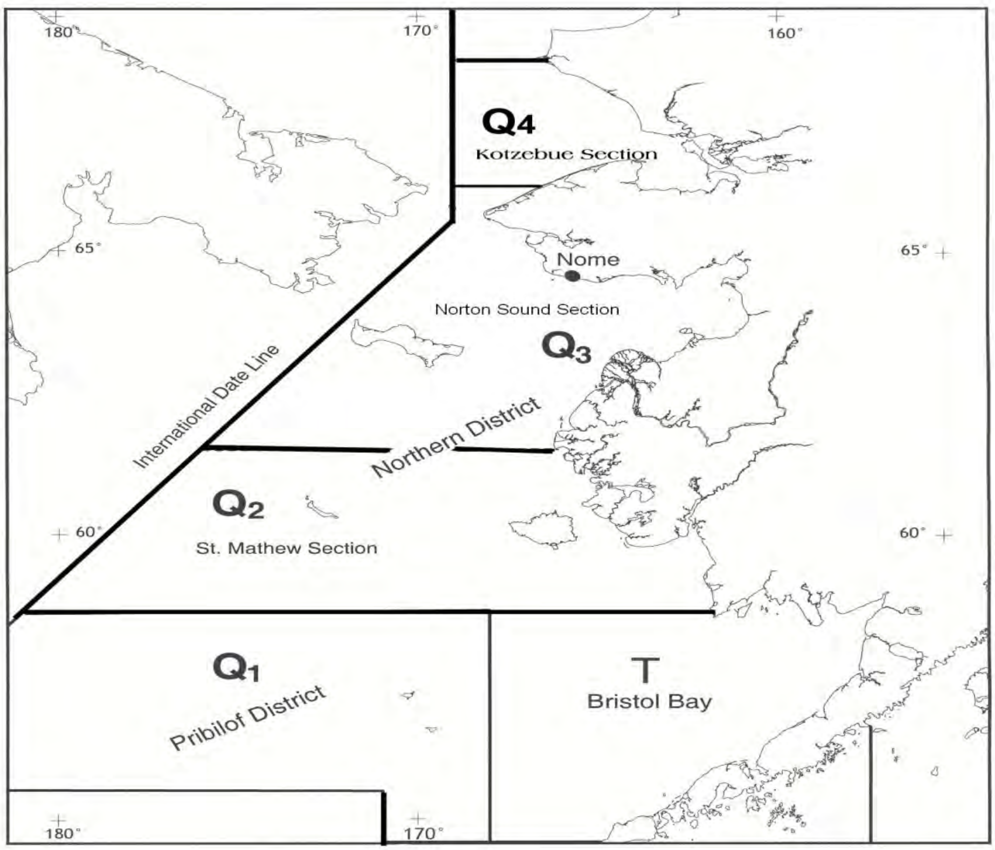


Figure 1. King crab fishing districts and sections of Statistical Area Q.

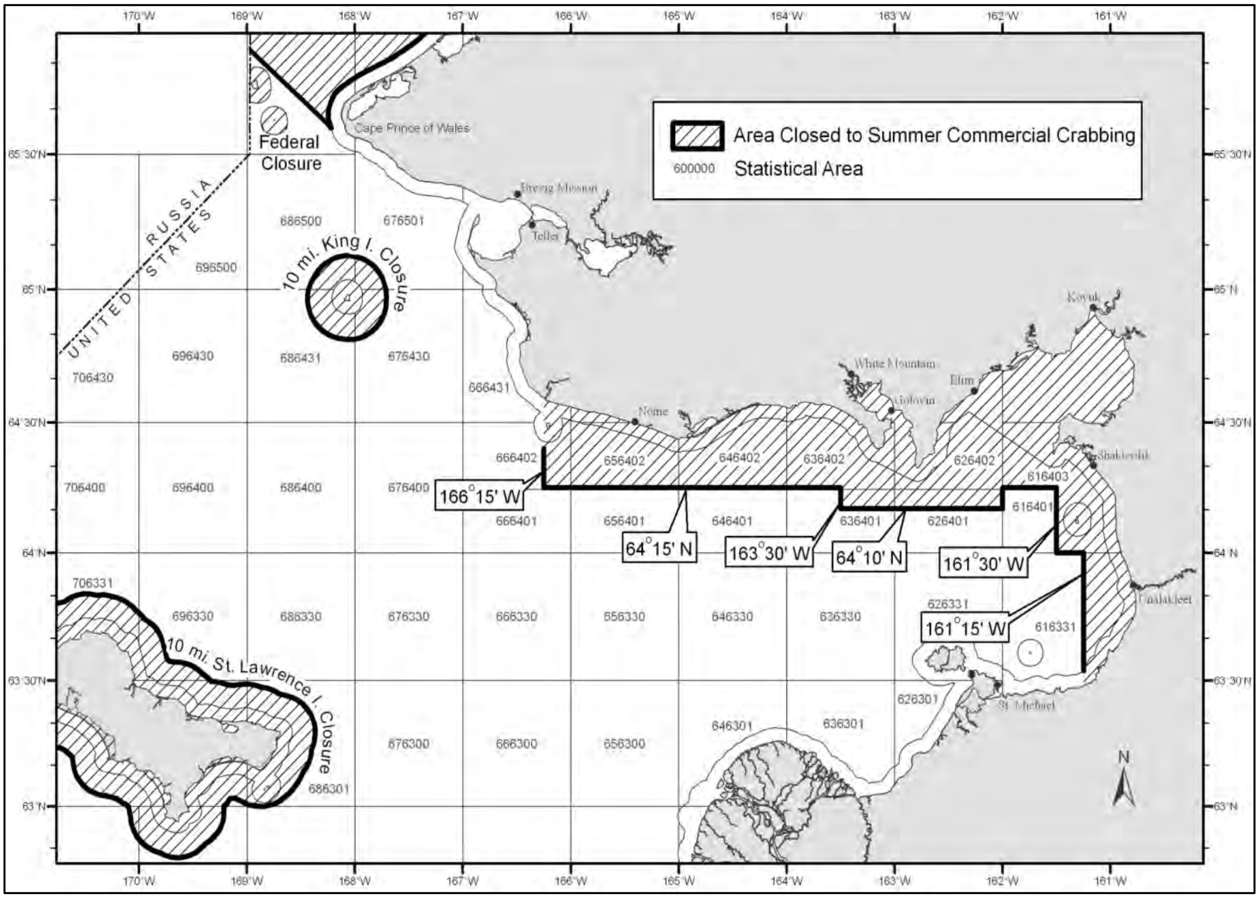


Figure 2. Closed water regulations in effect for the Norton Sound commercial crab fishery. Line around the coastline delineates the 3-mil3 state waters zone.

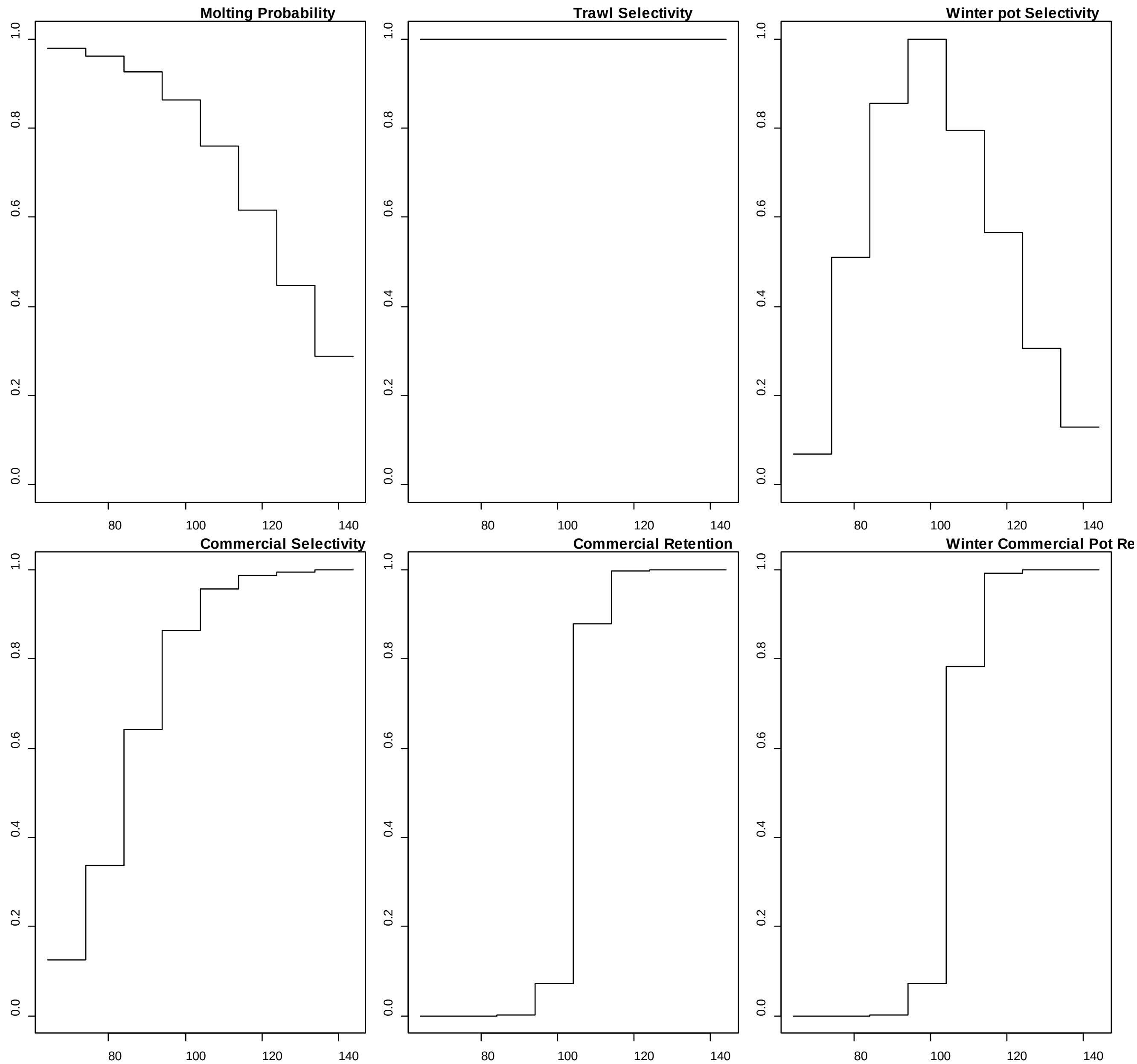


Figure 3. Model estimated annual molting probability, and selectivity for trawl survey, winter pot survey, summer commercial fishery, and summer and winter commercial retention. X-axis is carapace length (mm).

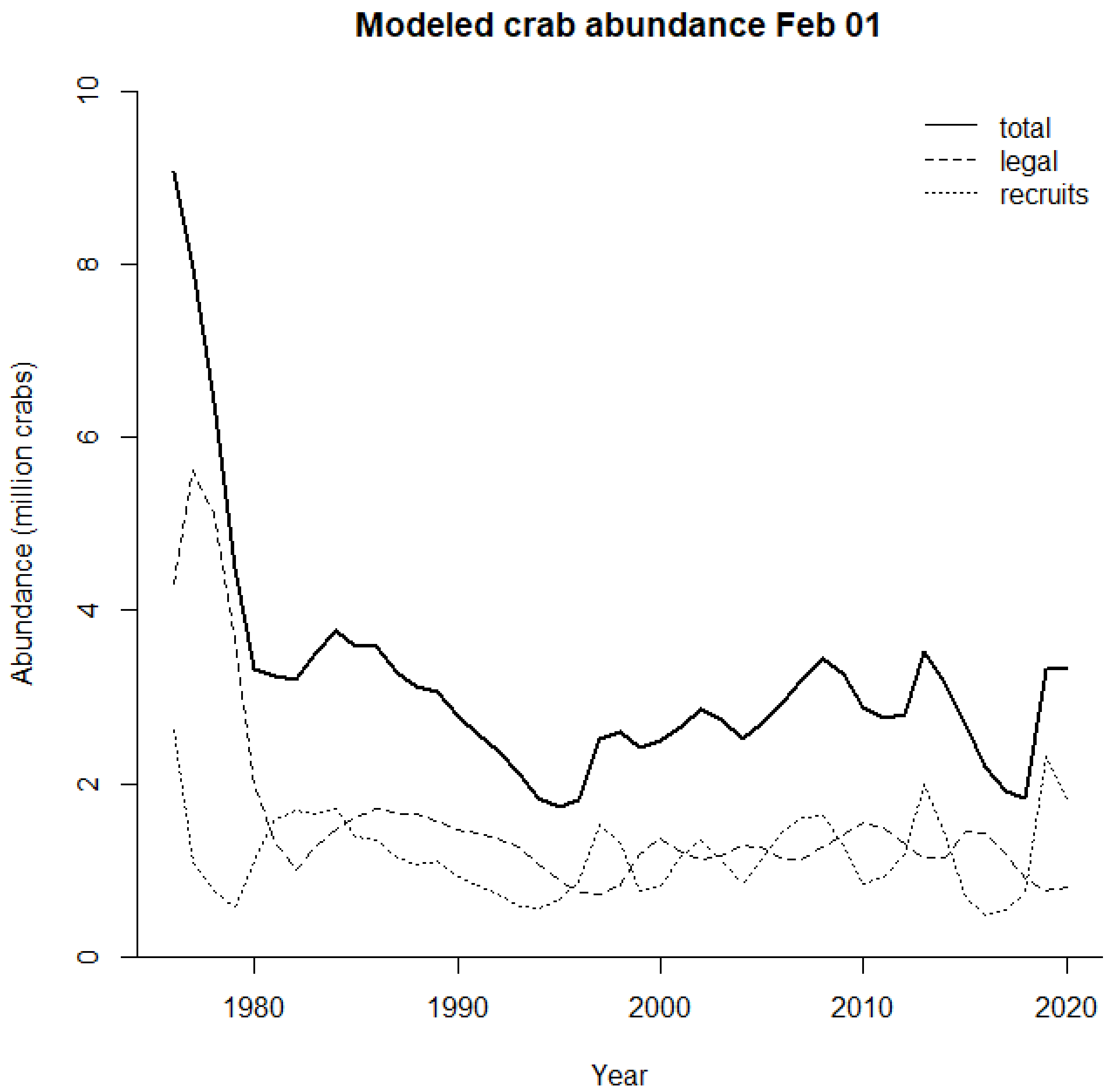


Figure 4. Model estimated abundances of total, legal (CL>104mm) and recruit (CL 64-94nn) males during1976-2019.

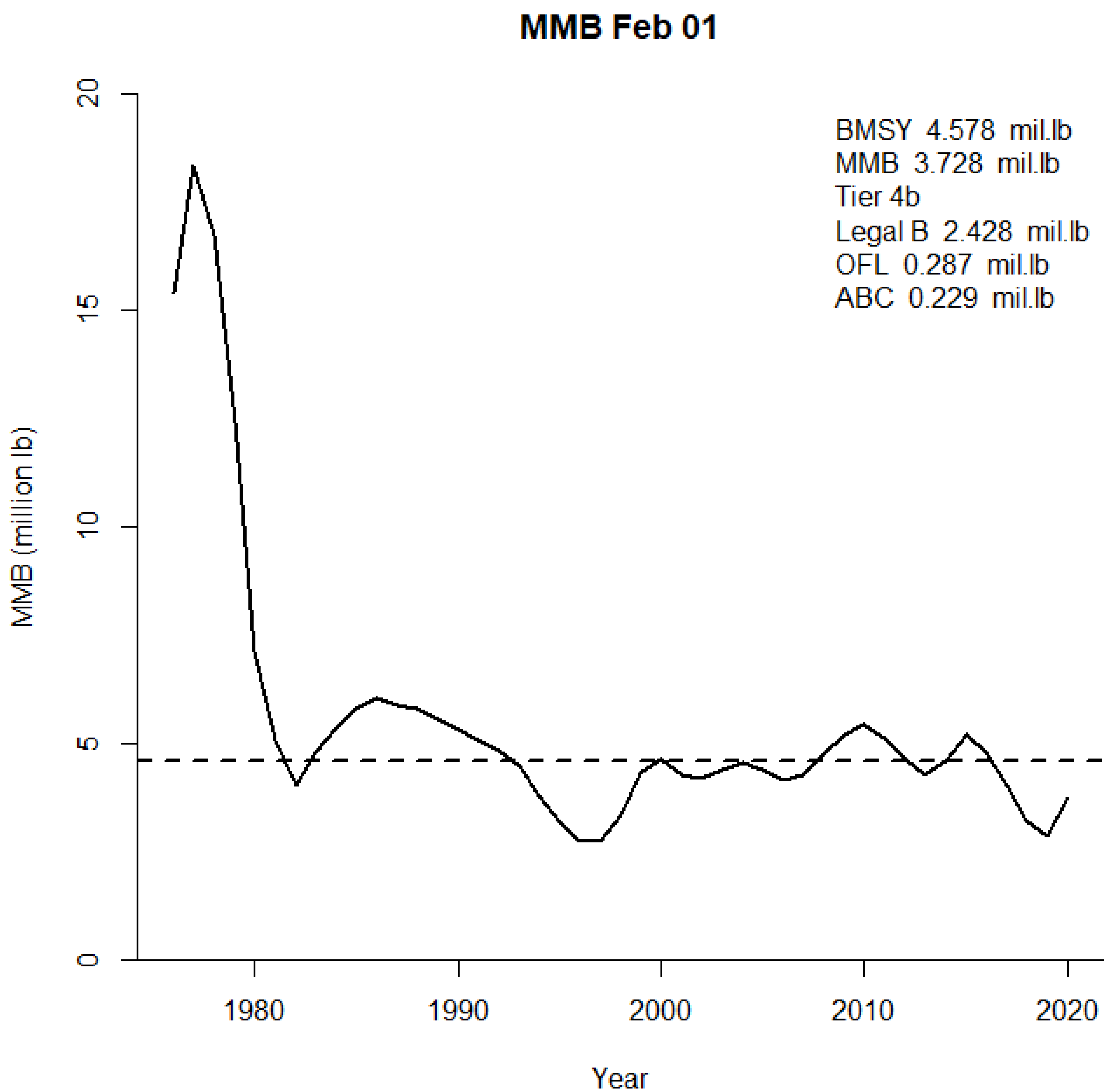


Figure 5. Estimated MMB during 1976-2019. Dash line shows Bmsy (Average MMB of 1980-2020). Dot indicate projected MMB of 2020.

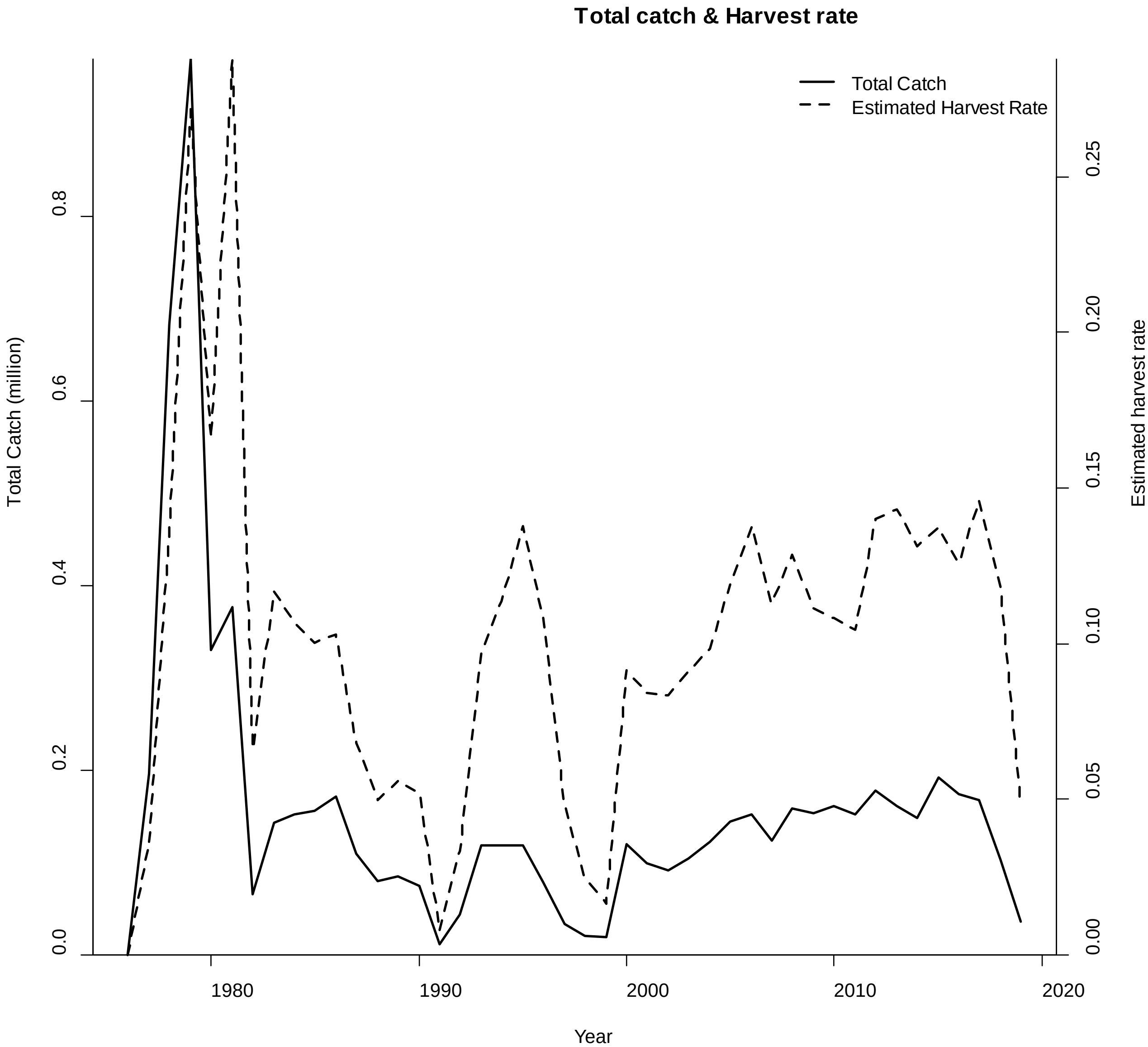


Figure 6. Commercial catch and estimated harvest rates of legal males over time.

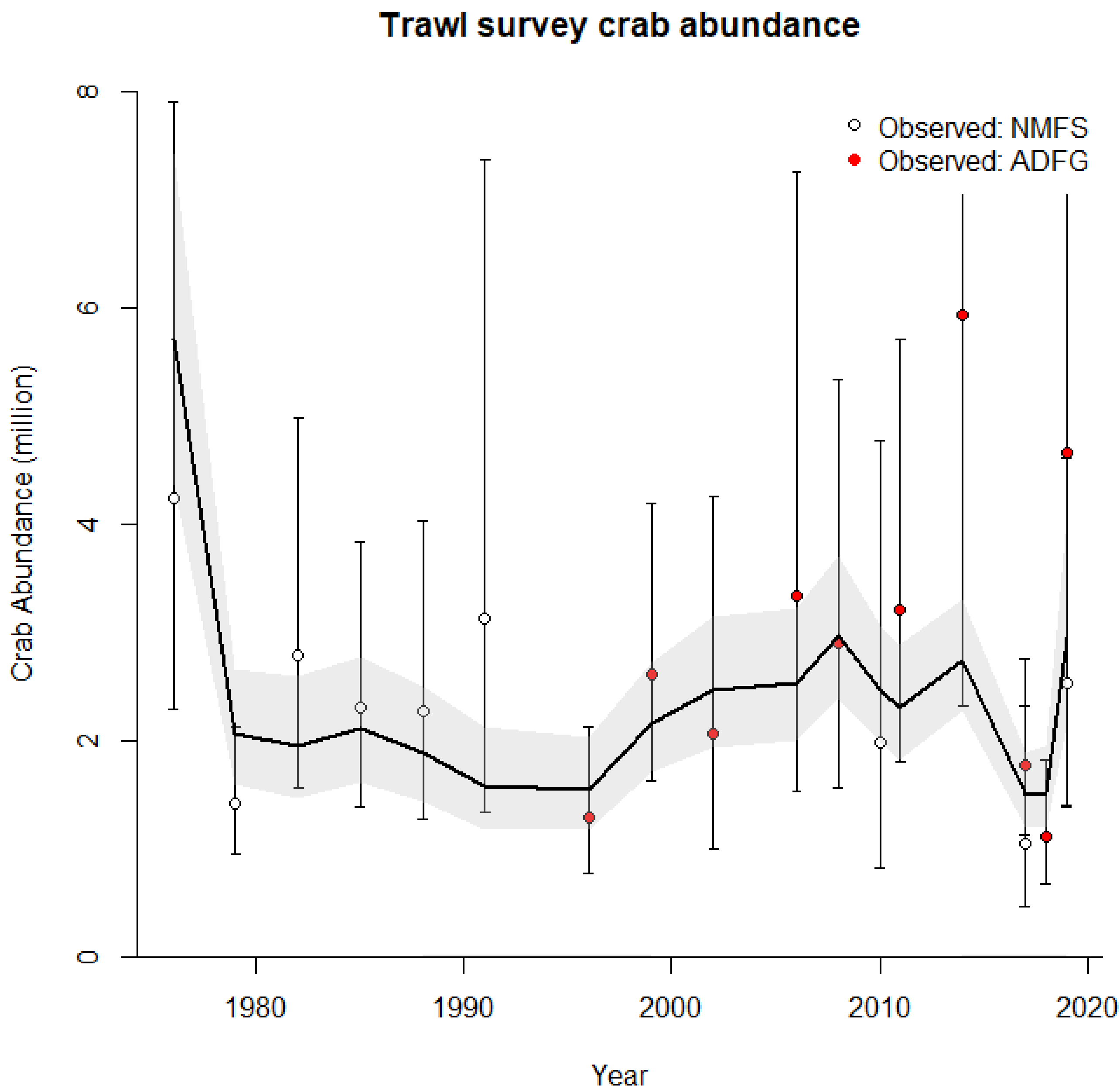


Figure 7. Observed (open circle) (White: NMFS, Red ADF&G) and model estimated (line) trawl survey male abundances with 95% lognormal Confidence Intervals (crab ≥ 64 mm CL). Shaded area indicate 95%CI lognormal CI of the model estimate.

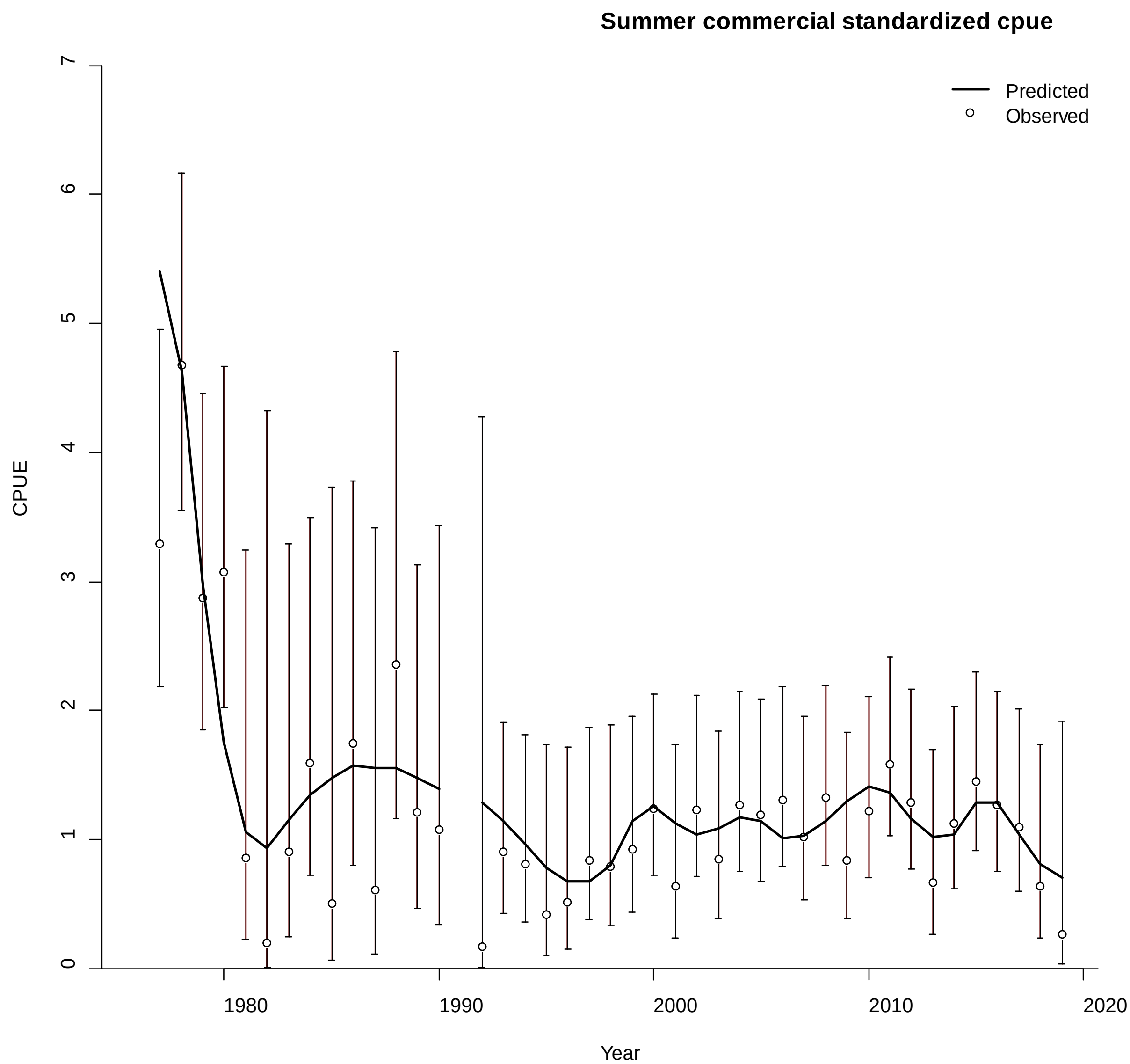


Figure 8. Observed (open circle) with 95% lognormal Confidence Intervals and model estimated (lines) standardized CPUE.

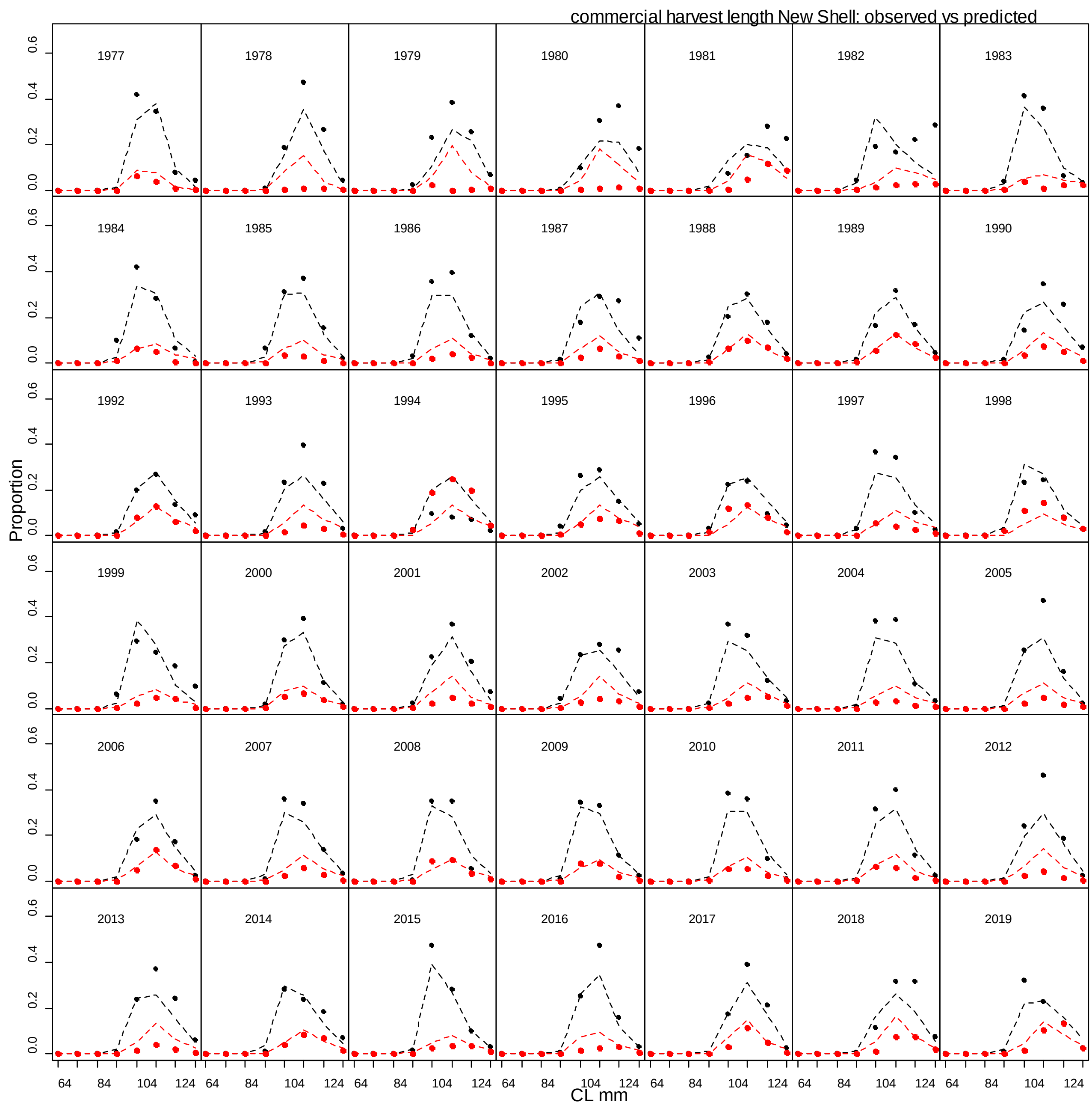


Figure 9. Predicted (line) vs. observed (dots: black New Shell, red Old Shell) length class proportions for the summer commercial harvest 1977-2019.

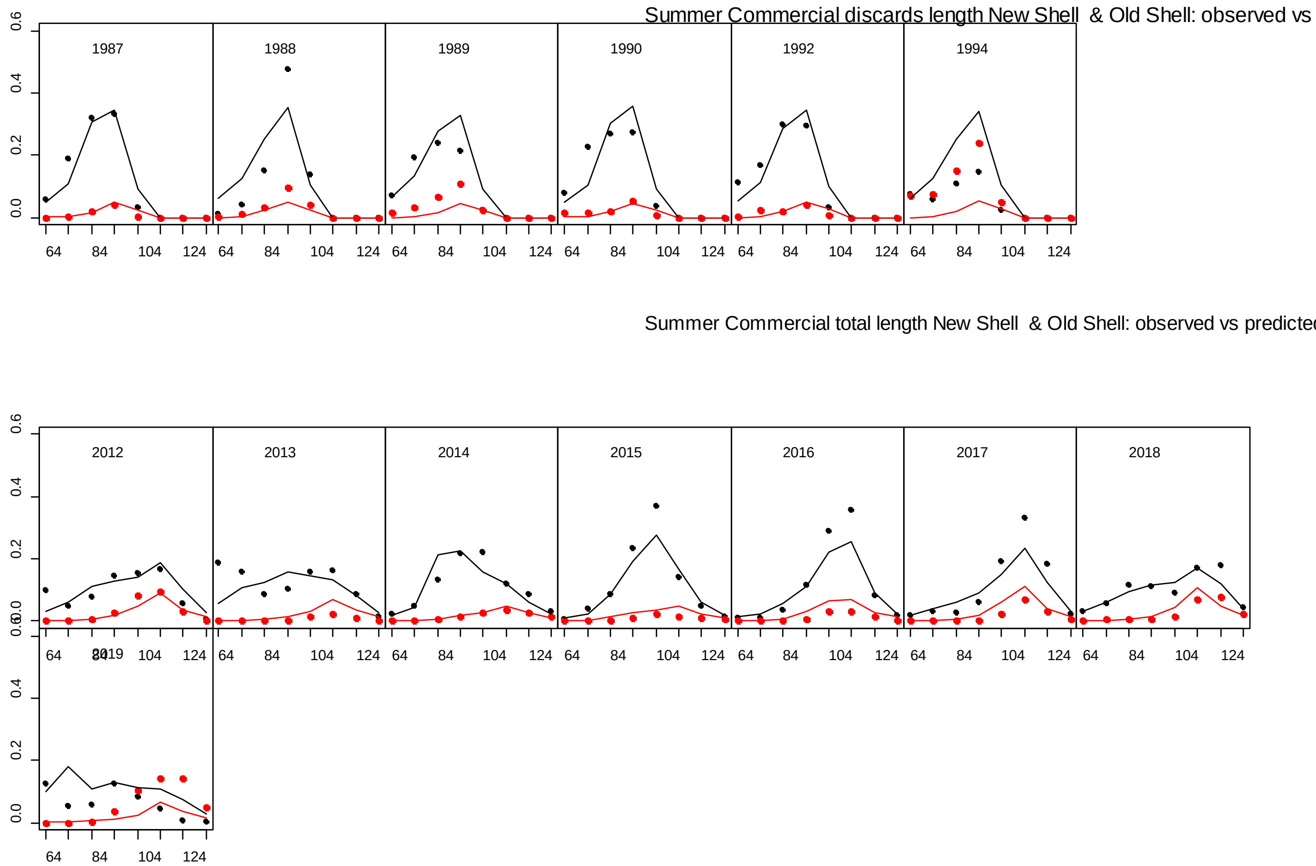


Figure 10. Predicted (line) vs. observed (dots: black New Shell, red Old Shell) length class proportions for summer commercial discards (1987-94) and total catch (2012-2019).

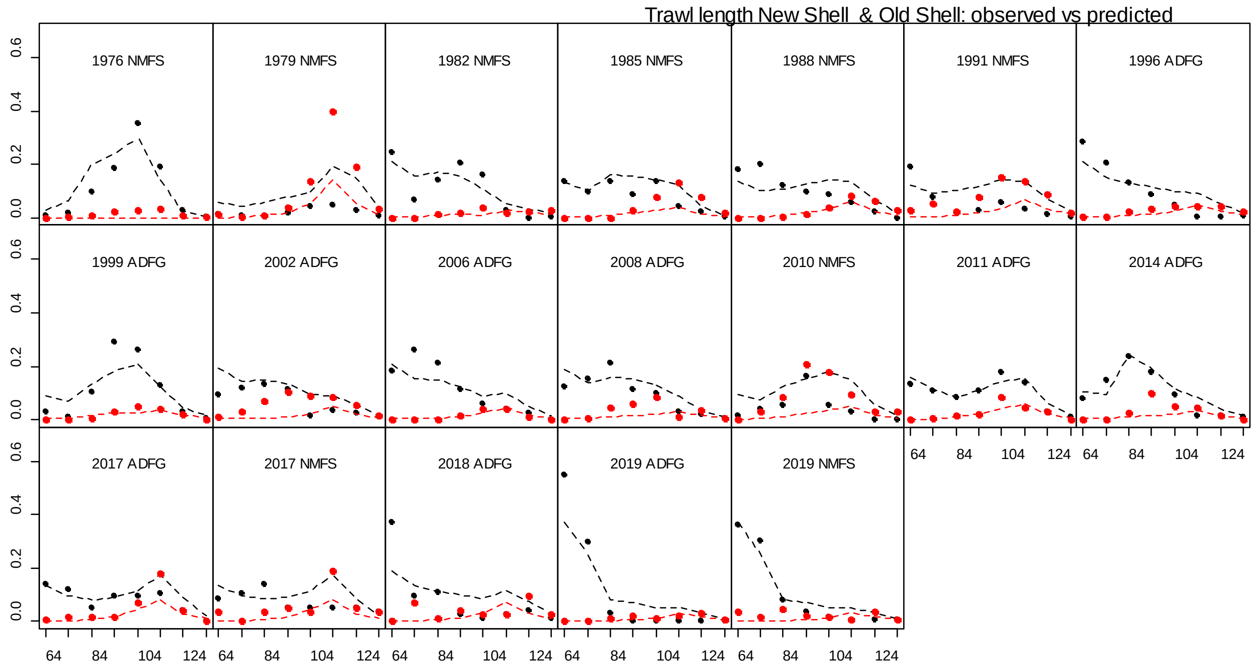


Figure 11. Predicted (line) vs. observed (dots: black New Shell, red Old Shell) length class proportions for summer trawl survey 1976 – 2019

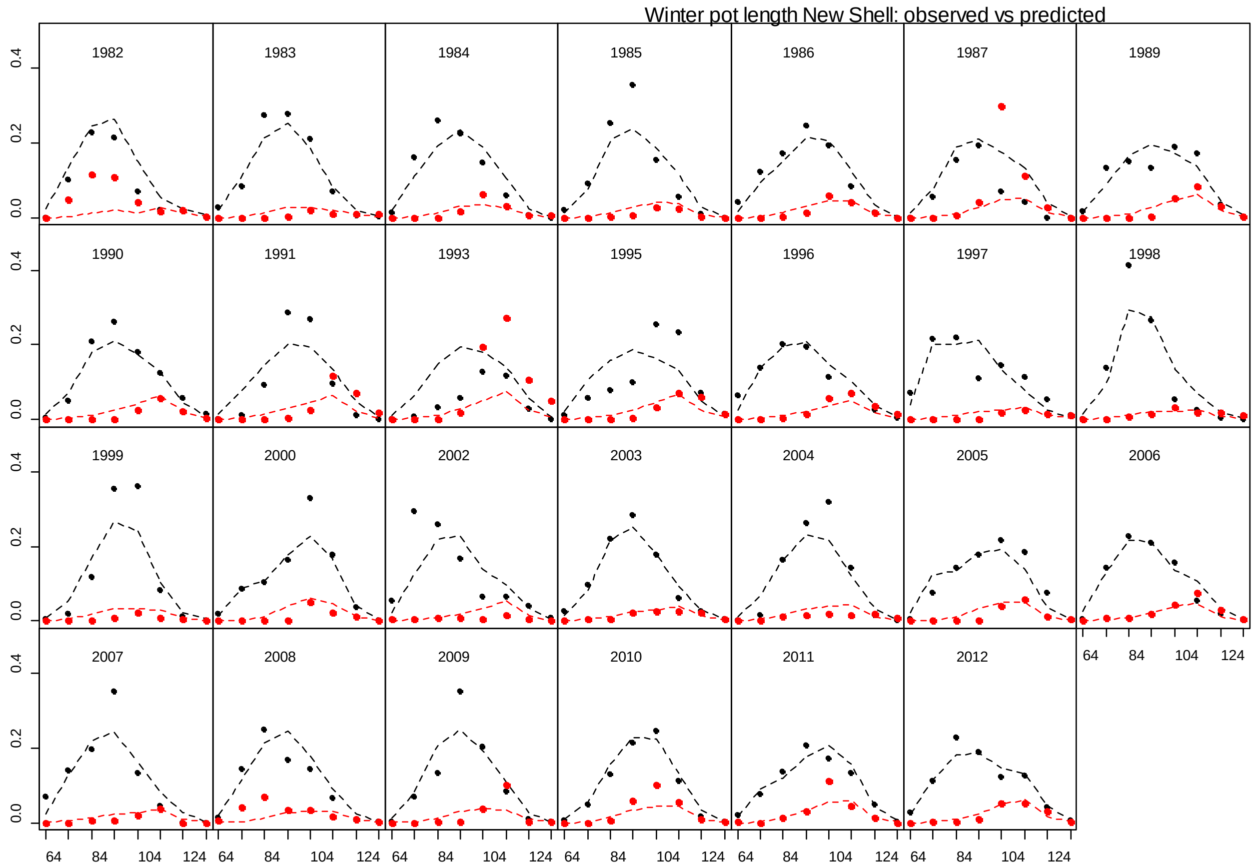


Figure 12. Predicted (line) vs. observed (dots: black New Shell, red Old Shell) length class proportions for winter pot survey 1982 – 2012

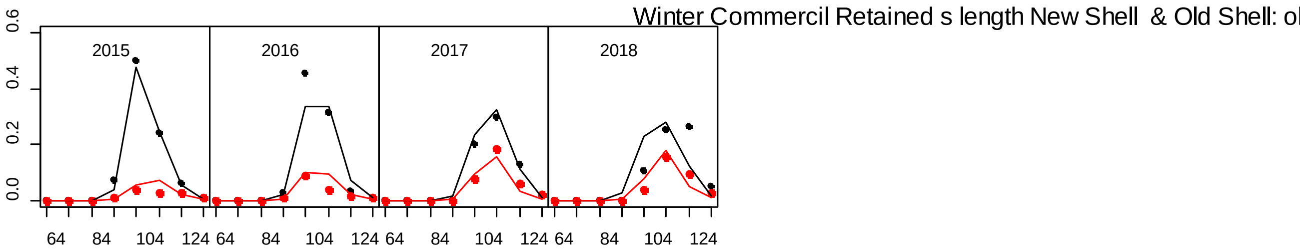


Figure 13. Predicted (line) vs. observed (dots: black New Shell, red Old Shell) length class proportions for winter commercial fishery 2015-2018

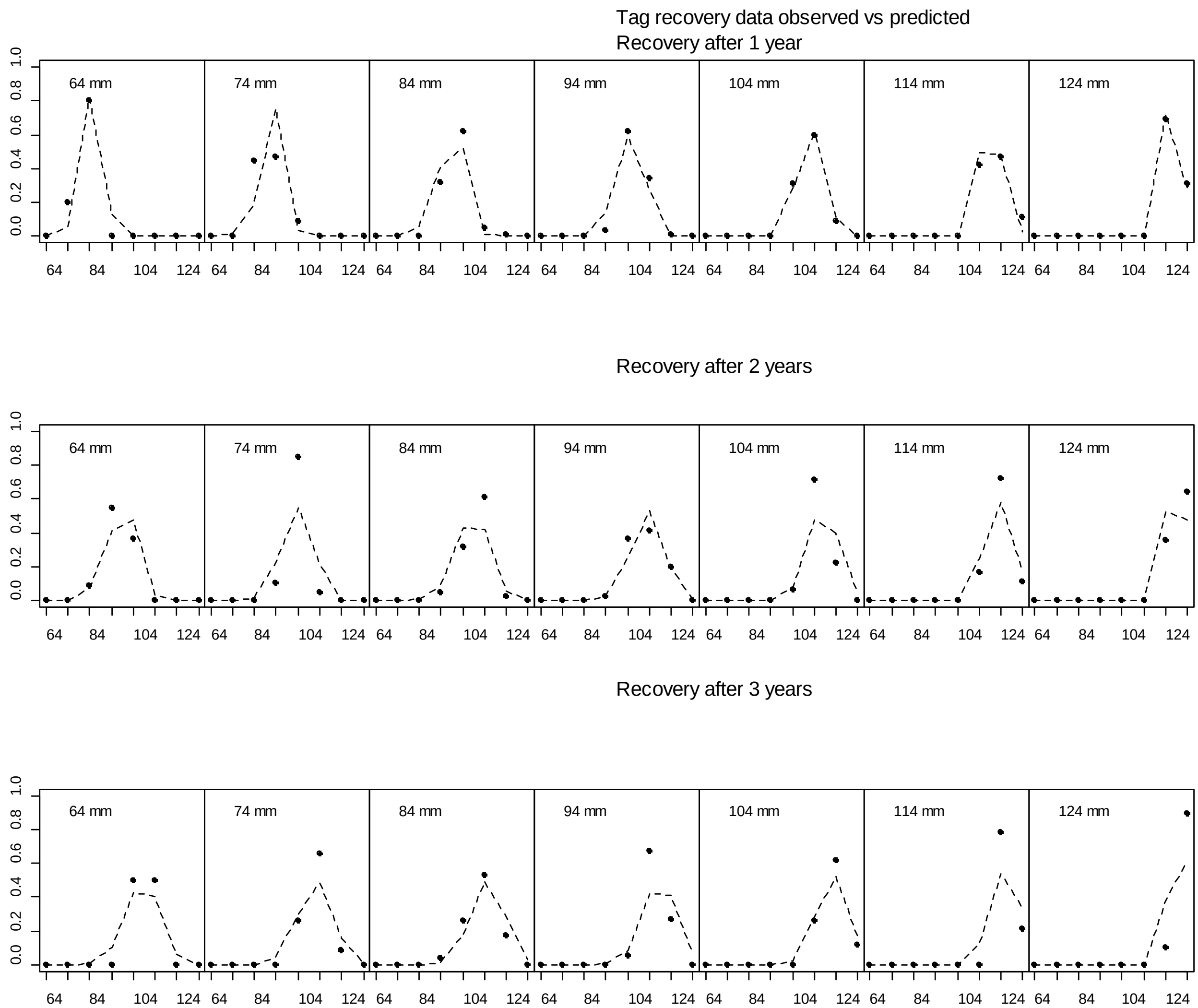


Figure 14. Predicted (line) vs. observed (dots: black New Shell, red Old Shell) length class proportions tag recovery data.

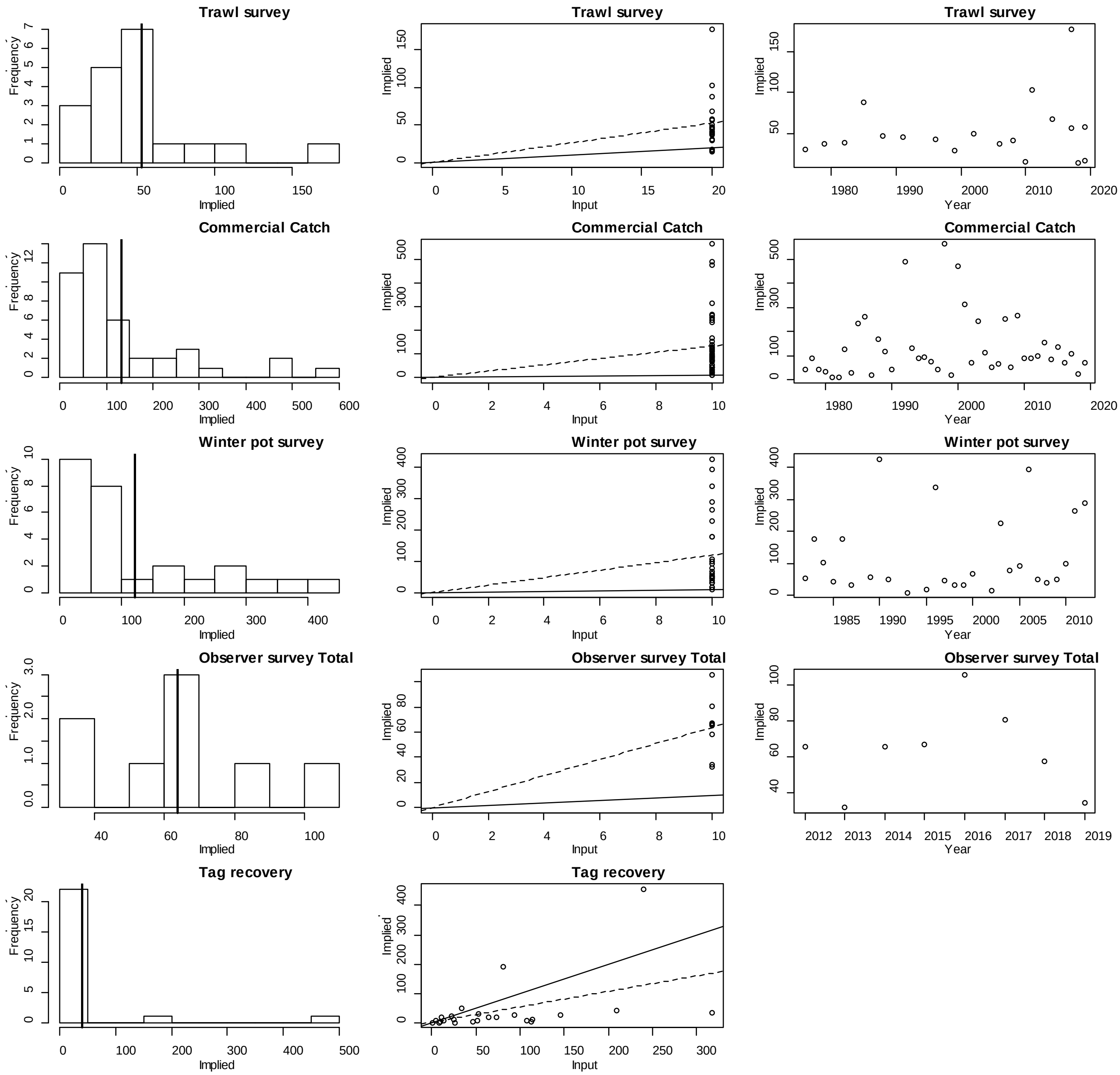


Figure 15. Input vs. model implied effective sample size. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the implied sample size. Figures in the second column show input sample sizes (x-axis) vs. implied effective sample sizes (y-axis). 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).

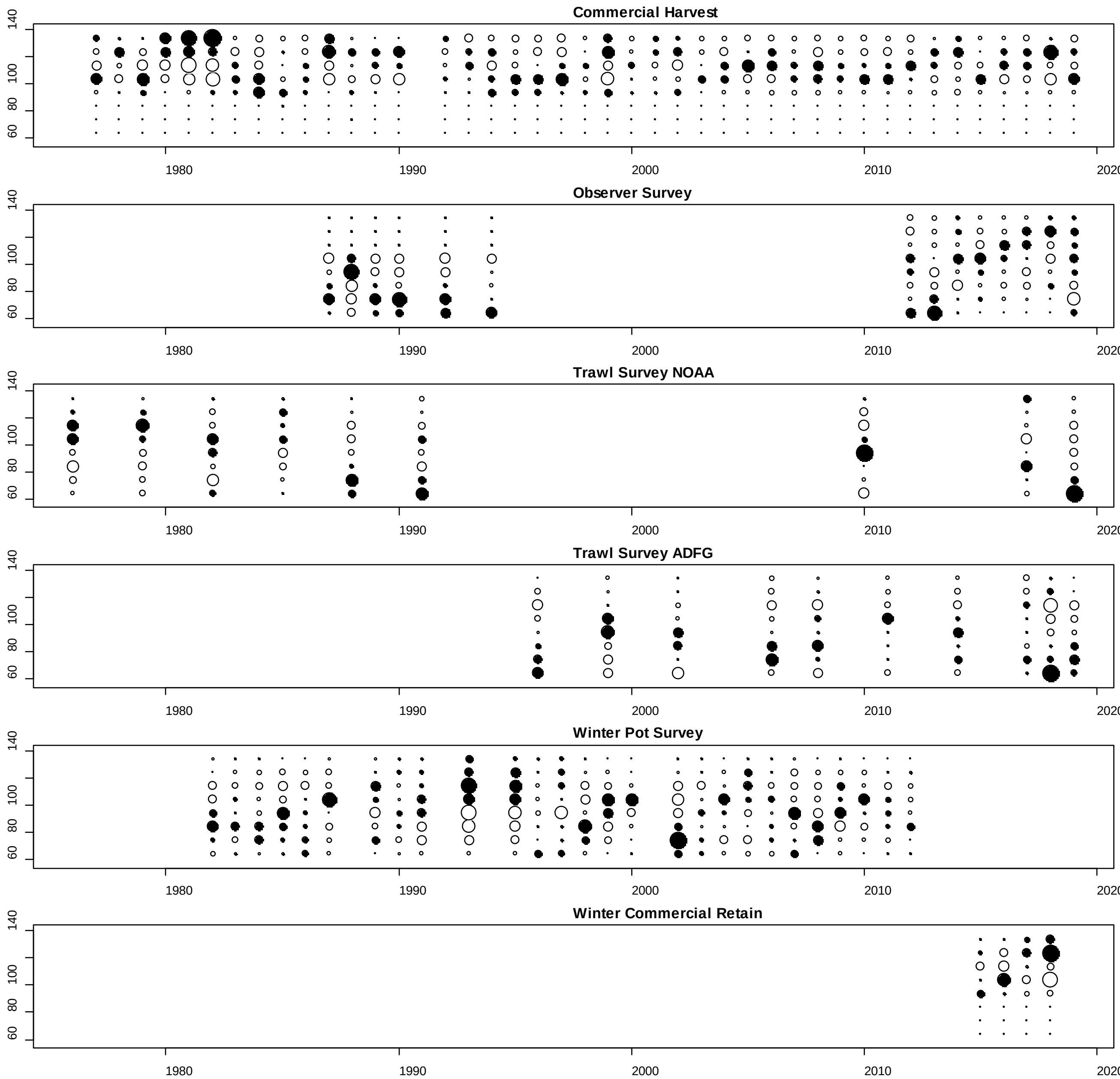


Figure 16. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

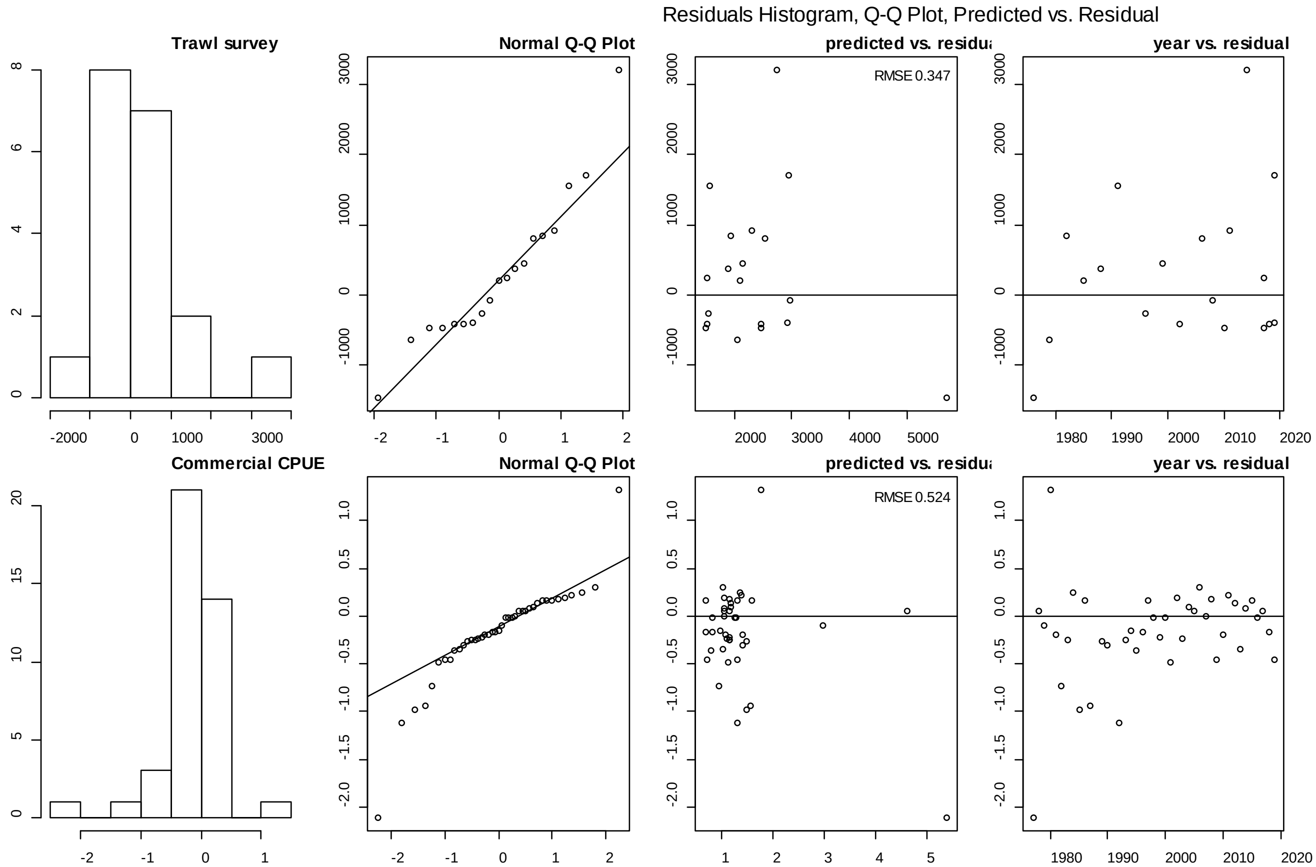


Figure 17. QQ Plot of Trawl survey and Commercial CPUE

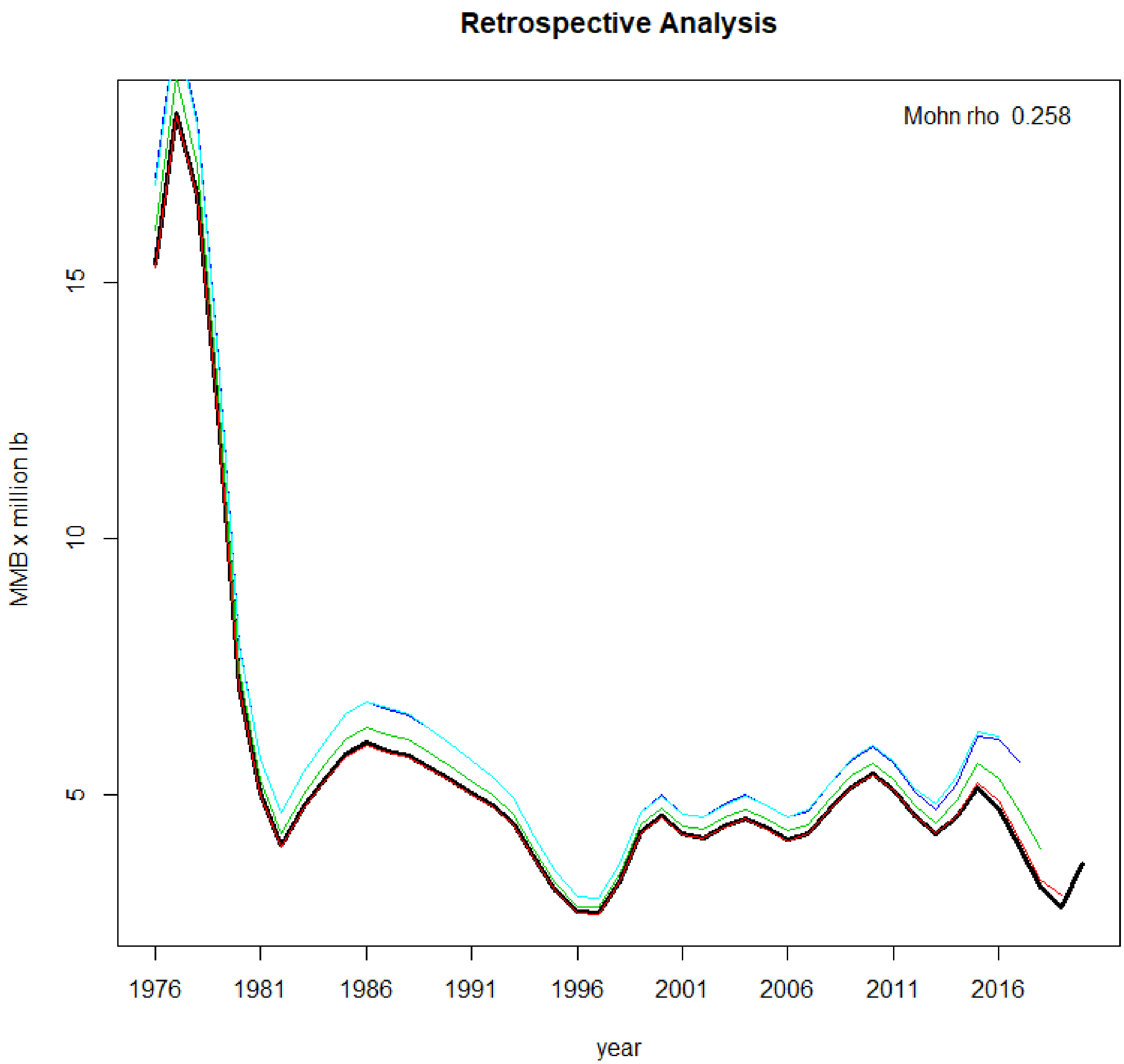


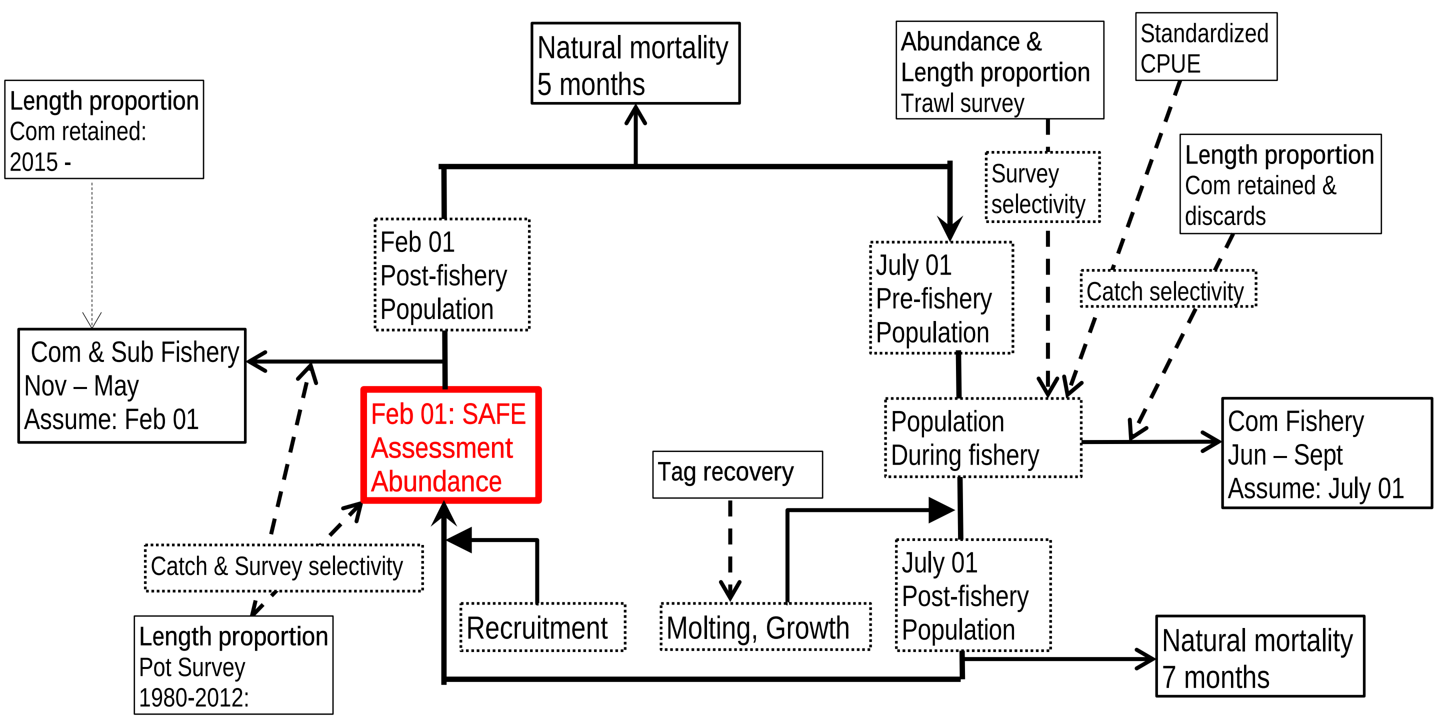
Figure 18. Retrospective Analyses of Norton Sound Red King Crab MMB from 2016 to 2019.

Appendix A. Description of the Norton Sound Red King Crab Model

a. Model description.

The model is an extension of the length-based model developed by Zheng et al. (1998) for Norton Sound red king crab. The model has 8 male length classes with model parameters estimated by the maximum likelihood method. The model estimates abundances of 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 and there were relatively small sample sizes for trawl and winter pot surveys. The model treats newshell and oldshell male crab separately but assumes they have the same molting probability and natural mortality.

Norton Sound Red King Crab Modeling Scheme



Timeline of calendar events and crab modeling events:

- **Model year starts February 1st to January 31st of the following year.**
- **All winter fishery harvest occurs on February 1st**
- **Molting and recruitment occur on July 1st**
- **Initial Population Date: February 1st 1976**

Initial pre-fishery summer crab abundance on February 1st 1976

Abundance of the initial pre-fishery population was assumed to consist of newshell crab to reduce the number of parameters, and estimated as

$$N_{l,1} = p_l e^{\log\_N_{76}} \tag{1}$$

where, length proportion of the first year (p_l) was calculated as

$$\begin{aligned} p_l &= \frac{\exp(a_l)}{1+\sum_{l=1}^{n-1}\exp(a_l)} \text{ for } l = 1,..,n\text{-}1 \\ p_n &= 1-\frac{\sum_{l=1}^{n-1}\exp(a_l)}{1+\sum_{l=1}^{n-1}\exp(a_l)} \end{aligned} \tag{2}$$

for model estimated parameters a_l.

Crab abundance on July 1st

Summer (01 July) crab abundance of new and oldshells consists of survivors of winter commercial and subsistence crab fisheries and natural mortality from 01Feb to 01July:

$$\begin{aligned} N_{s,l,t} &= (N_{w,l,t} - C_{w,t}P_{w,n,l,t} - C_{p,t}P_{p,n,l,t} - D_{w,n,l,t} - D_{p,n,l,t})e^{-0.42M_l} \\ O_{s,l,t} &= (O_{w,l,t} - C_{w,t-1}P_{w,o,l,t} - C_{p,t}P_{p,o,l,t} - D_{w,o,l,t} - D_{p,o,l,t})e^{-0.42M_l} \end{aligned} \tag{3}$$

where

$N_{s,l,t}$, $O_{s,l,t}$: summer abundances of newshell and oldshell crab in length class l in year t ,
$N_{w,l,t}$, $O_{w,l,t}$: winter abundances of newshell and oldshell crab in length class l in year t,
$C_{w,t}$, $C_{p,t}$: total winter commercial and subsistence catches in year t,
$P_{w,n,l,t}$, $P_{w,o,l,t}$: Proportion of newshell and oldshell length class l crab in year t, harvested by winter commercial fishery,
$P_{p,n,l,t}$, $P_{p,o,l,t}$: Proportion of newshell and oldshell length class l crab in year t, harvested by winter subsistence fishery,
$D_{w,n,l,t}$, $D_{w,o,l,t}$: Discard mortality of newshell and oldshell length class l crab in winter commercial

fishery in year t ,
$D_{p,n,l,t}$, $D_{p,o,l,t}$: Discard mortality of newshell and oldshell length class l crab in winter subsistence fishery in year t,
M_l : instantaneous natural mortality in length class l,
0.42 : proportion of the year from Feb 1 to July 1 is 5 months.

Length proportion compositions of winter commercial catch ($P_{w,n,l,t}$, $P_{w,o,l,t}$) in year t were estimated as:

$$P_{w,n,l,t} = N_{w,l,t} S_{w,l} P_{lg,l} / \sum_{l=1} [(N_{w,l,t} + O_{w,l,t}) S_{w,l} P_{lg,l}]$$
$$P_{w,o,l,t} = O_{w,l,t} S_{w,l} P_{lg,l} / \sum_{l=1} [(N_{w,l,t} + O_{w,l,t}) S_{w,l} P_{lg,l}] \qquad (4)$$

where
$P_{lg,l}$: the proportion of legal males in length class l ,
$S_{w,l}$: Selectivity of winter fishery pot.

Subsistence fishery does not have a size limit; however, crab of size smaller than length class 3 are generally not retained. Hence, we assumed proportion of length composition l = 1 and 2 as 0, and estimated length compositions ($l \geq 3$) as follows

$$P_{p,n,l,t} = N_{w,l,t} S_{w,l} / \sum_{l=3} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}]$$
$$P_{p,o,l,t} = O_{w,l,t} S_{w,l} / \sum_{l=3} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \qquad (5)$$

Crab abundance on Feb 1st

Newshell Crab: Abundance of newshell crab of year t and length-class l ($N_{w,l,t}$) year-t consist of: (1) new and oldshell crab that survived the summer commercial fishery and molted, and (2) recruitment ($R_{l,t}$) .

$$N_{w,l,t} = \sum_{l'=1}^{l'=l} G_{l',l} [(N_{s,l',t-1} + O_{s,l',t-1}) e^{-y_c M_l} - C_{s,t} (P_{s,n,l',t-1} + P_{s,o,l',t-1}) - D_{l',t-1}] m_{l'} e^{-(0.58-y_c) M_l} + R_{l,t-1} \qquad (6)$$

Oldshell Crab: Abundance of oldshell crabs of year t and length-class l ($O_{w,l,t}$) consists of the non-molting portion of survivors from the summer fishery:

$$O_{w,l,t} = [(N_{s,l,t-1} + O_{s,l,t-1}) e^{-y_c M_l} - C_{s,t} (P_{s,n,l,t-1} + P_{s,o,l,t-1}) - D_{l,t-1}] (1 - m_l) e^{-(0.58-y_c) M_l} \qquad (7)$$

where

$G_{l',l}$: a growth matrix representing the expected proportion of crabs growing from length class l' to length class l
$C_{s,t}$: total summer catch in year t
$P_{s,n,l,t-1}$, $P_{s,o,l,t-1}$: proportion of summer catch for newshell and oldshell crabs of length class l in year $t-1$,
$D_{l,t-1}$: summer discard mortality of length class l in year $t-1$,
m_l : molting probability of length class l,
y_c : the time in year from July 1 to the mid-point of the summer fishery,
0.58: Proportion of the year from July 1st to Feb 1st is 7 months is 0.58 year,
$R_{l,t-1}$: recruitment into length class l in year $t-1$.

Discards

Discards are crabs that were caught by fisheries but were not retained, which consists of summer commercial, winter commercial and winter subsistence.

Summer and winter commercial discards

In summer ($D_{l,t}$) and winter ($D_{w,n,l,t}$, $D_{w,o,l,t}$) commercial fisheries, sublegal males (<4.75 inch CW and <5.0 inch CW since 2005) are discarded. Those discarded crabs are subject to handling mortality. The number of discards was not directly observed, and thus was estimated from the model as: Observed Catch x (estimated abundance of crab that are not caught by commercial pot)/(estimated abundance of crab that are caught by commercial pot)

Model discard mortality in length-class l in year t from the summer and winter commercial pot fisheries is given by

$$D_{l,t} = C_{s,t} \frac{(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - P_{r,l})}{\sum_l (N_{s,l,t} + O_{s,l,t}) S_{s,l} P_{r,l}} hm_s \tag{8}$$

$$D_{w,n,l,t} = C_{w,t} \frac{N_{w,l,t} S_{w,l} (1 - P_{lg,l})}{\sum_l (N_{w,l,t} + O_{w,l,t}) S_{w,l} P_{lg,l}} hm_w \tag{9}$$

$$D_{w,o,l,t} = C_{w,t} \frac{O_{w,l,t} S_{w,l} (1 - P_{lg,l})}{\sum_l (N_{w,l,t} + O_{w,l,t}) S_{w,l} P_{lg,l}} hm_w \tag{10}$$

where

hm_s: summer commercial handling mortality rate assumed to be 0.2,
hm_w: winter commercial handling mortality rate assumed to be 0.2,
$S_{s,l}$: Selectivity of the summer commercial fishery,
$S_{w,l}$: Selectivity of the winter commercial fishery,
$S_{r,l}$: Retention selectivity of the summer commercial fishery,

Winter subsistence Discards

Discards (unretained) of winter subsistence fishery is reported in a permit survey ($C_{d,t}$), though its size composition is unknown. We assumed that subsistence fishers discarded all crabs of length classes 1 -2.

$$D_{p,n,l,t} = C_{d,t} \frac{N_{w,l,t} S_{w,l}}{\sum_{l=1}^{2} (N_{w,l,t} + O_{w,l,t}) S_{w,l}} hm_w \tag{11}$$

$$D_{p,o,l,t} = C_{d,t} \frac{O_{w,l,t} S_{w,l}}{\sum_{l=1}^{2} (N_{w,l,t} + O_{w,l,t}) S_{w,l}} hm_w \tag{12}$$

$C_{d,t}$: Winter subsistence discards catch,

Recruitment

Recruitment of year t, R_t, is a stochastic process around the geometric mean, R_0:

$$R_t = R_0 e^{\tau_t}, \tau_t \sim N(0, \sigma_R^2) \tag{13}$$

R_t of the last year was assumed to be an average of previous 5 years: $R_t = (R_{t-1} + R_{t-2} + R_{t-3} + R_{t-4} + R_{t-5})/5$.

R_t was assumed to be newshell crab of immature (< 94mm) length classes 1 to r:

$$R_{r,t} = p_r \ R_t \tag{14}$$

where r takes multinomial distribution, same as the equation (2)

Molting Probability

Molting probability for length class l, m_l, was estimated as an inverse logistic function of length-class mid carapace length (L) and parameters (α, β) where β corresponds to L_{50}.

$$m_l = \frac{1}{1+e^{\alpha(L-\beta)}} \tag{15}$$

Trawl net, summer commercial pot,

Trawl and summer commercial pot selectivity was assumed to be a logistic function of mid-length-class, constrained to be 0.999 at the largest length-class (L_{max}):

$$S_l = \frac{1}{1+e^{(\alpha(L_{\max}-L)+\ln(1/0.999-1))}} \tag{16}$$

Winter pot selectivity

Winter pot selectivity was assumed to be a dome-shaped with inverse logistic function of length-class mid carapace length (L) and parameters (α, β) where β corresponds to L_{50}.

$$S_{w,l} = \frac{1}{1+e^{\alpha(L-\beta)}} \tag{17}$$

Selectivity of the length classes $S_{w,s}$ (S= l_1, l_2) were individually estimated.

Growth transition matrix

The growth matrix $G_{l',l}$ (the expected proportion of crab molting from length class l' to length class l) was assumed to be normally distributed:

$$G_{l',l} = \begin{cases} \dfrac{\int_{lm_l-h}^{lm_l+h} N(L \mid \mu_{l'}, \sigma^2)dL}{\sum_{l=1}^{n}\int_{lm_l-h}^{lm_l+h} N(L \mid \mu_{l'}, \sigma^2)dL} & \text{when } l \geq l' \\ 0 & \text{when } l < l' \end{cases} \tag{18}$$

Where

$$N(x \mid \mu_{l'}, \sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}}\exp\left(-\frac{(L-\mu_{l'})^2}{\sigma^2}\right)$$
$$lm_l = L_1 + st \cdot l$$
$$\mu_l = L_1 + \beta_0 + \beta_1 \cdot l$$

Observation model

Summer trawl survey abundance

Modeled trawl survey abundance of year *t* ($B_{st,t}$) is July 1st abundance subtracted by summer commercial fishery harvest occurring from July 1st to the mid-point of summer trawl survey, multiplied by natural mortality occurring between the mid-point of commercial fishery date and trawl survey date, and multiplied by trawl survey selectivity. For the first year (1976) trawl survey, the commercial fishery did not occur.

$$\hat{B}_{st,t} = \sum_l [(N_{s,l,t} + O_{s,l,t}) e^{-y_c M_l} - C_{s,t} P_{c,t} (P_{s,n,l,t} + P_{s,o,l,t})] e^{-(y_{st} - y_c) M_l} S_{st,l} \quad (19)$$

where
y_{st} : the time in year from July 1 to the mid-point of the summer trawl survey,
y_c: the time in year from July 1 to the mid-point for the catch before the survey, ($y_{st} > y_c$: Trawl survey starts after opening of commercial fisheries),
$P_{c,t}$: the proportion of summer commercial crab harvested before the mid-point of trawl survey date.
$S_{st,l}$: Selectivity of the trawl survey.

Winter pot survey CPUE

Winter pot survey cpue (f_{wt}) was calculated with catchability coefficient *q* and exploitable abundance:

$$\hat{f}_{wt} = q_w \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \quad (20)$$

Summer commercial CPUE

Summer commercial fishing CPUE (f_t) was calculated as a product of catchability coefficient *q* and mean exploitable abundance minus one half of summer catch, A_t:

$$\hat{f}_t = q_i (A_t - 0.5 C_t) \quad (21)$$

Because the fishing fleet and pot limit configuration changed in 1993, q_1 is for fishing efforts before 1993, q_2 is from 1994 to present.

Where A_t is exploitable legal abundance in year *t*, estimated as

$$A_t = \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} S_{r,l}] \quad (22)$$

Summer pot survey abundance (Removed from likelihood components)
Abundance of *t*-th year pot survey was estimated as

$$\hat{B}_{p,t} = \sum_l [(N_{s,l,t} + O_{s,l,t})\, e^{-y_p M_l}] S_{p,l} \qquad (23)$$

Where
y_p : the time in year from July 1 to the mid-point of the summer pot survey.
Length composition

Summer commercial catch

Length compositions of the summer commercial catch for new and old shell crabs $P_{s,n,l,t}$ and $P_{s,o,l,t}$, were modeled based on the summer population, selectivity, and legal abundance:

$$\hat{P}_{s,n,l,t} = N_{s,l,t} S_{s,l} S_{r,l} / A_t \qquad \text{(Alternative model)}$$
$$\hat{P}_{s,o,l,t} = O_{s,l,t} S_{s,l} S_{r,l} / A_t \qquad (24)$$

Summer commercial fishery discards (1977-1995)

Length/shell compositions of observer discards were modeled as

$$\hat{P}_{b,n,l,t} = N_{s,l,t} S_{s,l} (1 - P_{lg,l}) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - P_{lg,l})]$$
$$\hat{P}_{b,o,l,t} = O_{s,l,t} S_{s,l} (1 - P_{lg,l}) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - P_{lg,l})] \qquad (25)$$

Summer commercial fishery total catch (2012-present)

Length/shell compositions of observer discards were modeled as

$$\hat{P}_{t,n,l,t} = N_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}]$$
$$\hat{P}_{t,o,l,t} = O_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}] \qquad (26)$$

Summer trawl survey

Proportions of newshell and oldshell crab, $P_{st,n,l,t}$ and $P_{st,o,l,t}$ were given by

$$\hat{P}_{st,n,l,t} = \frac{[N_{s,l,t}\, e^{-y_c M_l} - C_{s,t}\, P_{c,t}\, \hat{P}_{s,n,l',t}] e^{-(y_{st}-y_c)M_l} S_{st,l}}{\sum_l [(N_{s,l,t} + O_{s,l,t}) e^{-y_c M_l} - C_{s,t} P_{c,t} (\hat{P}_{s,n,l',t} + \hat{P}_{s,o,l',t})] e^{-(y_{st}-y_c)M_l} S_{st,l}}$$
$$\hat{P}_{st,o,l,t} = \frac{[O_{s,l,t}\, e^{-y_c M_l} - C_{s,t}\, \hat{P}_{s,o,l',t}\, P_{c,t}] e^{-(y_{st}-y_c)M_l} S_{st,l}}{\sum_l [(N_{s,l,t} + O_{s,l,t}) e^{-y_c M_l} - C_{s,t} P_{c,t} (\hat{P}_{s,n,l,t} + \hat{P}_{s,o,l,t})] e^{-(y_{st}-y_c)M_l} S_{st,l}} \quad (27)$$

Winter pot survey

Winter pot survey length compositions for newshell and oldshell crab, $P_{sw,n,l,t}$ and $P_{sw,o,l,t}$ ($l \geq 1$) were calculated as

$$\hat{P}_{sw,n,l,t} = N_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}]$$
$$\hat{P}_{sw,o,l,t} = O_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \quad (28)$$

Spring Pot survey 2012-2015

Winter pot survey length compositions for newshell and oldshell crab, $P_{sw,n,l,t}$ and $P_{sw,o,l,t}$ ($l \geq 1$) were assumed to be supper crab population caught by winter pot survey gears

$$\hat{P}_{sp,n,l,t} = N_{s,l,t} S_{w,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{w,l}]$$
$$\hat{P}_{sp,o,l,t} = O_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{w,l}] \quad (29)$$

Estimates of tag recovery

The proportion of released tagged length class *l'* crab recovered after *t-th* year with length class of *l* by a fishery of *s-th* selectivity (S_l) was assumed to be proportional to the growth matrix, catch selectivity, and molting probability (m_l) as

$$\hat{P}_{l',l,t,s} = \frac{S_l \cdot [X^t]_{l',l}}{\sum_{l=1}^{n} S_l \cdot [X^t]_{l',l}} \quad (30)$$

where X is a molting probability adjusted growth matrix with each component consisting of

$$X_{l',l} = \begin{cases} m_{l'} \cdot G_{l',l} & \text{when } l' \neq l \\ m_l \cdot G_{l',l} + (1\text{-}m_i) & \text{when } l' = l \end{cases} \quad (31)$$

c. Likelihood components.

Under assumptions that measurement errors of annual total survey abundances and summer commercial fishing efforts follow lognormal distributions and each type of length composition has a multinomial error structure (Fournier and Archibald 1982; Methot 1989), the log-likelihood function is

$$\sum_{i=1}^{i=4}\sum_{t=1}^{t=n_i} K_{i,t}\left[\sum_{l=1}^{l=n} P_{i,l,t}\ln(\hat{P}_{i,l,t}+\kappa) - \sum_{l=1}^{l=n} P_{i,l,t}\ln(P_{i,l,t}+\kappa)\right]$$
$$-\sum_{t=1}^{t=n_i}\frac{[\ln(q\cdot\hat{B}_{i,t}+\kappa)-\ln(B_{i,t}+\kappa)]^2}{2\cdot ln(CV_{i,t}^2+1)}$$
$$-\sum_{t=1}^{t=n_i}\left[\frac{\ln\left[\ln(CV_t^2+1)+w_t\right]}{2}+\frac{[\ln(\hat{f}_t+\kappa)-\ln(f_t+\kappa)]^2}{2\cdot\left[\ln(CV_t^2+1)+w_t\right]}\right] \quad (32)$$
$$-\sum_{t=1}\frac{\tau_t^2}{2\cdot SDR^2}$$
$$+W\sum_{s=1}^{s=2}\sum_{t=1}^{t=3}\sum_{l'=1}^{l'=n} K_{l',t,s}\left[\sum_{l=1}^{l=n} P_{l',l,t}\ln(\hat{P}_{l',l,t,s}+\kappa) - \sum_{l=1}^{l=n} P_{l',l,t}\ln(P_{l',l,t,s}+\kappa)\right]$$

where

i: length/shell compositions of :

1 triennial summer trawl survey,
2 annual winter pot survey,
3 summer commercial fishery retained catch,
4 observer discards or total catch during the summer fishery
5 spring pot survey.

$K_{i,t}$: the effective sample size of length/shell compositions for data set i in year t,
$P_{i,l,t}$: observed and estimated length compositions for data set i, length class l, and year t.
κ : a constant equal to 0.0001,
CV : coefficient of variation for the survey abundance,
$B_{i,k,t}$: observed and estimated annual total abundances for data set i and year t,
f_t : observed and estimated summer fishing CPUE,
w^2_t: extra variance factor,
SDR : Standard deviation of recruitment = 0.5,
$K_{l',t}$: sample size of length class l' released and recovered after t-th in year,
$P_{l',l,t,s}$: observed and estimated proportion of tagged crab released at length l' and recaptured at length l, after t-th year by commercial fishy pot selectivity s,
W: weighting for the tagging survey likelihood

It is generally believed that total annual commercial crab catches in Alaska are fairly accurately reported. Thus, total annual catch was assumed known.

b. Software used: AD Model Builder (Fournier et al. 2012).

d. Parameter estimation framework:

i. Parameters Estimated Independently

The following parameters were estimated independently: natural mortality (M =0.18), proportions of legal males by length group.

Natural mortality was based on an assumed maximum age, t_{max}, and the 1% rule (Zheng 2005):

$$M = -\ln(p)/t_{\max},$$

where p is the proportion of animals that reach the maximum age and is assumed to be 0.01 for the 1% rule (Shepherd and Breen 1992, Clarke et al. 2003). The maximum age of 25, which was used to estimate M for U.S. federal overfishing limits for red king crab stocks results in an estimated M of 0.18. Among the 199 recovered crabs from the tagging returns during 1991-2007 in Norton Sound, the longest time at liberty was 6 years and 4 months from a crab tagged at 85 mm CL. The crab was below the mature size and was likely less than 6 years old when tagged. Therefore, the maximum age from tagging data is about 12, which does not support the maximum age of 25 chosen by the CPT.

Proportions of legal males (CW > 4.75 inches) by length group were estimated from the ADF&G trawl data 1996-2011 (Table 11).

ii. Parameters Estimated Conditionally

Estimated parameters are listed in Table 10. Selectivity and molting probabilities based on these estimated parameters are summarized in Tables 11.

A likelihood approach was used to estimate parameters

e. Definition of model outputs.

i. Estimate of mature male biomass (MMB) is on **February 1st** and is consisting of the biomass of male crab in length classes 4 to 8

$$MMB = \sum_{l=4} (N_{w,l,} + O_{w,l,}) wm_l$$

wm_l: mean weight of each length class (Table 11).

ii. Projected legal male biomass for winter and summer fishery OFL was calculated as

$$Legal\_B = \sum_{l} (N_{w,l,} + O_{w,l,}) S_{s,l} P_{lg,l} wm_l \text{ Baseline model}$$

$$Legal\_B = \sum_l (N_{w,l,} + O_{w,l,}) S_{s,l} S_{r,l} wm_l \text{ Alternative model}$$

iii. Recruitment: the number of males in length classes 1, 2, and 3.

iv.

f. OFL

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

$$OFL_r = \text{Winter harvest (Hw)} + \text{Summer harvest (Hs)} \quad (1)$$

And

$$p = \frac{Hw}{OFL_r} \quad (2)$$

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

At given fishery mortality (F_{OFL}), Winter harvest is a fishing mortality

$$Hw = (1 - e^{-x \cdot F})B_w \quad (3)$$

$$Hs = (1 - e^{-(1-x) \cdot F})B_s \quad (4)$$

where B_s is a summer crab biomass after winter fishery and x ($0 \le x \le 1$) is a fraction that satisfies equation (2)

Since B_s is a summer crab biomass after winter fishery and 5 months of natural morality ($e^{-0.42M}$)

$$\begin{aligned} B_s &= (B_w - Hw)e^{-0.42M} \quad (5) \\ &= (B_w - (1 - e^{-x \cdot F})B_w)e^{-0.42M} \\ &= B_w e^{-x \cdot F - 0.42M} \end{aligned}$$

Substituting *0.42M* to *m*, summer harvest is

$$\begin{aligned} Hs &= (1 - e^{-(1-x) \cdot F})B_s \quad (6) \\ &= (1 - e^{-(1-x) \cdot F})B_w e^{-x \cdot F - m} = (e^{-(x \cdot F + m)} - e^{-(F+m)})B_w \end{aligned}$$

Thus, OFL is

$$\begin{aligned} OFL &= Hw + Hs = (1 - e^{-xF})B_w + (e^{-(x \cdot F + m)} - e^{-(F+m)})B_w \quad (7) \\ &= (1 - e^{-xF} + e^{-(xF+m) \cdot} - e^{-(F+m) \cdot})B_w \\ &= [1 - e^{-(F+m) \cdot} - (1 - e^{-m \cdot})e^{-xF \cdot}]B_w \end{aligned}$$

Combining (2) and (7),

$$p = \frac{Hw}{OFL_r} = \frac{(1-e^{-xF})B_w}{[1-e^{-(F+m)\cdot} - (1-e^{-m\cdot})e^{-xF\cdot}]B_w} \tag{8}$$

Solving (8) for x

$$\begin{aligned}
&(1-e^{-xF}) = p[1-e^{-(F+m)\cdot} - (1-e^{-m\cdot})e^{-xF\cdot}] \\
&e^{-xF} - p(1-e^{-m\cdot})e^{-xF\cdot} = 1 - p[1-e^{-(F+m)\cdot}] \\
&[1-p(1-e^{-m\cdot})]e^{-xF\cdot} = 1 - p[1-e^{-(F+m)\cdot}] \\
&e^{-xF\cdot} = \frac{1-p[1-e^{-(F+m)\cdot}]}{1-p(1-e^{-m\cdot})}
\end{aligned} \tag{9}$$

Combining (7) and (9), and substituting back,

revised retained OFL is

$$OFL = Legal\_B_w\left(1-e^{-(F_{OFL}+0,42M)} - (1-e^{-0.42M})\left(\frac{1-p(1-e^{-(F_{OFL}+0.42M)})}{1-p(1-e^{-0.42M})}\right)\right)$$

Further combining (3) and (9), Winter fishery harvest rate (Fw) i

$$\begin{aligned}
Fw &= (1-e^{-x\cdot F}) = 1 - \frac{1-p[1-e^{-(F+m)\cdot}]}{1-p(1-e^{-m\cdot})} = \frac{1-p(1-e^{-m\cdot}) - 1 + p[1-e^{-(F+m)\cdot}]}{1-p(1-e^{-m\cdot})} \\
&= \frac{p(e^{-m\cdot} - e^{-(F+m)\cdot})}{1-p(1-e^{-m\cdot})} = \frac{p(1-e^{-F\cdot})e^{-0.42M\cdot}}{1-p(1-e^{-0.42M\cdot})}
\end{aligned} \tag{10}$$

Summer fishery harvest rate (Fs) is

$$\begin{aligned}
Fs &= (e^{-(x\cdot F+m)} - e^{-(F+m)}) = (e^{-x\cdot F} - e^{-F})e^{-m} \\
&= \left(\frac{1-p[1-e^{-(F+m)\cdot}]}{1-p(1-e^{-m\cdot})} - e^{-F}\right)e^{-m} \\
&= \left(\frac{1-p[1-e^{-(F+m)\cdot}] - e^{-F} + p(e^{-F} - e^{-(F+m\cdot)})}{1-p(1-e^{-m\cdot})}\right)e^{-m} \\
&= \left(\frac{1-p+pe^{-(F+m)\cdot} - e^{-F} + pe^{-F} - pe^{-(F+m\cdot)}}{1-p(1-e^{-m\cdot})}\right)e^{-m} \\
&= \frac{(1-p)(1-e^{-F})e^{-m}}{1-p(1-e^{-m\cdot})} = \frac{(1-p)(1-e^{-F})e^{-0.24M}}{1-p(1-e^{-0.24M\cdot})}
\end{aligned} \tag{11}$$

Appendix B. Norton Sound Red King Crab CPUE Standardization

Note: This is an update of model by G. Bishop (SAFE 2013).

Methods

Data Source & Cleaning

Commercial fishery harvest data were obtained from ADF&G fish ticket database, which included: Landing Date, Fish Ticket Number, Vessel Number, Permit Fishery ID, Statistical Area(s) fished, Effort, and Number and Pounds of Crab harvested (Table A2-1,2,3, Figure A2-1). Fish ticket database may have multiple entries of identical Fish Ticket Number, Vessel Number, Permit Fishery ID, and Statistical Area. In those cases, at least one Effort data are missing or zero with the Number and Pounds of Crab harvested. These entries indicate that crab were either retained from the commercial fishery (i.e., not sold), or dead loss.

Following data cleaning and combining methods were conducted.

1. Sum crab number and efforts by Fish Ticket Number, Vessel Number, Permit Fishery ID, Statistical Area.
2. Remove data of missing or zero Efforts, Number of Crab, Pounds of Crab (Those are considered as true missing data).
3. Calculate CPUE as Number of Crab/Effort.

Data Censoring

During 1977-92 period, vessels of 1 year of operation and/or 1 delivery per year harvested 20-90% of crab (Table A2-5, Figure A2-2). For instance, all vessels did only 1 delivery in 1989, and in 1988 64% of crab were harvested by 1 vessel that did only 1 delivery. On the other hand, during the 1993-2017 period of post super-exclusive fishery status, the majority of commercial crab fishery and harvest was done by vessels with more than 5 years of operations and more than 5 deliveries per year. For 1977 – 1992, censoring was made for vessels of more than 2 years of operations. Increasing deliveries to more than one would result in no estimates for some years. For 1993 – 2018, censoring was made for vessels of more than 5 years of operations and 5 deliveries per year.

Analyses

A GLM was constructed as

$$\ln(CPUE) = YR + PD + VSL + MSA + WOY + PF$$

Where YR: Year, PD: Fishery periods (1977-1992, 1993-2004,2005-2018), VSL: Vessel, MSA: Statistical Area, WOY: Week of Year, and PF: Permit vs open fishery (Table 1). All variables were treated as categorical. Inclusion of interaction terms was not considered because they were absent (SAFE 2013).

For selection of the best model, forward and backward stepwise selection was conducted. (R step function)

```
fit <- glm(L.CPUE.NO ~ factor(YR) + factor(VSL) + factor(WOY) +
factor(MSA) + factor(PF) + factor(PD),,data=NSdata.C)
step <- step(fit, direction='both', trace = 10)
best.glm<-glm(formula(step), data=NSdata.C)
```

Table B-13. List of variables in the fish ticket database. Variables in bold face were used for generalized linear modeling.

Variable	Description
YR	Year of commercial fishery
VSL	Unique vessel identification number
Fish Ticket Number	Unique delivery to a processor by a vessel
PF	Unique Permit Fishery categories
PD	Fishery period: 1977-1992, 1993-2004,2005-2018
Statistical Area	Unique fishery area.
MOA	Modified statistical area, combining each statistical area into 4 larger areas: Inner, Mid, Outer, Outer North
Fishing Beginning Date	Date of pots set
Landing Date	Date of crab landed to processor
WOY	Week of Landing Date **(calculated)**
Effort	The number of pot lift
Crab Numbers	Total number of crabs harvested from pots
Crab Pounds	Total pounds of crab harvested from pots
ln(CPUE)	ln(Crab Numbers/Effort) **(calculated)**

Table B-2. Permit fisheries, descriptions, and years with deliveries for Norton Sound summer commercial red king crab harvest data.

Permit fishery	Type	Description	Years
K09Q	Open access	KING CRAB , POT GEAR VESSEL UNDER 60', BERING SEA	1994–2002
K09Z	Open access	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND	1992–2017
K09ZE	CDQ	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND CDQ, NSEDC	2000–2017
K09ZF	CDQ	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND CDQ, YDFDA	2002–2004
K91Q	Open access	KING CRAB , POT GEAR VESSEL 60' OR OVER, BERING SEA	1978–1989
K91Z	Open access	KING CRAB , POT GEAR VESSEL 60' OR OVER, NORTON SOUND	1982–1994

Table B-3. Modified statistical area definitions used for analysis of Norton Sound summer commercial red king crab harvest data.

Modified statistical area	Statistical areas included
Inner	616331, 616401, 626331, 626401, 626402
Mid	636330, 636401, 636402, 646301, 646330, 646401, 646402
Outer	656300, 656330, 656401, 656402, 666230, 666300, 666330, 666401
Outer North	666402, 666431, 676300, 676330 ,676400, 676430, 676501, 686330

Table B-4. Final generalized linear model formulae and AIC selected for Norton Sound summer commercial red king crab fishery. The dependent variable is ln(CPUE) in numbers.

Var	Df	Deviance	Resid DF	Resid Dev	AIC
YR	41	1312.43	6274	5082.7	
VSL	90	574.57	6143	3770.3	
WOY	15	82.89	6129	3195.7	
MSA	3	65.83	6125	3047.0	
PF	6	20.14	6119	3026.9	13547
+PD+MOY	3				13547.67

Table B-5. Standardized (censored/full data), and scaled arithmetic observed CPUE indices.

Year	Censored	
	CPUE	SE
1977	3.29	0.68
1978	4.68	0.65
1979	2.87	0.64
1980	3.07	0.65
1981	0.86	0.64
1982	0.20	0.62
1983	0.90	0.65
1984	1.59	0.65
1985	0.50	0.66
1986	1.74	0.70
1987	0.61	0.64
1988	2.36	0.86
1989	1.21	0.61
1990	1.08	0.68
1991		
1992	0.17	0.60
1993	0.90	0.35
1994	0.81	0.34
1995	0.42	0.34
1996	0.51	0.34
1997	0.84	0.35
1998	0.79	0.36
1999	0.92	0.36
2000	1.24	0.34
2001	0.64	0.34
2002	1.23	0.34
2003	0.85	0.34
2004	1.27	0.34
2005	1.19	0.34
2006	1.31	0.34
2007	1.02	0.34
2008	1.32	0.34
2009	0.84	0.34
2010	1.22	0.34
2011	1.58	0.34
2012	1.29	0.34
2013	0.67	0.33
2014	1.12	0.34
2015	1.45	0.34
2016	1.27	0.34
2017	1.10	0.34
2018	0.64	0.34

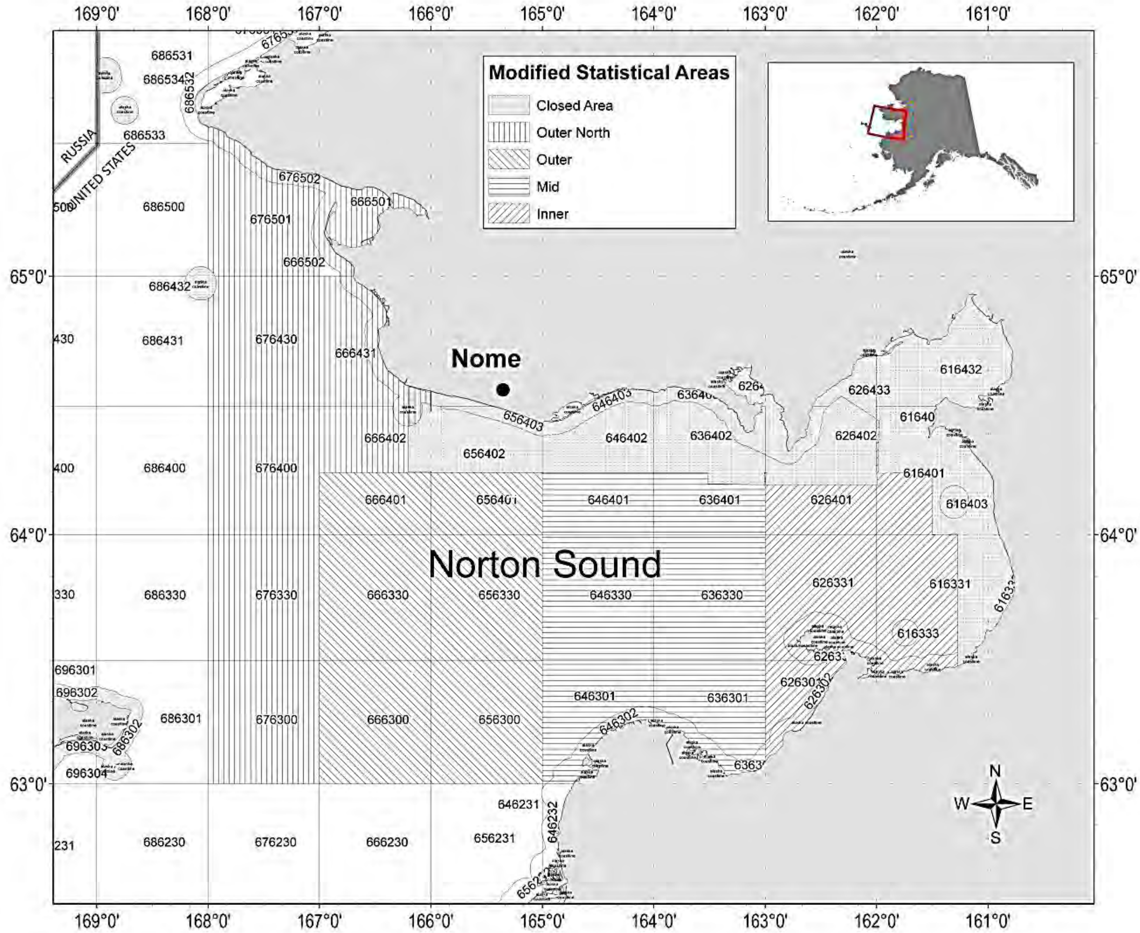


Figure A2-1. Closed area and statistical area boundaries used for reporting commercial harvest information for red king crab in Registration Area Q, Northern District, Norton Sound Section and boundaries of the new *Modified Statistical Areas* used in this analysis.

Appendix C. Norton Sound Red King Crab Summer Commercial fishery Discards Estimation

Formal methodologies have not been established for estimating Red King Crab discards by Norton Sounds Summer commercial fishery from observer data. Here, I describe a few methods and discuss pros and cons of each method.

Data source and description of survey protocols

Norton Sound Summer Commercial fishery observer survey started in 2009 as a potential feasibility project, and formal data collection started since 2012. The observer survey in Norton Sound is voluntary. Due to small boat size, the boat that can take a fishery observer is limited. Fishery observer often work as a crew member. During the fishery, an observe inspect every pots. All lengths/shell condition/sex of red king crab in the pots were measured, and the fisherman sorts out discards that are noted. **Observed discarded crabs are deemed accurate.** However, it is uncertain whether fishing behaviors of the volunteer fishermen are the same as other unobserved fishermen. Observed fishermen tend to have large boat and catcher and sellers. Here are possible concerns:

1. The observed fishermen may go to better fishing grounds with more legal crab and less sub-legals: **higher legal retain CPUE and lower discards CPUE than unobserved (lower discards proportion)**
2. The observed fishermen may not mind sorting out crabs and may choose areas: **higher legal retain CPUE and higher discards CPUE than unobserved (higher discards proportion)**
3. The observed fishermen may keep more legal crabs that are not accepted by NSEDC: **lower discards CPUE than unobserved (lower discards proportion)**

Data Source & Cleaning

From 2012 to 2018, crab catches of 3-4 volunteer crab fishing vessels were observed. Annual observed pots ranged 69 to 199 and total observed crabs ranging from 2200 to 5300 (Table 1). All observed data were combined.

Estimation Methods

Two methods were considered: CPUE and Proportion method. CPUE method expands observed CPUE (Observed number of crab)/(observed pots) to all fisheries pot lifts, whereas proportional method expands observed proportion of discards to retained: (observed number of discards)/(observed number of retained) to all fisheries retained catch.

CPUE has two methods: LNR and Subtraction. LNR simply expands CPUE of discards, whereas Subtraction expands CPUE of total catch and subtract total retained catch.

LNR method

LNR method simply expands CPUE of discards to total pot lifts

$$CPUE_{obs} = \frac{(N_{obs,sub} + N_{obs,ld})}{P_{obs}}$$

Where $N_{obs,\ sub}$ and $N_{obs,\ ld}$ are observed number of sublegal and legal crabs discarded, and P_{obs} is the number of pot-lifts by the observed fishermen during the observed period.

$$D_{LNR} = CPUE_{obs} \cdot P_{FT.total}$$

Where $P_{FT.total,}$ is total number of pot lifts of all fishermen recorded in fish tickets.

Observer bias corrected LNR method adds correction to CPUE of the observed fishermen by multiplying the CPUE ratio between observed fishermen ($CPUE_{FT.obs}$) and unobserved fishermen ($CPUE_{FT.unobs}$) derived from fish tickets.

$$CPUE_{FT.obs} = \frac{(N_{FT.obs})}{P_{FT.obs}} \qquad CPUE_{FT.unobs} = \frac{(N_{FT.unobs})}{P_{FT.unobs}}$$

Where $N_{FT.obs}$ and $N_{FT.unobs}$ are total number of crab delivered (thorough out season) by observed and unobserved fishermen, and $P_{FT.obs}$ and $P_{FT.unobs}$ total number of pot lifts by observed and unobserved fishermen.

$$D_{LNR2} = \left(\frac{CPUE_{FT.unobs}}{CPUE_{FT.obs}} \right) \cdot D_{LNR}$$

Subtraction method

Subtraction method expands total catch CPUE and subtract total retained catch

$$CPUE_{T.obs} = \frac{(N_{obs})}{P_{obs}}$$

Where N_{obs} is a total number of crab caught by the observed fishermen during the observed period.

$$D_{Sub} = CPUE_{T.obs} \cdot P_{FT.total} - N_{FT.total}$$

Where $N_{FT.total}$ is the total number of retained crab during the season.

Bias corrected Subtraction method is simply bias corrected total catch minus retained catch

$$D_{Sub2} = \left(\frac{CPUE_{FT.unobs}}{CPUE_{FT.obs}} \right) CPUE_{T.obs} P_{FT.total} - N_{FT.total}$$

Finally, the proportion method that expands ratio of discards to retained.

$$D_{prop} = \frac{(N_{obs,sub} + N_{obs,ld})}{N_{obs,lr}} N_{FT.total}$$

Where $N_{obs.lr}$ is observed number of retained legal crabs by observed fishermen during the observed periods.

In assessment model, total number of crabs discarded by summer commercial fishery is modeled as

$$D_{l,t} = \frac{\widehat{N}_{F.D}}{\widehat{N}_{F.R}} N_{FT.total}$$

where $N_{F.R}$ and $N_{F.D}$ are model estimated number of crab retained and discarded, which is essentially the same ss proportional method.

Results

While general annual discards trends were similar among the 3 methods, the number of discards differed (Table 2). Overall, the Subtraction method estimated the highest and the Proportional method estimated the lowest. Bias correction method (LNR2, Sub2) reduced high by discards estimates of 2013 and 2015.

Discussion

The CPUE method assumes that observed CPUE would represent total CPUE or that there is no difference in CPUE between observed and unobserved fishermen. Difference between LNR and Subtraction method is that LNR method assumes that observed discards are accurate whereas subtraction method assumes that observed discards are biased but observed total catches are accurate. On the other hand, the proportional method assumes that observed discards proportions would represent total proportion or that every fisherman has similar crab composition.

In Norton Sound observer survey, discarded crabs are more likely accurate because separation of retained vs discards are often done in corporation with the fishermen. However, fishermen and timing of observation are limited to convenience of volunteer fishermen who have larger boat (so that observer can be on board) and are high also catchers. They would be more efficient in catching legal crabs with fewer discards than those with small boats. They would also take observers when they expect higher catch.

In fact, season total retained legal crab CPUE by observed fishermen were generally higher than other unobserved fishermen (Table 2). Furthermore, their CPUE was generally higher during the periods when observers were on board. Observed fishermen appeared to go different fishing area from those of all fishermen (Table 4). Those suggest that subtraction method would probably overestimate discards. Direction of bias for LNR and proportional methods are difficult to evaluate. If the observed fishermen tend to better avoid catching sublegal crabs (e.g., lower sublegal proportion), the proportional method would underestimate discard catch. But, as they have higher catch CPUE, their discards catch CPUE could still be higher than those of unobserved fishermen. Then, discards catch estimate by LNR method could overestimate as well as underestimate.

Table 14. Observed pot lifts, catch, and total pot lifts and catch from 2012 to 2018

	Observer Survey					Fish Tickets	
	Pot lifts	Sublegal	Legal retained	Legal discards		pot lifts	Retained
Year	P_{obs}	$N_{obs.sub}$	$N_{obs.lr}$	$N_{obs.ld}$	Female	$P_{FT.total}$	$N_{FT.total}$
2012	78	898	1055	177	152	10041	161113
2013	199	2775	2166	258	123	15058	130603
2014	147	1504	1838	341	104	10127	129656
2015	69	969	1676	577	224	8356	144224
2016	67	264	1700	169	878	8,009	138997
2017	110	432	2174	122	373	9440	135322
2018	78	547	1096	10	574	8797	89613
2019	28	123	142	1	89	5436	24913

Table 2. Retained Crab CPUE between observed (CPUE.ob) during the observer survey, and season total CPUE between observed and unobserved fishermen derived from fish ticket data.

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

Table 3. The number of discarded crab estimated by 5 methods.

Year	LNR	LNR2	Sub	Sub2	Prop	Model
2012	138386	150043	113084	136182	164167	94564
2013	229502	173750	262797	167229	182880	120486
2014	127104	104697	124070	79340	130150	147066
2015	187223	135910	245965	139023	133037	88430
2016	51760	32965	115976	23394	35403	50228
2017	47543	34870	98790	36384	34484	46441
2018	62820	60714	96816	90566	45542	45848
2019	24074	23362	26729	24203	21755	28887

Table 4. Average legal crab proportion caught by 2012-2018 trawl survey and Summer commercial harvest proportion in major fishing stat area

	Catch proportion	
STAT Area	All fishermen	Observed Fishermen
666401	15%	7%
656401	21%	18%
646401	19%	46%
636401	33%	19%
626401	15%	2%

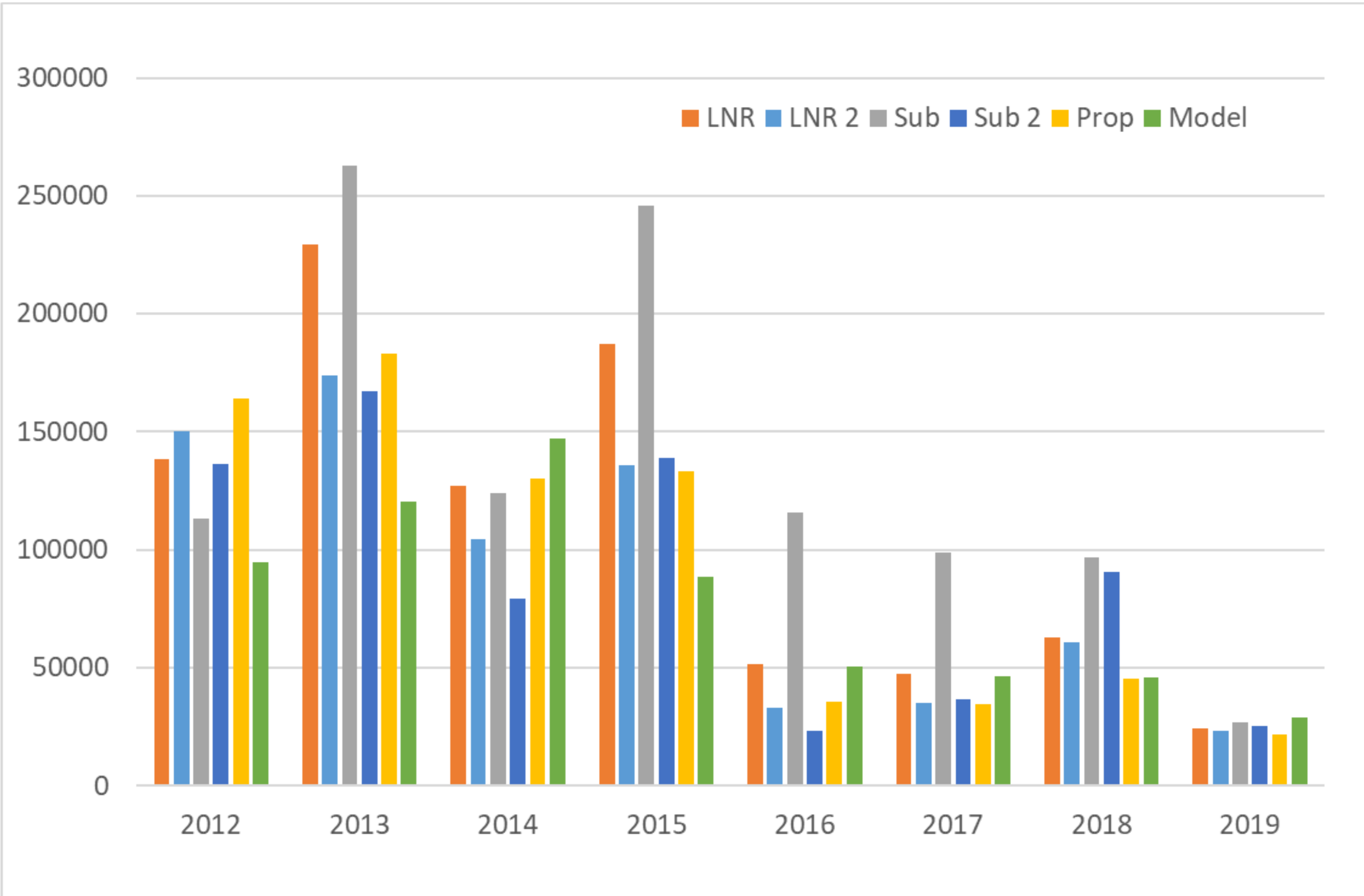


Figure 1. The number of discarded crab estimated by 3 methods.

Appendix D – Model 19.0

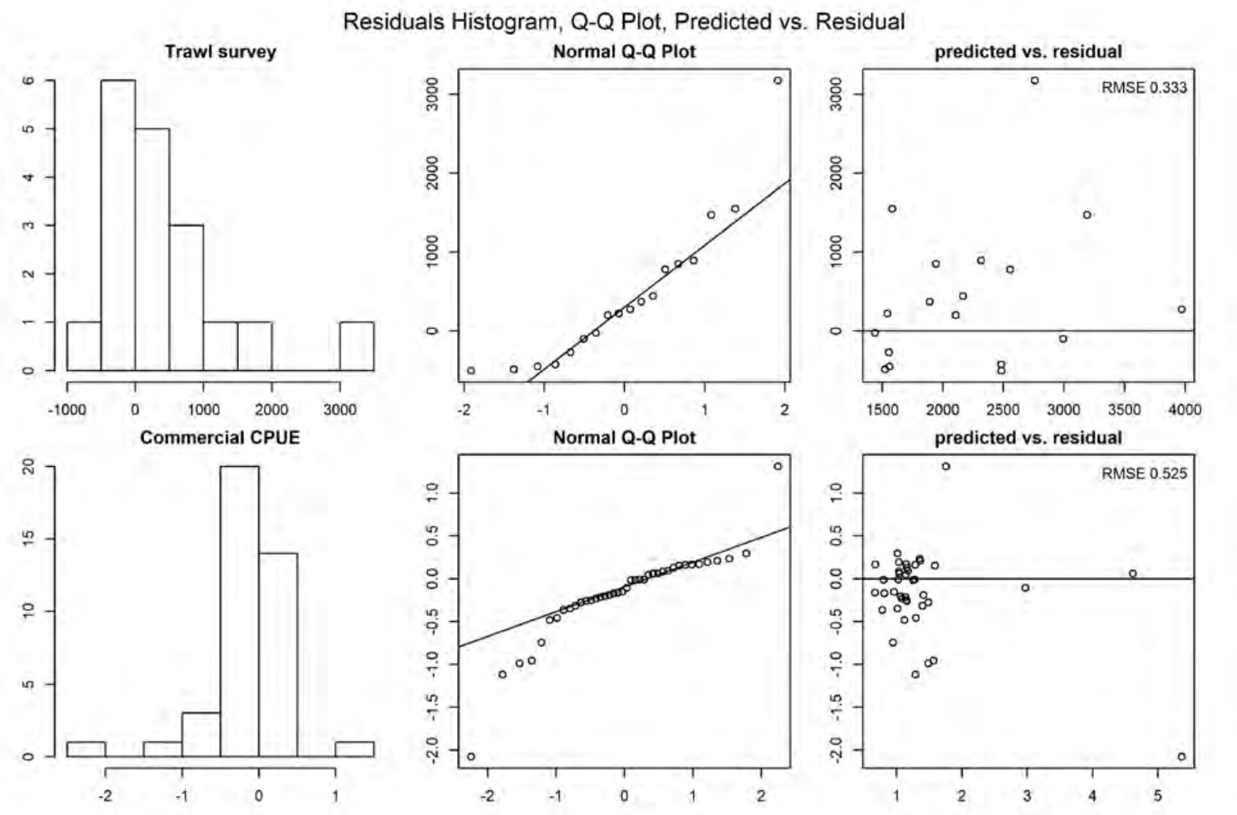


Figure D1-1. QQ plot of trawl survey and commercial CPUE.

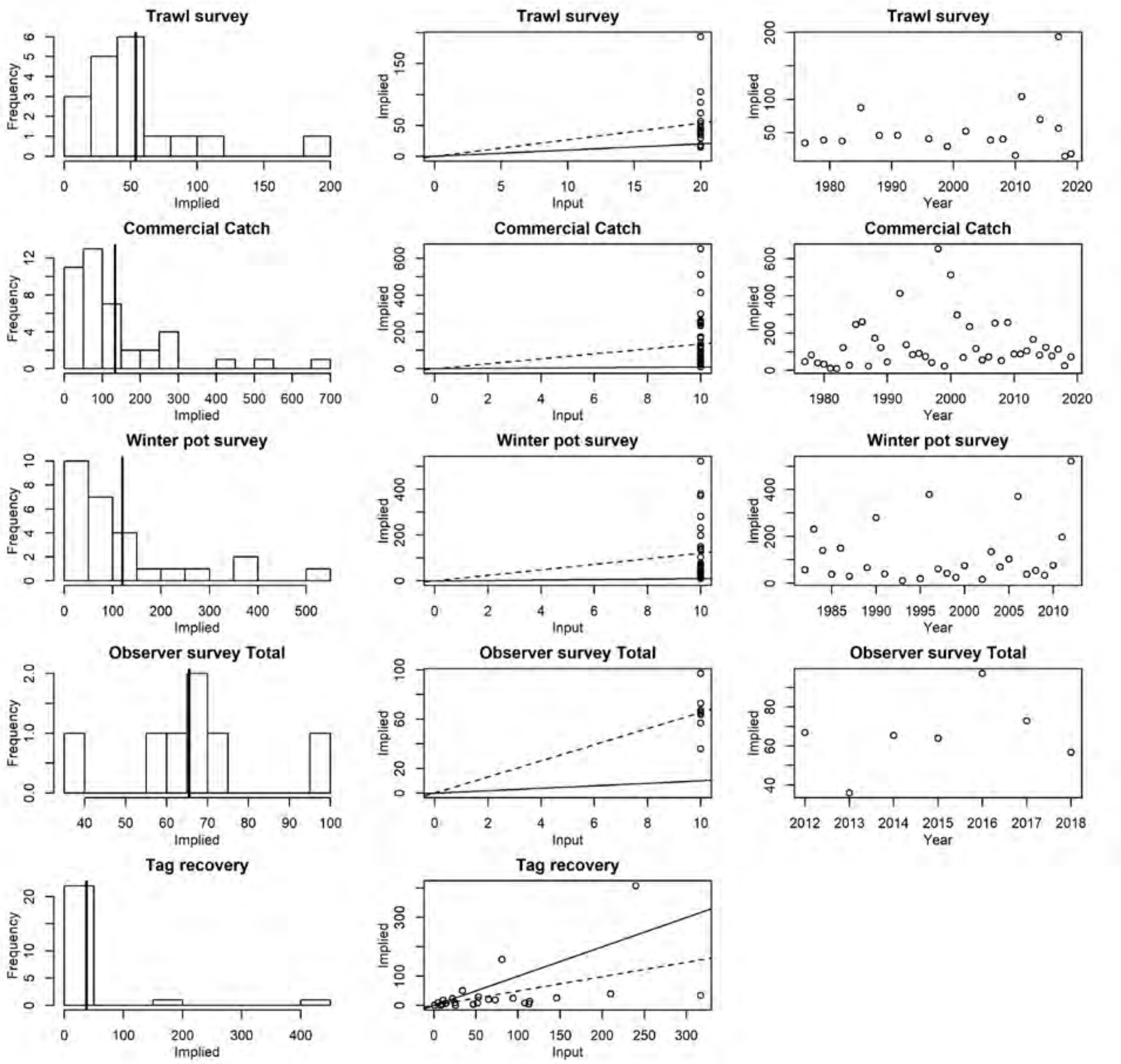


Figure D1-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

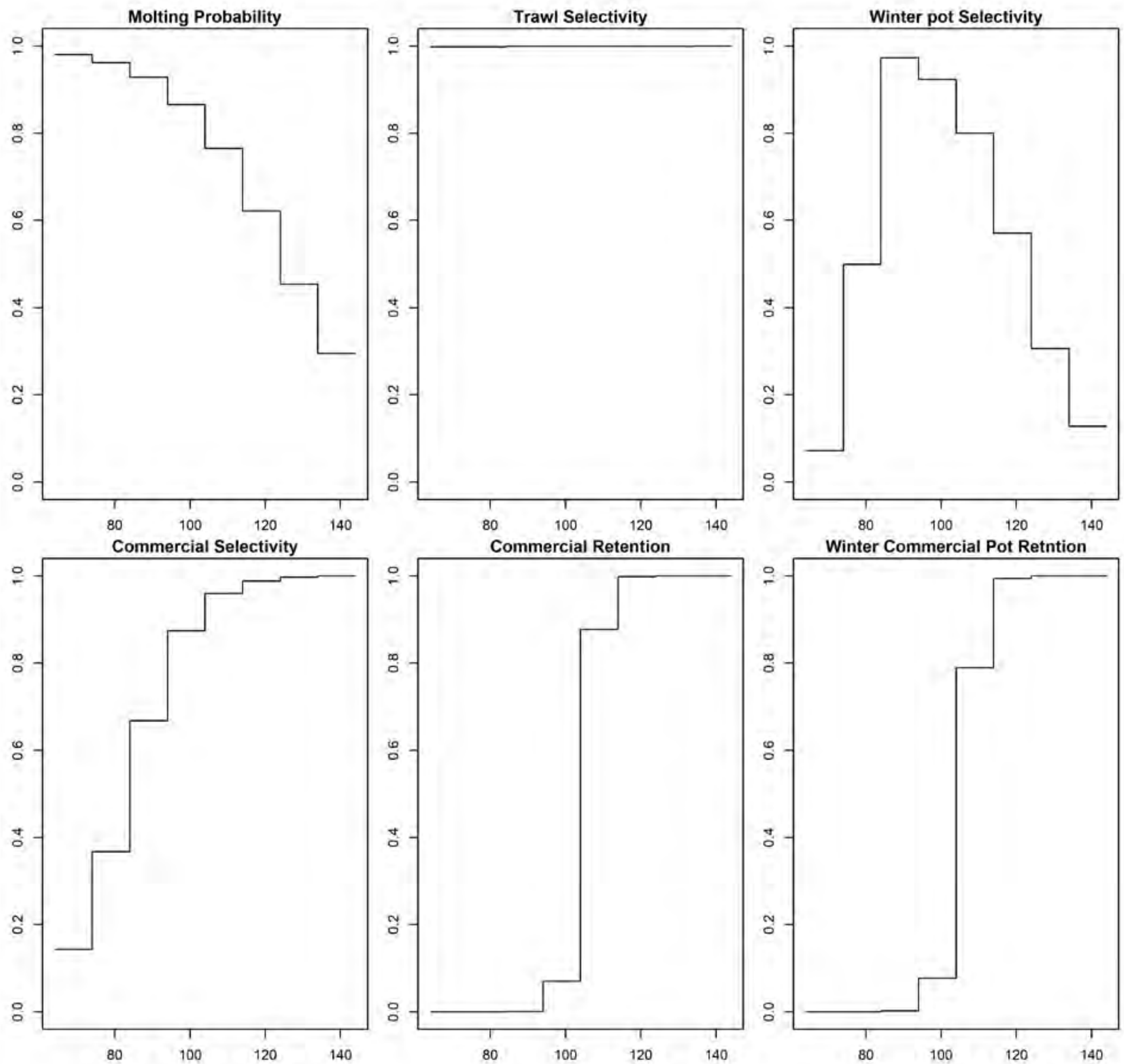


Figure D1-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

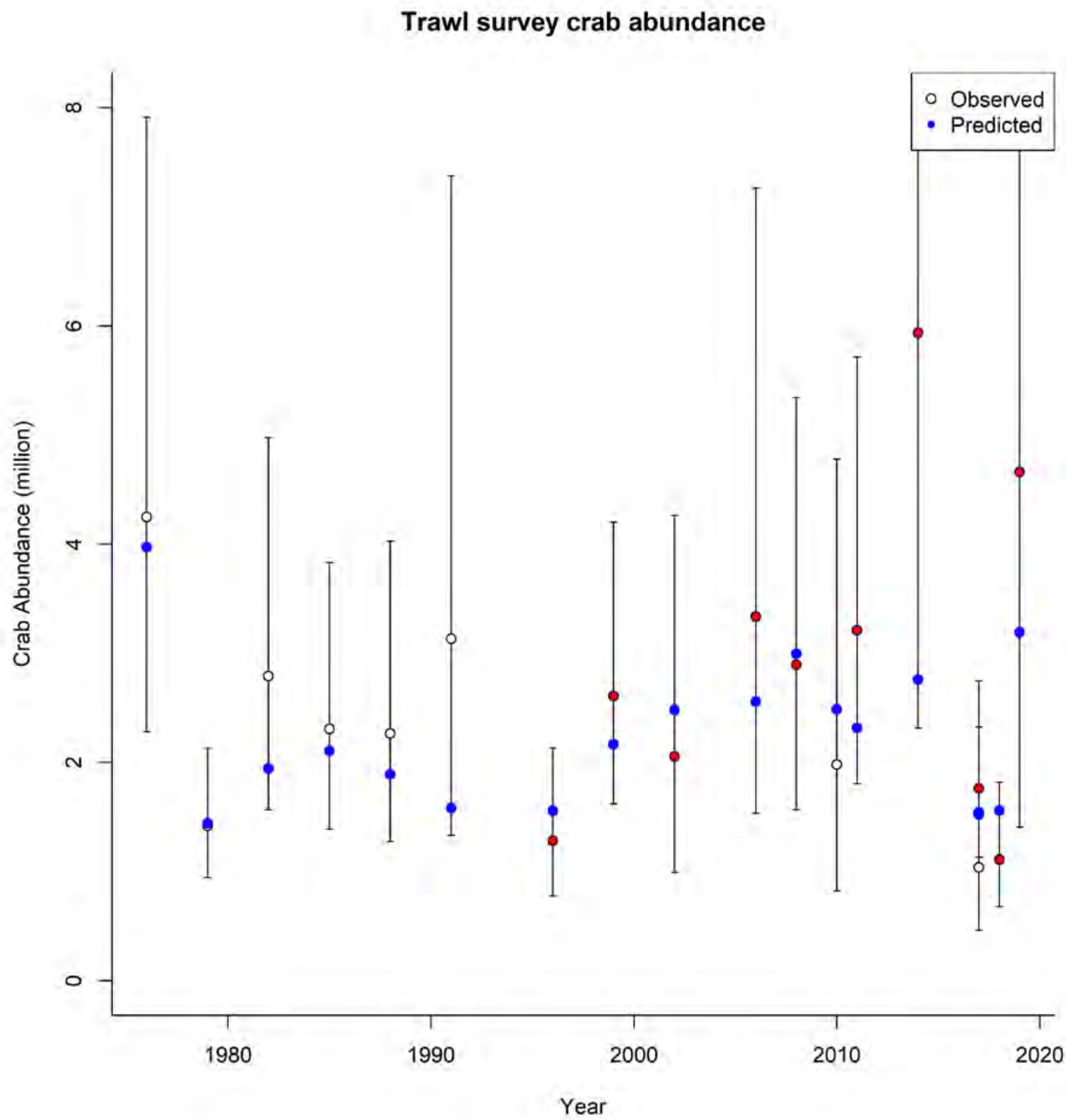


Figure D1-4. Estimated trawl survey male abundance (blue). Observed: white: NOAA trawl Survey, red: ADG&G trawl survey

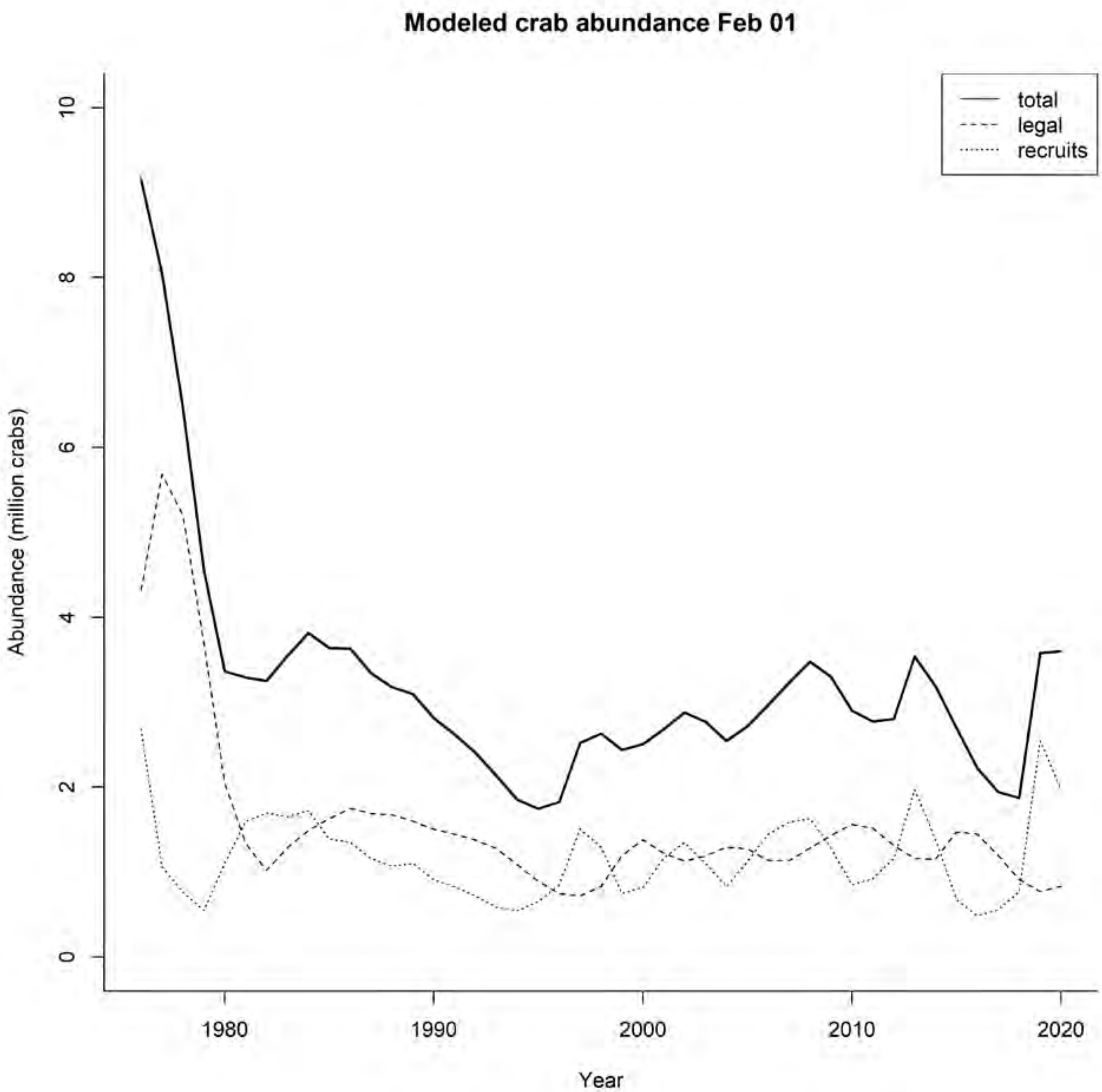


Figure D1-5. Estimated abundance of legal males.

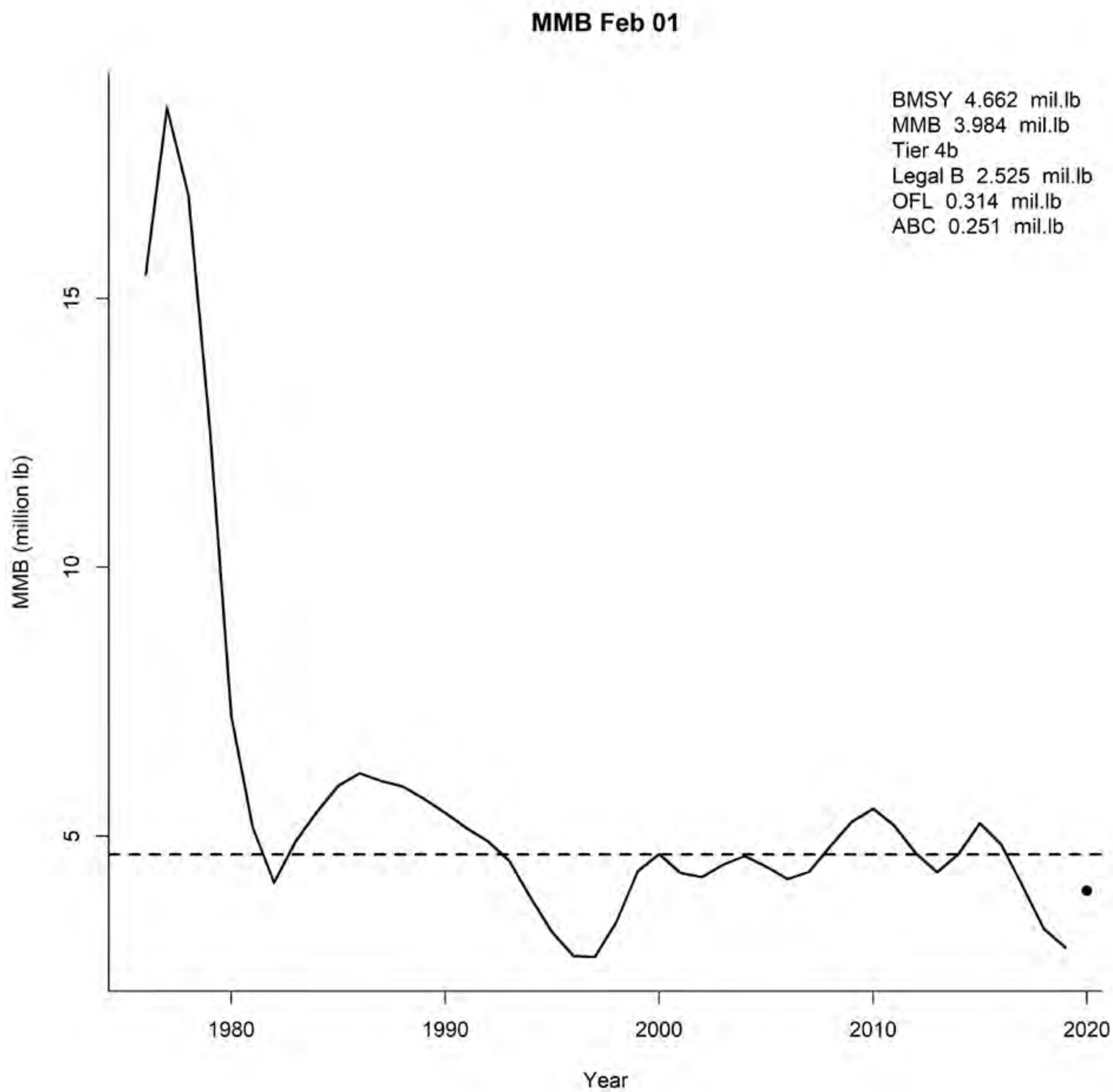


Figure D1-6. Estimated mature male biomass. Dash line shows Bmsy.

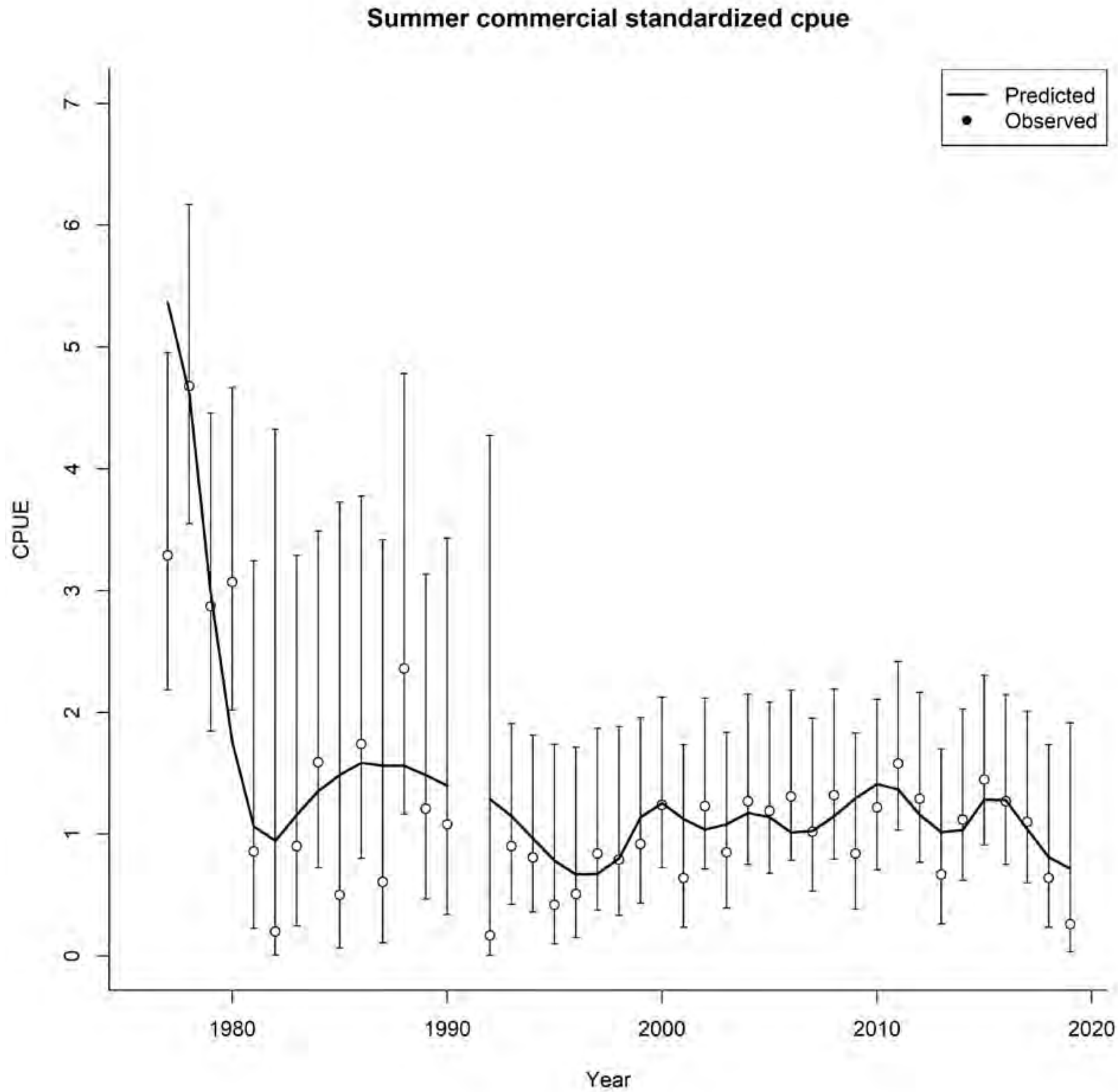


Figure D1-7. Summer commercial standardized cpue. Vertical line incicates lognormal 95%CI

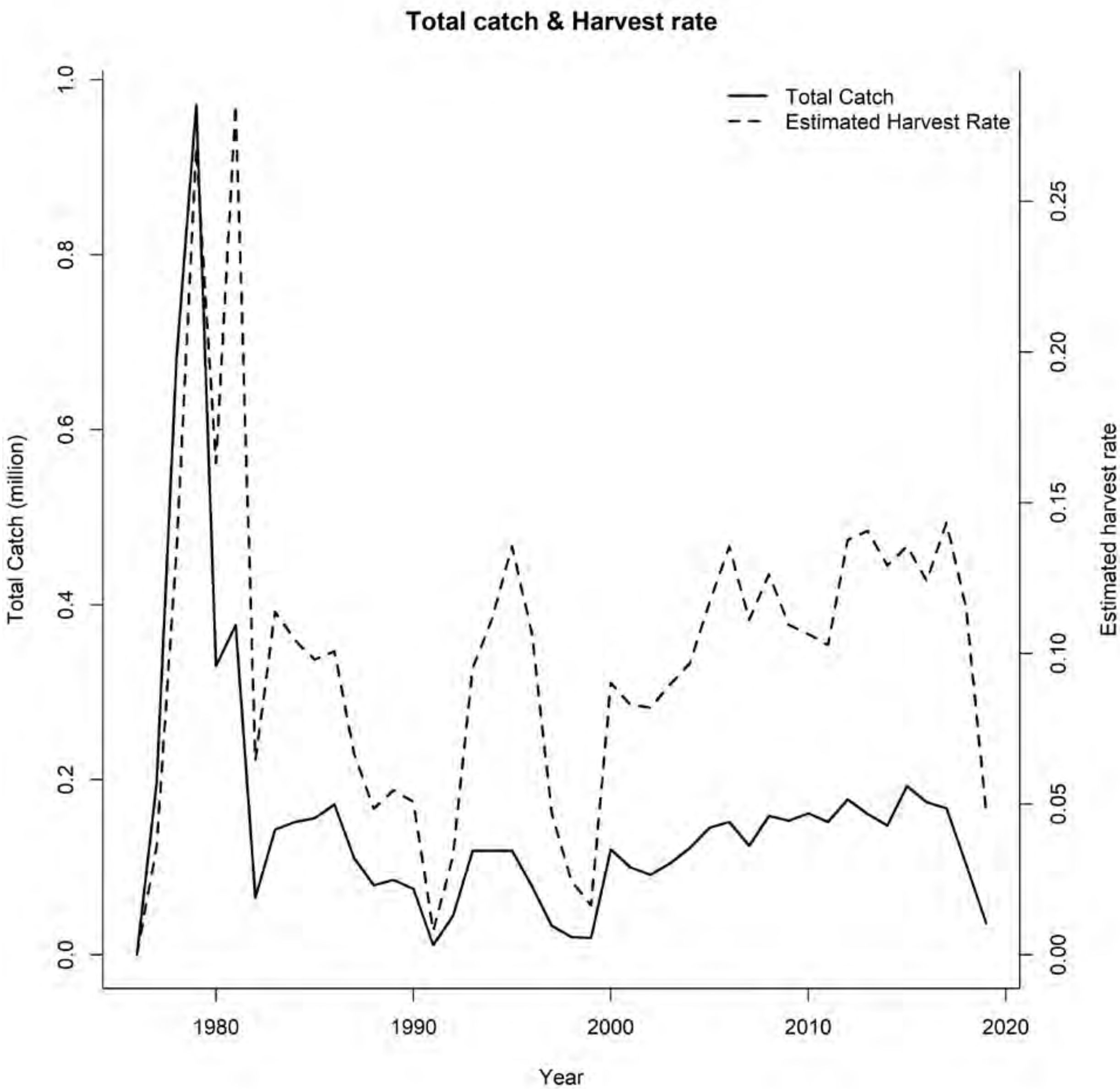


Figure D1-8. Total catch and estimated harvest rate 1976-2019.

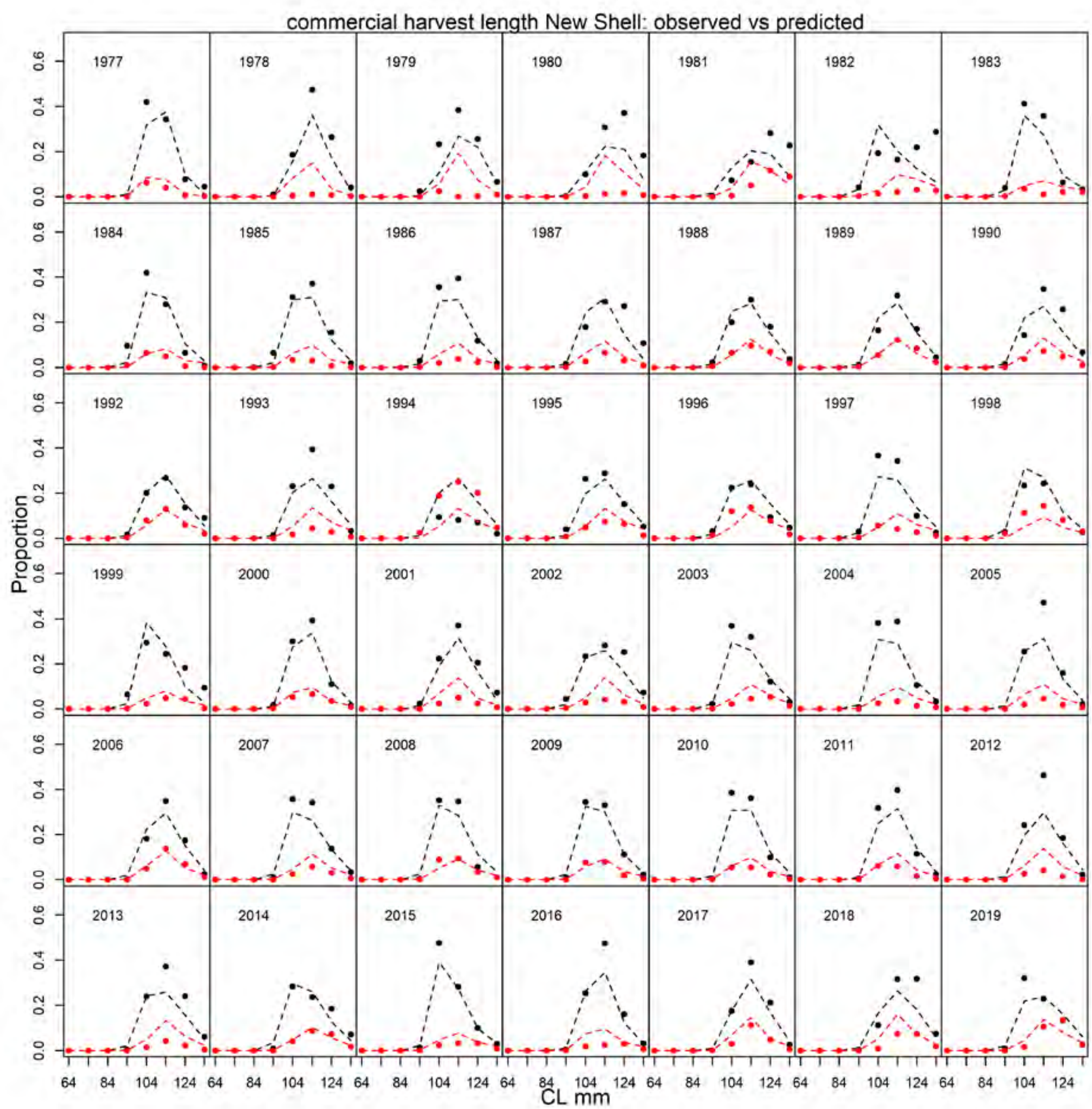


Figure D1-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Black: newshell, Red: oldshell

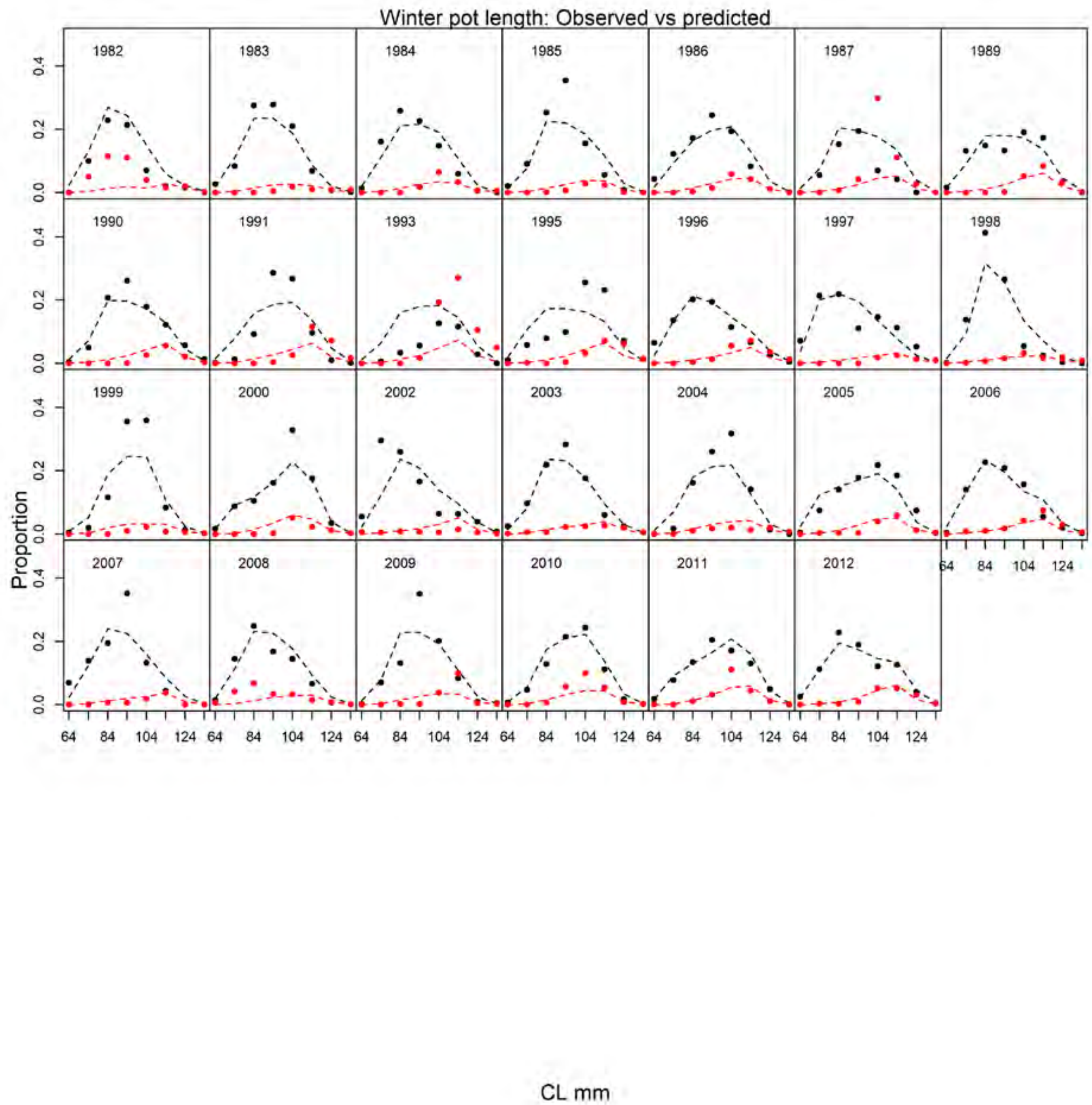


Figure D1-10. Predicted (dashed line) vs. observed (dots) length class proportions for the winter and spring pot survey. Black: newshell, Red: oldshell

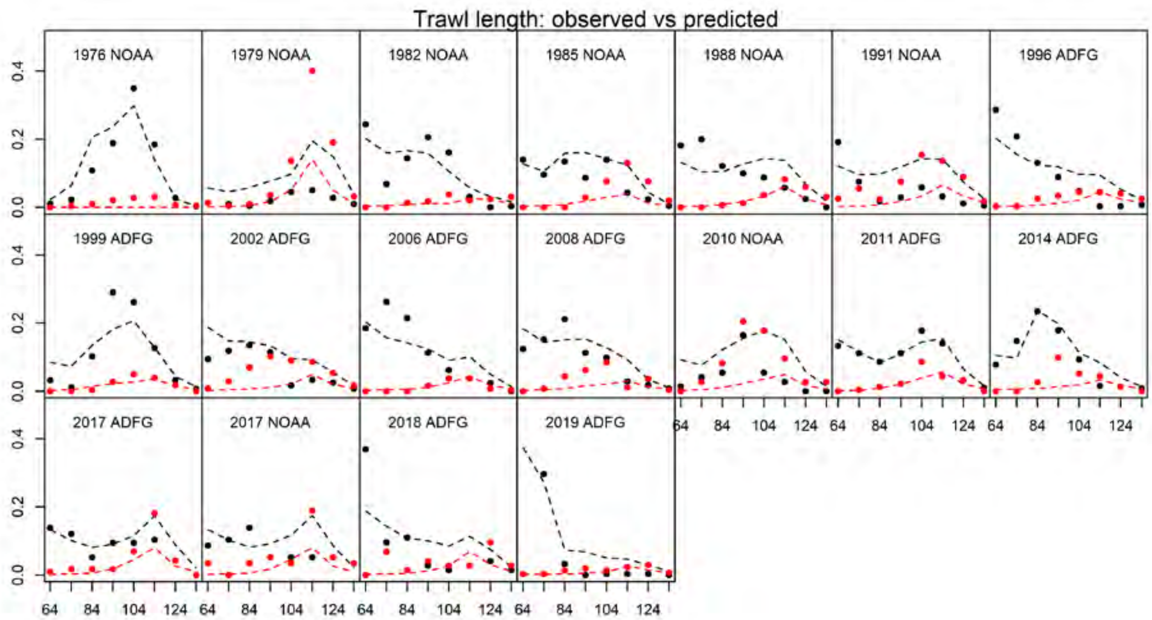


Figure D1-11. Predicted (dashed) vs. observed (dots) length class proportions for Trawl survey. Black: newshell, Red: oldshell

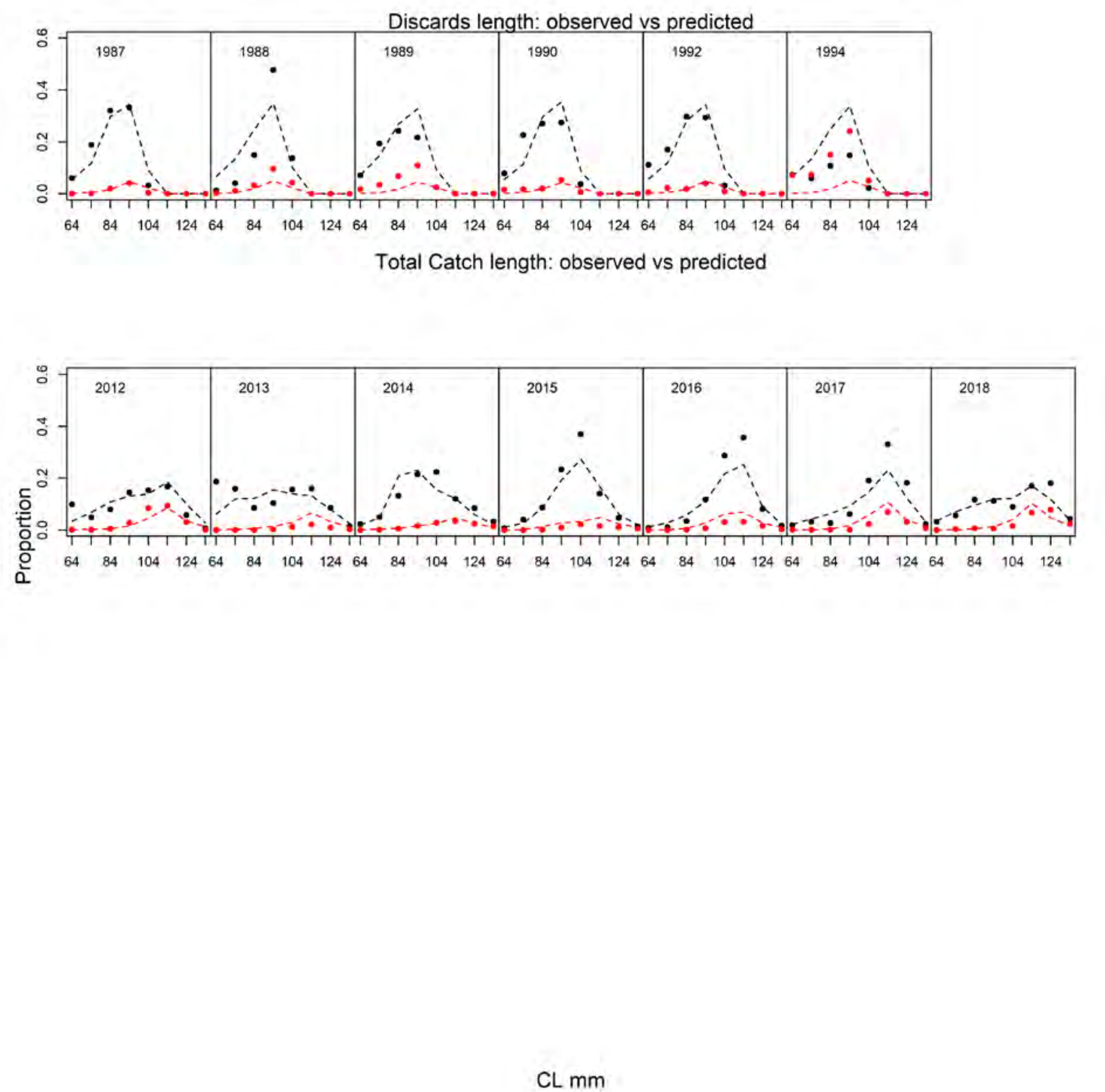


Figure D1-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

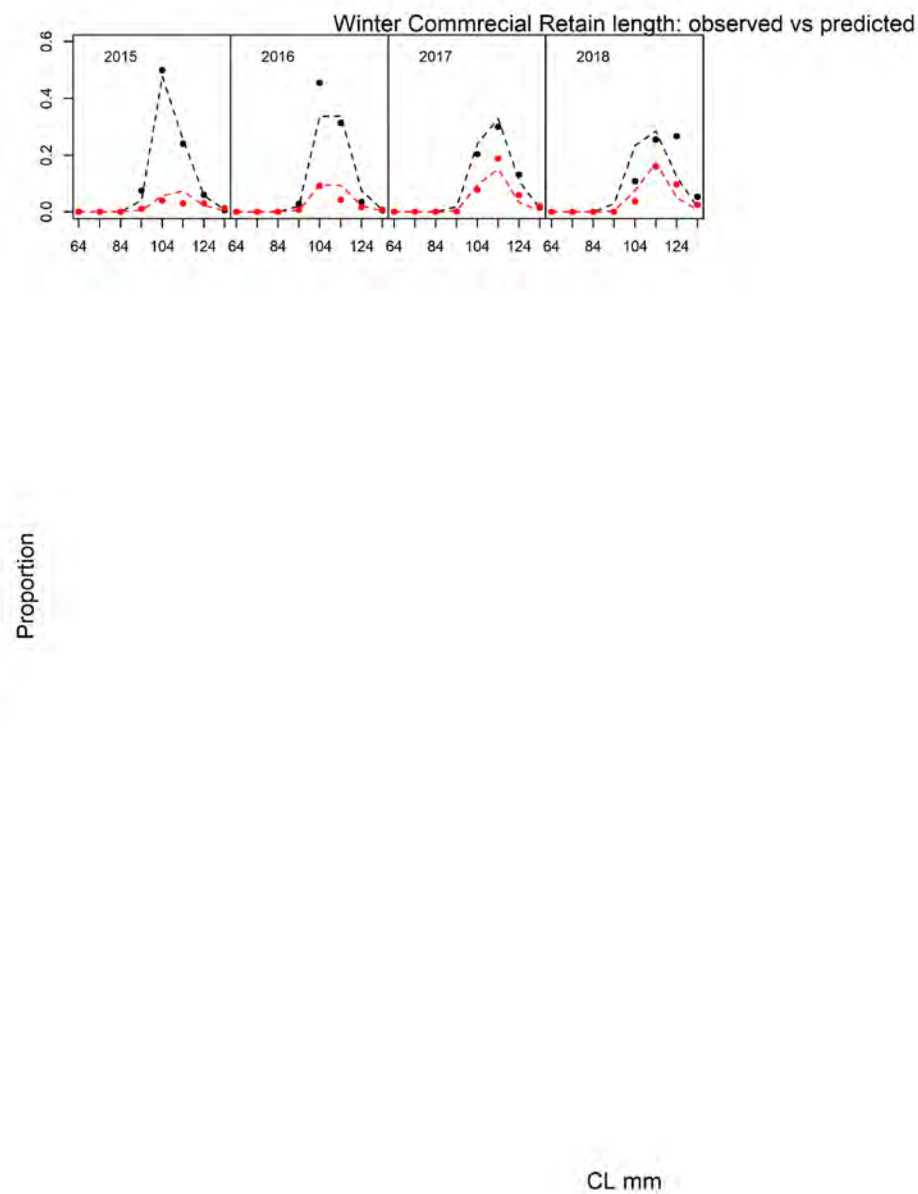


Figure D1-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

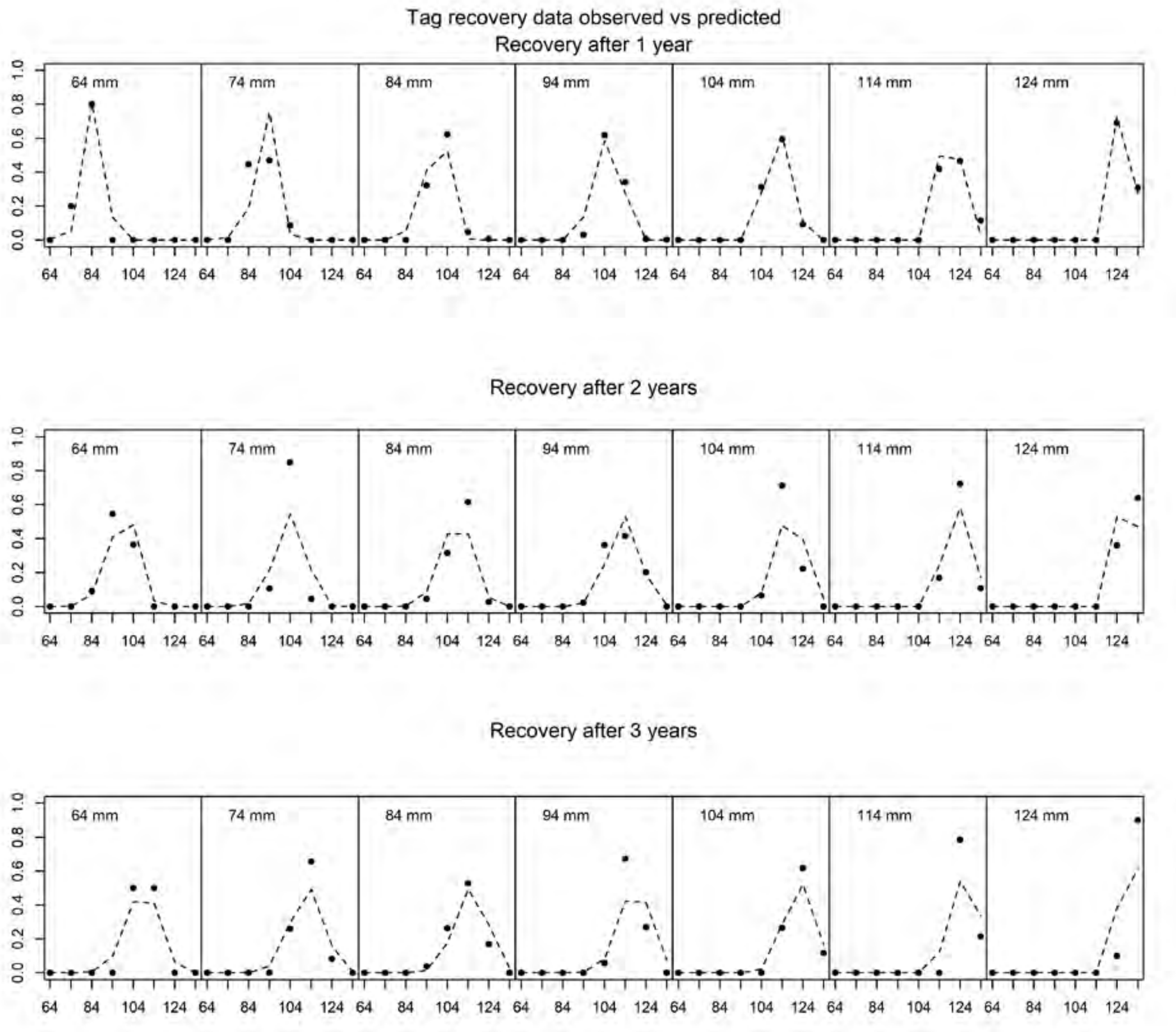


Figure D1-13. Predicted vs. observed length class proportions for tag recovery data.

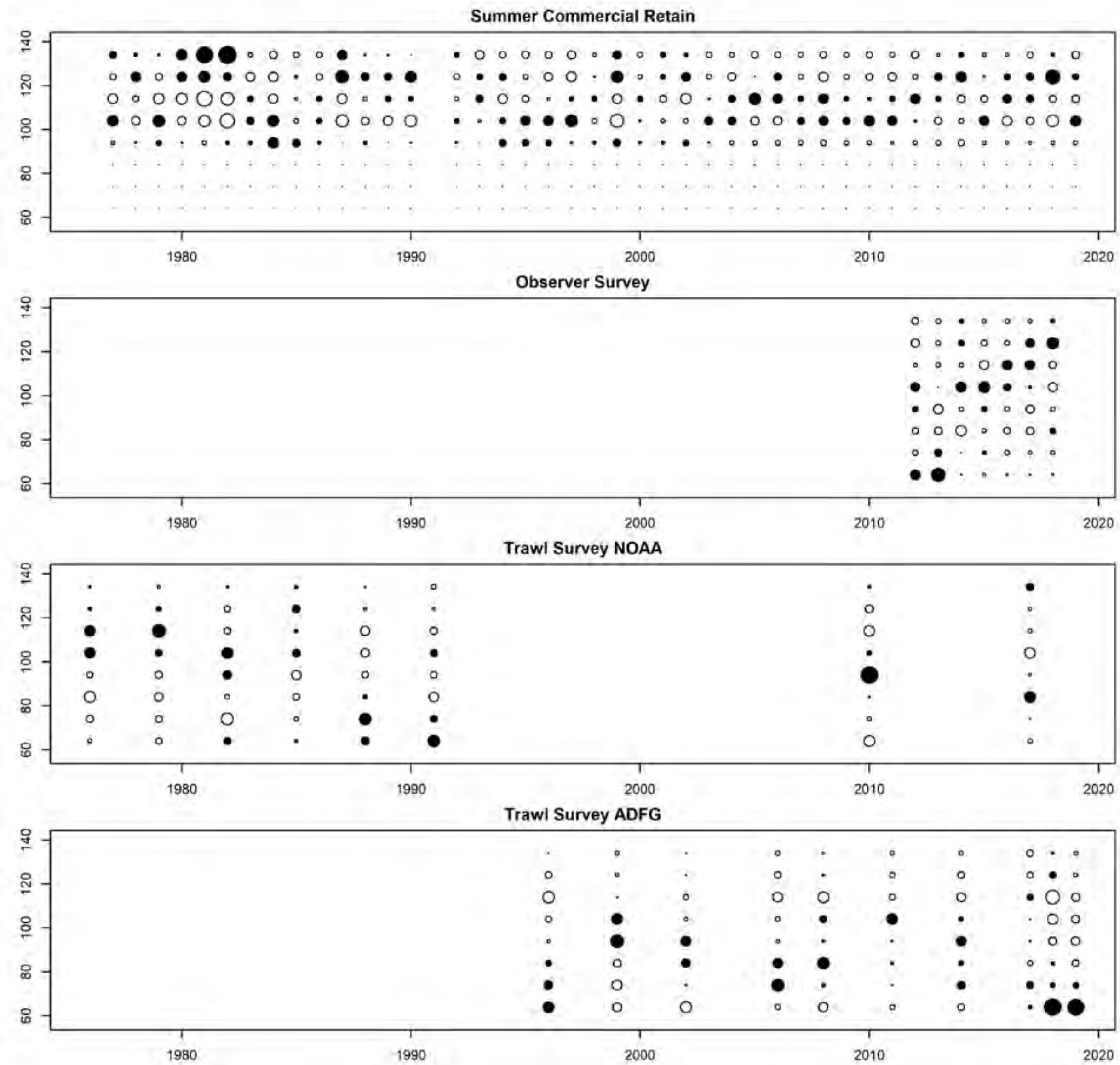


Figure D1-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

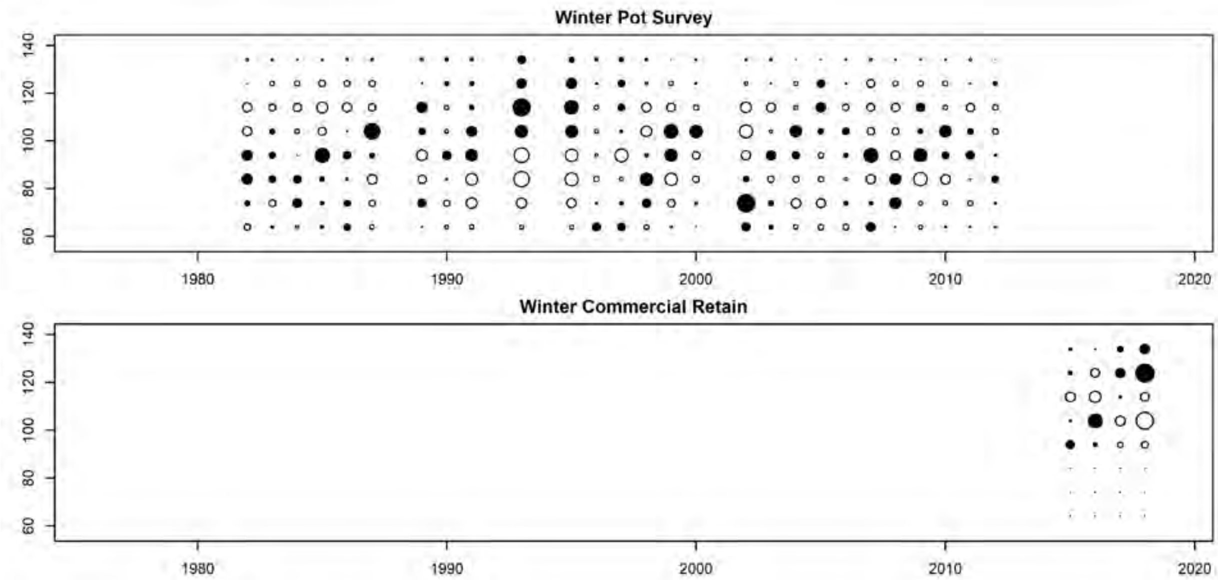


Figure D1-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table D1. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.783	0.111
log_q_2		
log_N_{76}	9.122	0.109
R_0	6.478	0.083
a_1	1.752	4.587
a_2	2.769	4.260
a_3	3.934	4.107
a_4	4.072	4.094
a_5	4.300	4.085
a_6	3.537	4.114
a_7	2.101	4.383
r1	10.000	0.283
r2	9.655	0.332
log_a	-2.682	0.090
log_b	4.835	0.015
log_ϕ_{st1}	-5.000	0.051
log_ϕ_{wa}	-2.206	0.301
log_ϕ_{wb}	4.796	0.032
Sw1	0.072	0.035
Sw2	0.499	0.126
log_ϕ_l	-2.086	0.057
$log\_\phi ra$	-0.787	0.129
$log\_\phi rb$	4.646	0.008
$log\_\phi wra$	-0.965	0.553
$log\_\phi wrb$	4.654	0.038
$w^2{}_t$	0.000	0.000
q	0.700	0.113
σ	3.886	0.208
β_1	12.393	0.700
β_2	7.661	0.171
ms78	3.248	0.255

Appendix D - Model 19.0 Update

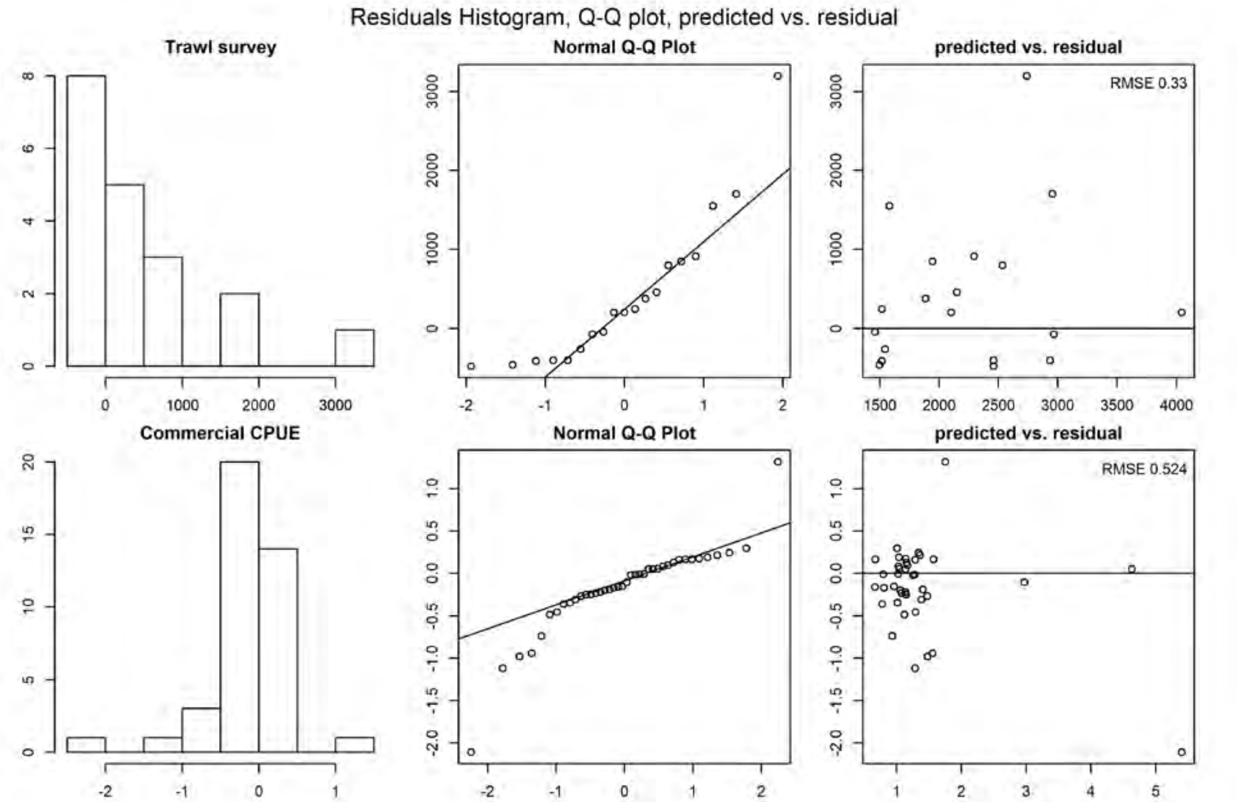


Figure C8-1. QQ plot of trawl survey and commercial CPUE.

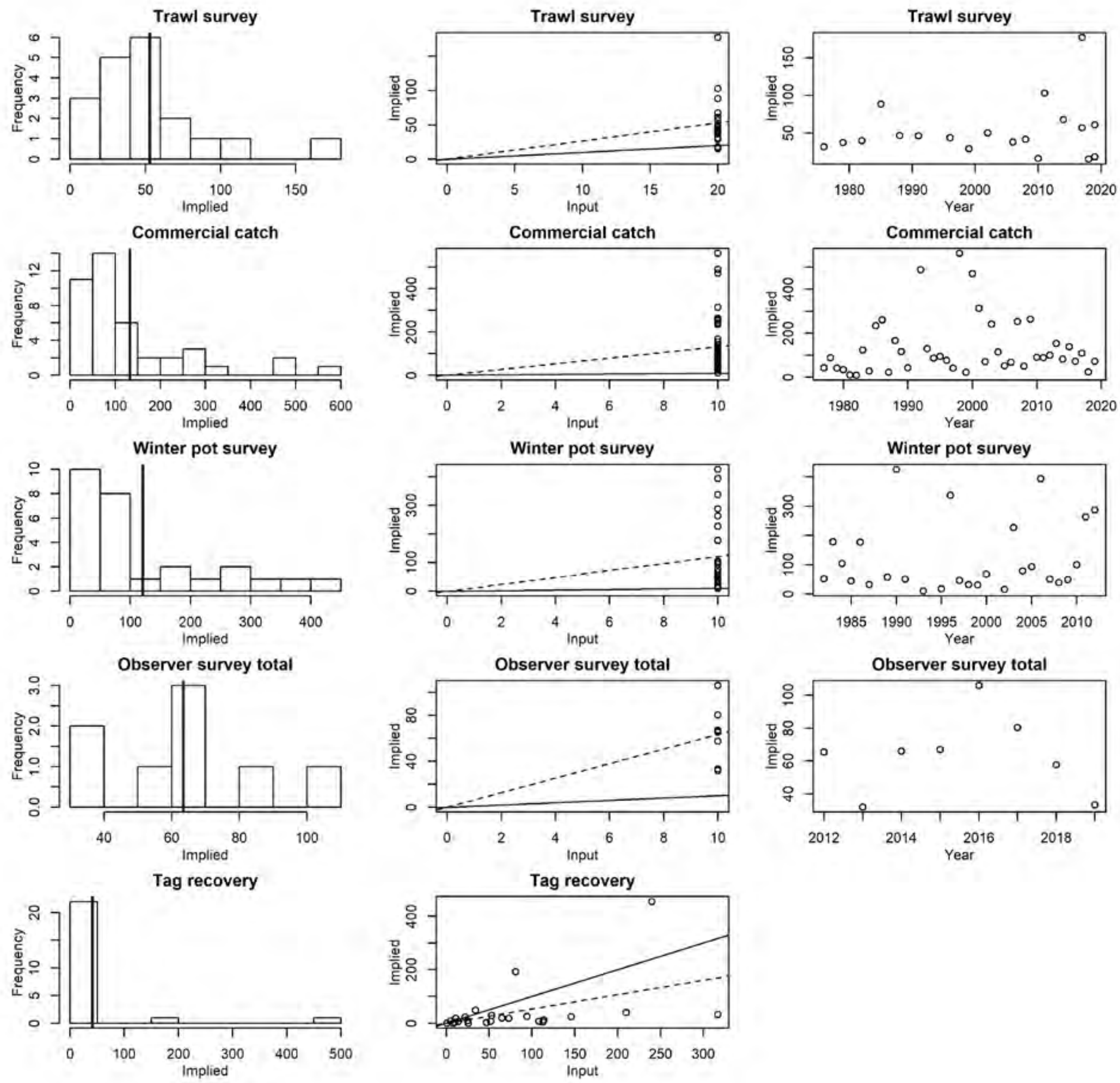


Figure C8-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

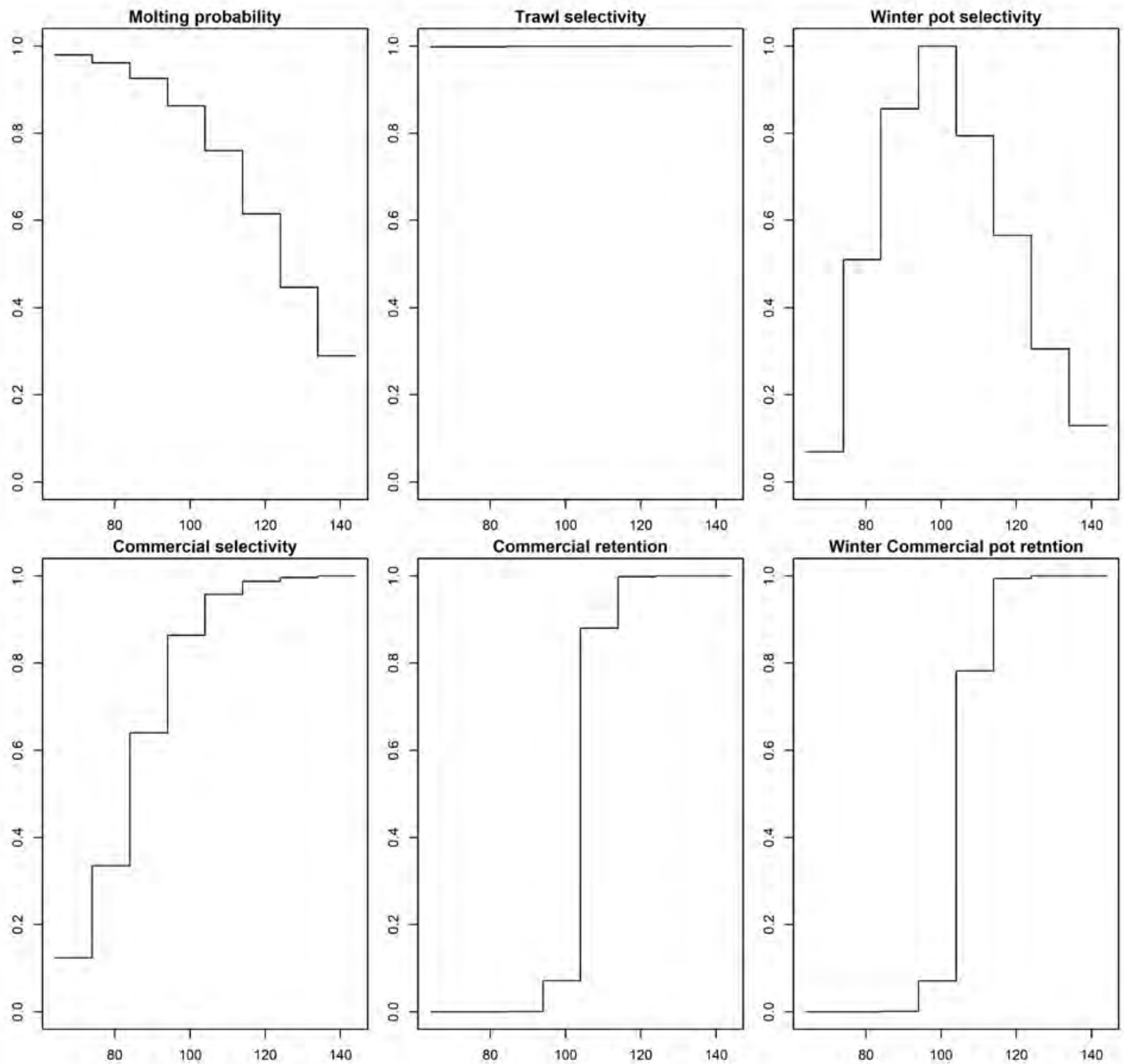


Figure C8-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

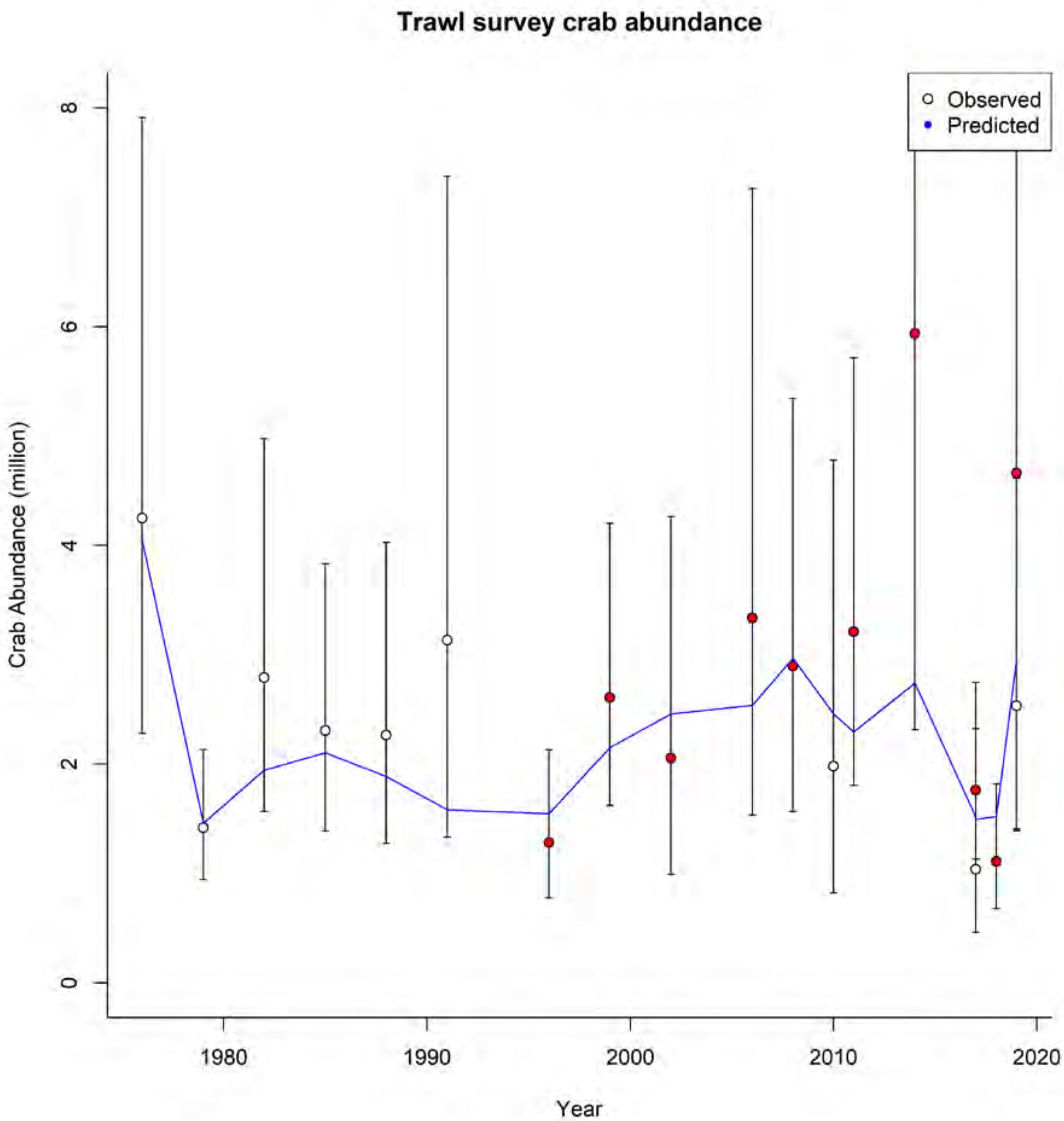


Figure C8-4. Estimated trawl survey male abundance (blue line). Observed: white: NOAA trawl Survey, red: ADG&G trawl survey

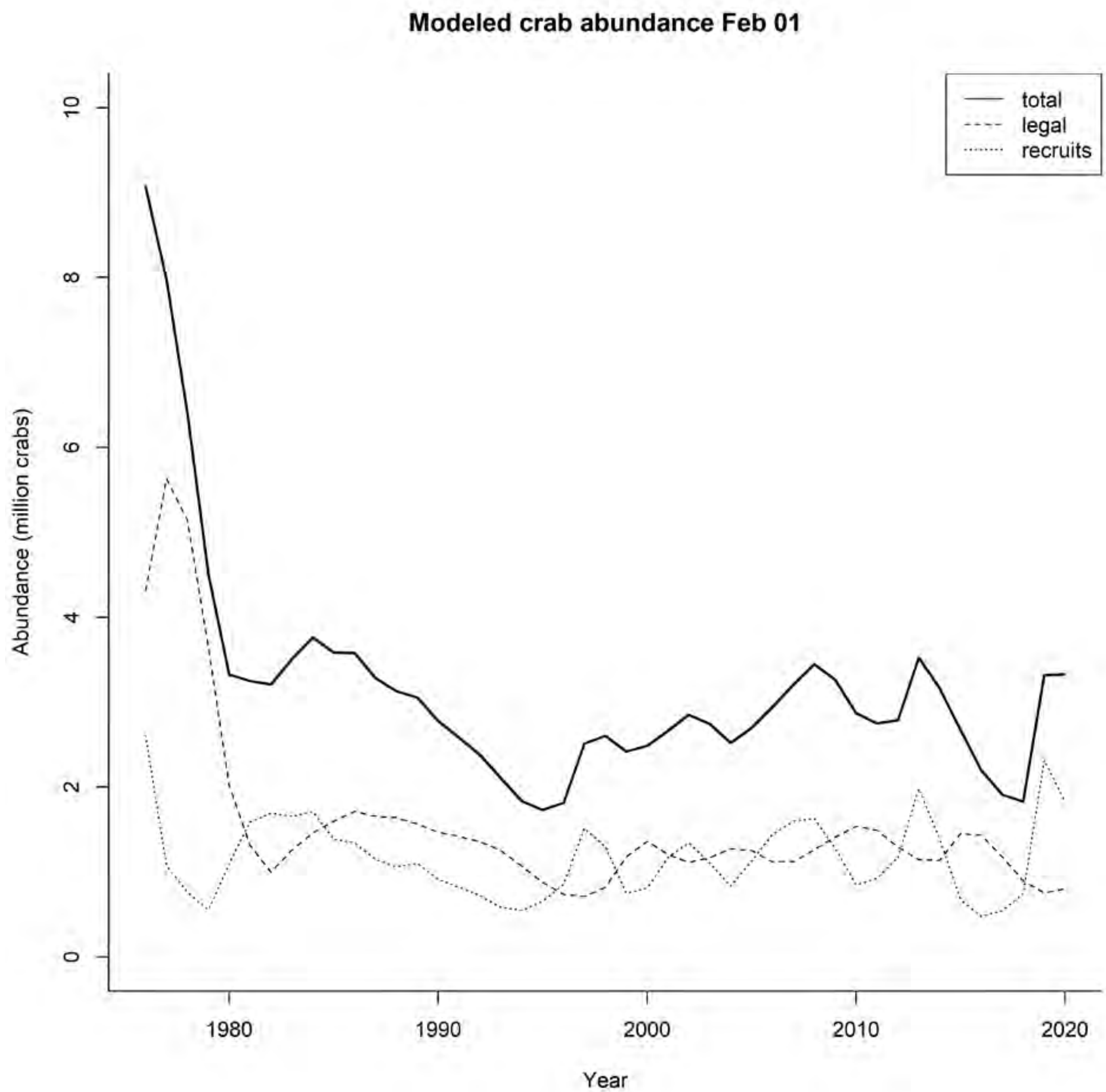


Figure C8-5. Estimated abundance of legal males.

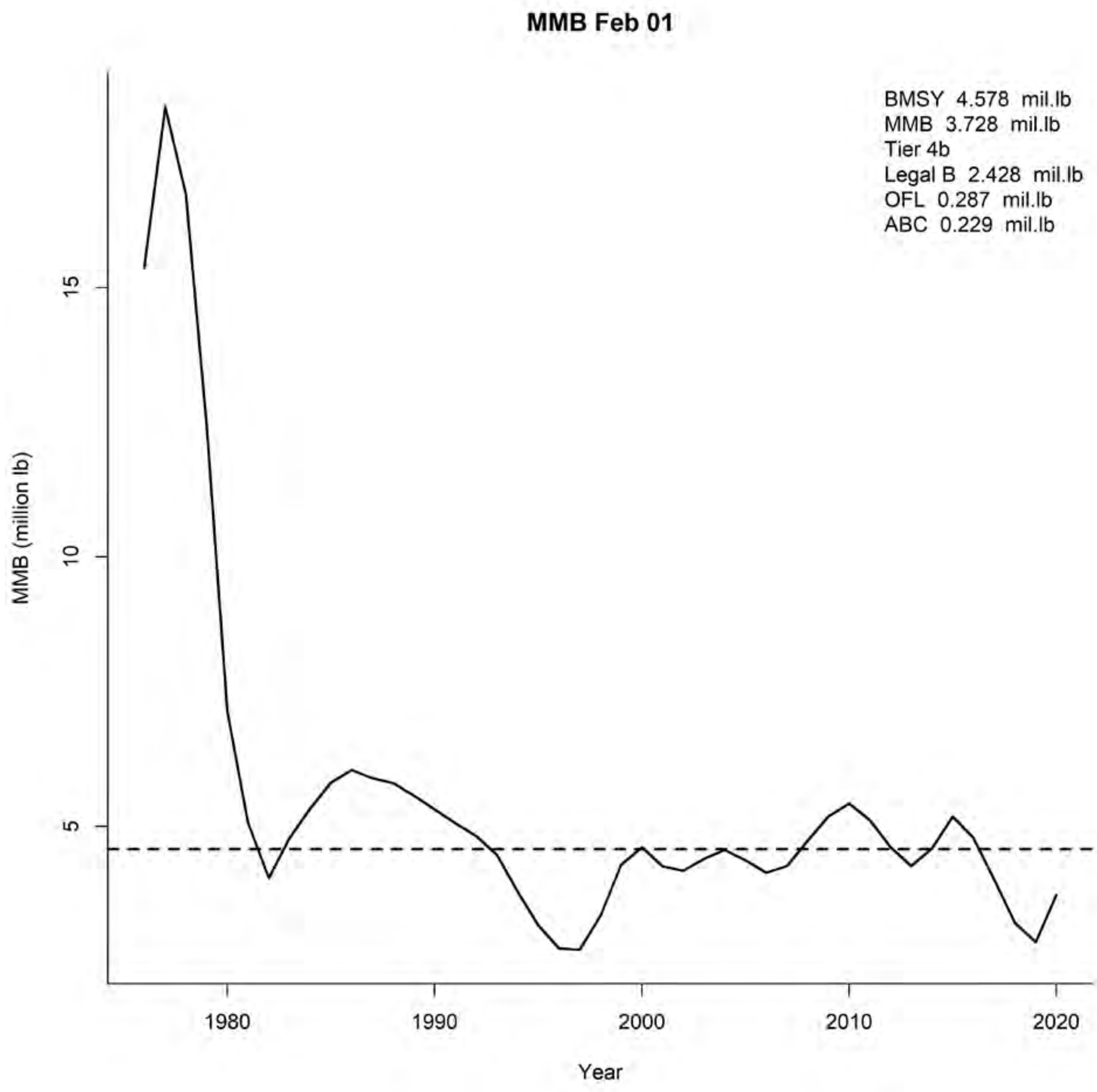


Figure C8-6. Estimated mature male biomass. Dash line shows Bmsy.

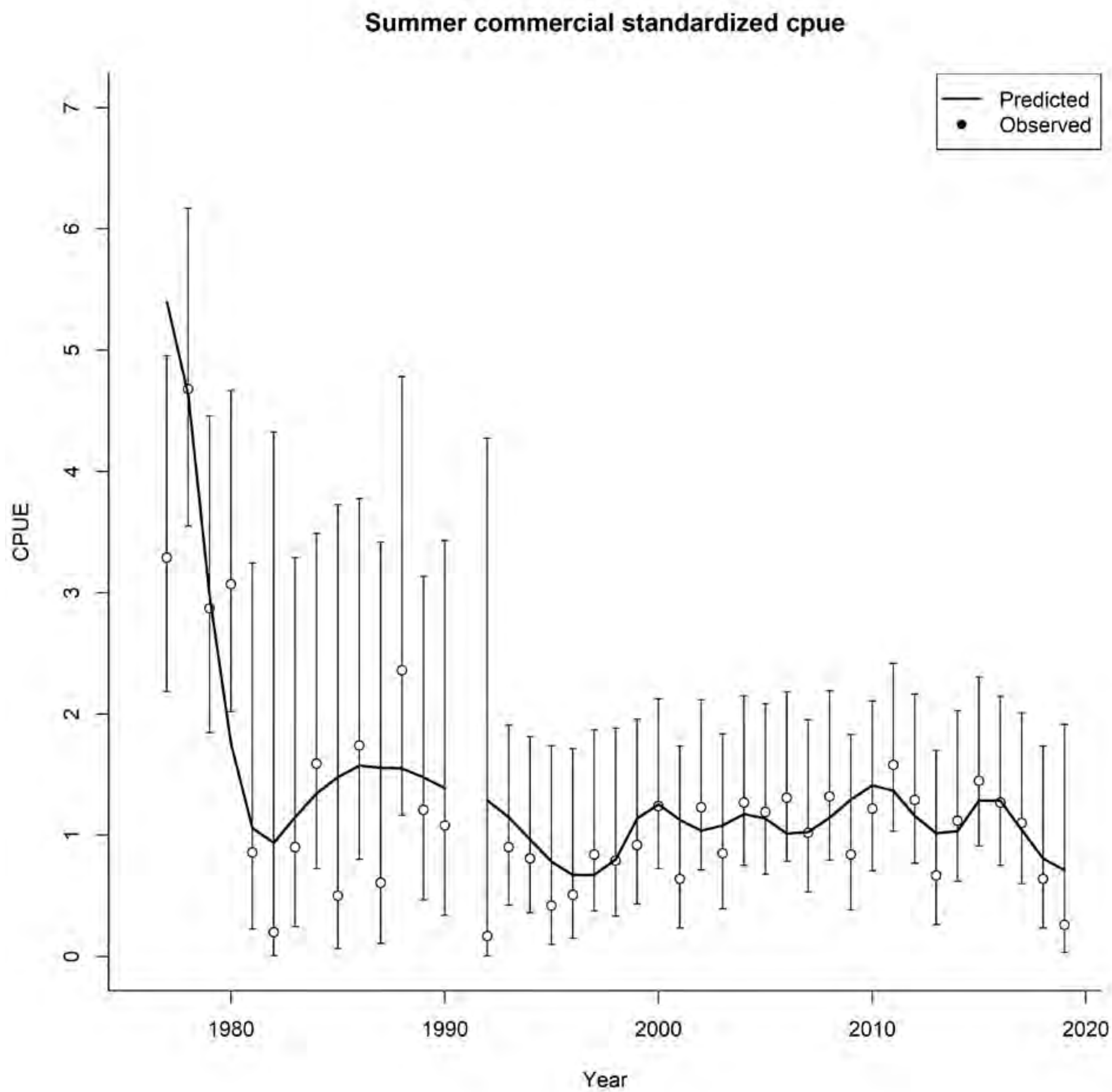


Figure C8-7. Summer commercial standardized cpue. Vertical line incicates lognormal 95%CI

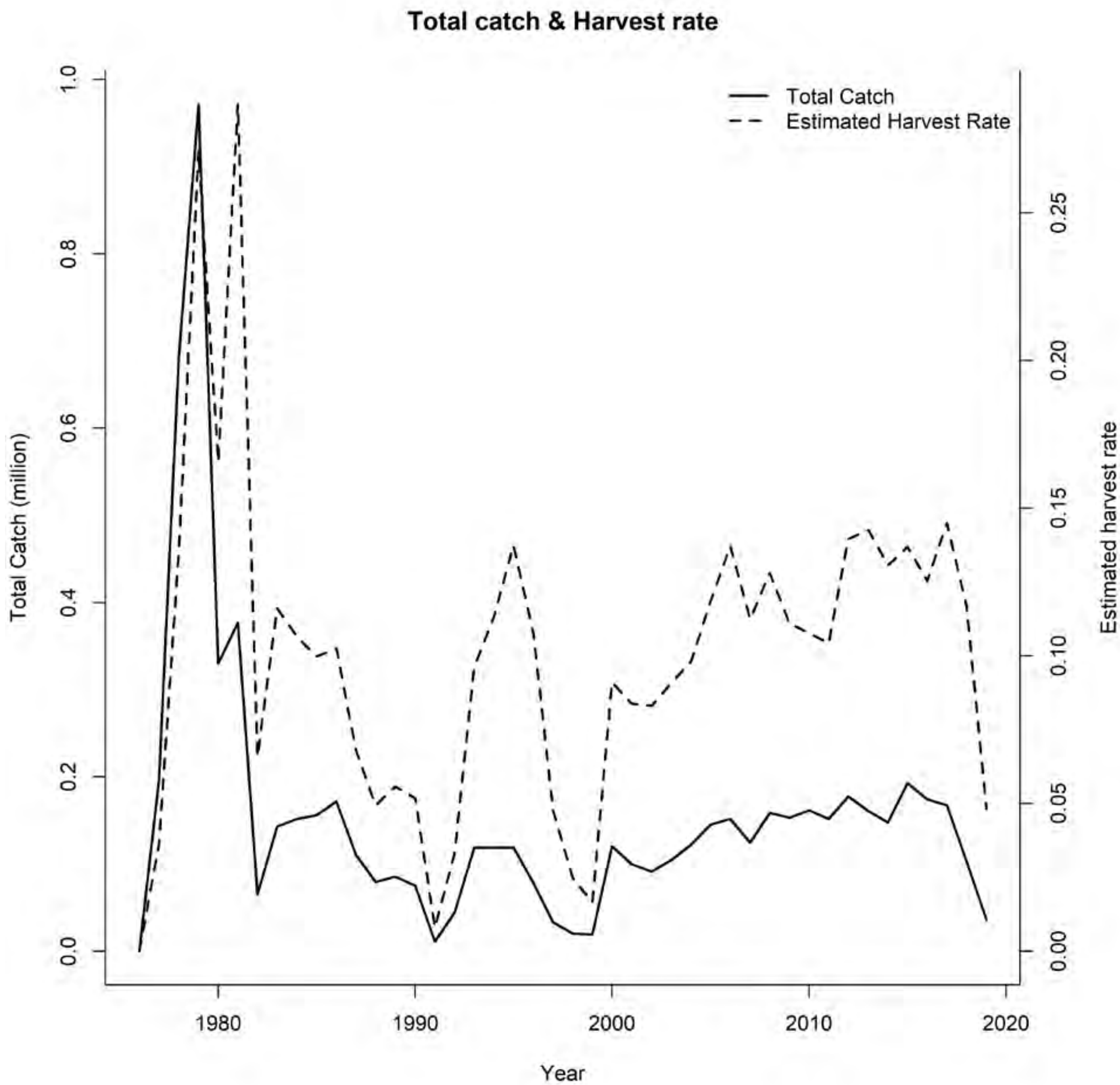


Figure C8-8. Total catch and estimated harvest rate.

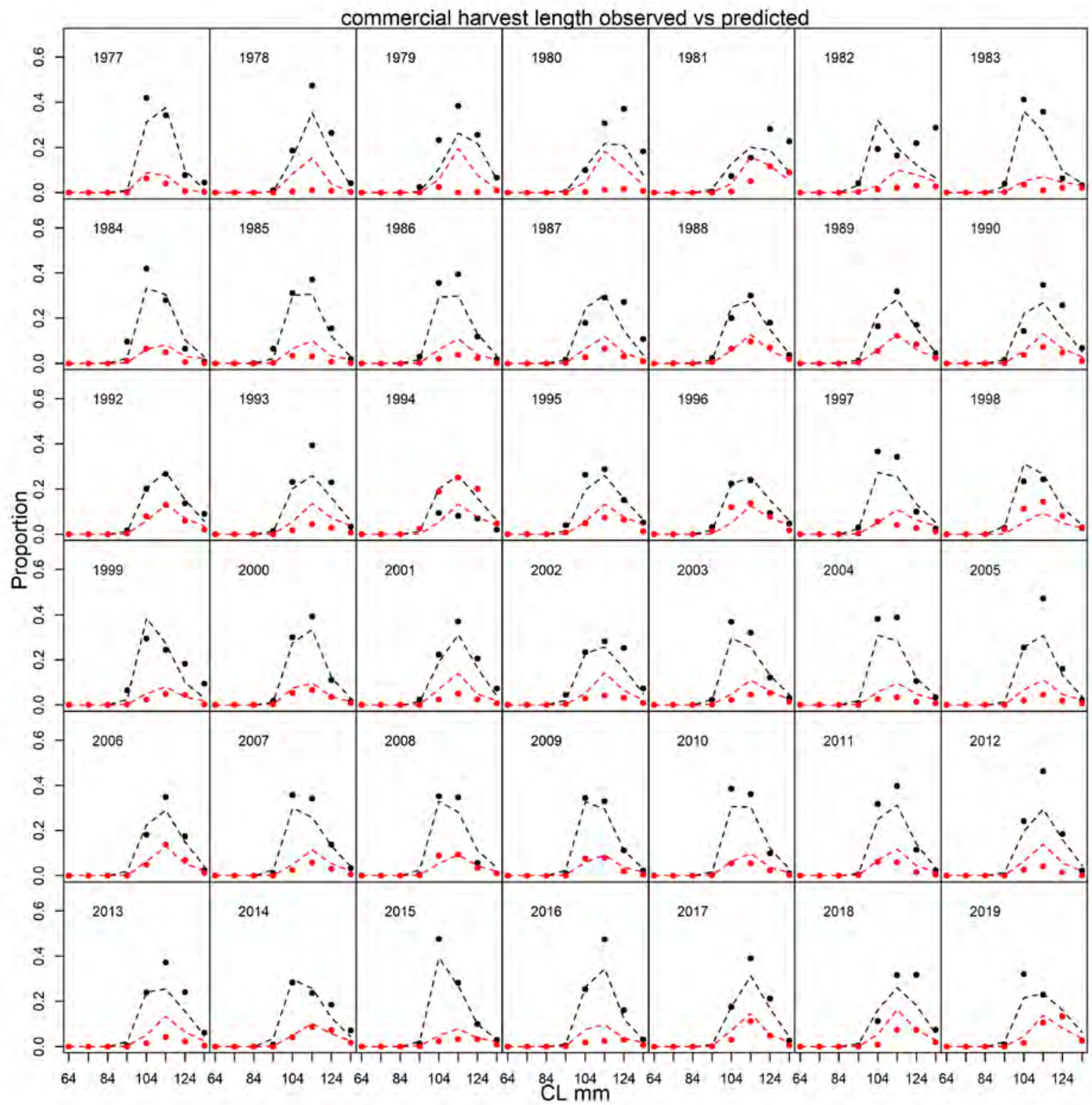


Figure C8-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Bladk: newshell, Red: oldshell

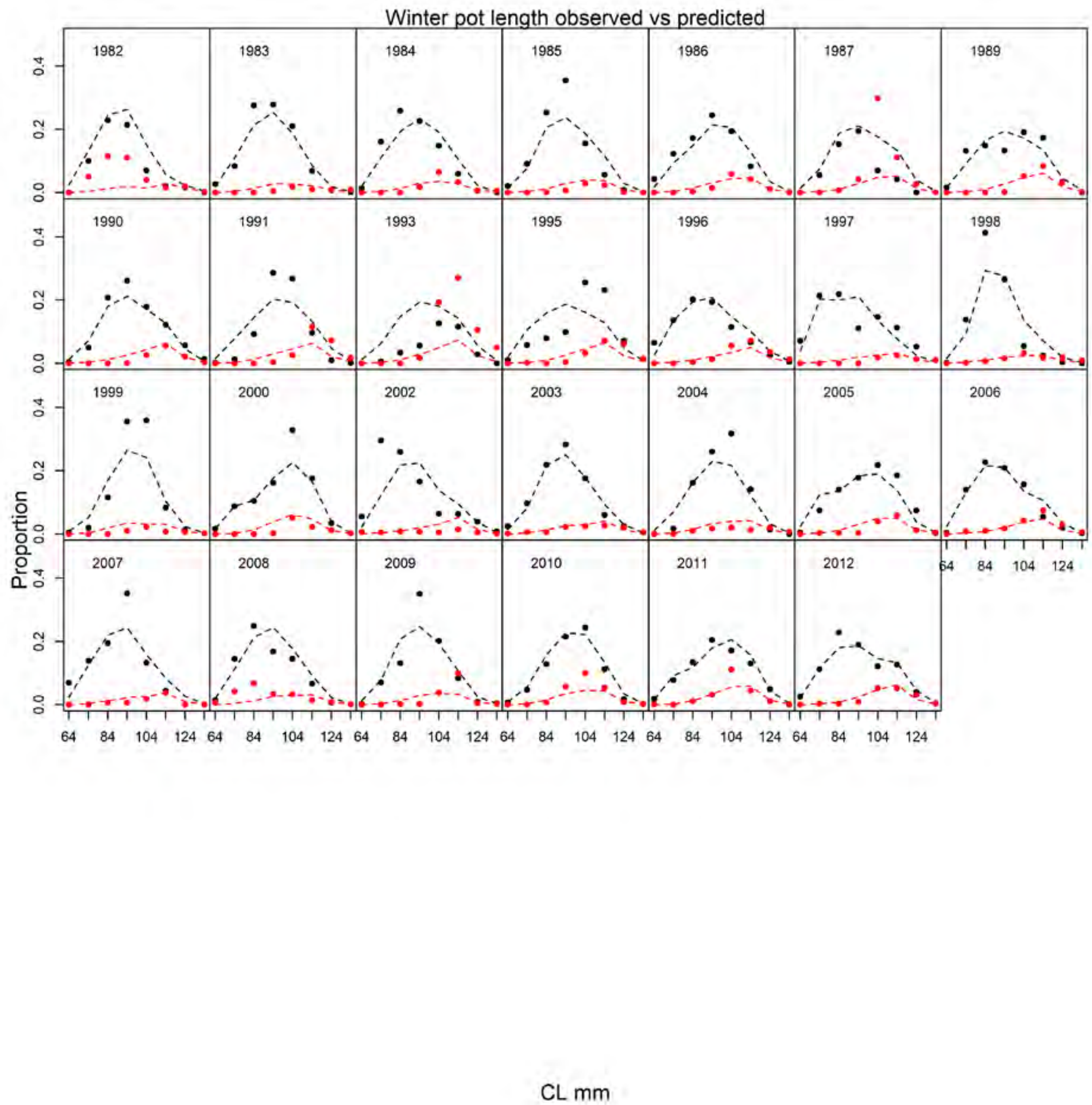


Figure C8-10. Predicted (dashed) vs. observed (dots) length class proportions for the winter pot survey. Black: newsehll, Red: oldshell

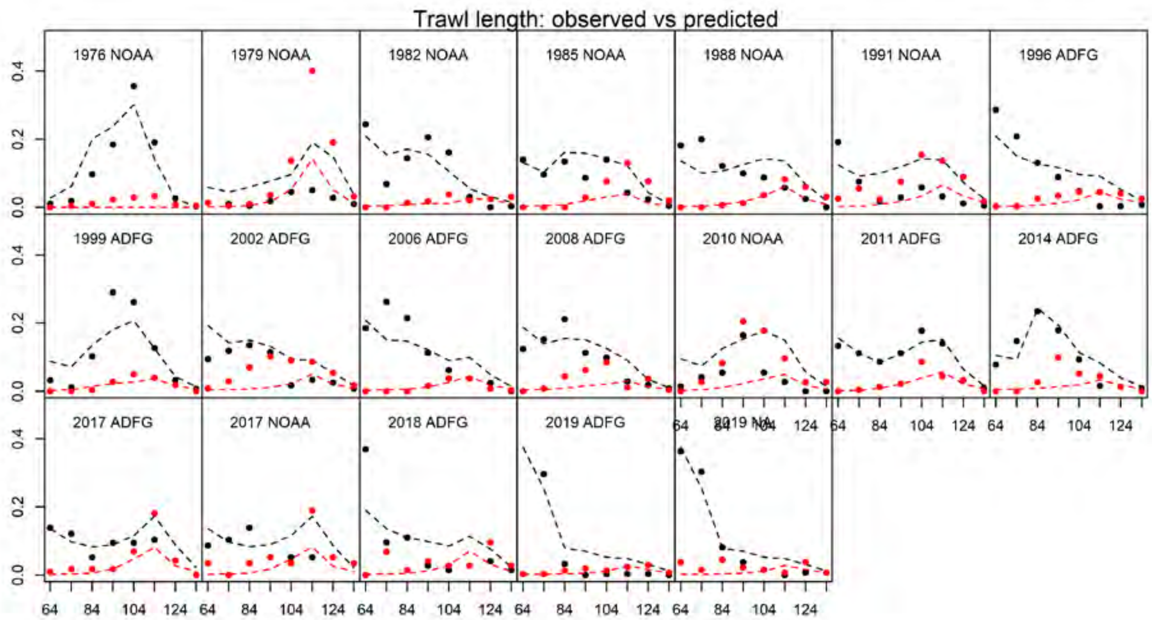


Figure C8-11. Predicted (dashed) vs. observed (dots) length class proportions for trawl survey. Black: newshell, Red: oldshell

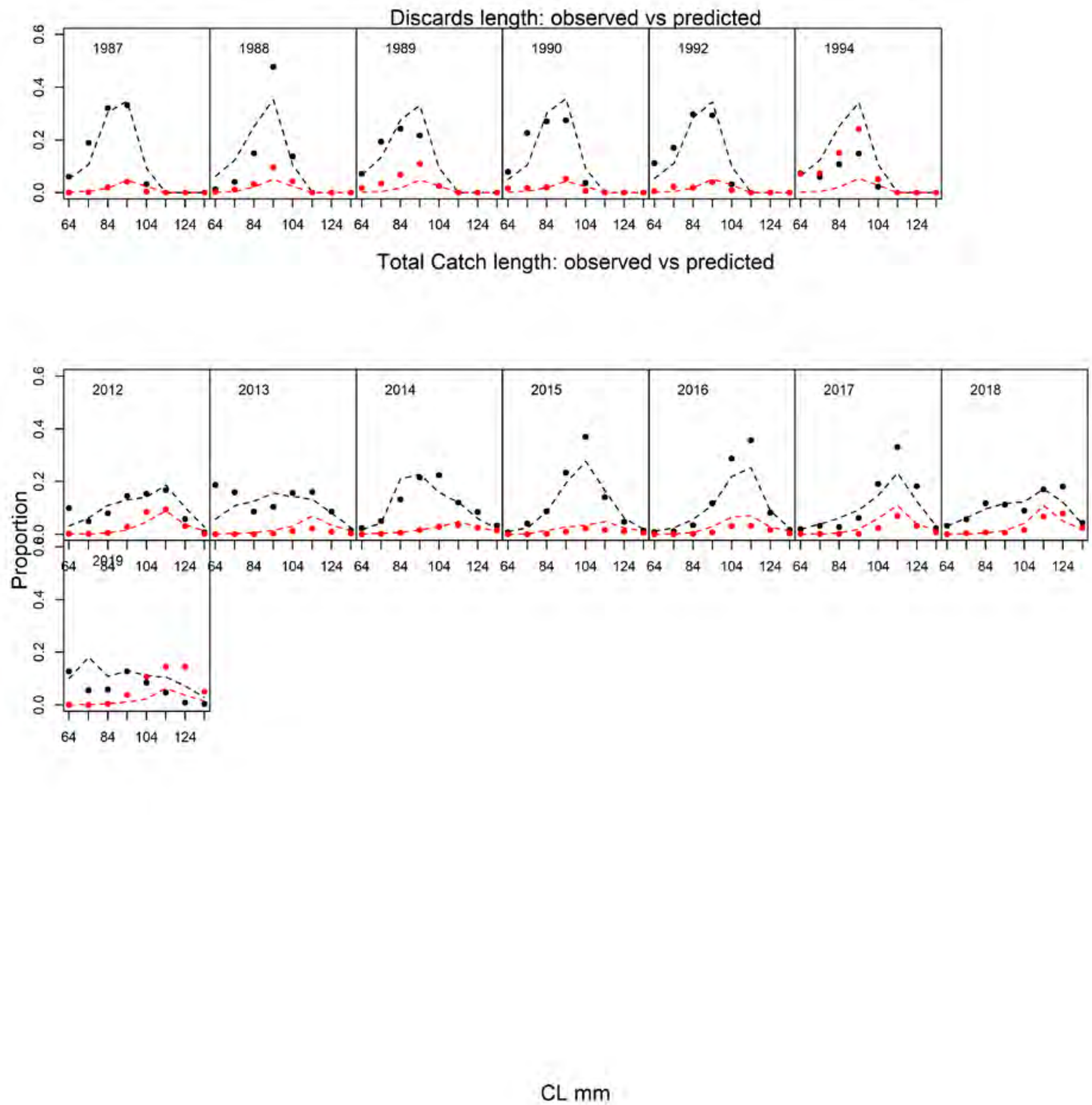


Figure C8-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newsehll, Red: oldshell

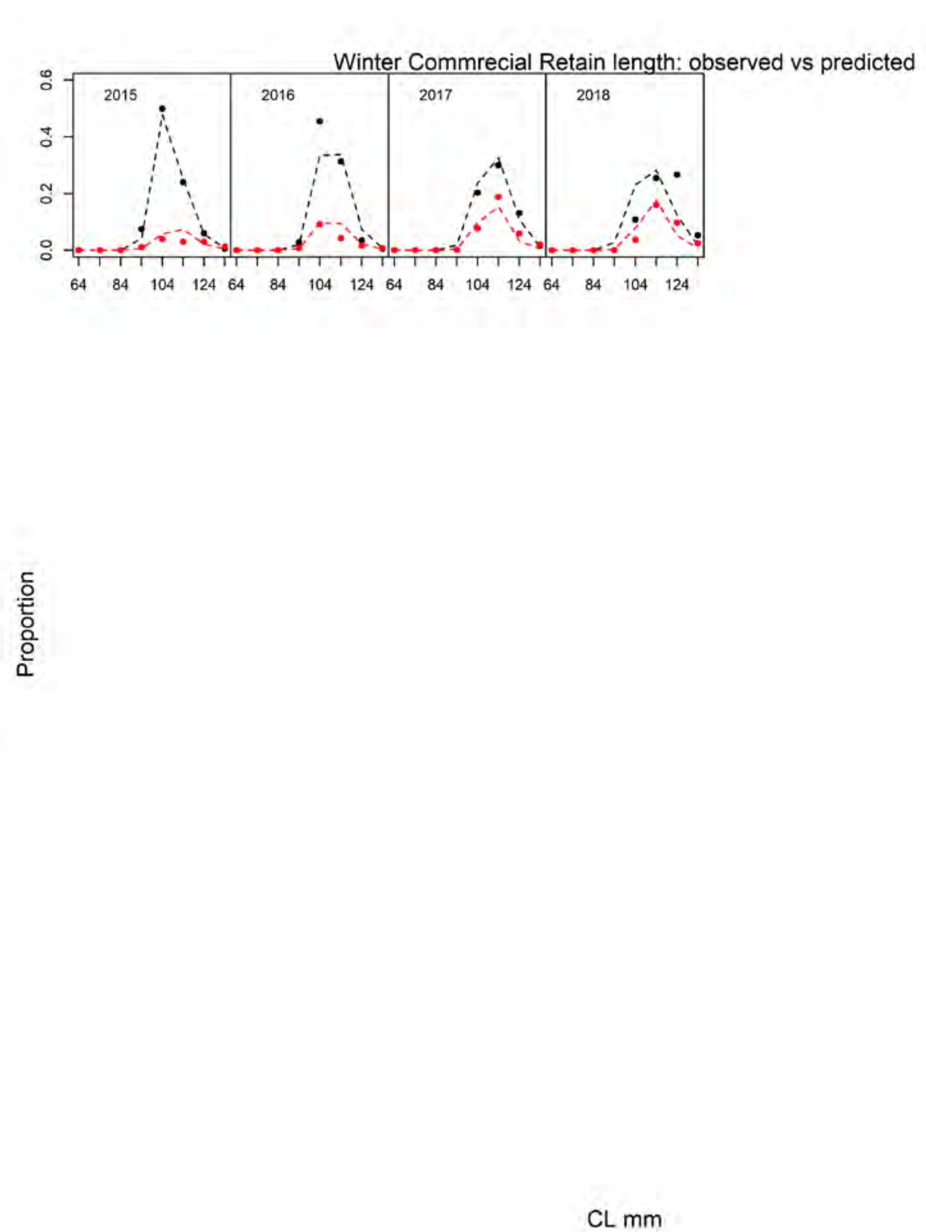


Figure C8-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

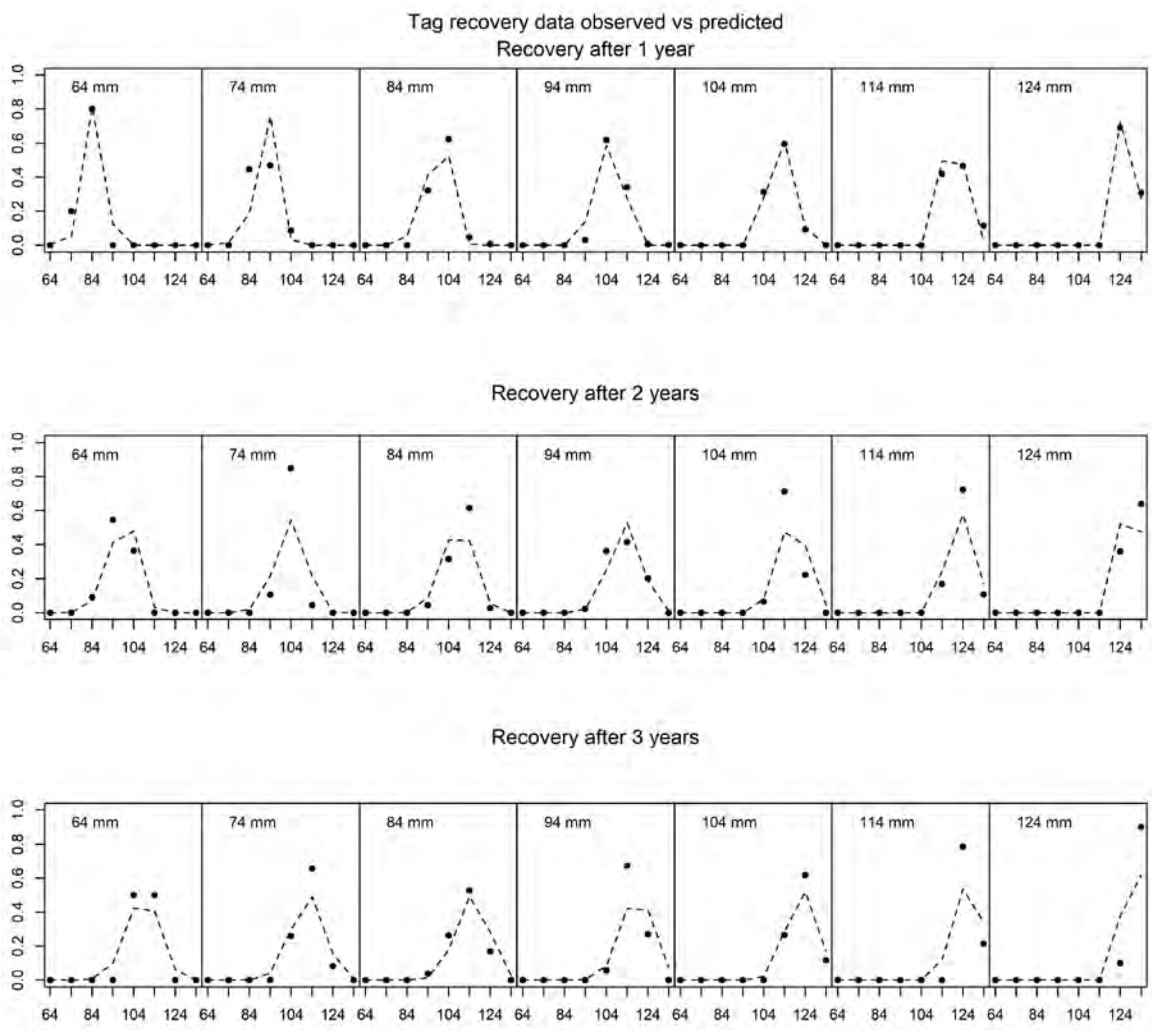


Figure C8-13. Predicted vs. observed length class proportions for tag recovery data.

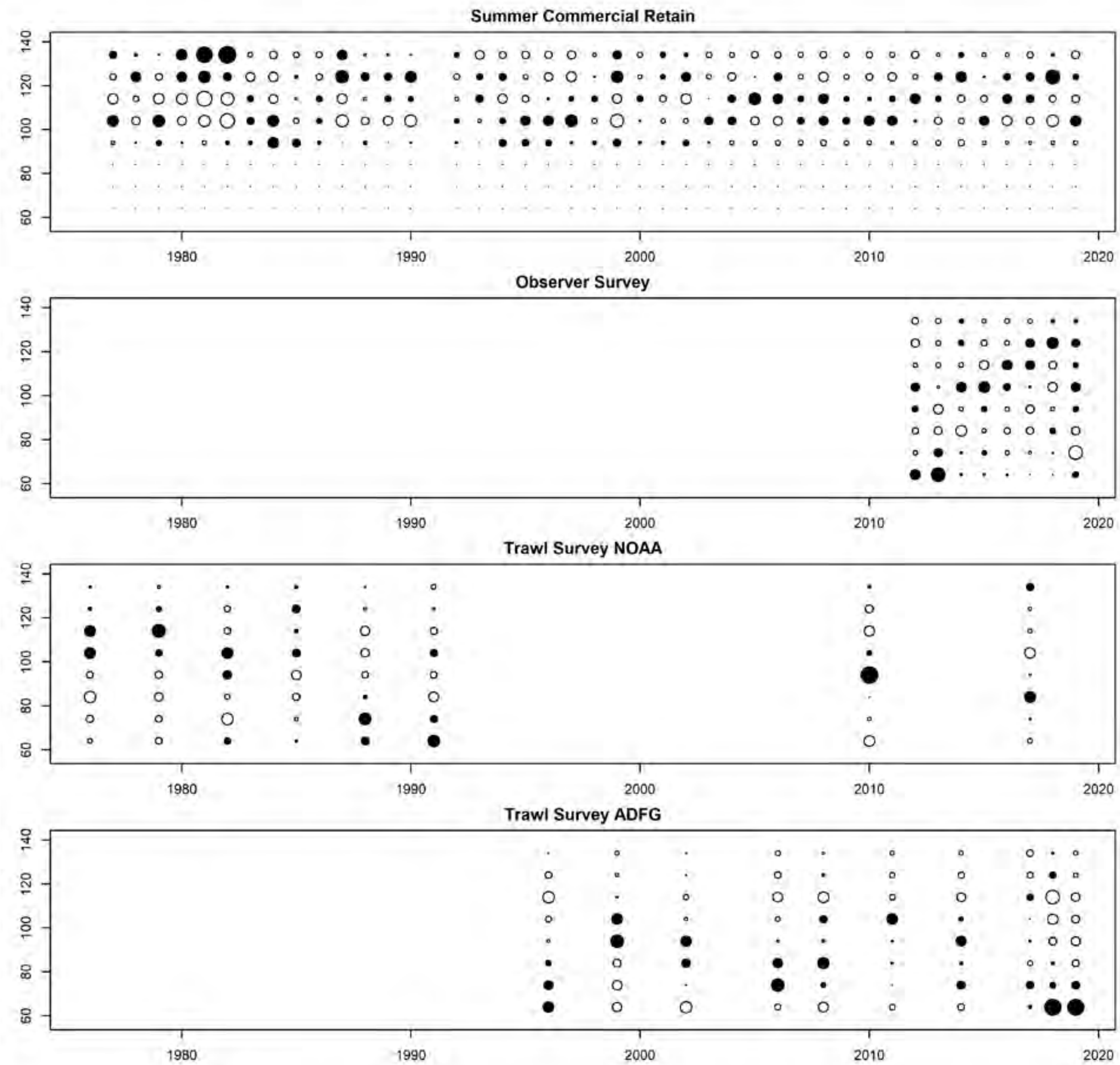


Figure C8-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

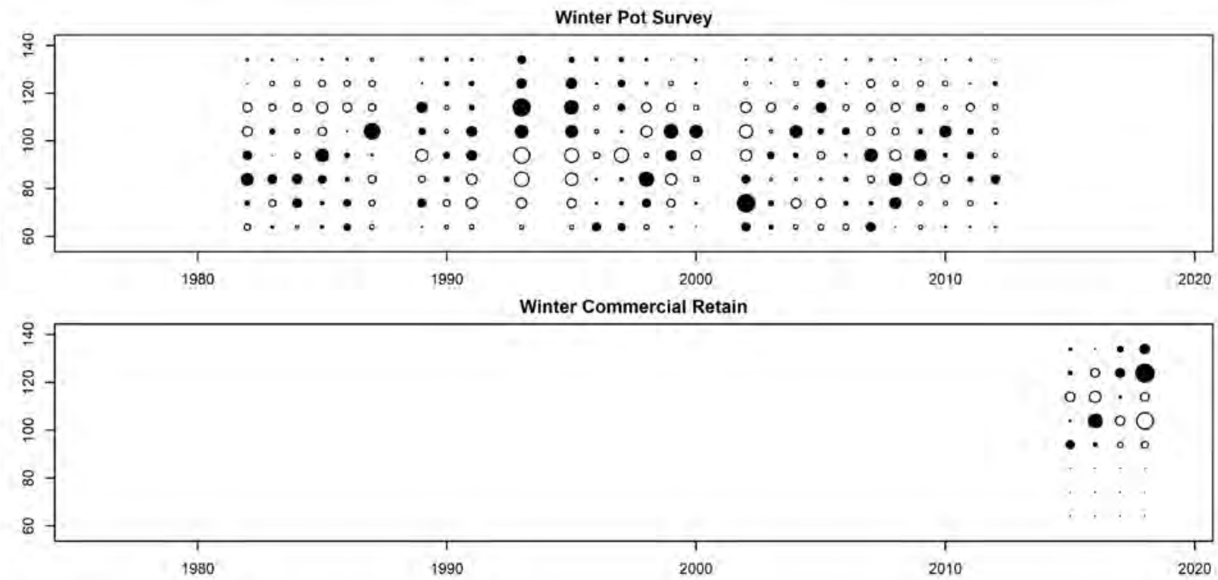


Figure C8-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table C8. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.768	0.110
log_q_2		
log_N_{76}	9.113	0.108
R_0	6.462	0.081
a_1	1.903	4.455
a_2	2.722	4.207
a_3	3.896	4.024
a_4	4.071	4.008
a_5	4.305	3.997
a_6	3.545	4.026
a_7	2.060	4.297
r1	10.000	0.270
r2	9.578	0.322
log_a	-2.682	0.089
log_b	4.831	0.015
log_ϕ_{st1}	-5.000	0.048
log_ϕ_{wa}	-2.220	0.269
log_ϕ_{wb}	4.795	0.029
Sw1	0.069	0.034
Sw2	0.510	0.121
log_ϕ_{l}	-2.067	0.052
$log\_\phi ra$	-0.787	0.129
$log\_\phi rb$	4.646	0.008
$log\_\phi wra$	-0.954	0.536
$log\_\phi wrb$	4.656	0.037
w^2_t	0.000	0.000
q	0.710	0.114
σ	3.853	0.209
β_1	12.196	0.704
β_2	7.713	0.173
ms78	3.226	0.252

Appendix D - Model 19.1

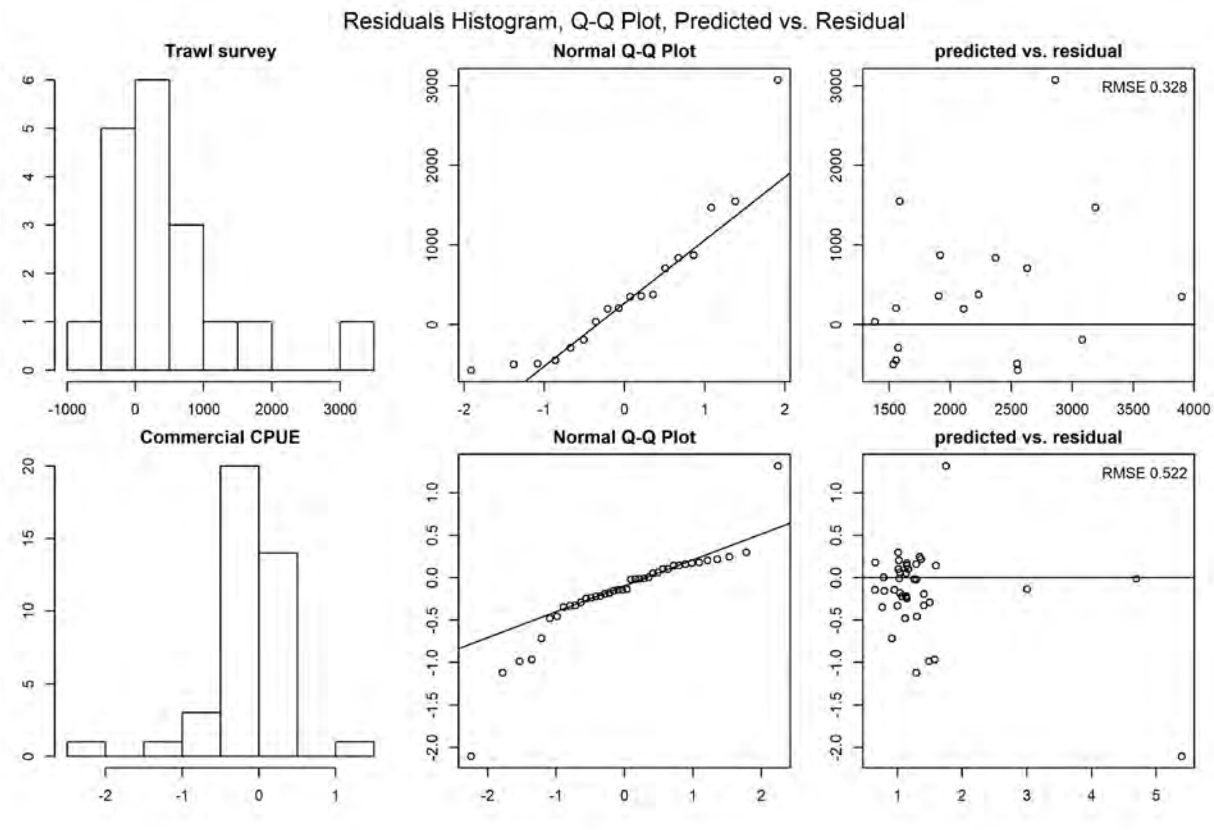


Figure D2-1. QQ Plot of Trawl survey and commercial CPUE.

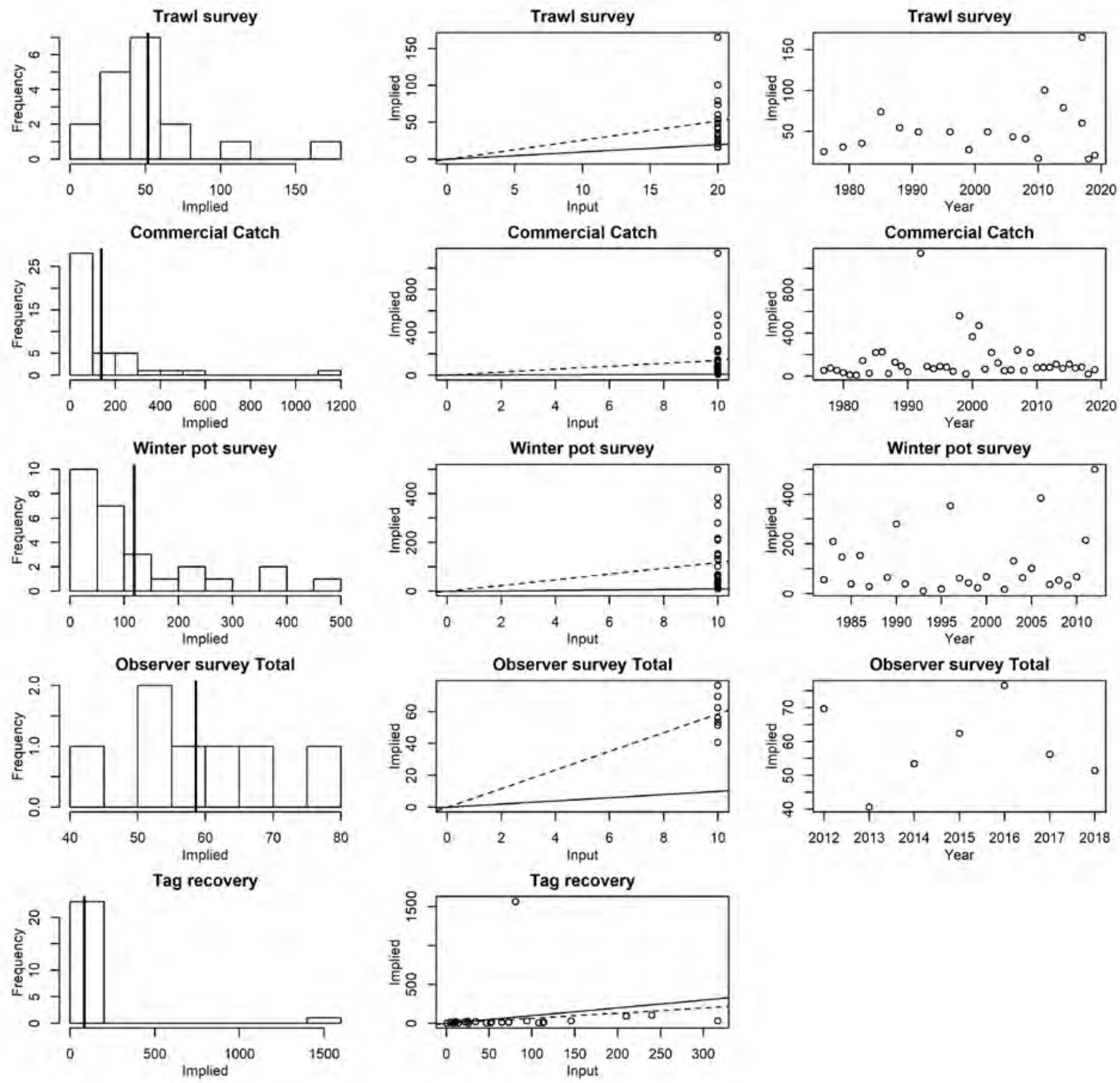


Figure D2-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

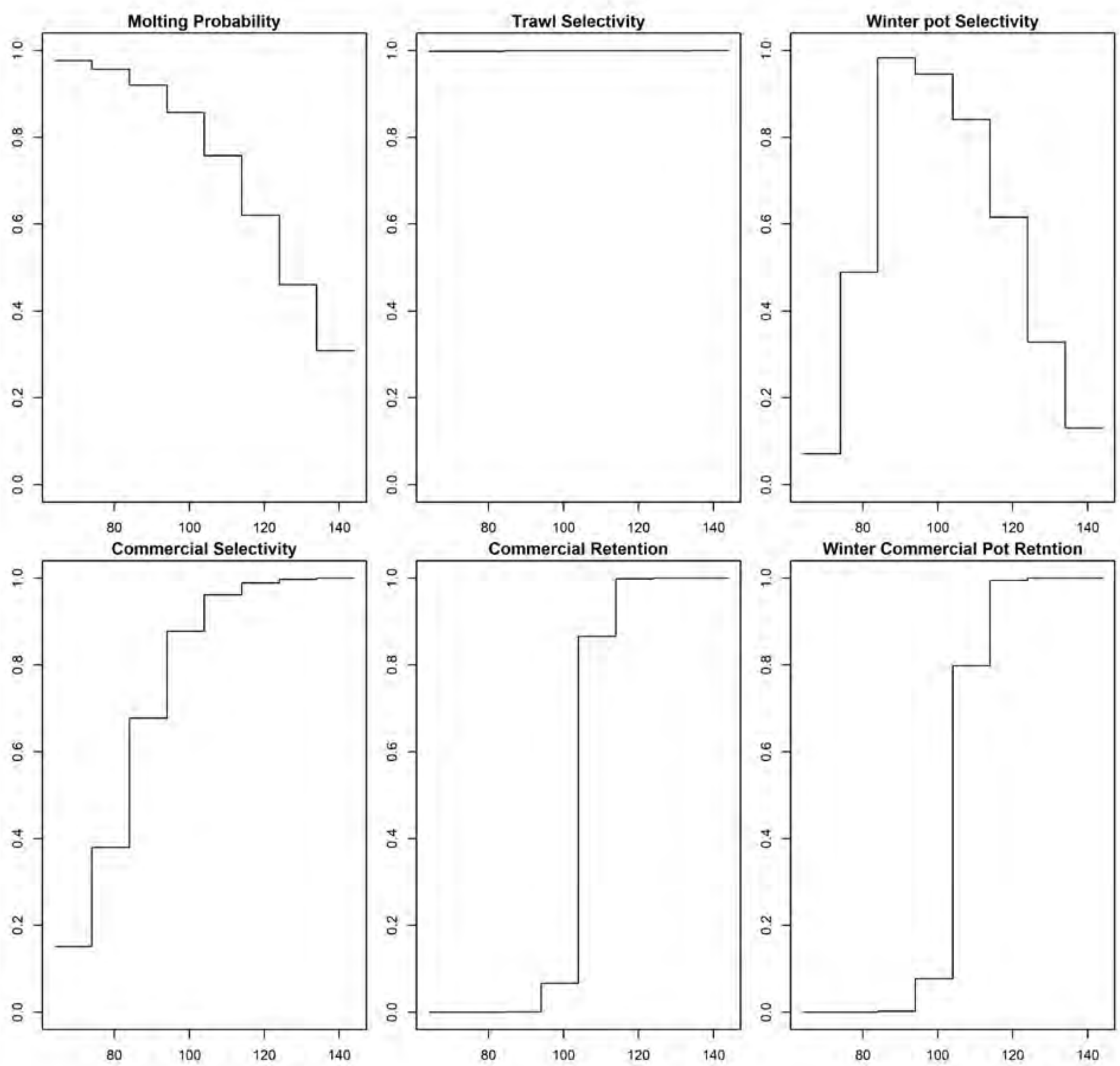


Figure D2-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

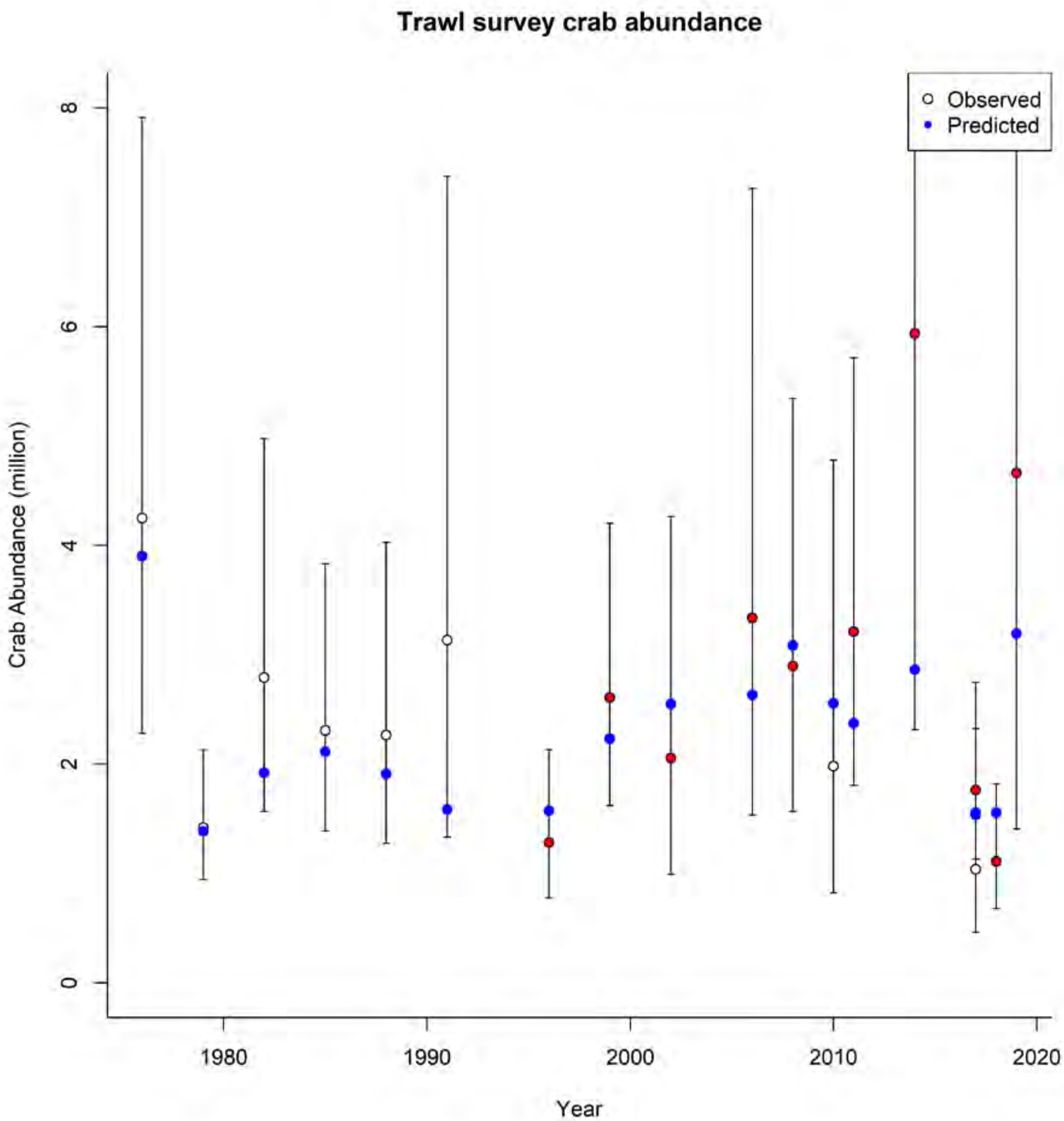


Figure D2-4. Estimated trawl survey male abundance (blue) (crab >= 64 mm CL). Observed: White: NOAA trawl survey, Red: ADG&G trawl survey

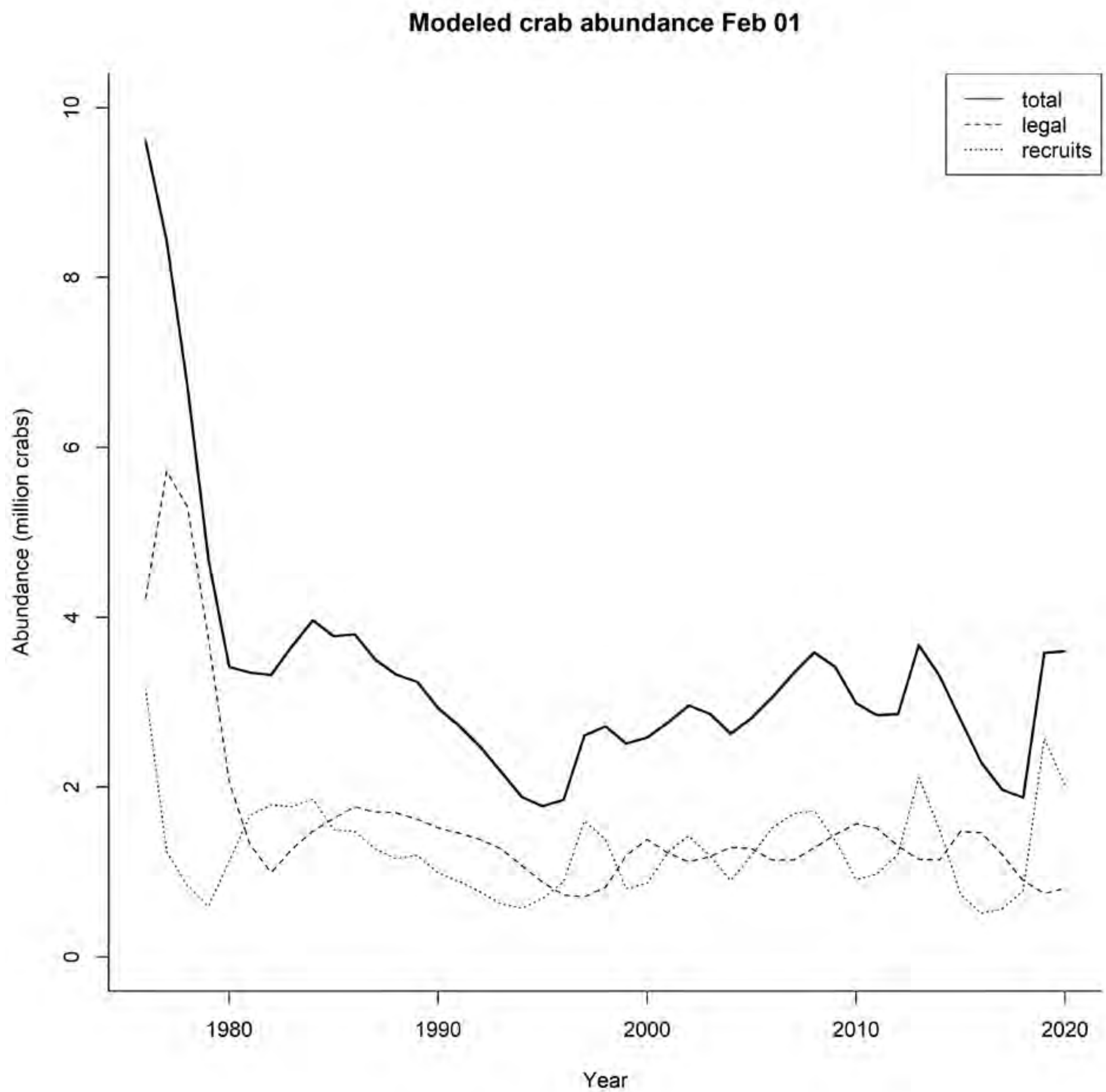


Figure D2-5. Estimated abundance of legal males.

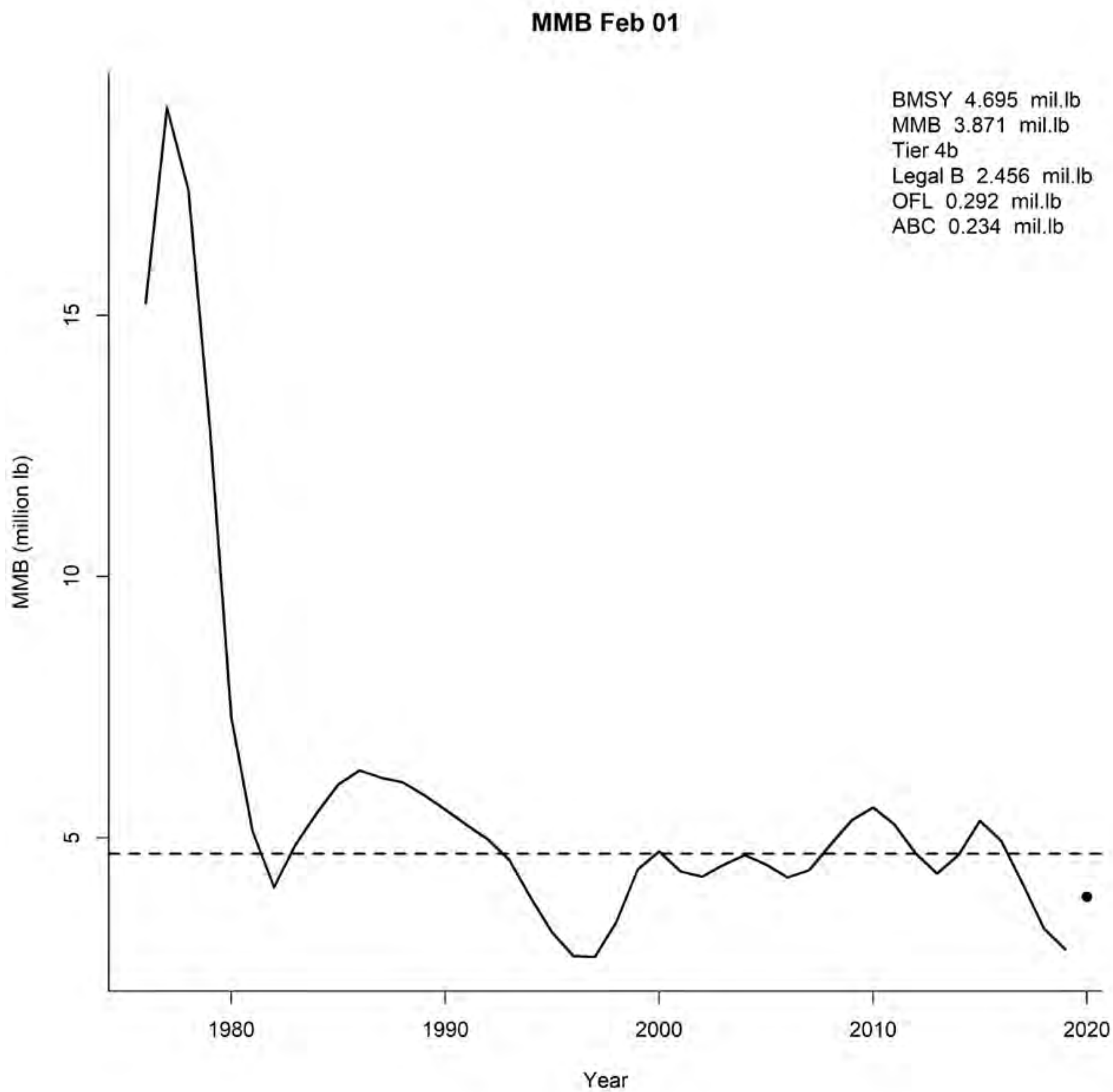


Figure D2-6. Estimated abundance of Mature Male Biomass. Dash line shows Bmsy.

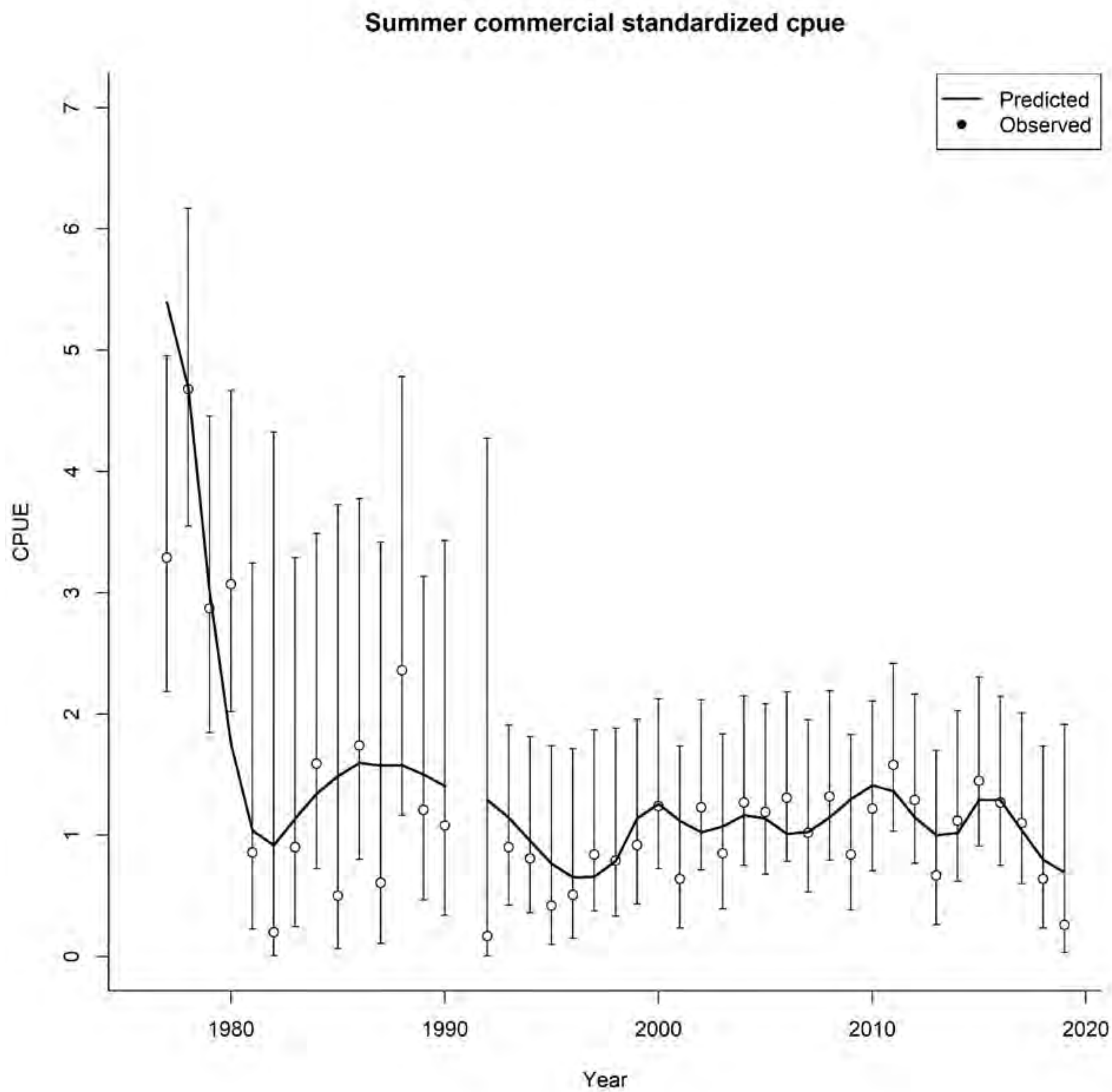


Figure D2-7. Summer commercial standardized cpue.

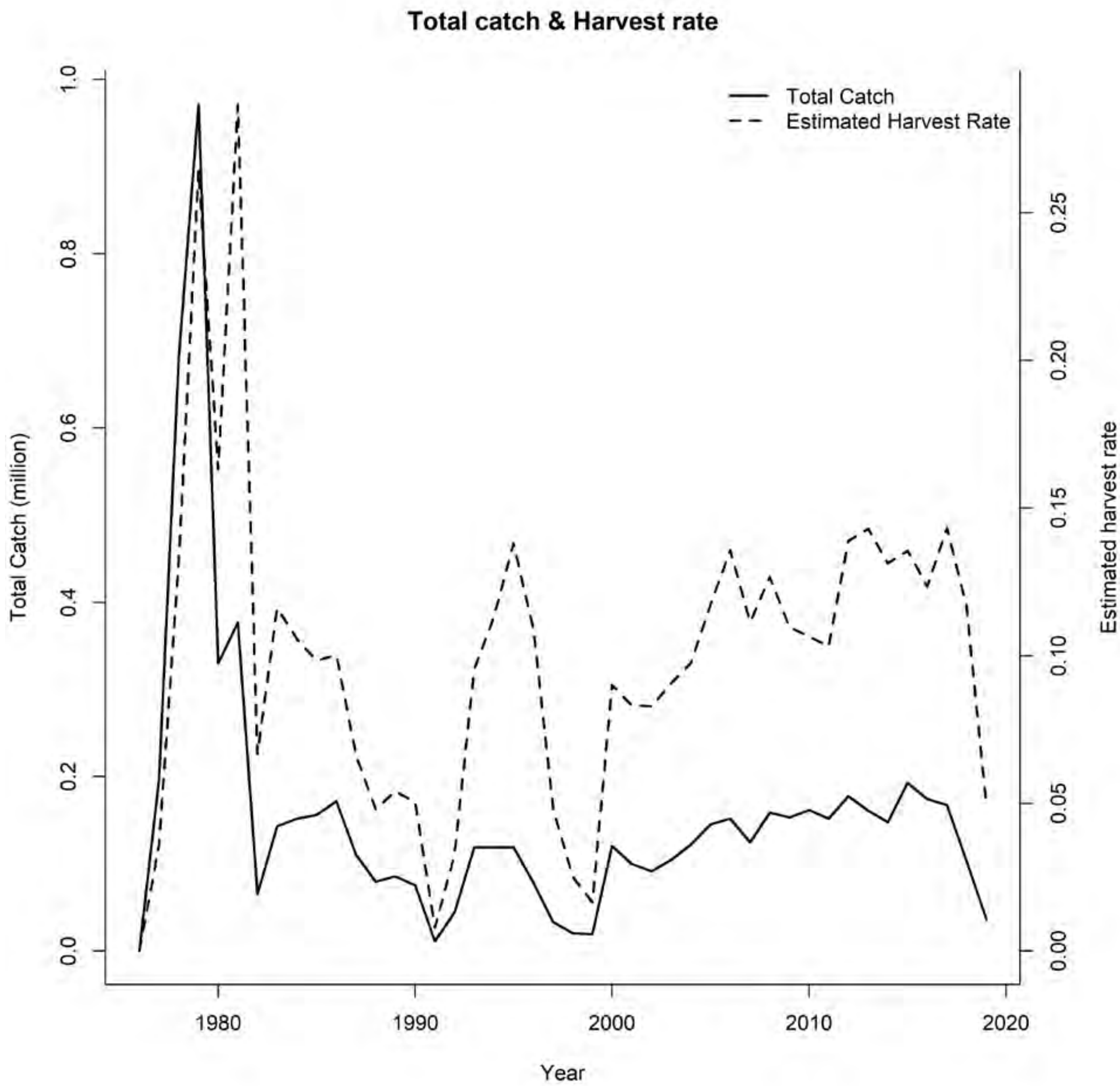


Figure D2-8. Total catch and estimated harvest rate.

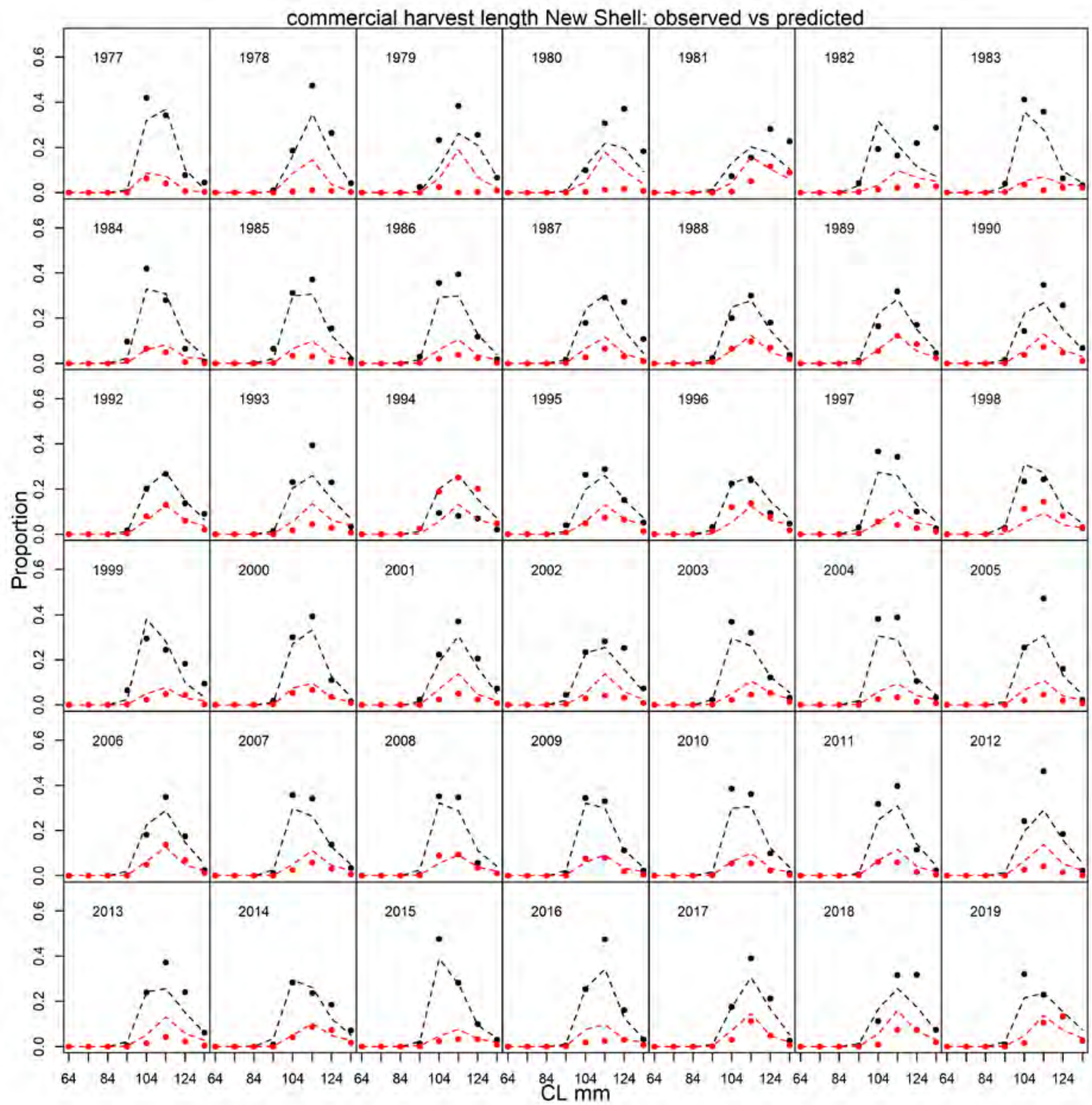


Figure D2-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Black: newshell, Red: oldshell

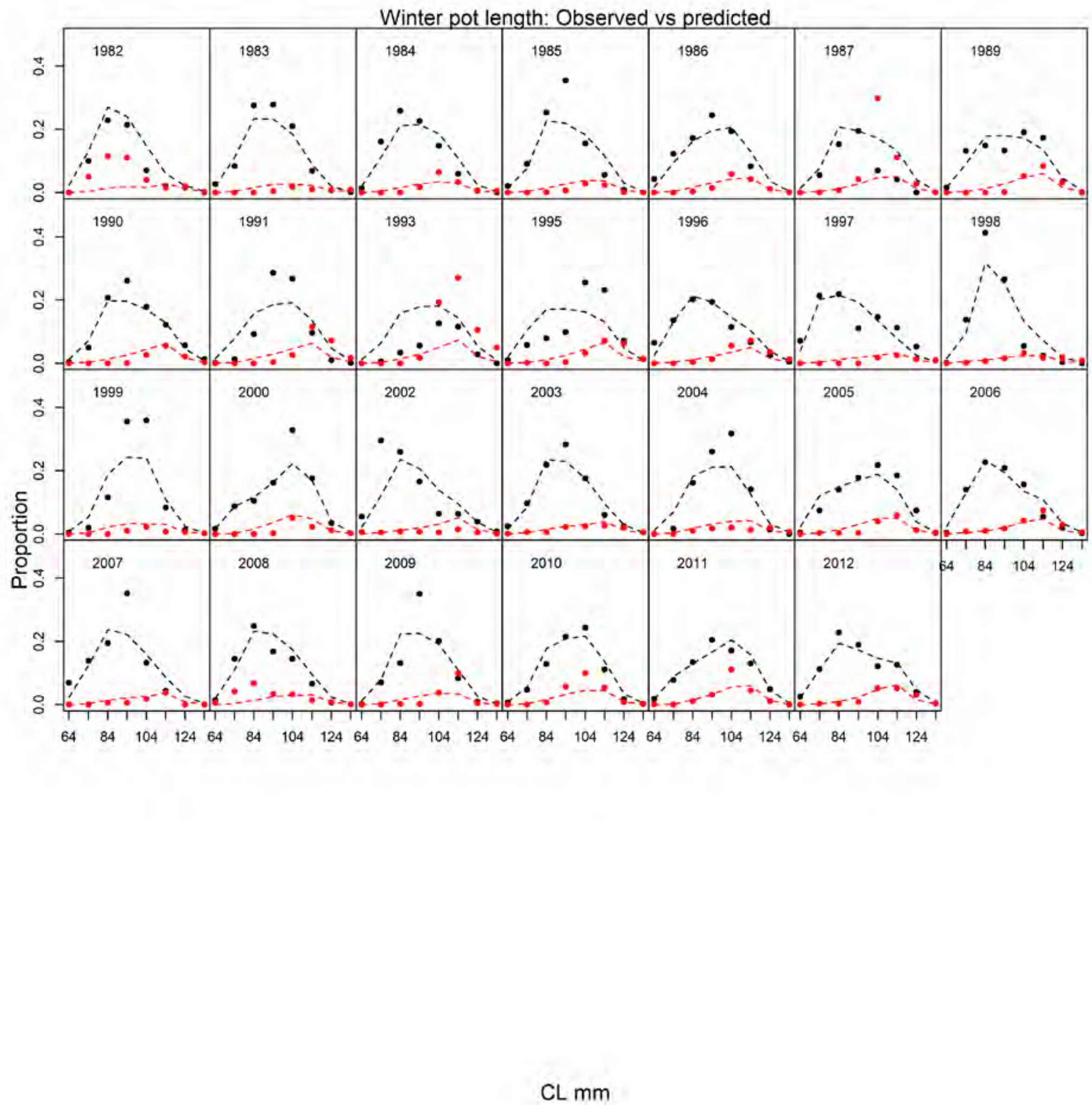


Figure D2-10. Predicted (dashed line) vs. observed (dots) length class proportions for the winter and spring pot survey. Black: newshell, Red: oldshell

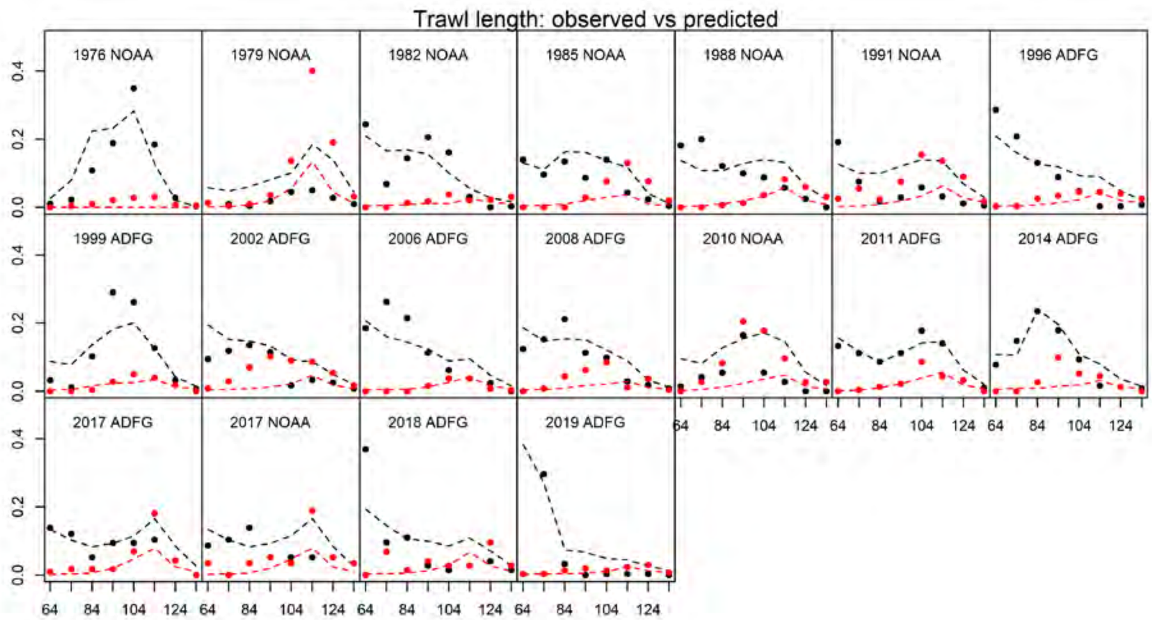


Figure D2-11. Predicted (dashed) vs. observed (dots) length class proportions for trawl survey. Black: newshell, Red: oldshell

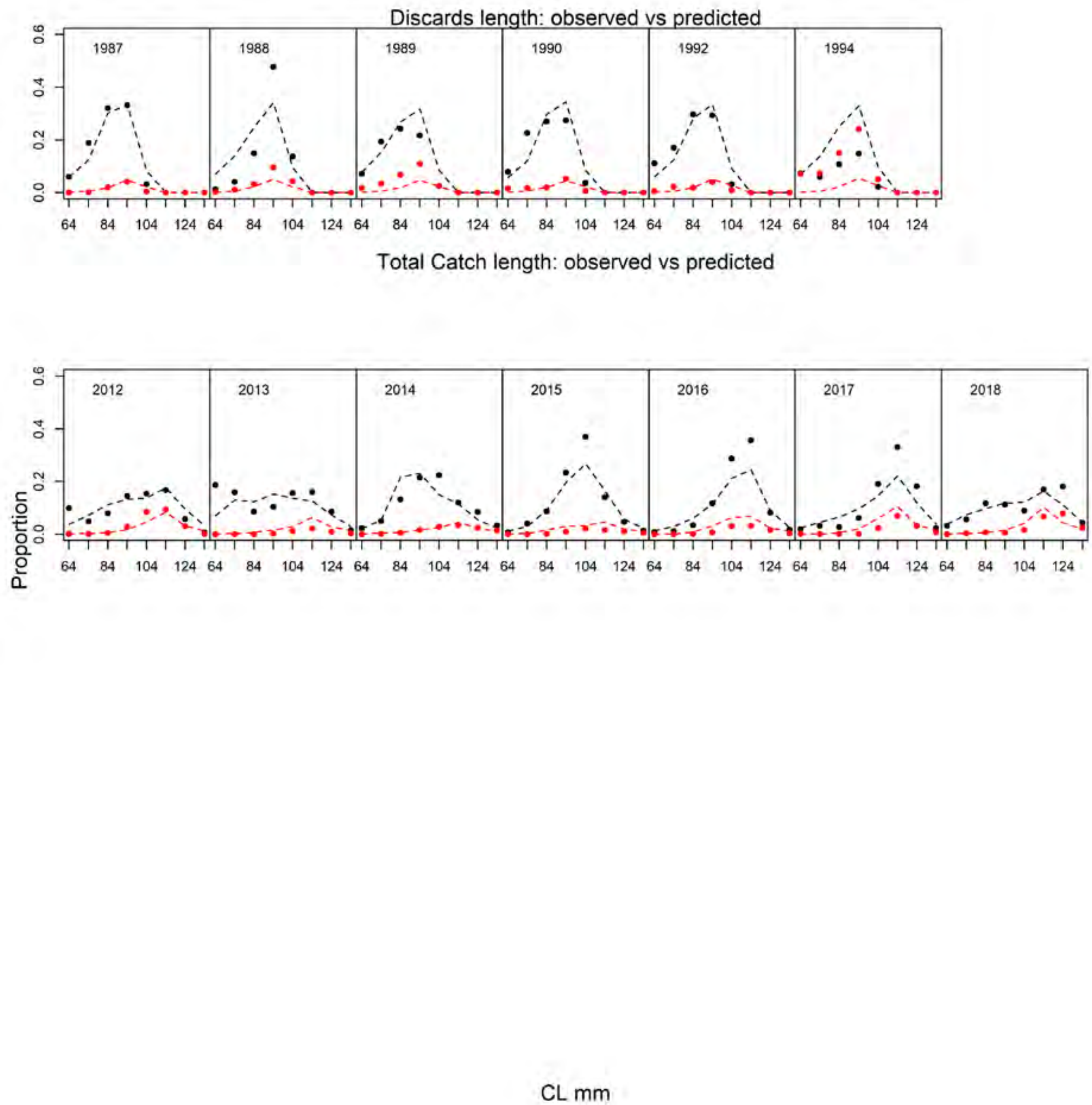


Figure D2-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

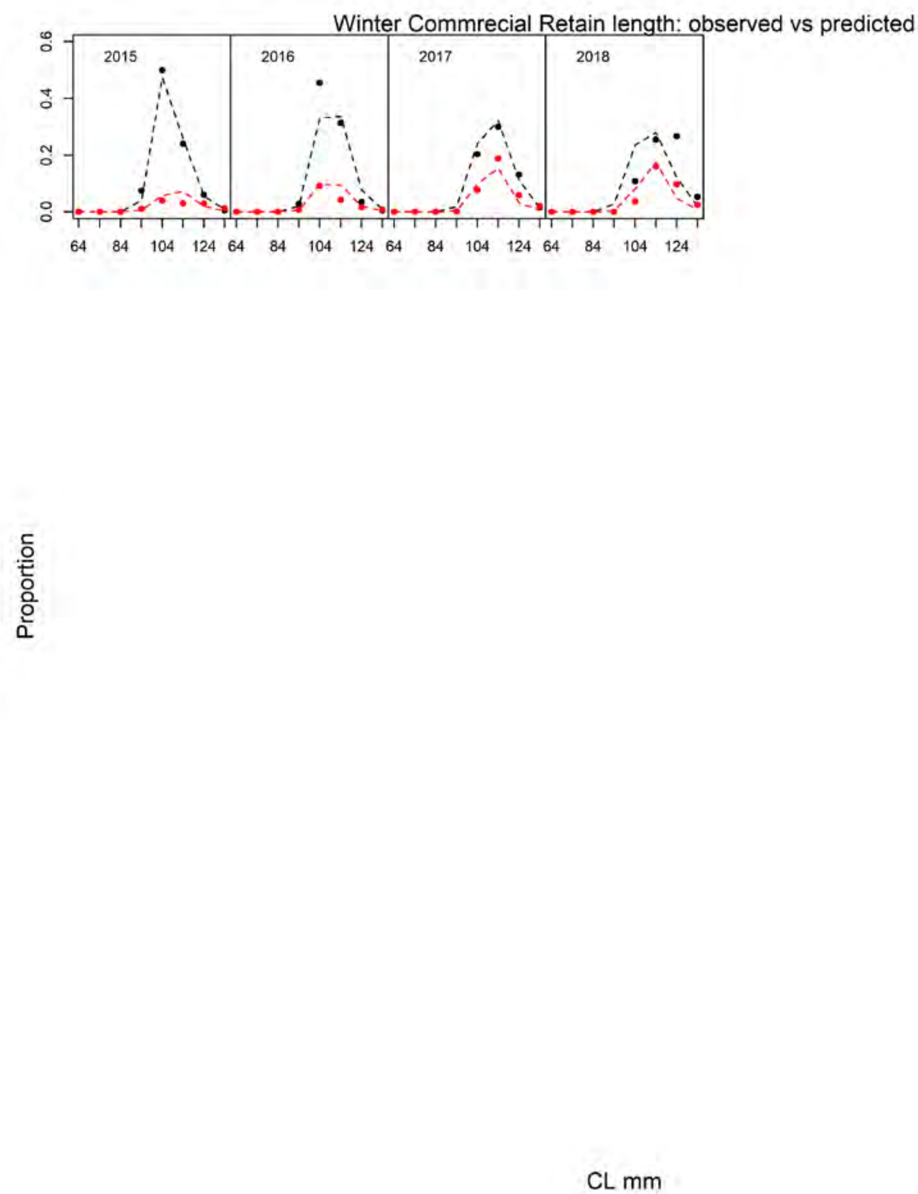


Figure D2-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

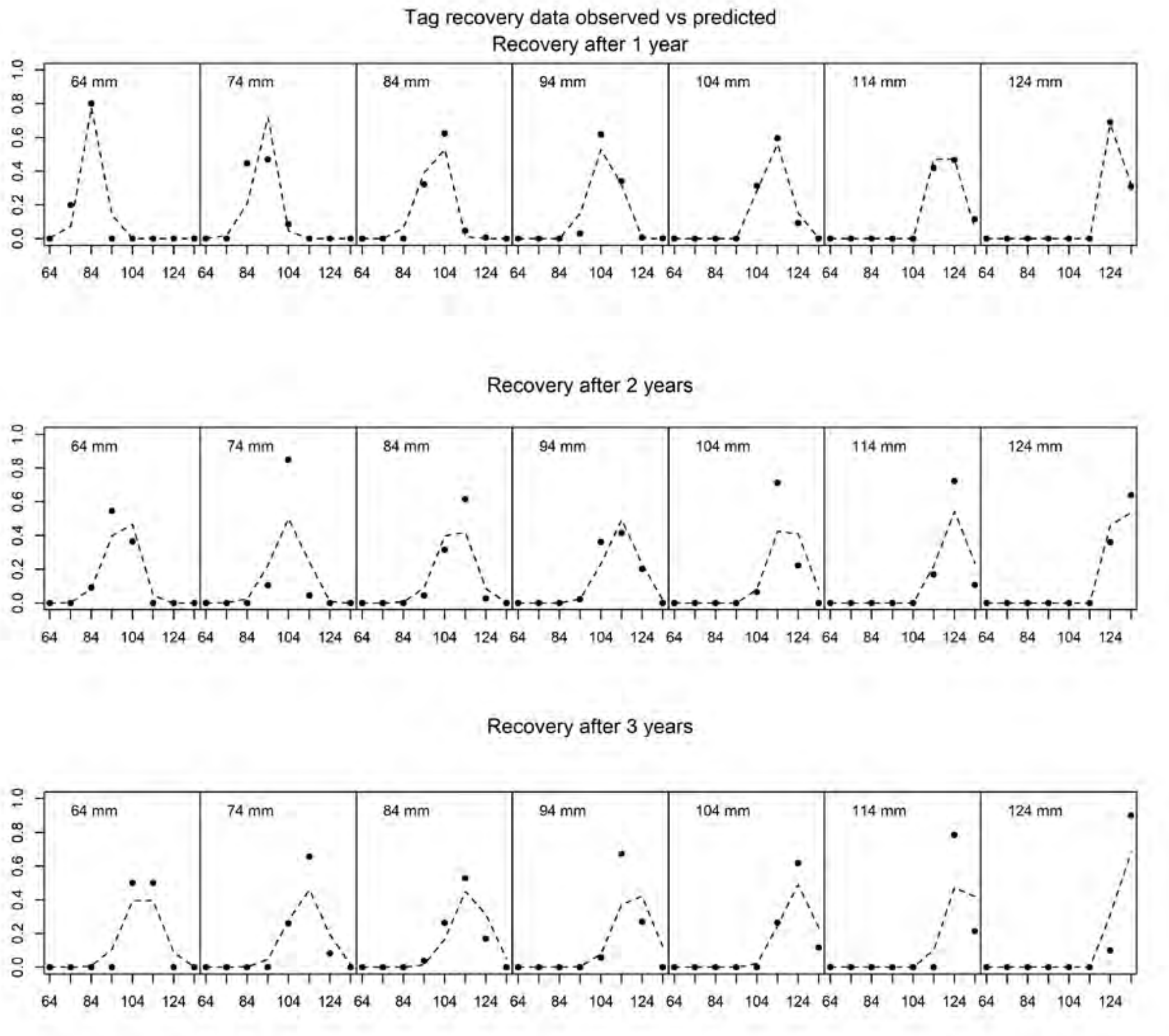


Figure D2-13. Predicted vs. observed length class proportions for tag recovery data.

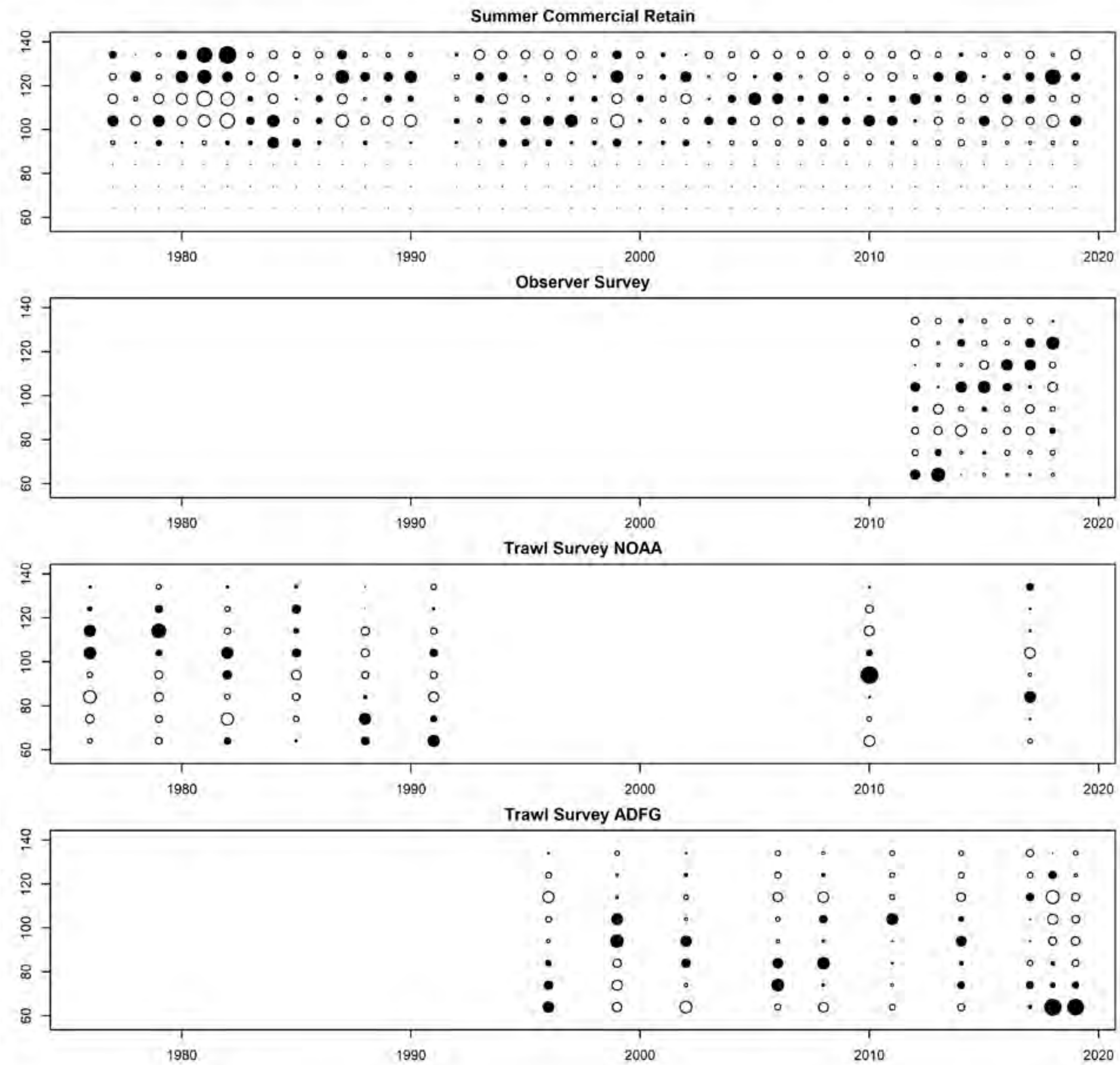


Figure D2-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

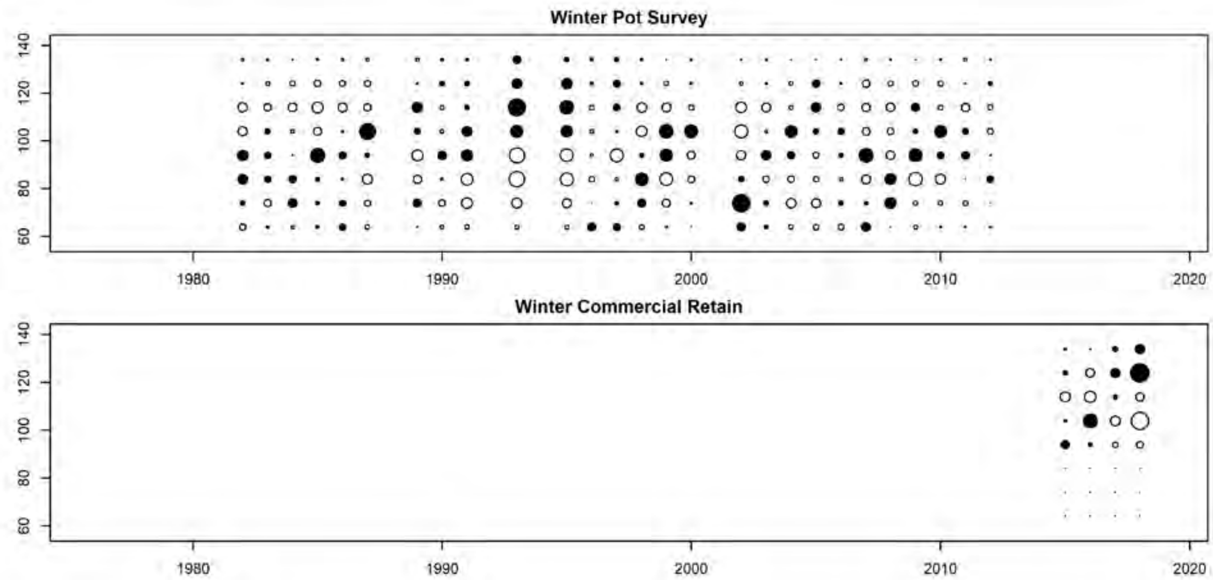


Figure D2-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table D2. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.775	0.112
log_q_2		
log_N_{76}	9.171	0.112
R_0	6.526	0.084
a_1	2.214	5.073
a_2	3.308	4.774
a_3	4.334	4.654
a_4	4.373	4.646
a_5	4.566	4.637
a_6	3.777	4.663
a_7	2.265	4.871
r1	10.000	0.312
r2	9.616	0.362
log_a	-2.733	0.099
log_b	4.837	0.016
log_ϕ_{st1}	-5.000	0.080
log_ϕ_{wa}	-2.130	0.297
log_ϕ_{wb}	4.808	0.030
Sw1	0.071	0.034
Sw2	0.490	0.120
log_ϕ_{l}	-2.093	0.055
$log\_\phi ra$	-0.798	0.128
$log\_\phi rb$	4.648	0.008
$log\_\phi wra$	-0.953	0.561
$log\_\phi wrb$	4.653	0.038
w^2_t	0.000	0.000
q	0.677	0.109
σ	4.232	0.255
β_1	11.829	0.926
β_2	7.919	0.221
ms78	3.554	0.280

Appendix D - Model 19.2

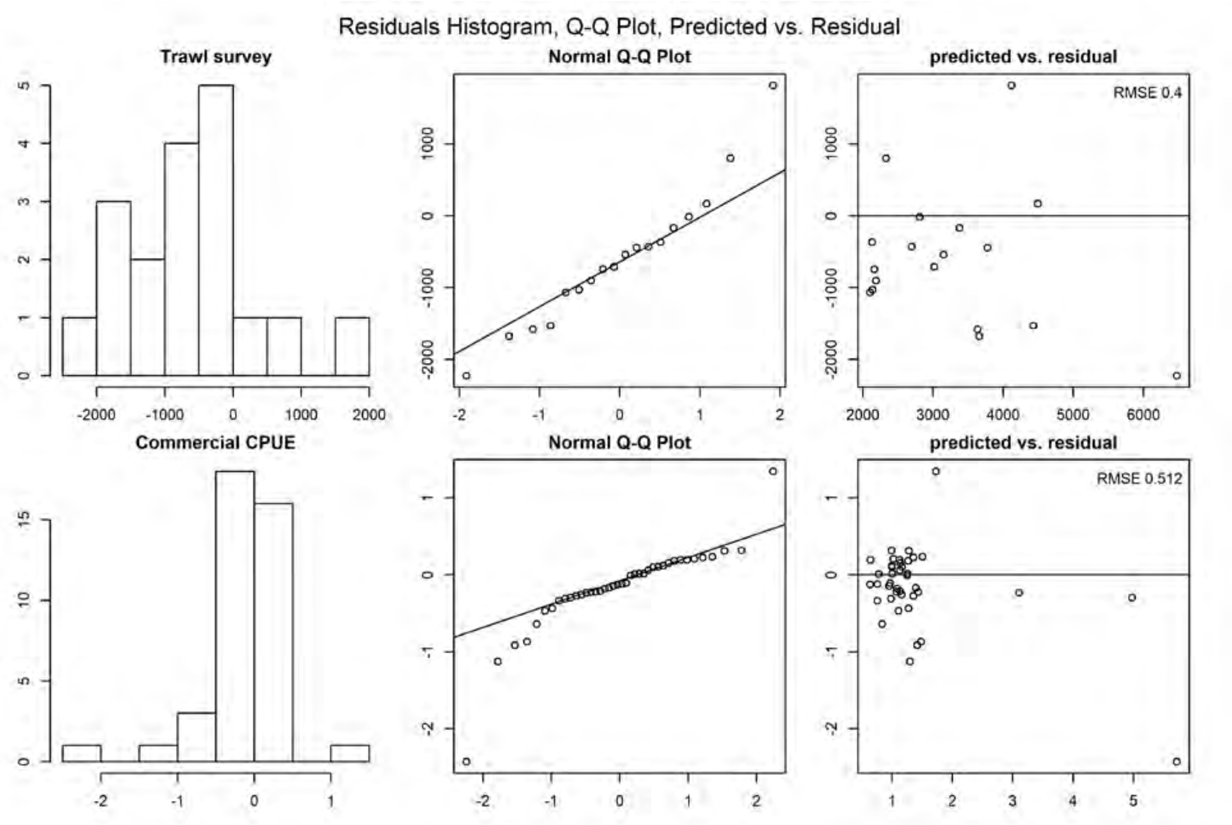


Figure D3-1. QQ Plot of Trawl survey and commercial CPUE.

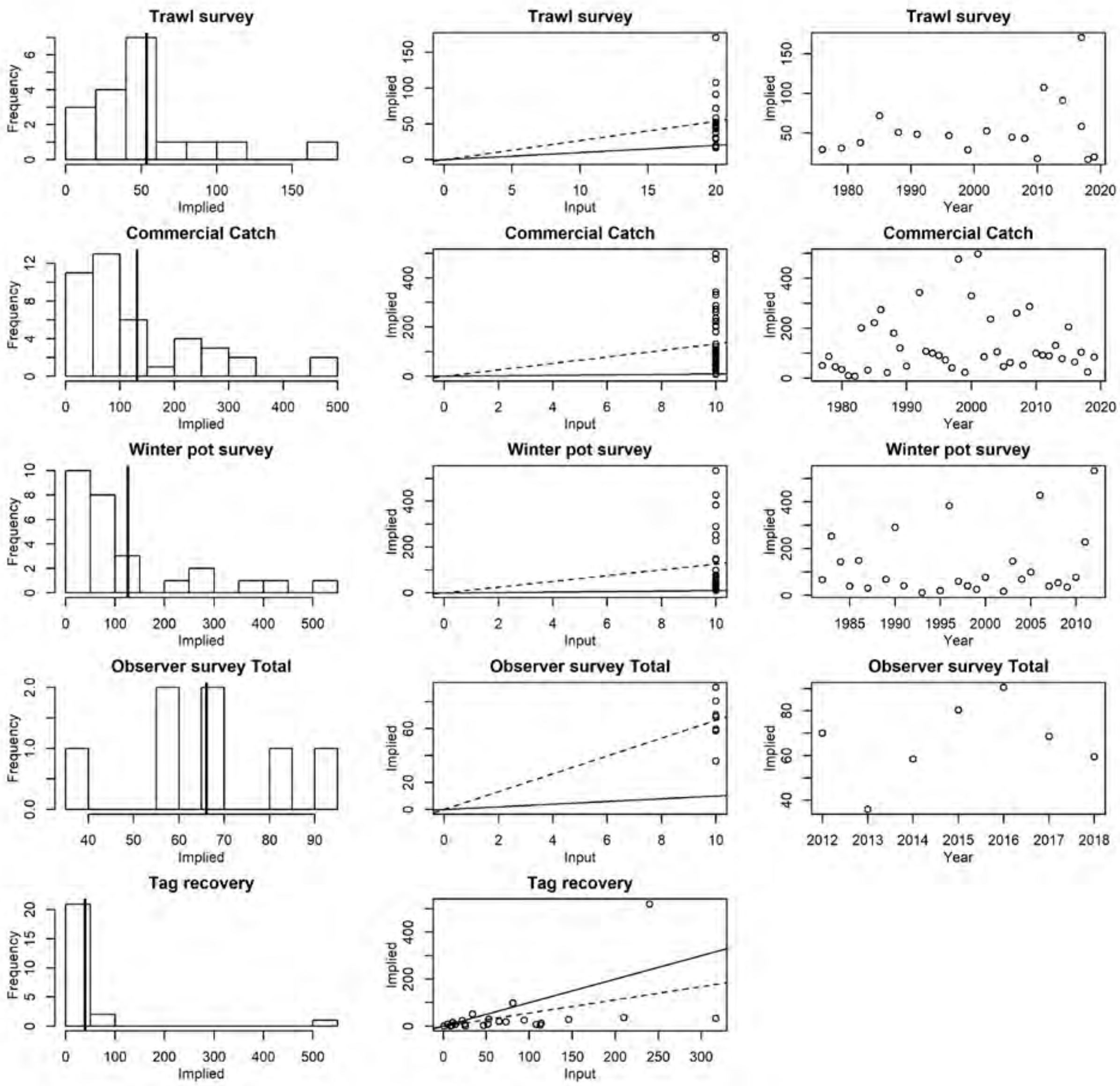


Figure D3-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

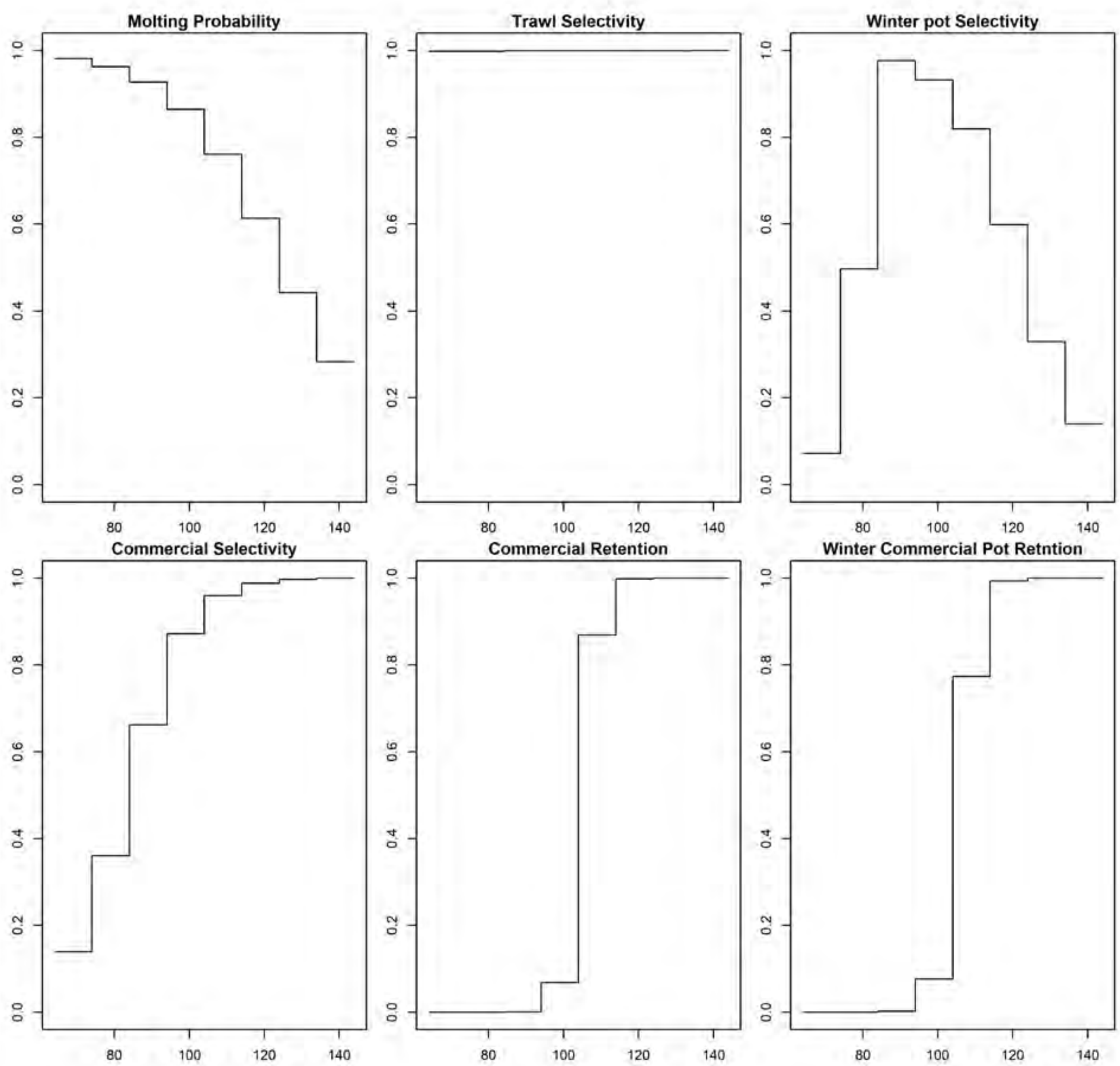


Figure D3-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

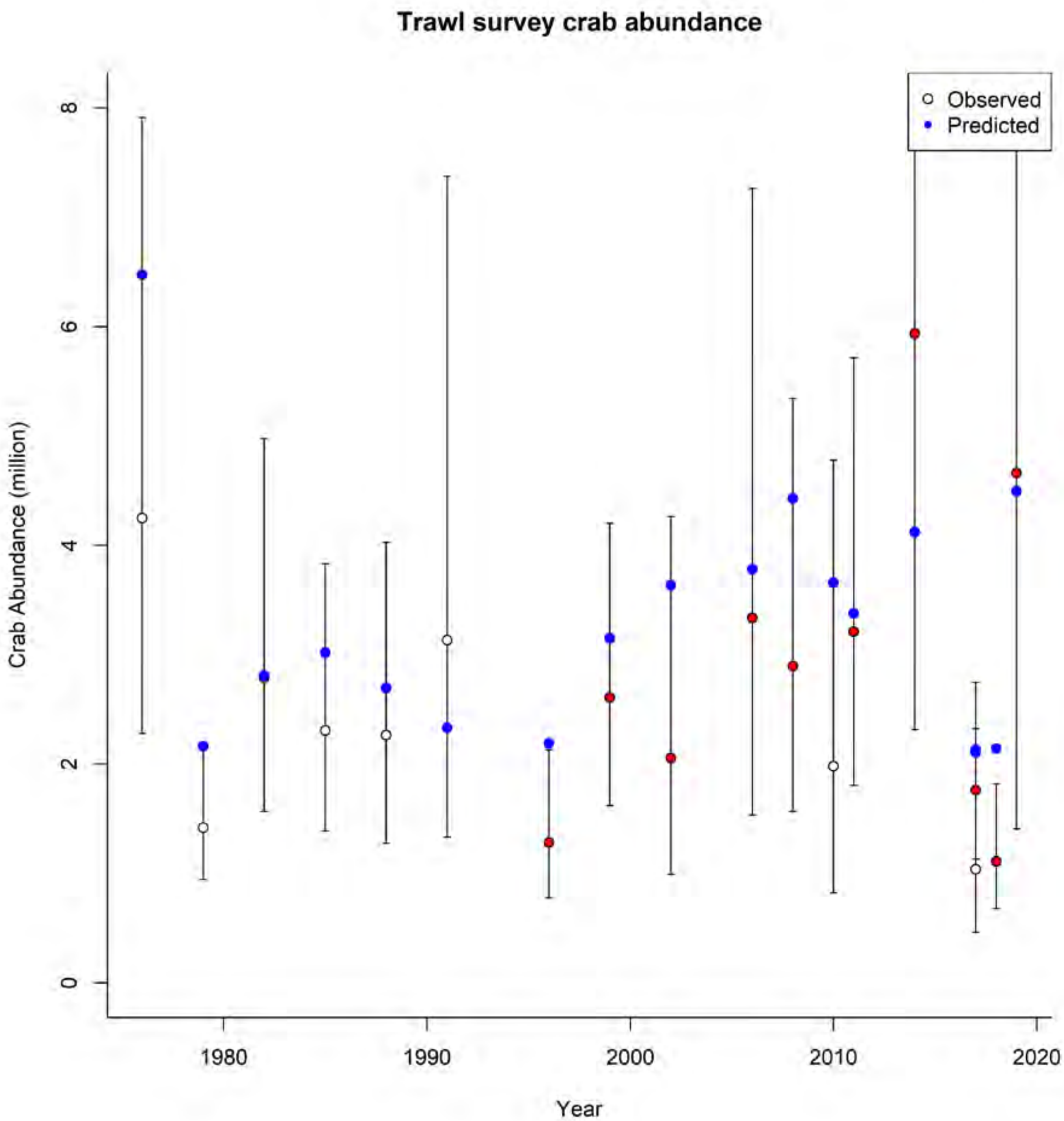


Figure D3-4. Estimated trawl survey male abundance (blue) (crab >= 64 mm CL). Observed: White: NOAA trawl survey, Red: ADG&G trawl survey

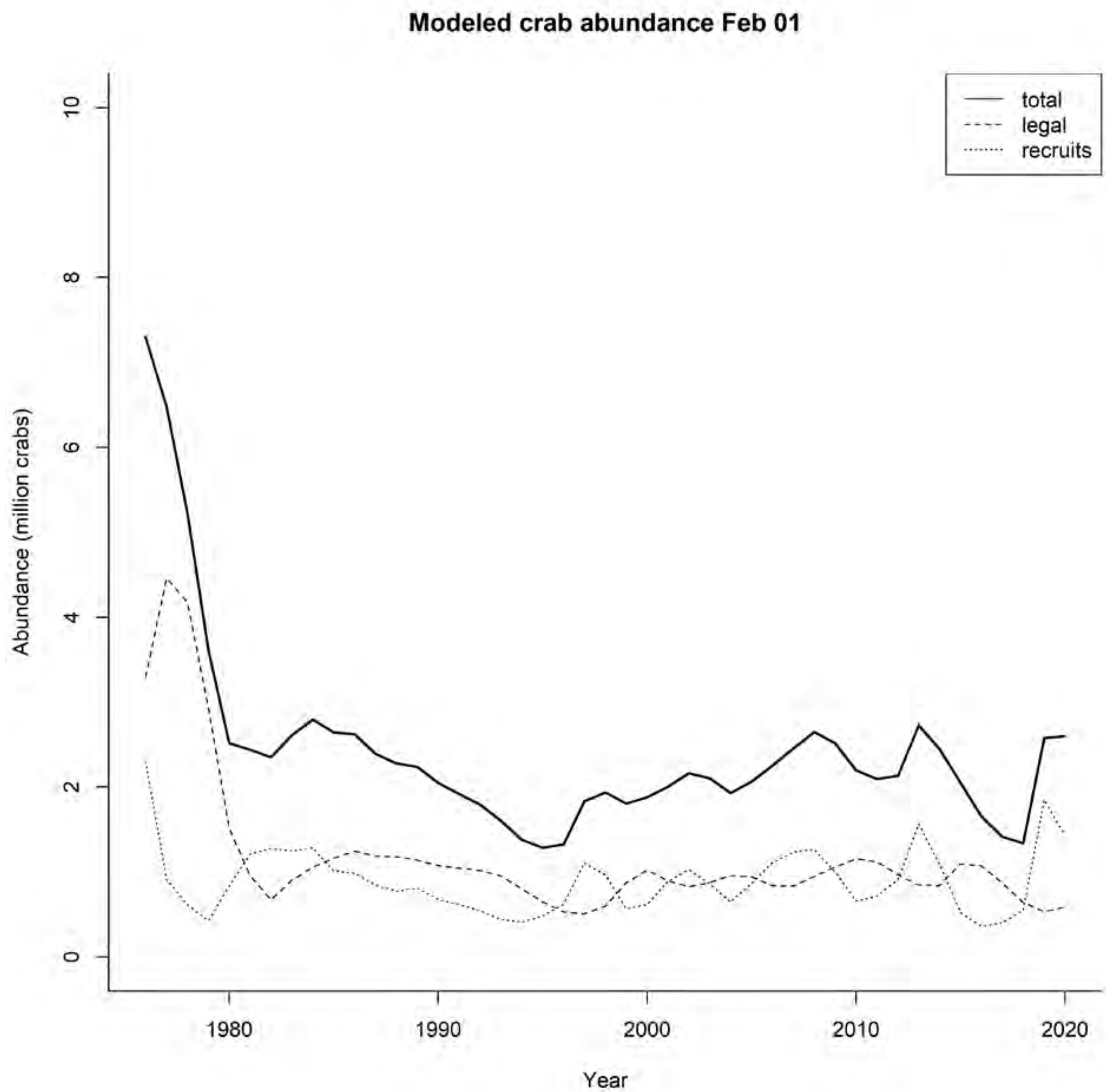


Figure D3-5. Estimated abundance of legal males.

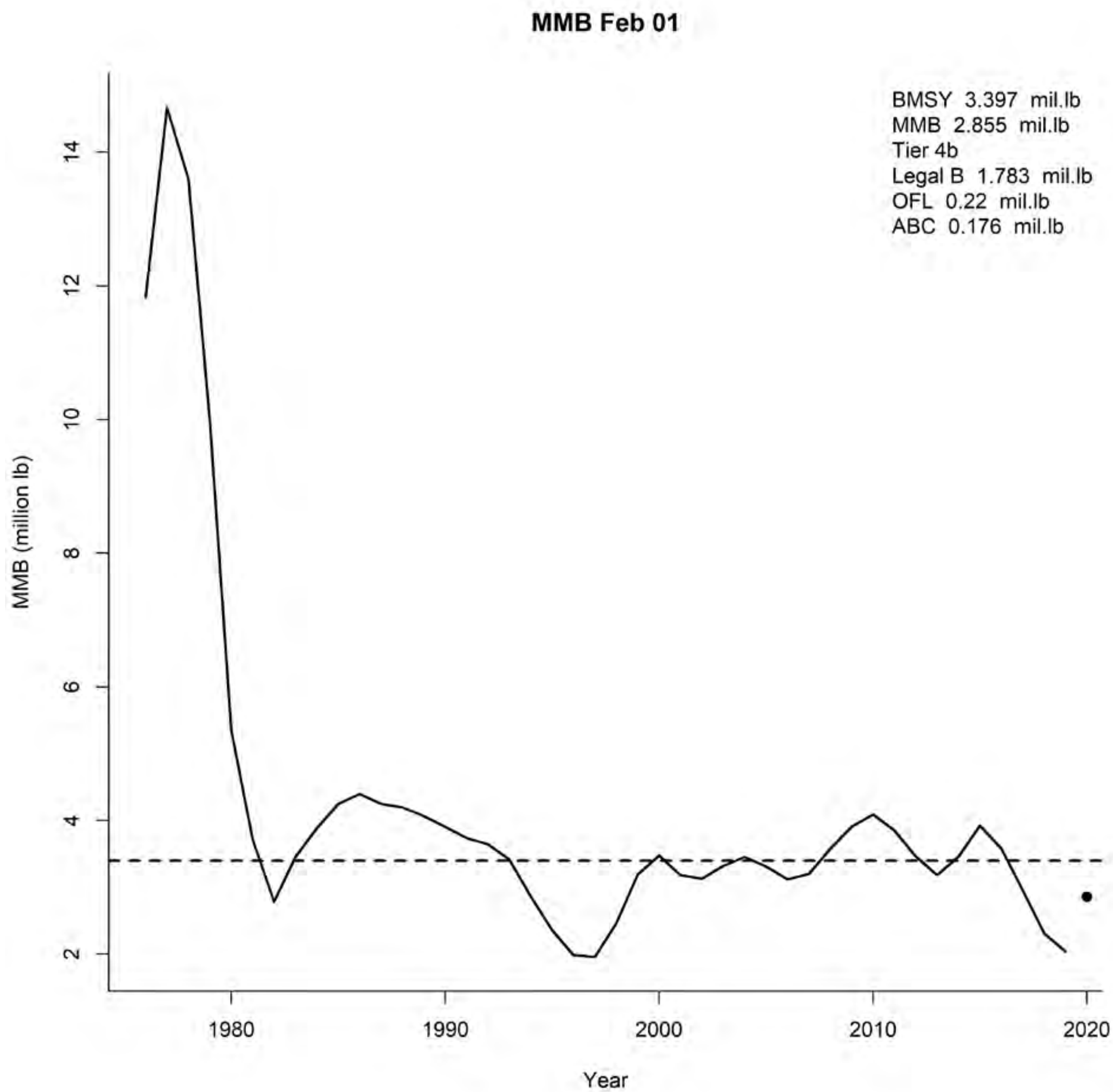


Figure D3-6. Estimated abundance of Mature Male Biomass. Dash line shows Bmsy.

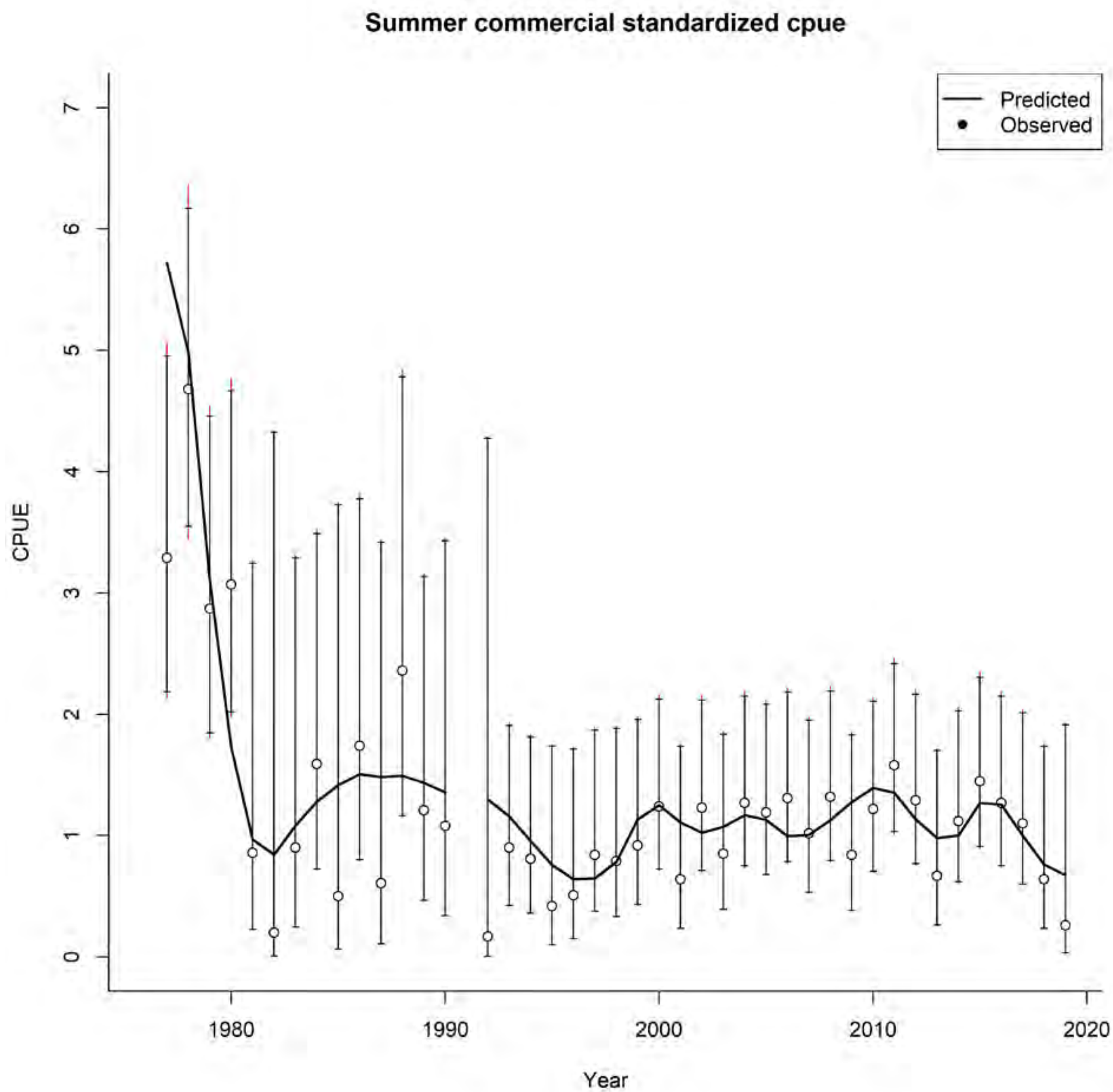


Figure D3-7. Summer commercial standardized cpue.

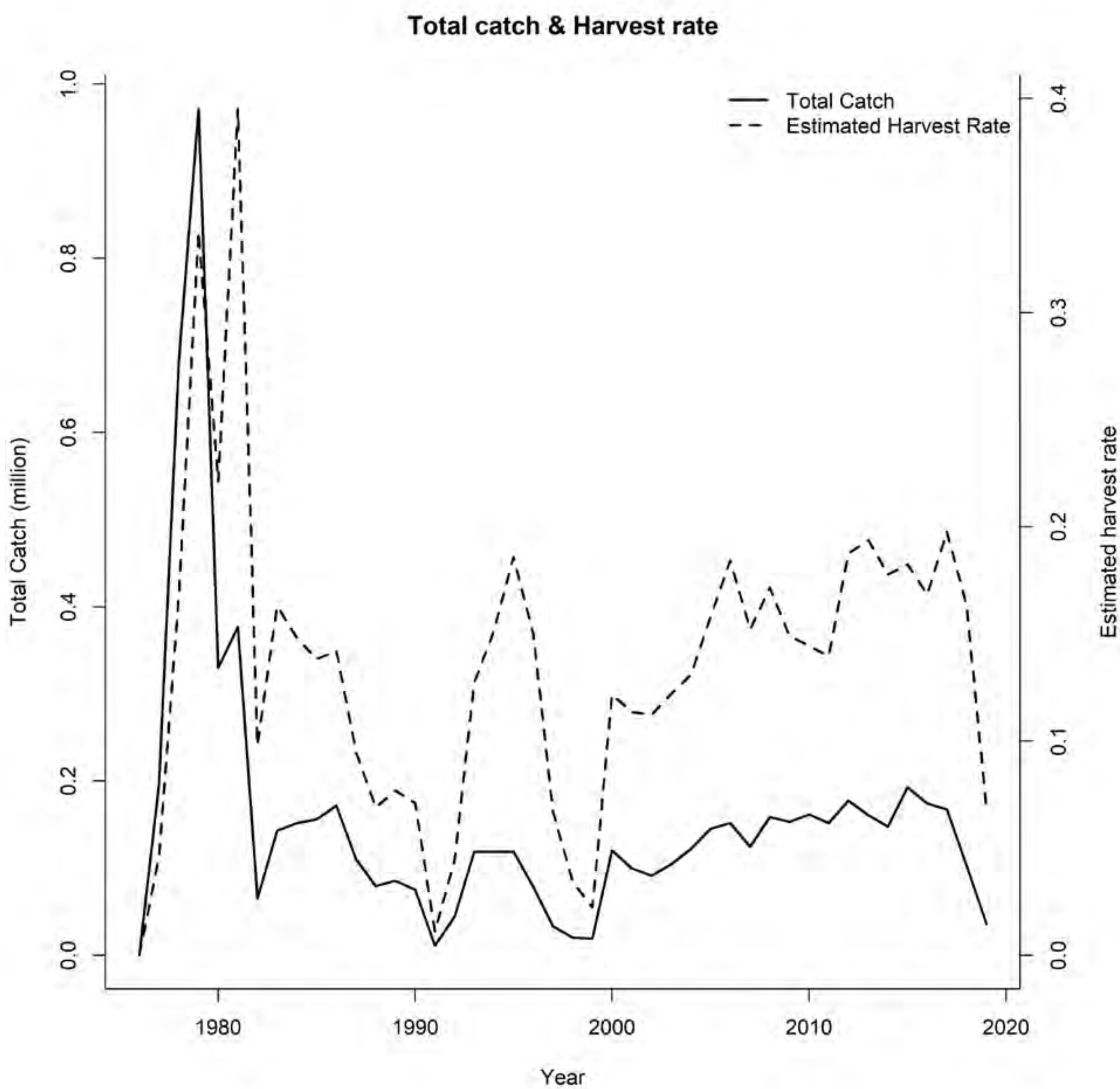


Figure D3-8. Total catch and estimated harvest rate.

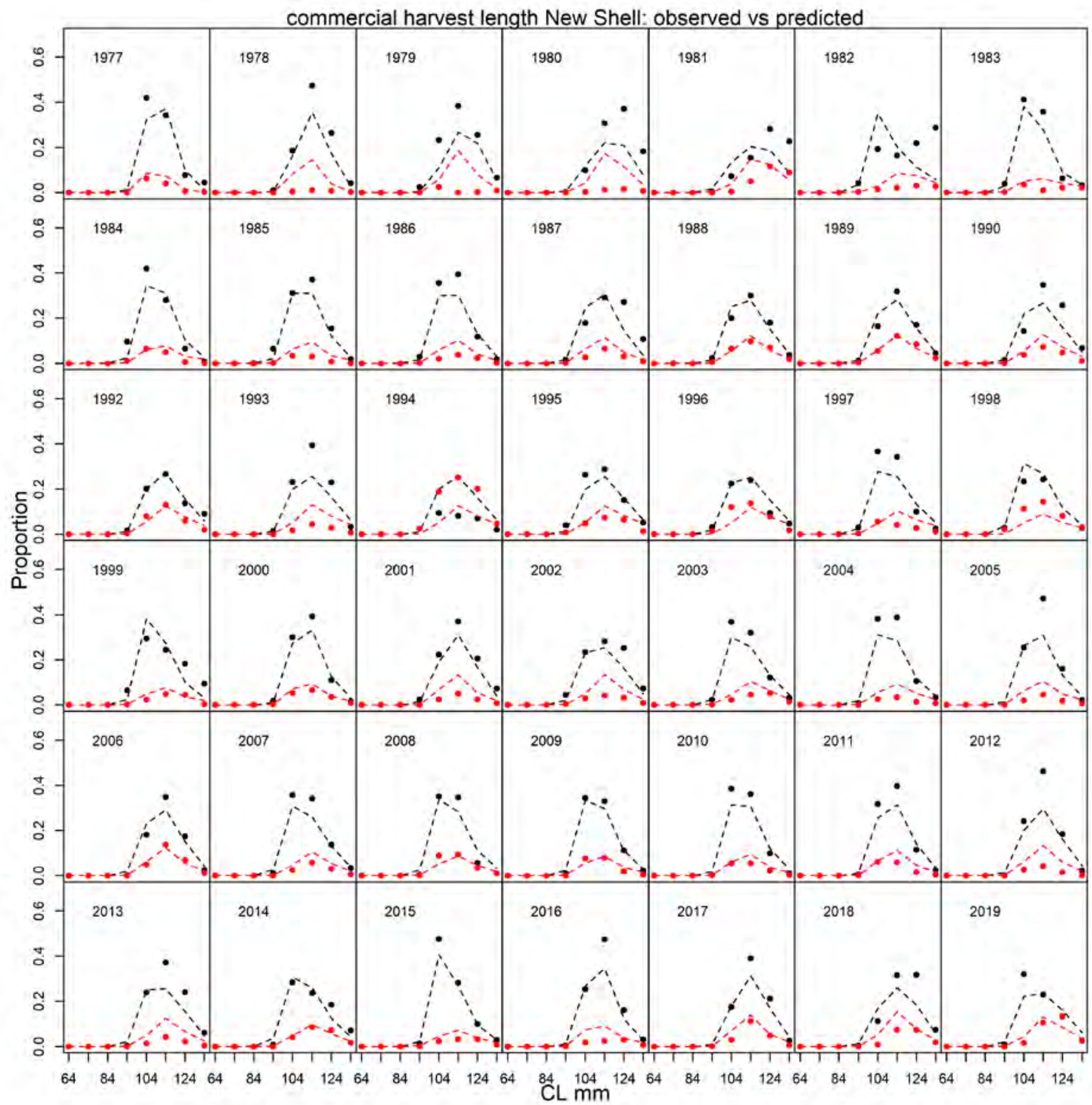


Figure D3-9. Predicted (dashed) vs. observed (dots) length class proportions for commercial catch. Black: newshell, Red: oldshell

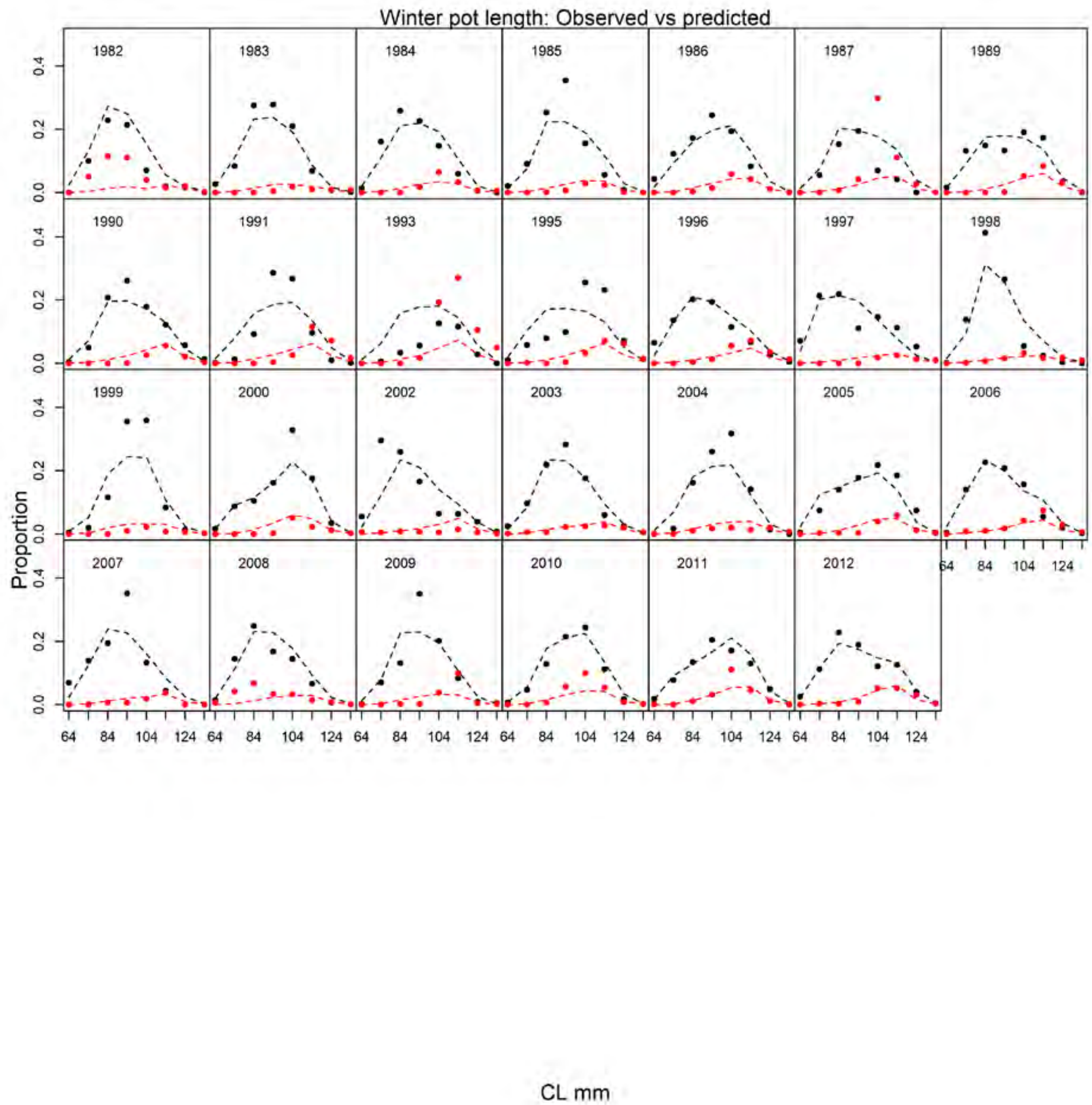


Figure D3-10. Predicted (dashed line) vs. observed (dots) length class proportions for the winter and spring pot survey. Black: newshell, Red: oldshell

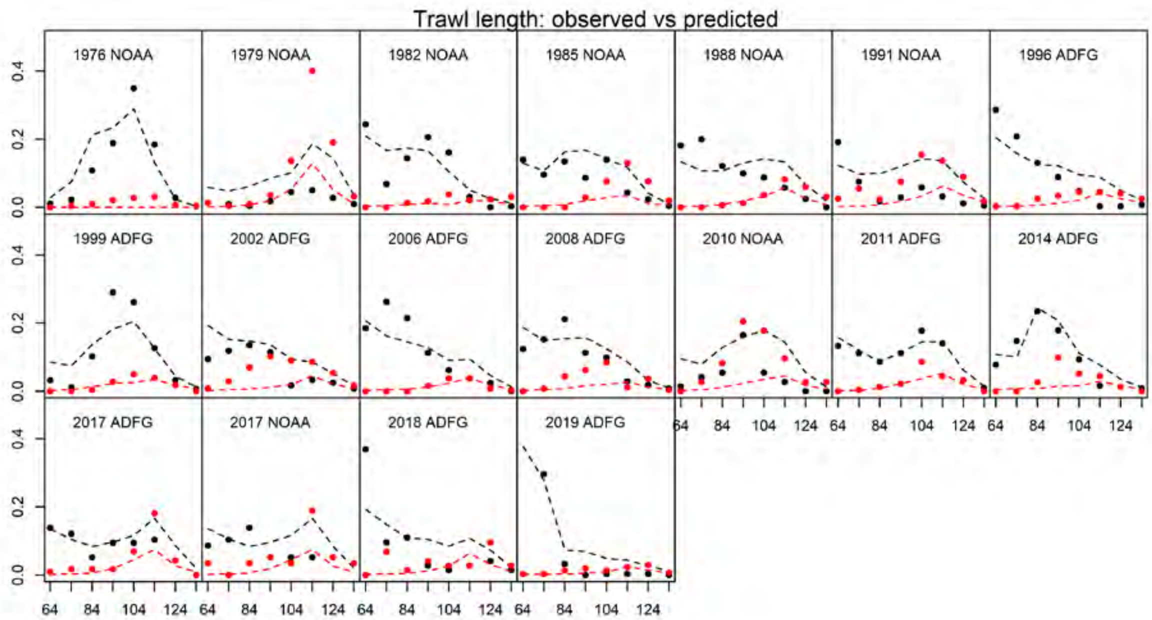


Figure D3-11. Predicted (dashed) vs. observed (dots) length class proportions for trawl survey. Black: newshell, Red: oldshell

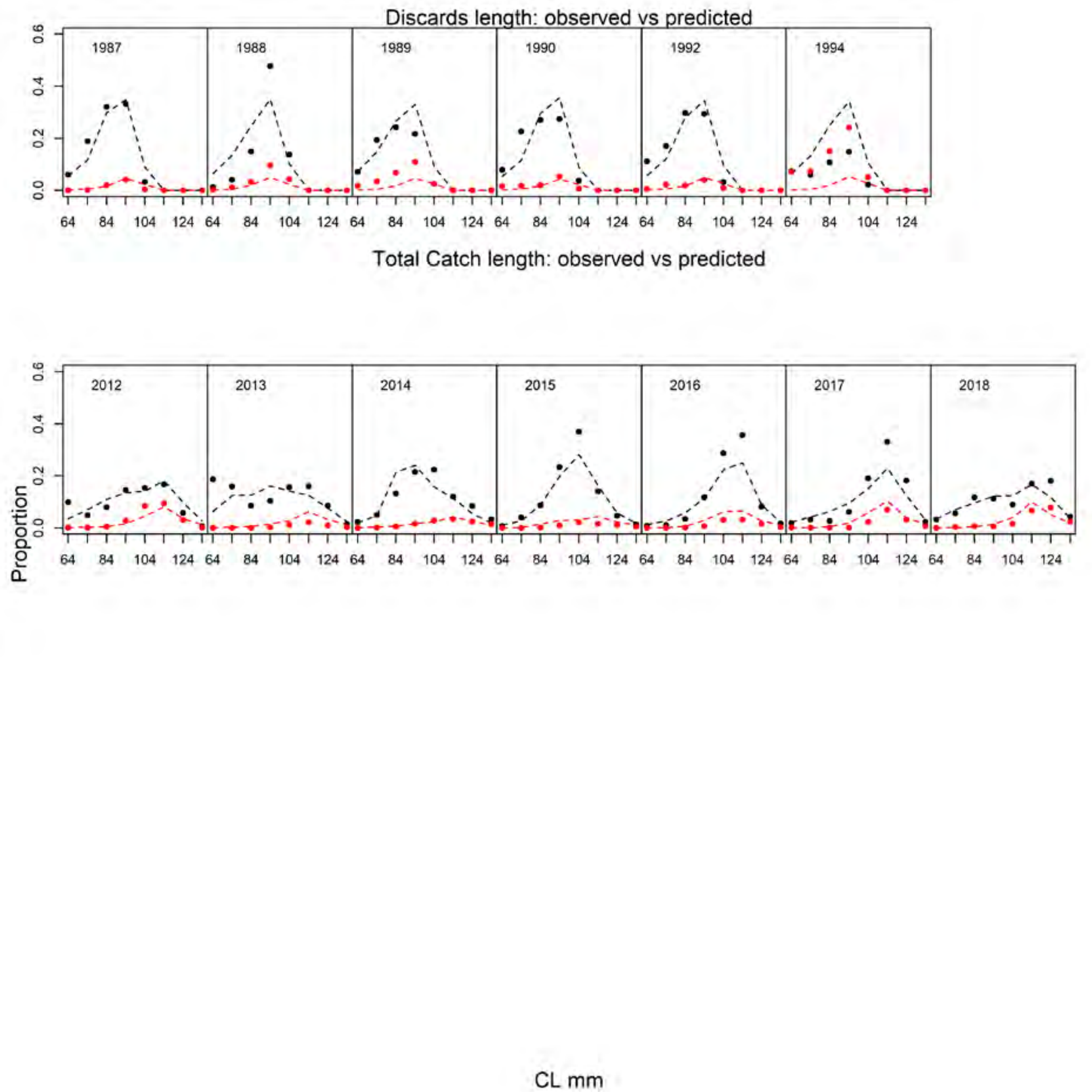


Figure D3-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

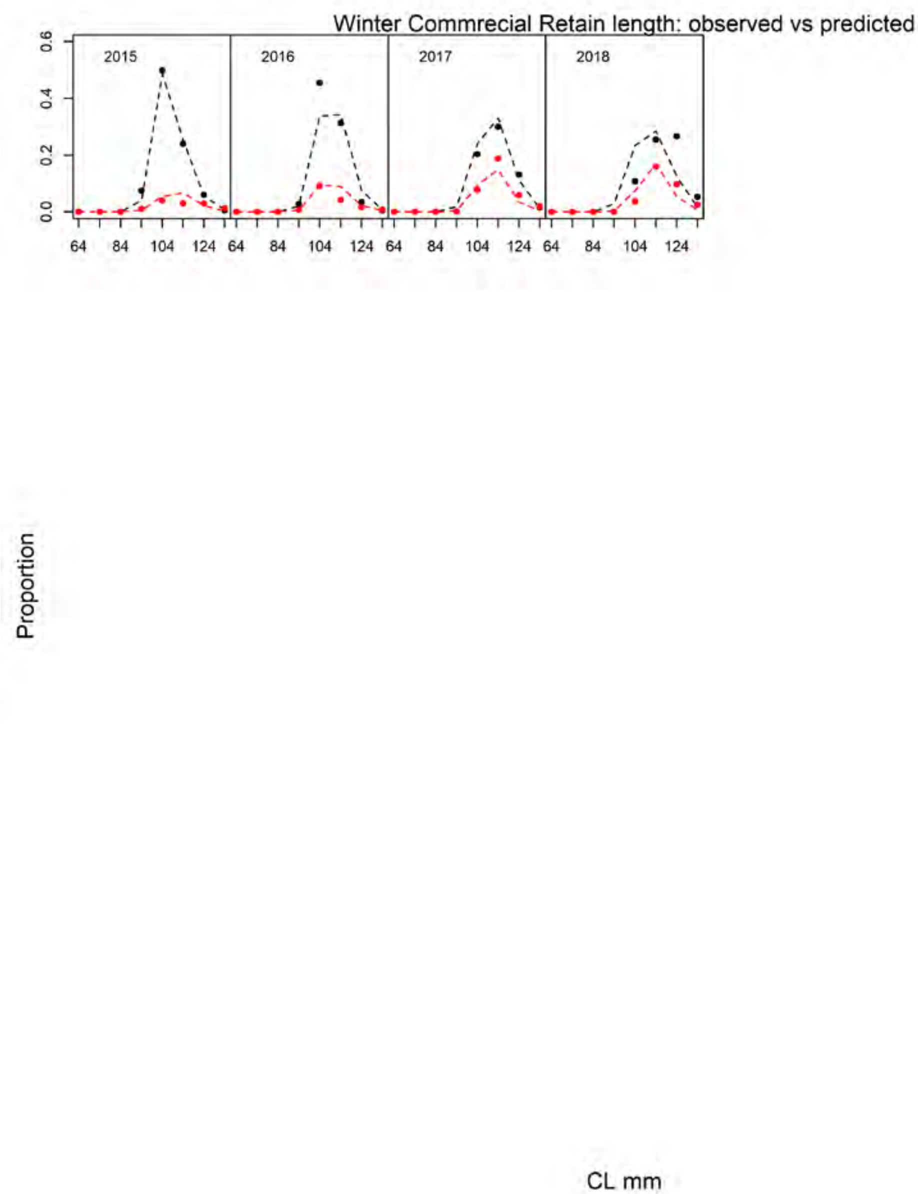


Figure D3-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

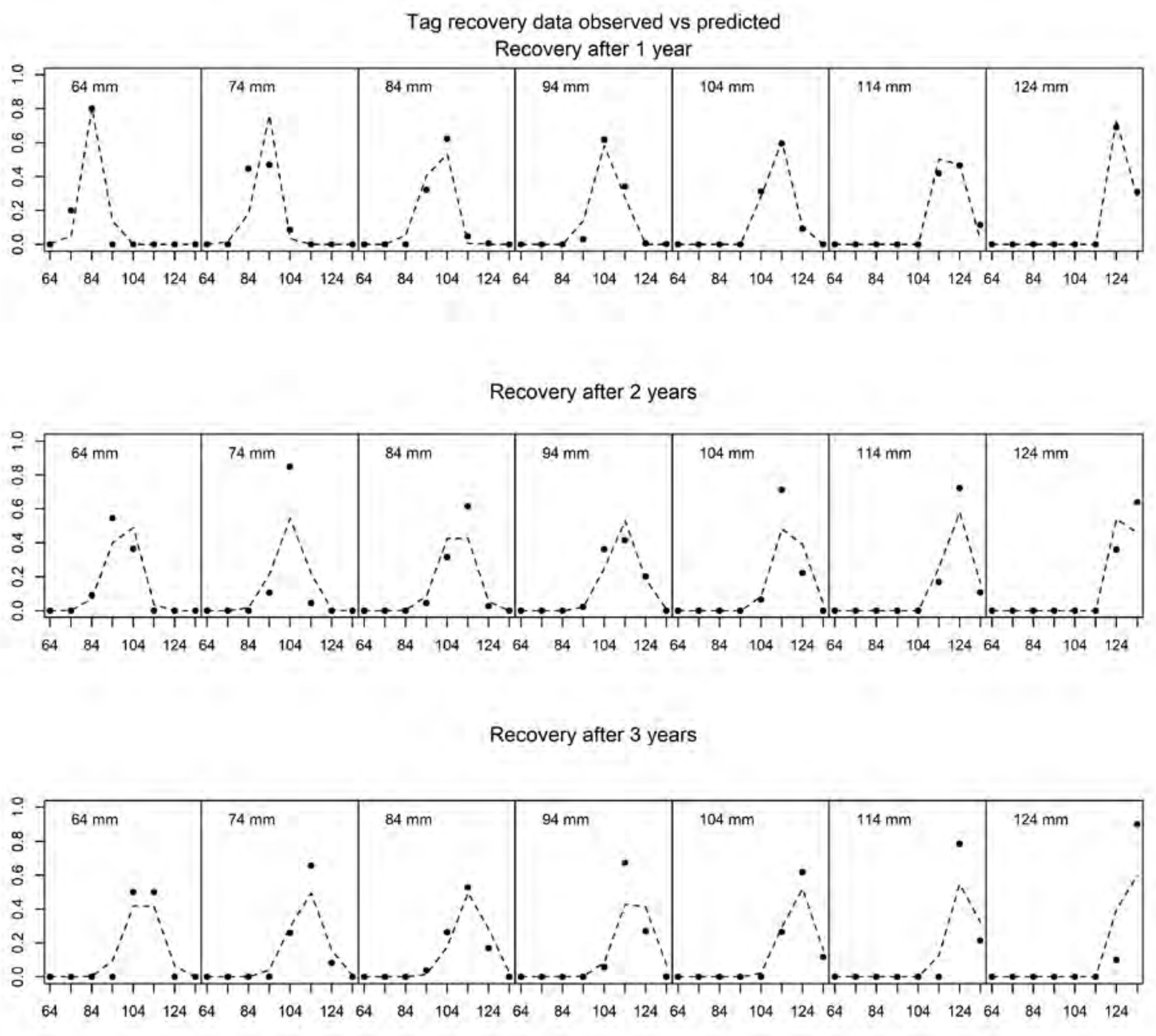


Figure D3-13. Predicted vs. observed length class proportions for tag recovery data.

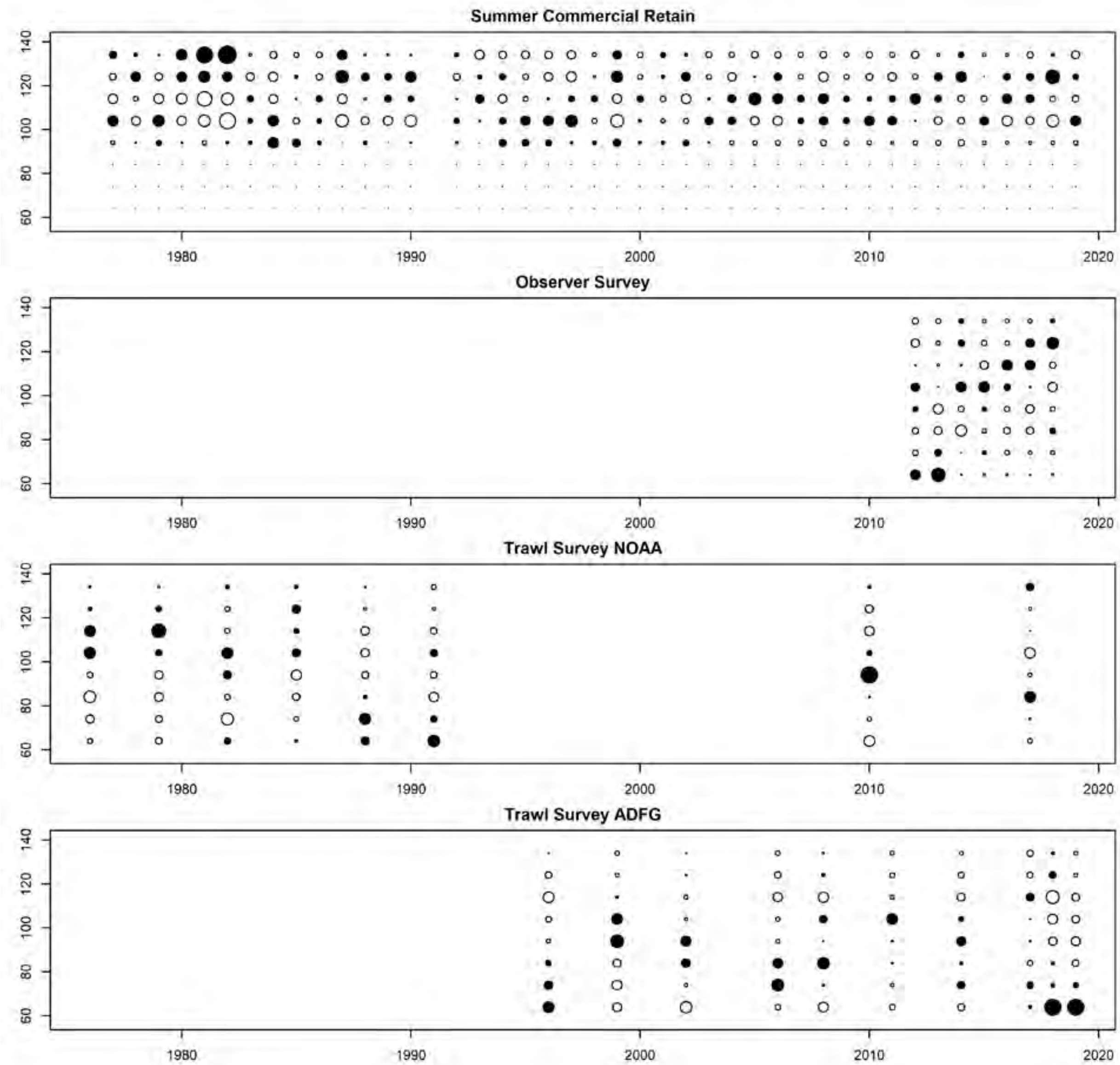


Figure D3-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

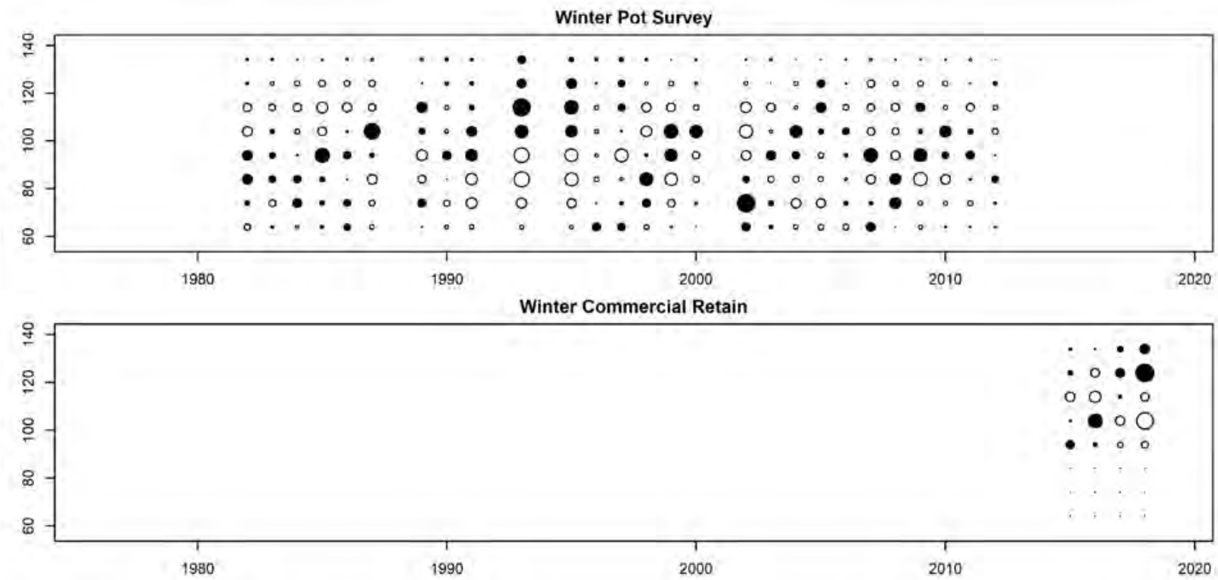


Figure D3-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table D3. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.471	0.123
log_q_2		
log_N_{76}	8.895	0.091
R_0	6.206	0.095
a_1	2.091	4.628
a_2	3.055	4.325
a_3	4.093	4.166
a_4	4.189	4.152
a_5	4.400	4.142
a_6	3.609	4.172
a_7	2.110	4.440
r1	10.000	0.335
r2	9.671	0.376
log_a	-2.665	0.089
log_b	4.829	0.015
log_ϕ_{st1}	-5.000	0.113
log_ϕ_{wa}	-2.198	0.316
log_ϕ_{wb}	4.805	0.032
Sw1	0.072	0.035
Sw2	0.497	0.124
log_ϕ_{l}	-2.082	0.056
$log\_\phi ra$	-0.796	0.128
$log\_\phi rb$	4.647	0.008
$log\_\phi wra$	-0.988	0.536
$log\_\phi wrb$	4.656	0.037
w^2_t	0.004	0.019
q ADFG	1.400	0.217
σ	3.870	0.209
β_1	12.524	0.705
β_2	7.636	0.173
ms78	2.883	0.259

Appendix D - Model 19.3

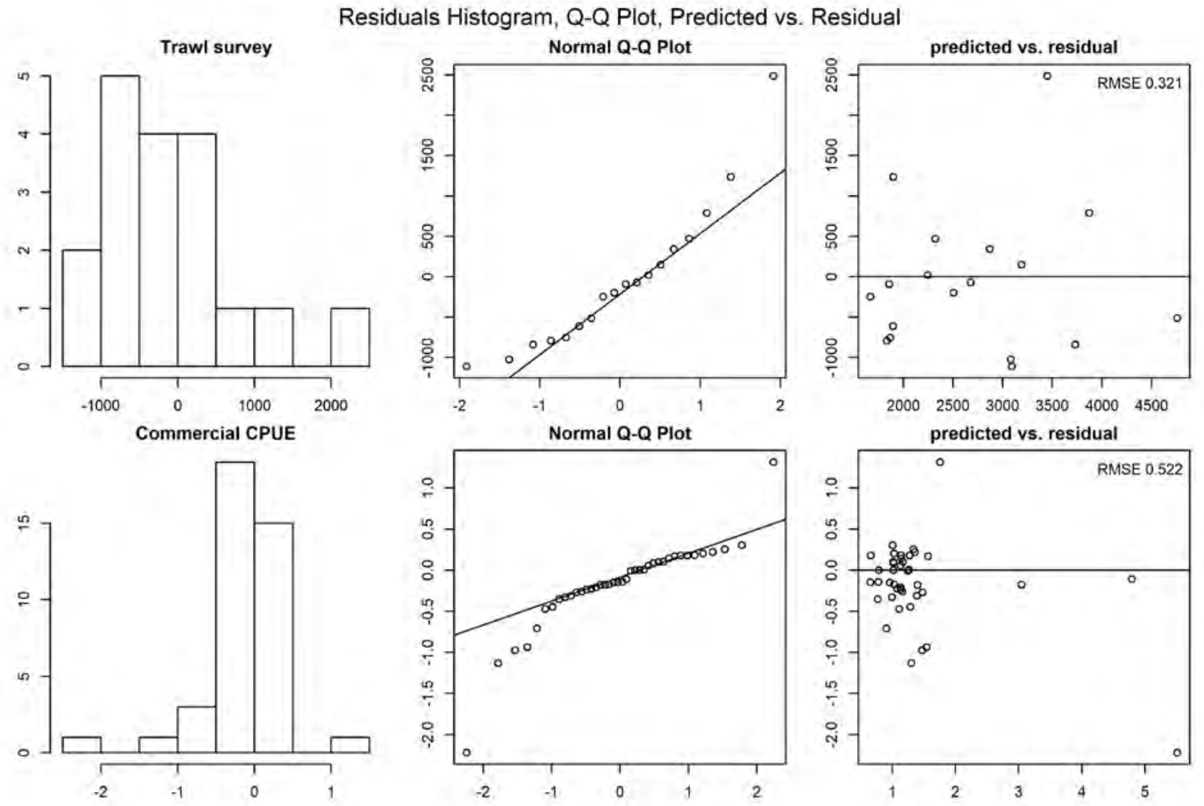


Figure D4-1. QQ Plot of trawl survey and commercial CPUE.

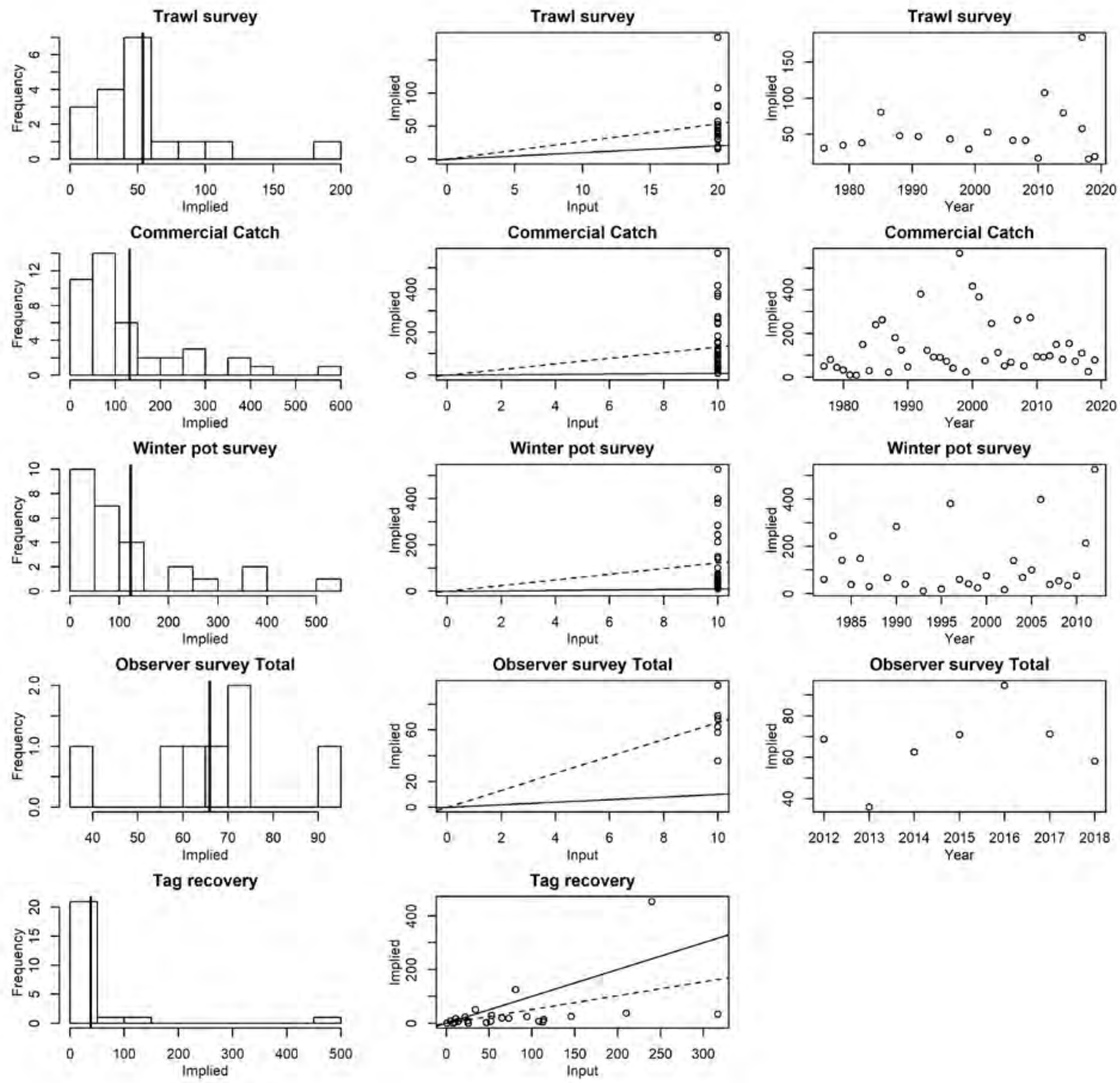


Figure D4-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

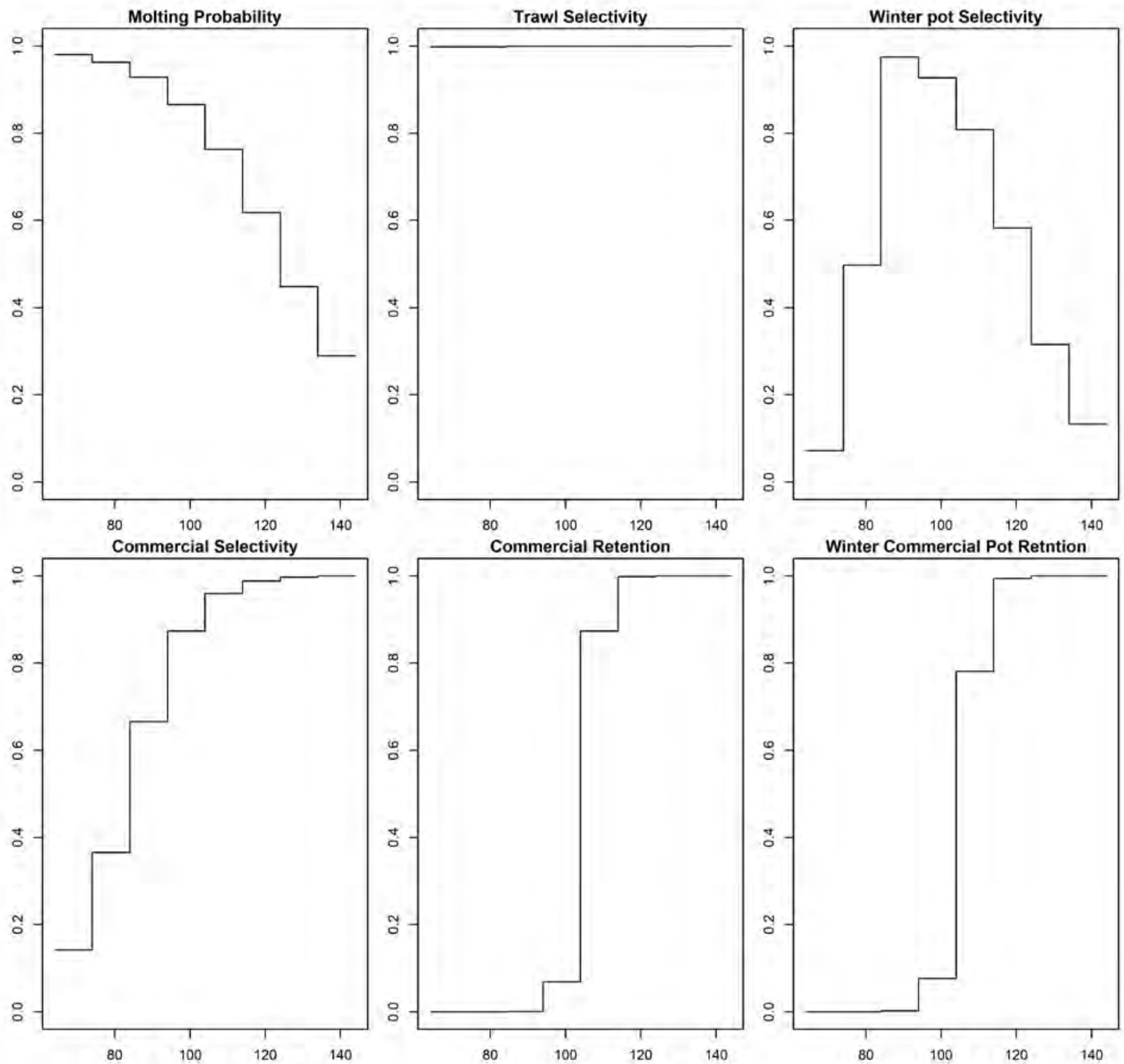


Figure D4-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

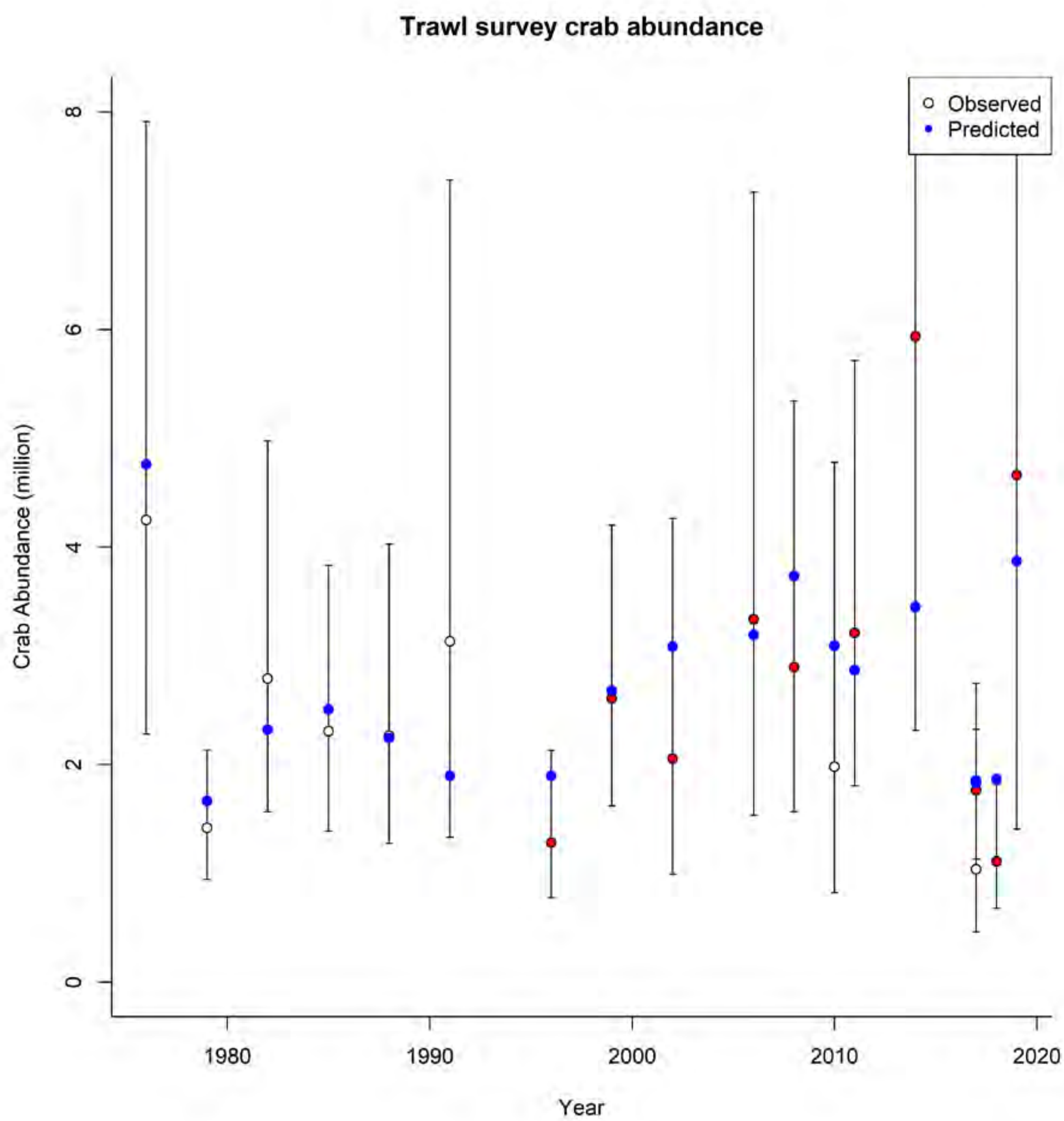


Figure D4-4. Estimated trawl survey male abundance (blue) (crab >= 64 mm CL). Observed: White: NOAA trawl survey, Red: ADG&G trawl survey

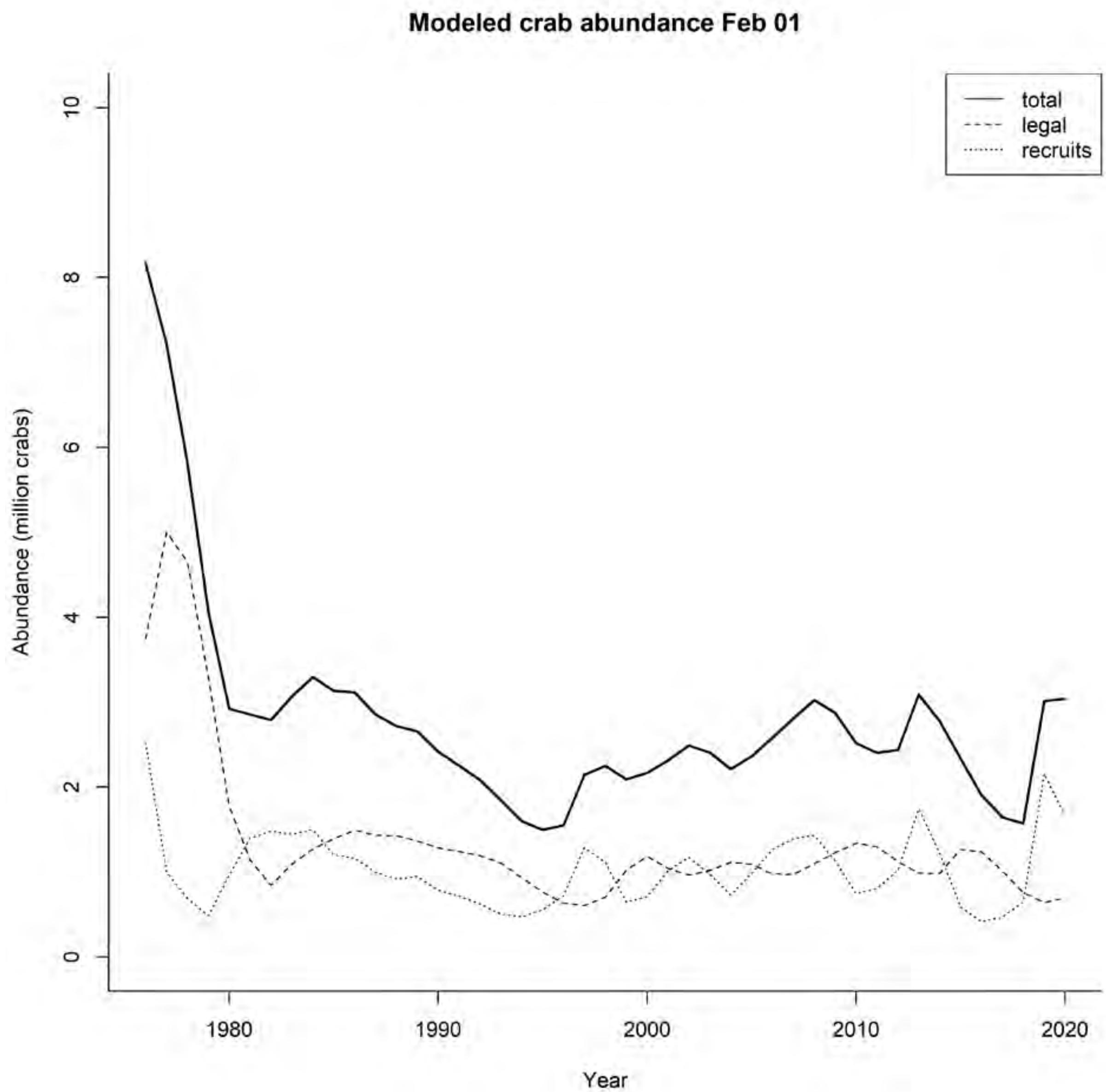


Figure D4-5. Estimated abundance of legal males.

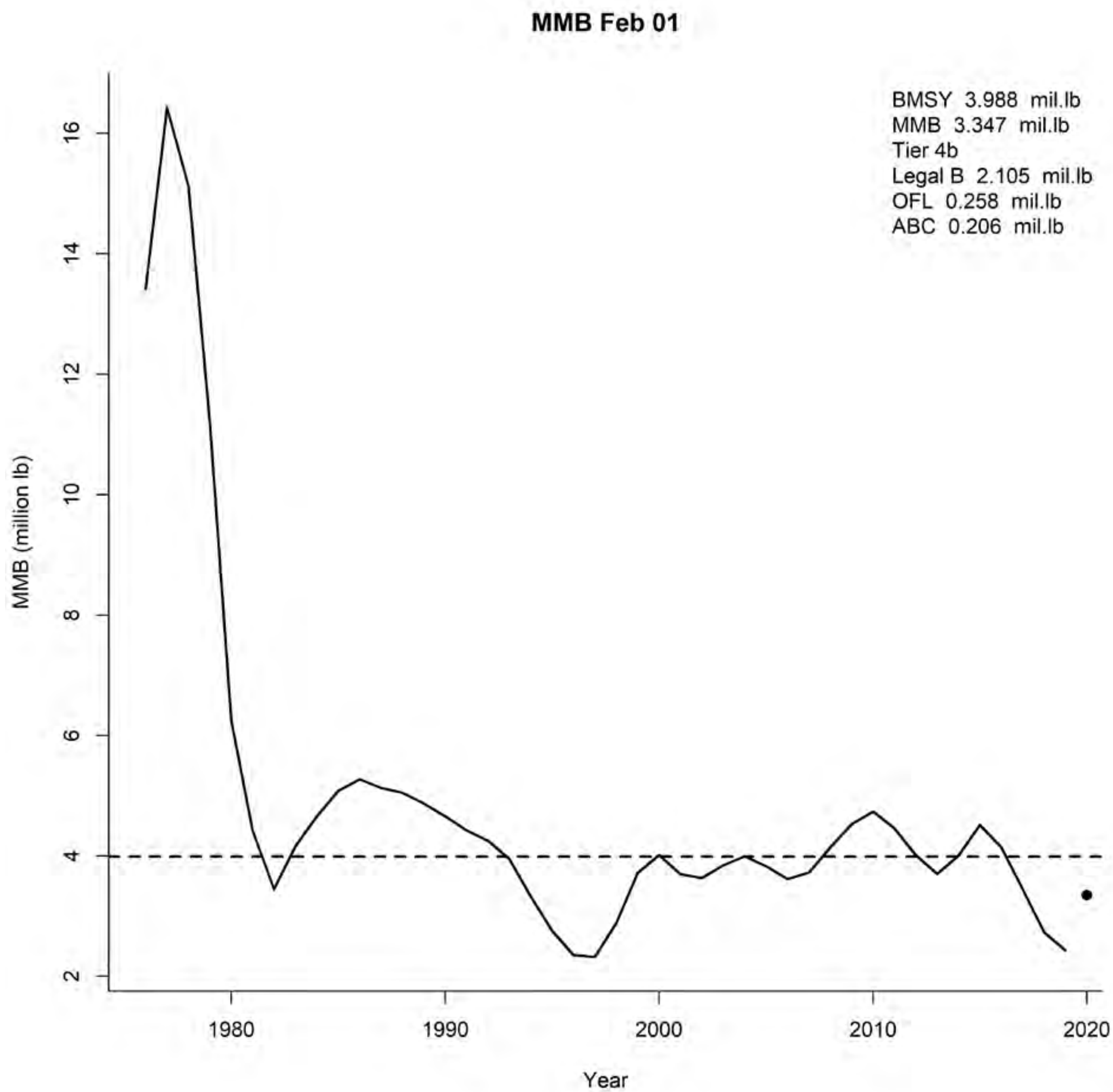


Figure D4-6. Estimated abundance of Mature Male Biomass. Dash line shows Bmsy.

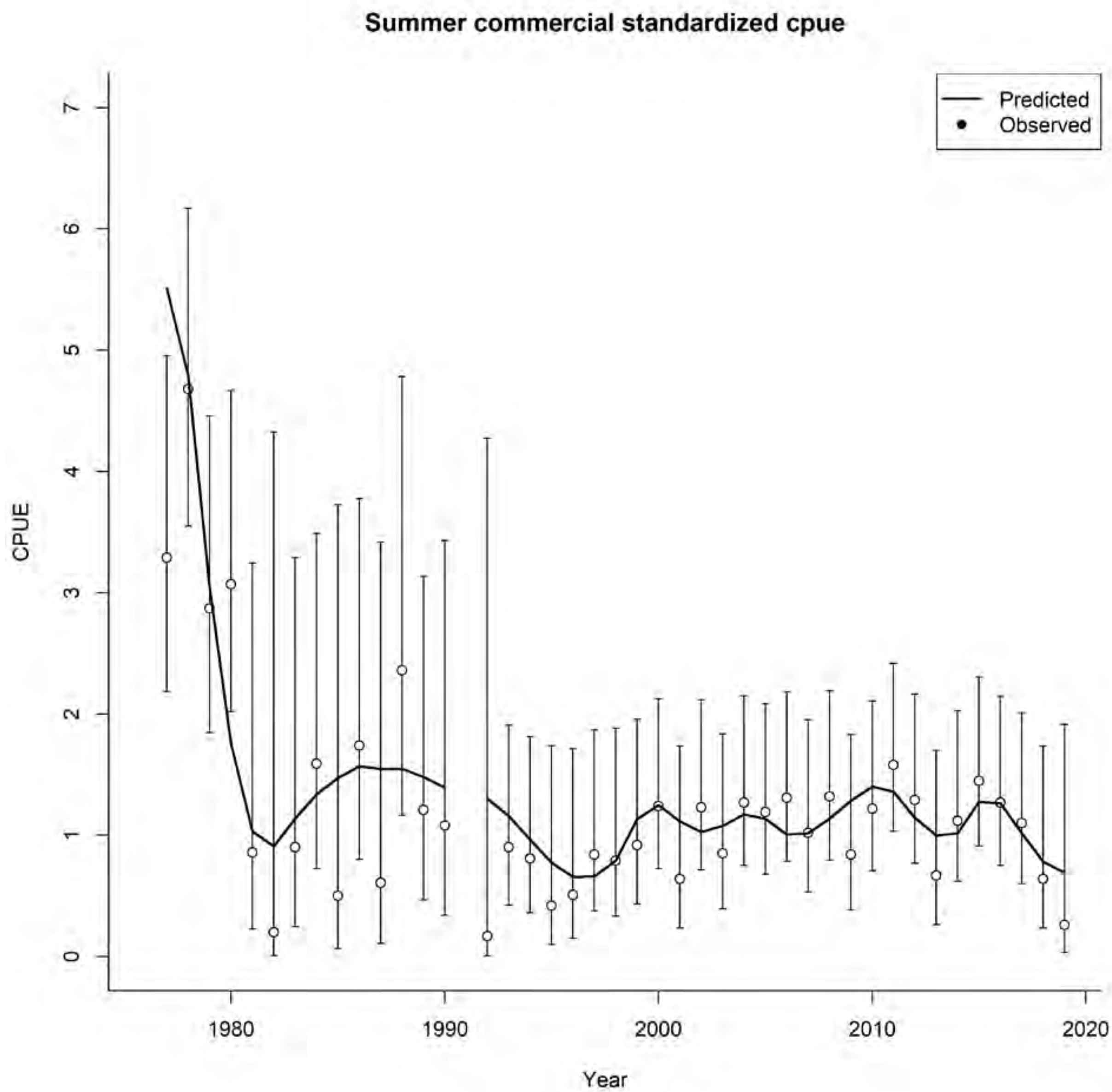


Figure D4-7. Summer commercial standardized cpue.

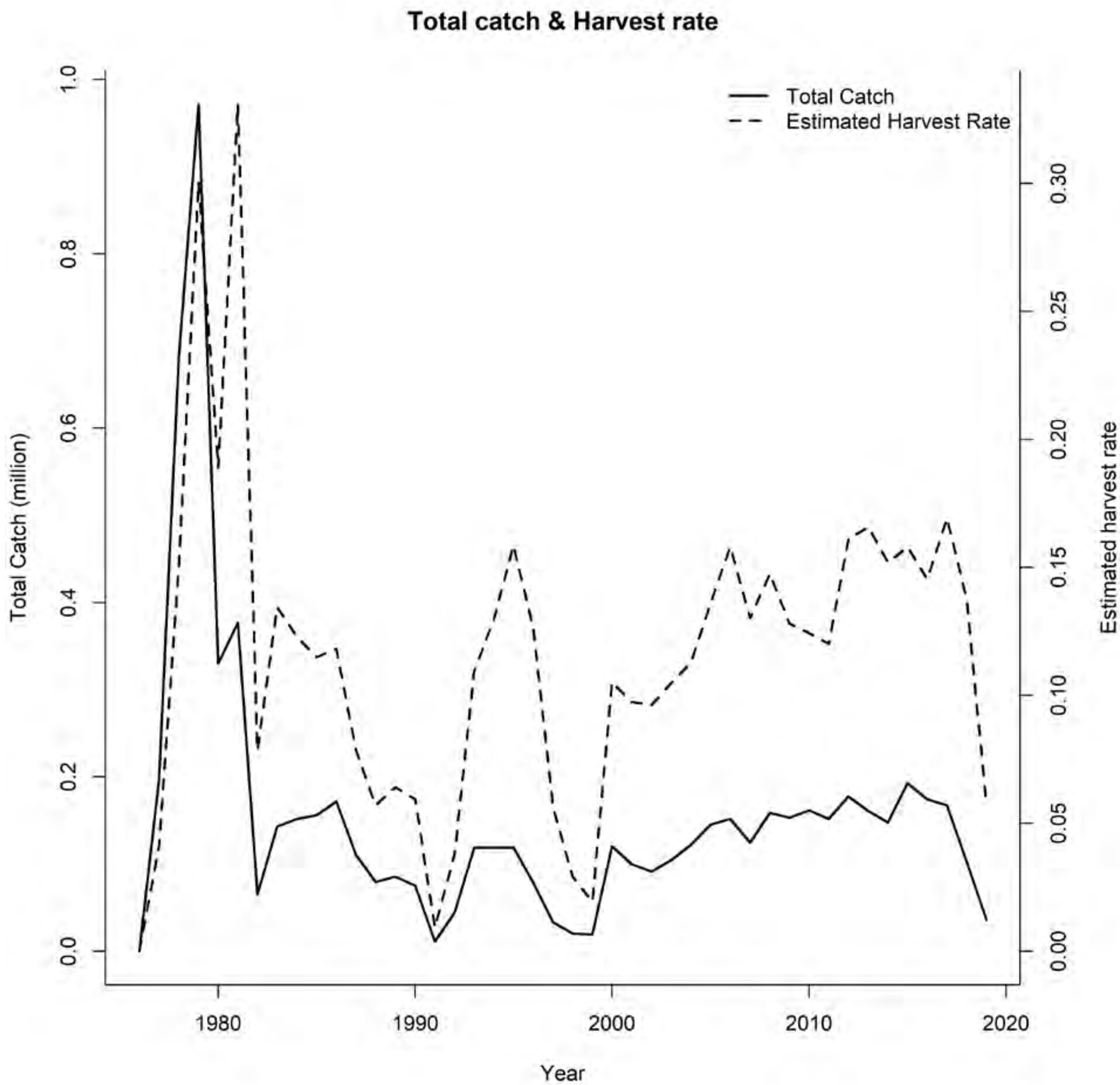


Figure D4-8. Total catch and estimated harvest rate.

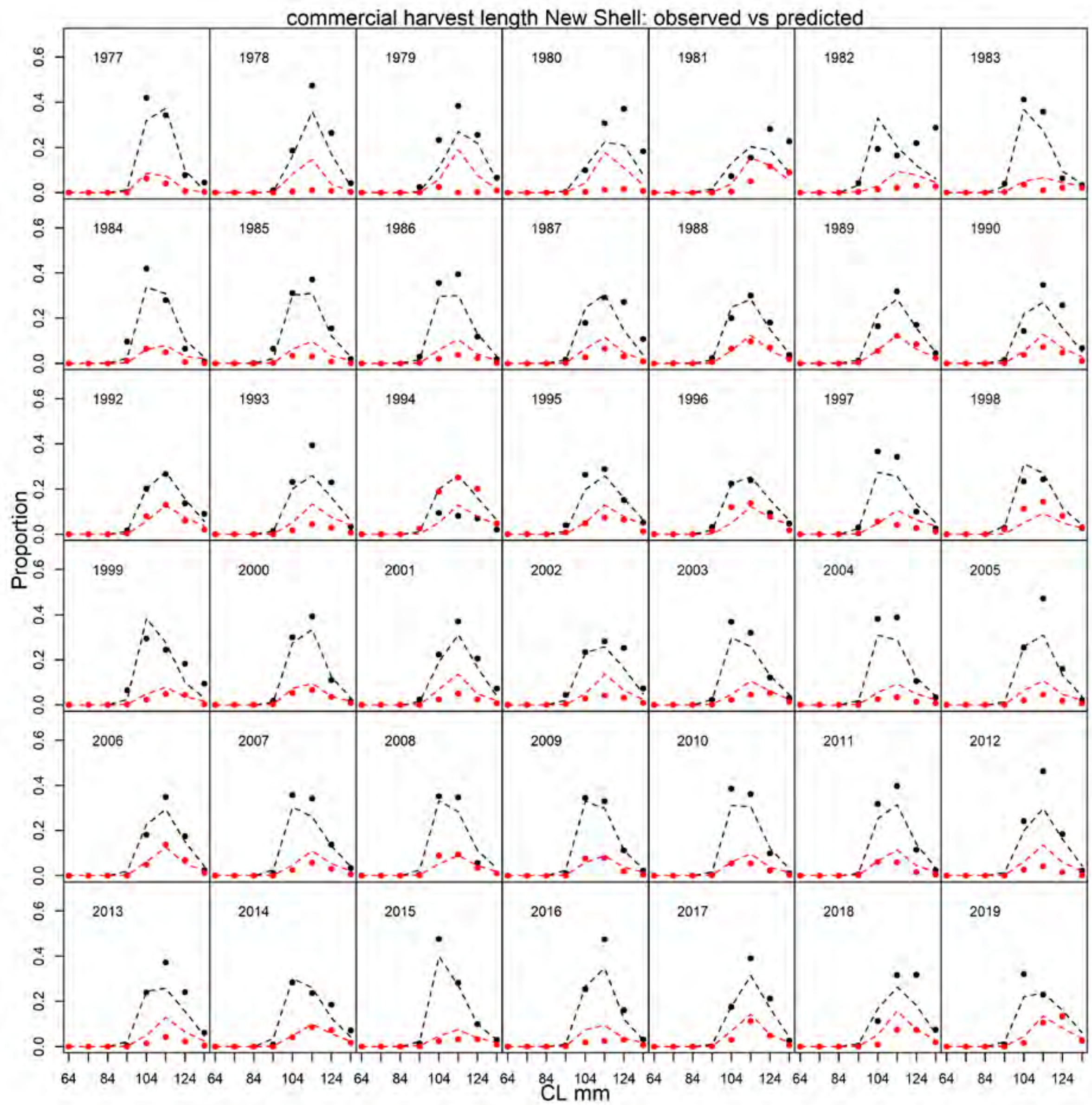


Figure D4-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Black: newshell, Red: oldshell

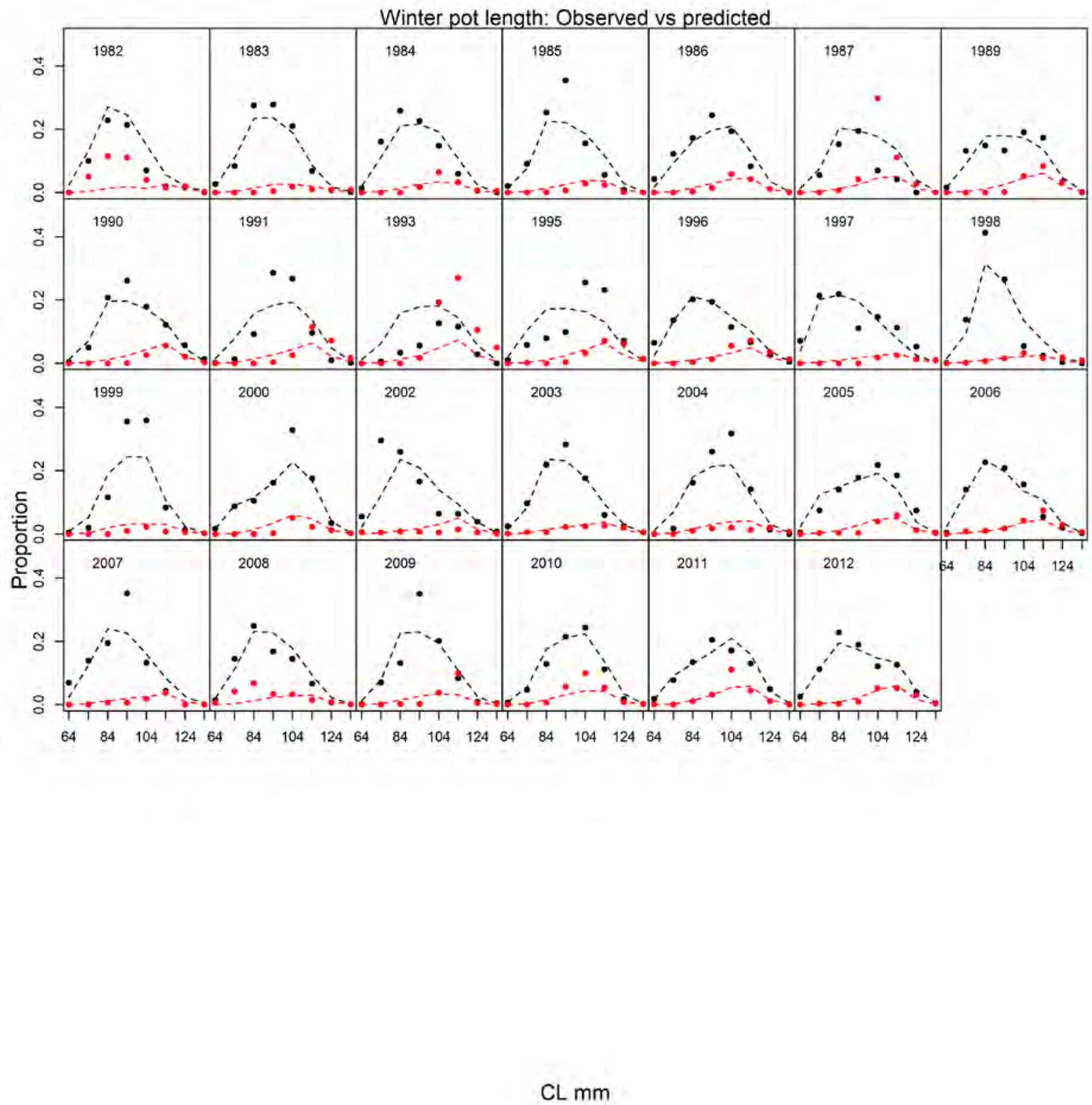


Figure D4-10. Predicted (dashed line) vs. observed (dots) length class proportions for the winter and spring pot survey. Black: newshell, Red: oldshell

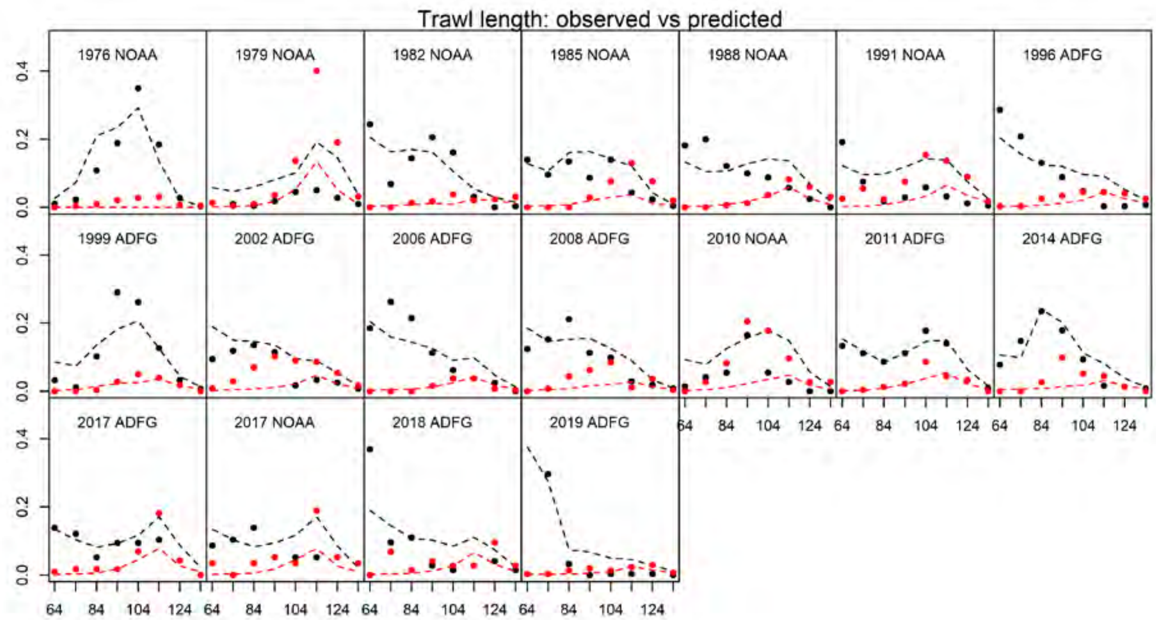


Figure D4-11. Predicted (dashed) vs. observed (dots) length class proportions for trawl survey. Black: newshell, Red: oldshell

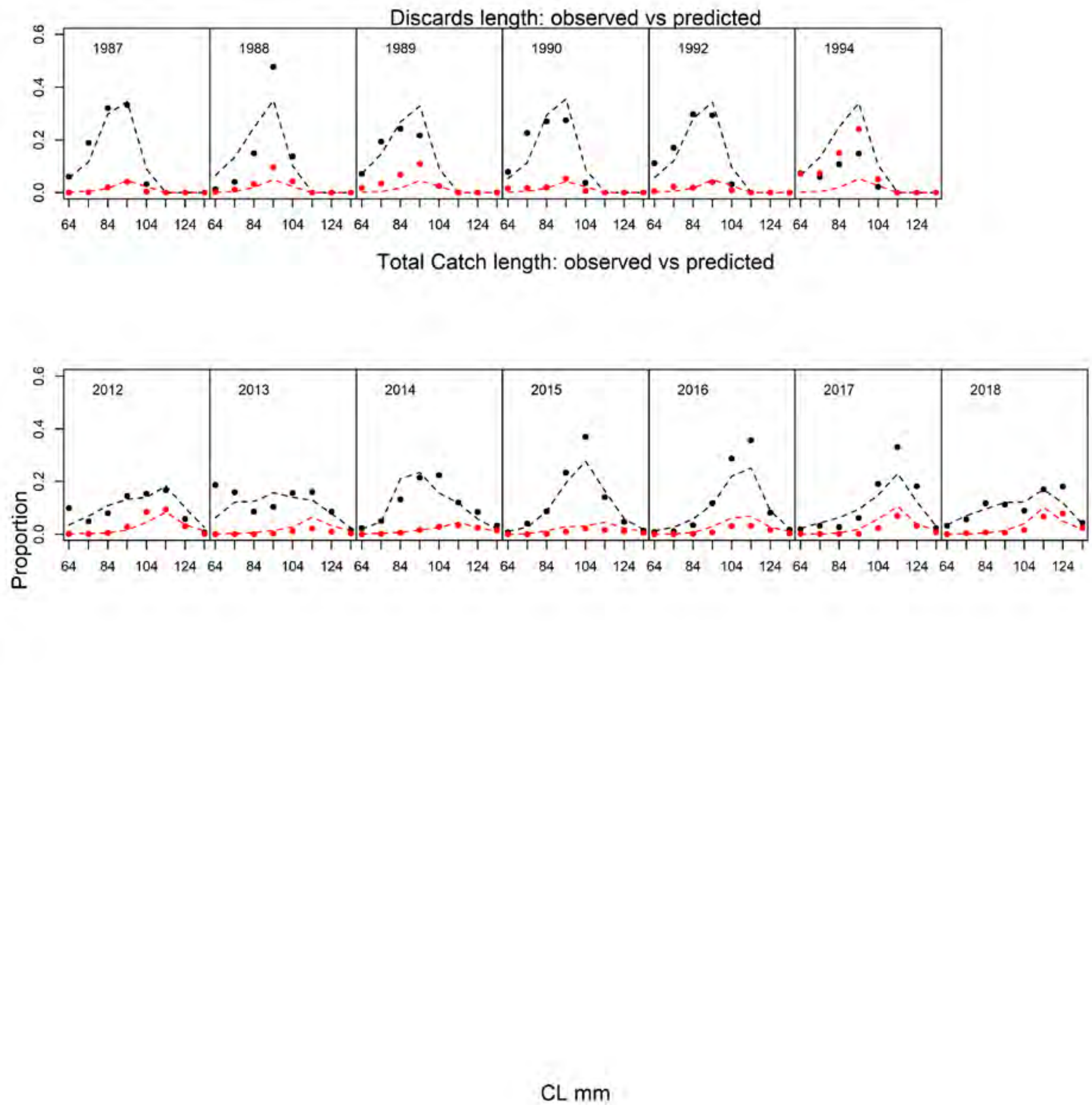


Figure D4-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

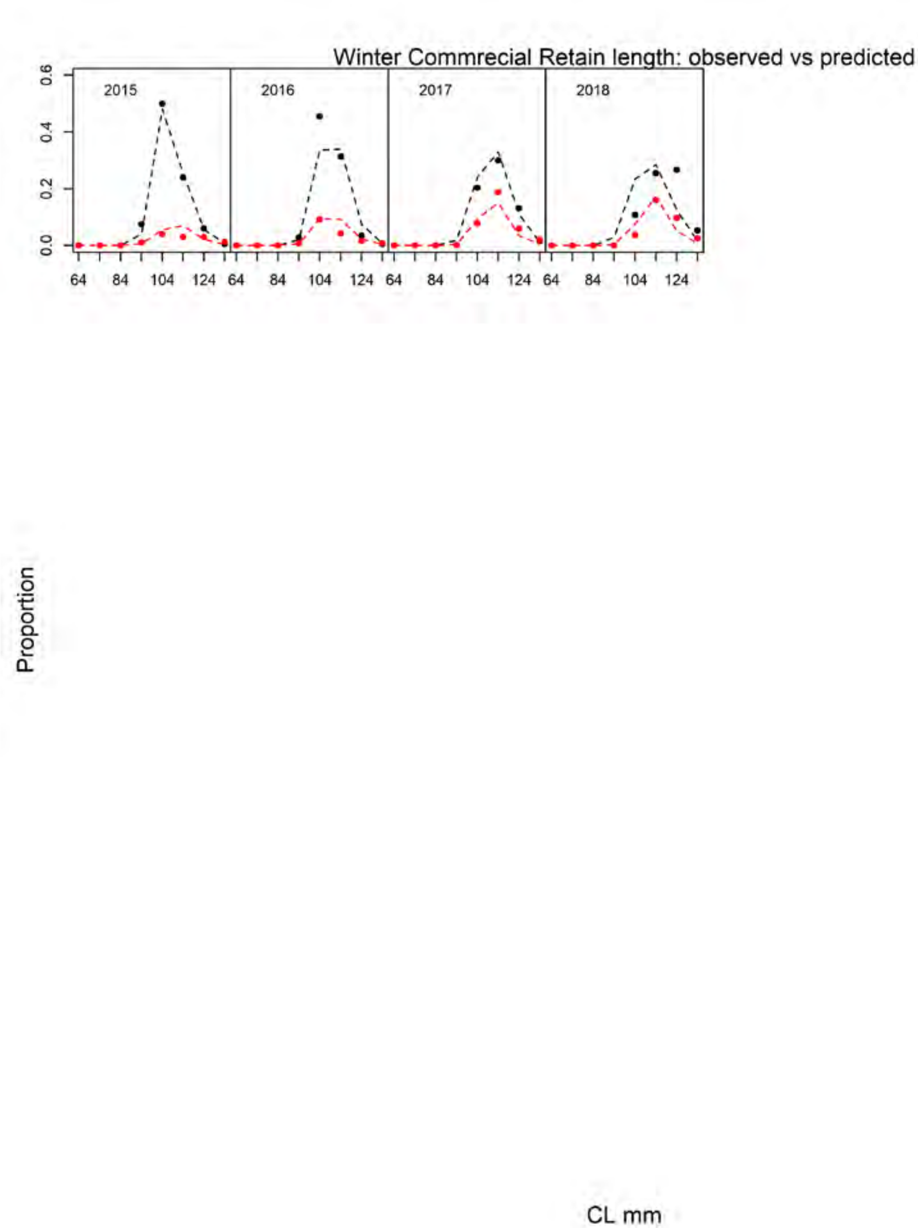


Figure D4-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

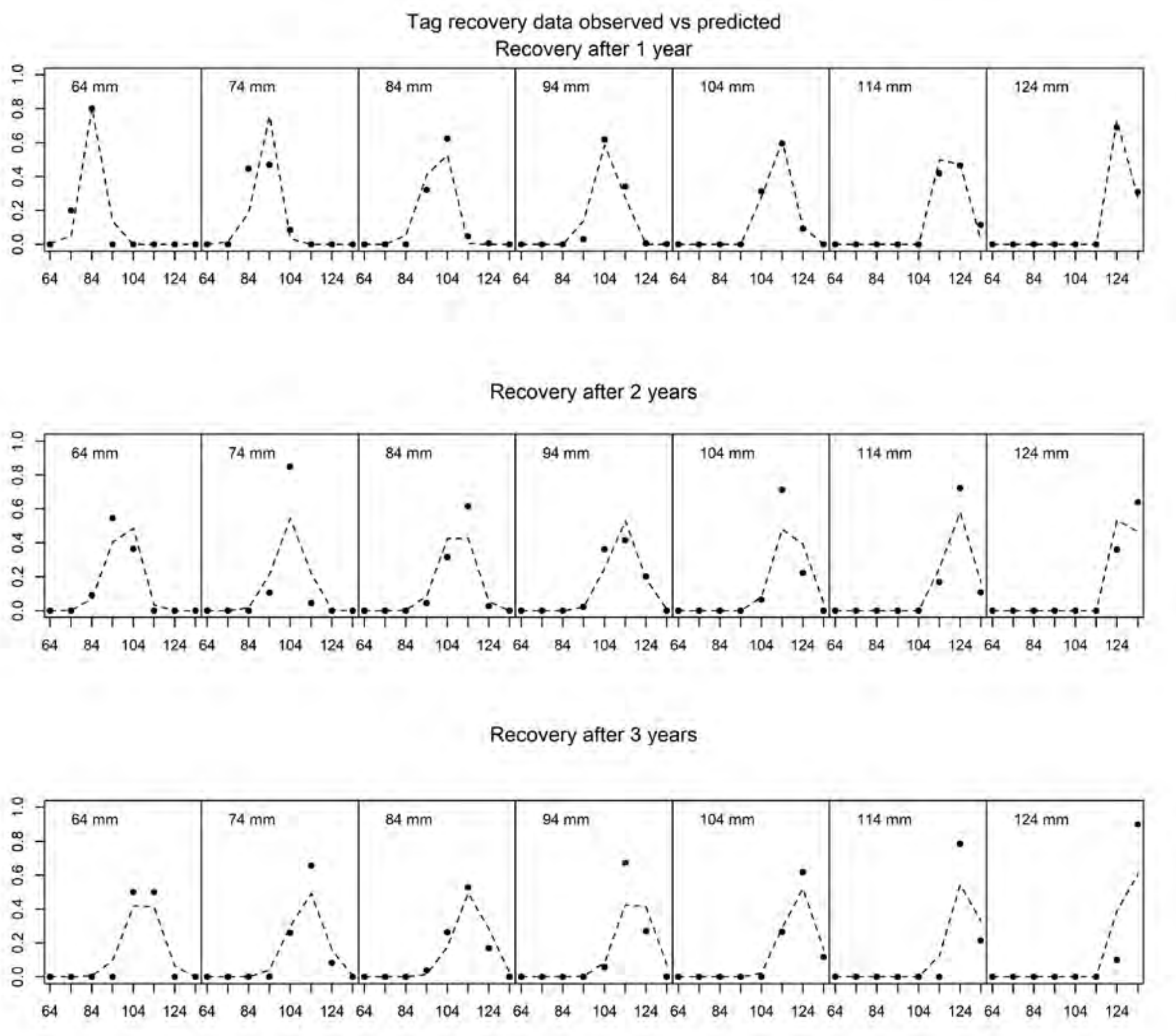


Figure D4-13. Predicted vs. observed length class proportions for tag recovery data.

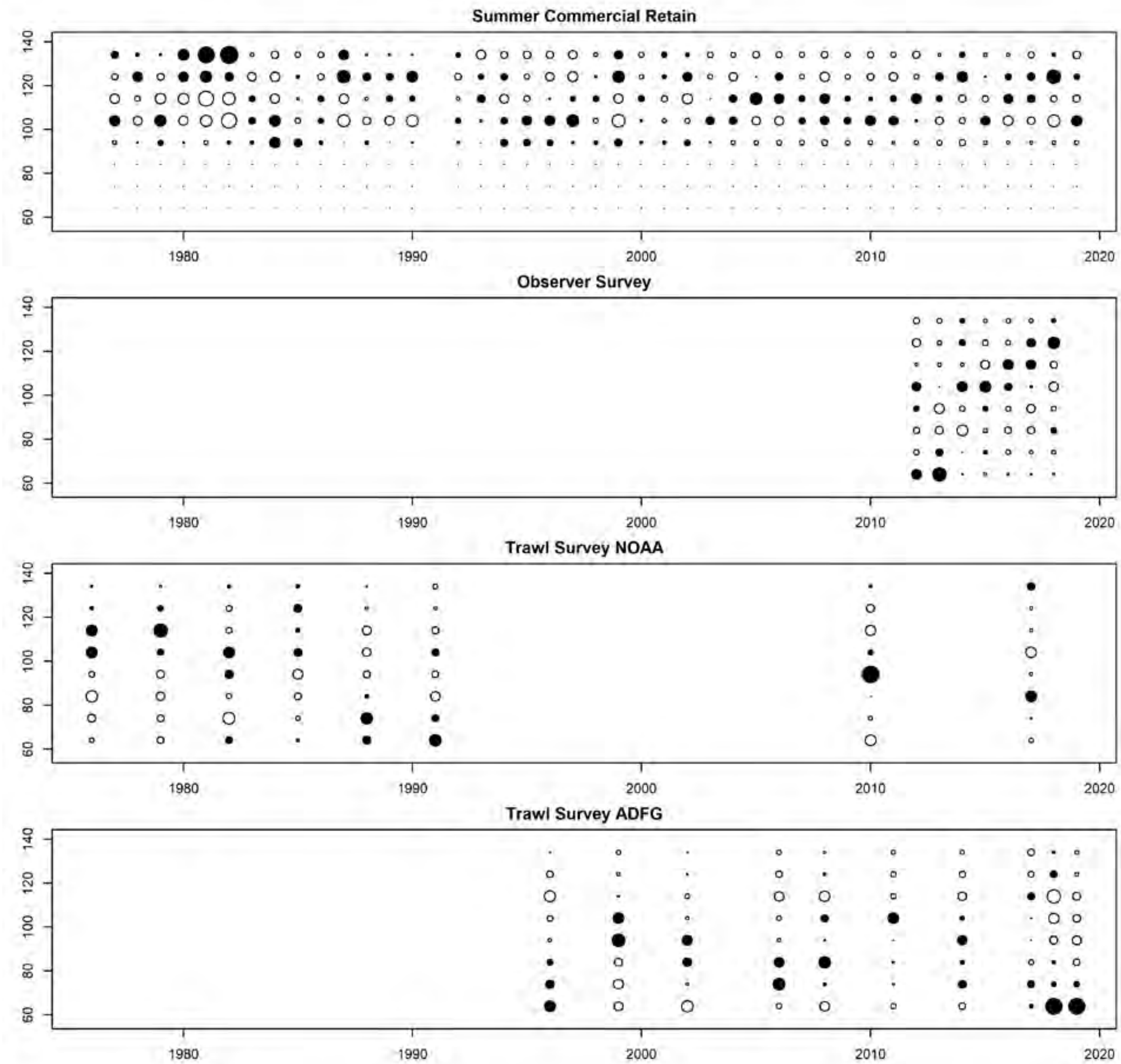


Figure D4-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

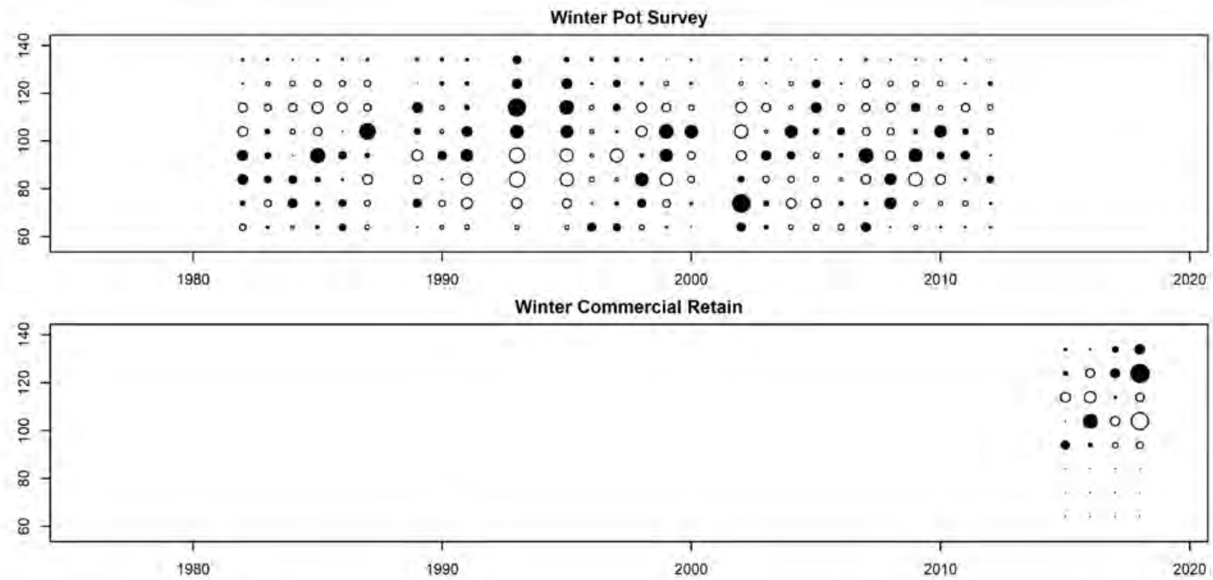


Figure D4-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table D4. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.627	0.227
log_q_2		
log_N_{76}	9.008	0.174
R_0	6.341	0.191
a_1	1.968	4.606
a_2	2.959	4.289
a_3	4.020	4.140
a_4	4.124	4.127
a_5	4.344	4.117
a_6	3.570	4.146
a_7	2.106	4.414
r1	10.000	0.305
r2	9.663	0.351
log_a	-2.674	0.090
log_b	4.832	0.016
log_ϕ_{st1}	-5.000	0.067
log_ϕ_{wa}	-2.203	0.307
log_ϕ_{wb}	4.800	0.032
Sw1	0.072	0.035
Sw2	0.498	0.125
log_ϕ_l	-2.085	0.056
log_ϕra	-0.791	0.129
log_ϕrb	4.647	0.008
log_ϕwra	-0.977	0.543
log_ϕwrb	4.655	0.037
w^2_t	0.000	0.000
q NOAA	0.811	0.197
q ADFG	1.200	0.290
σ	3.878	0.209
β_1	12.453	0.707
β_2	7.649	0.173
ms78	3.083	0.342

Appendix D - Model 19.4

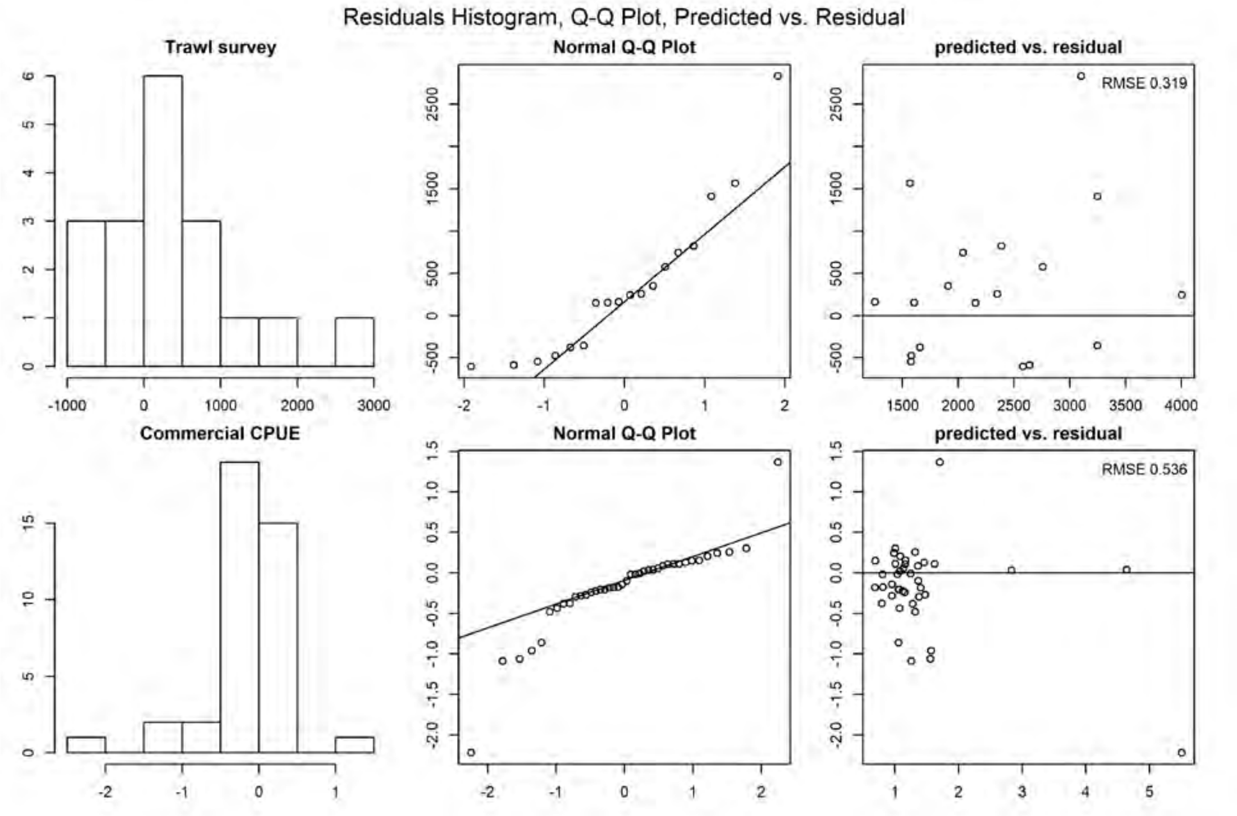


Figure D5-1. QQ Plot of trawl survey and commercial CPUE.

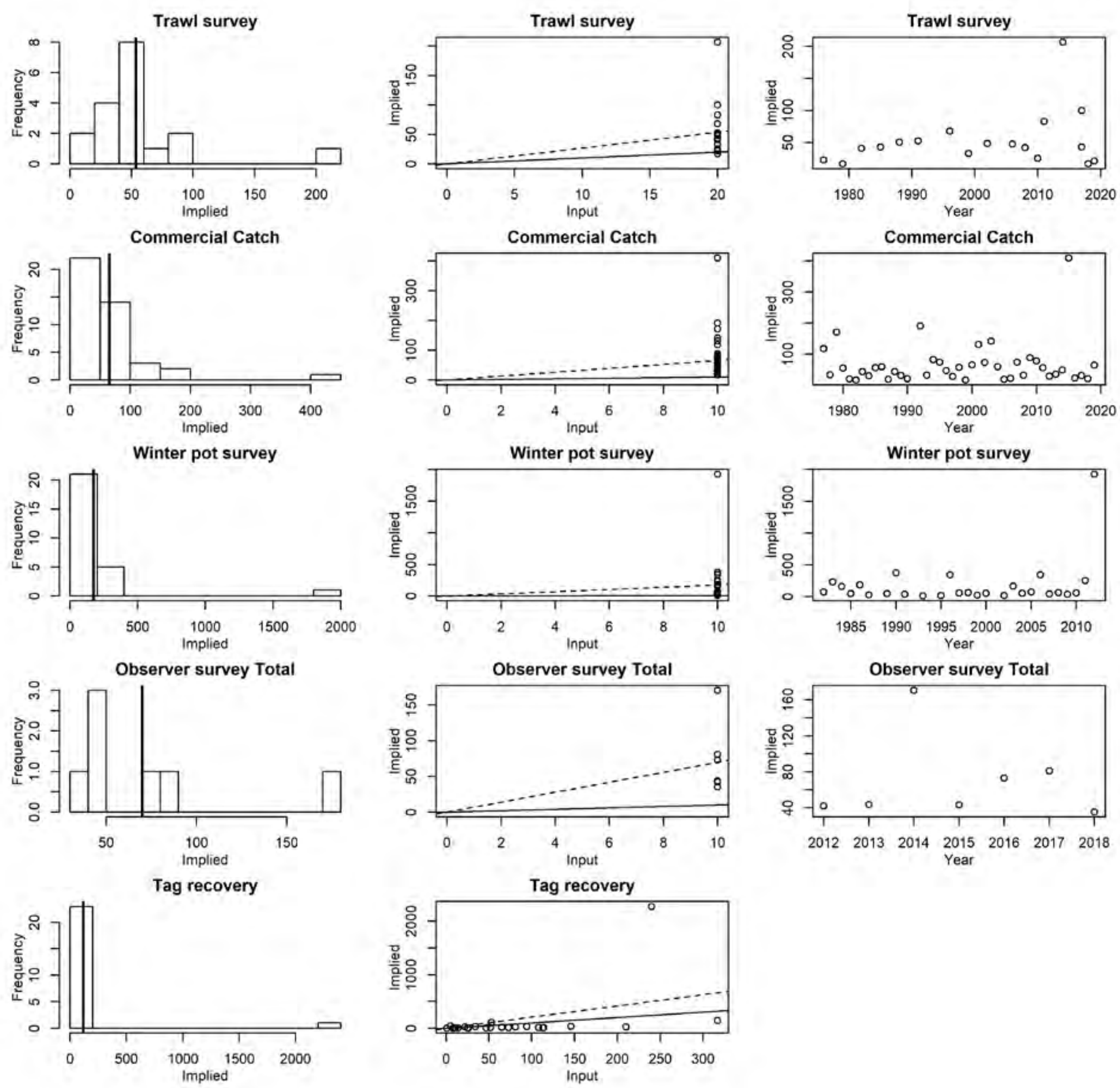


Figure D5-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

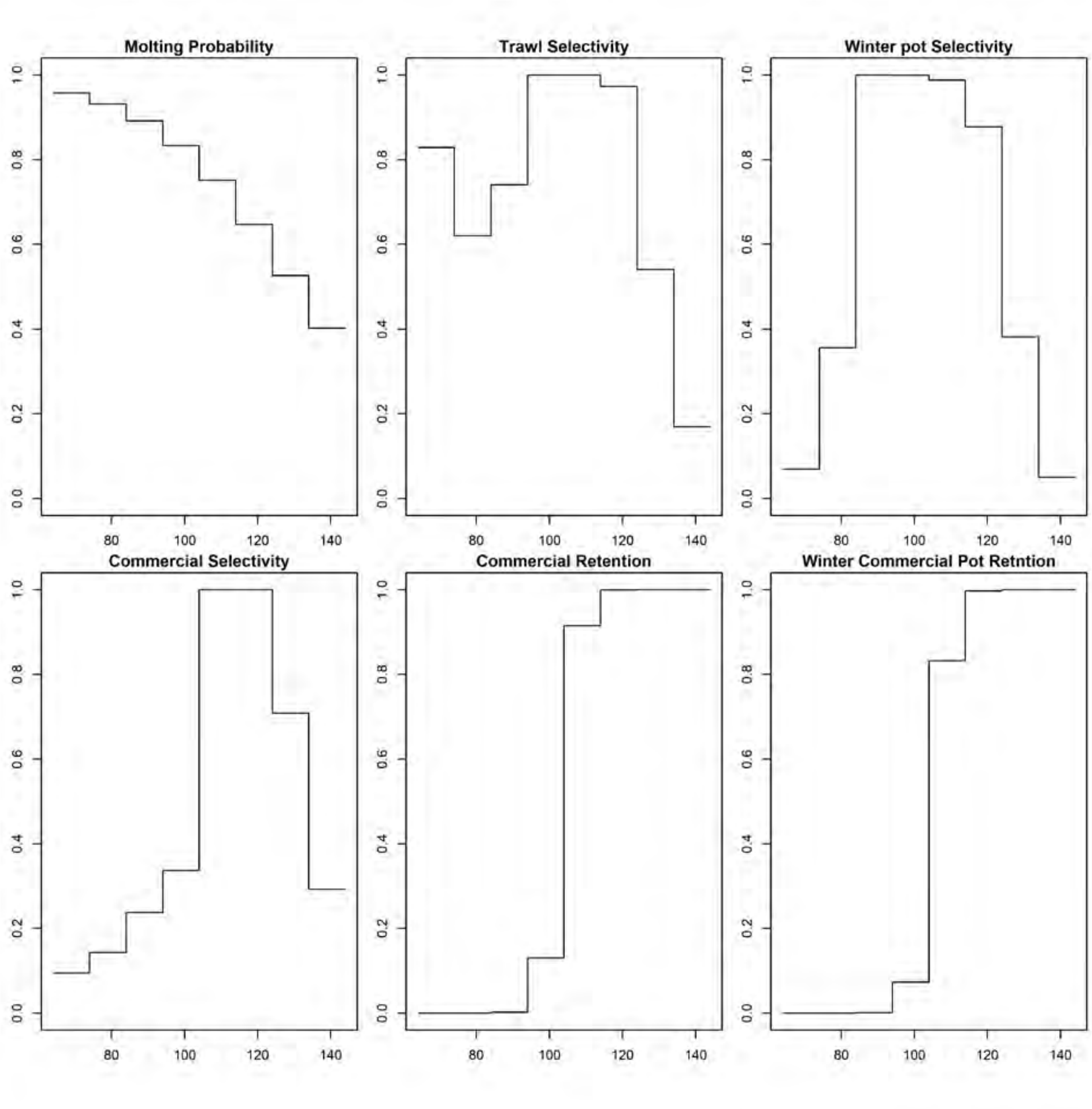


Figure D5-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

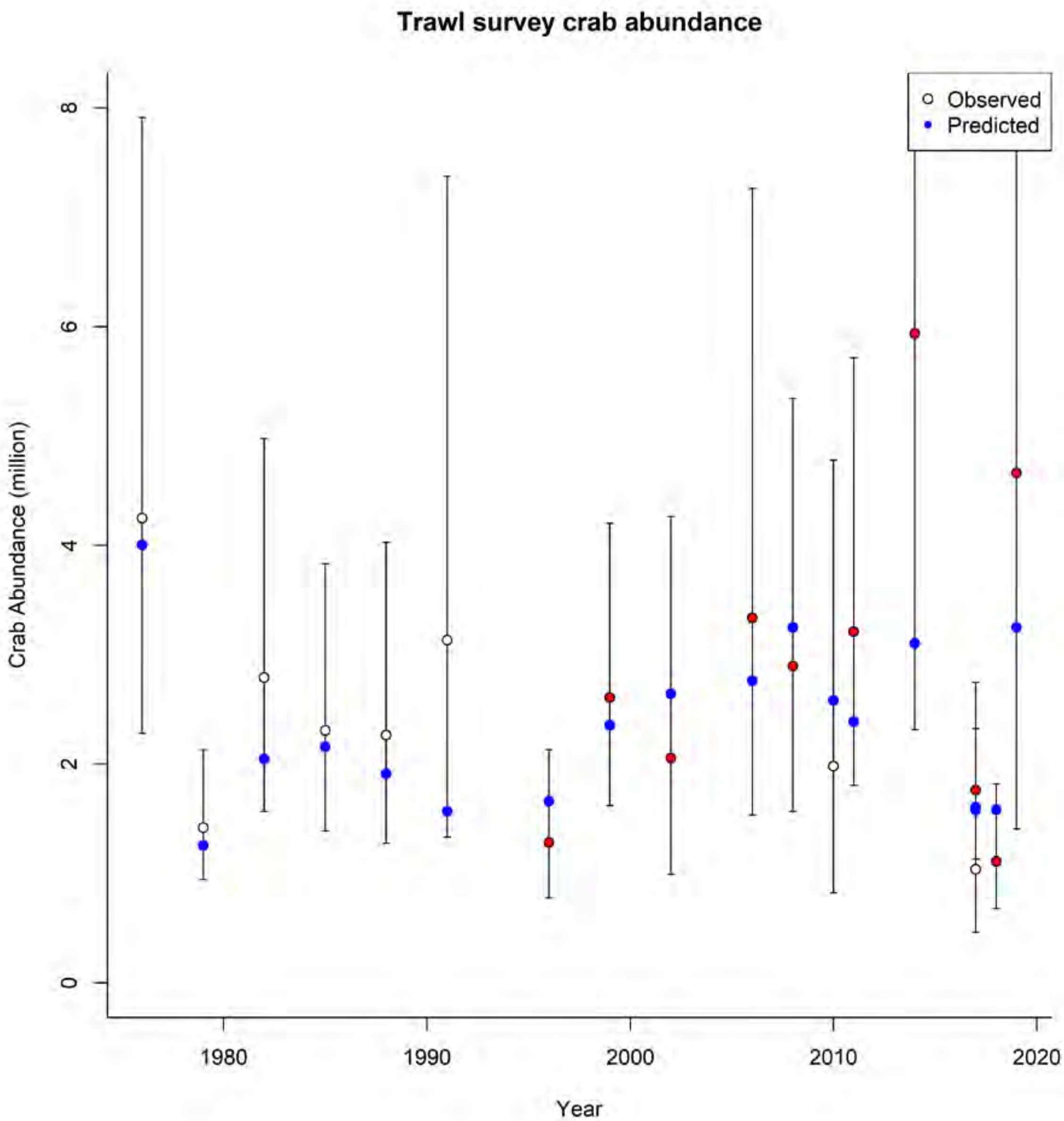


Figure D5-4. Estimated trawl survey male abundance (blue) (crab >= 64 mm CL). Observed: White: NOAA trawl survey, Red: ADG&G trawl survey

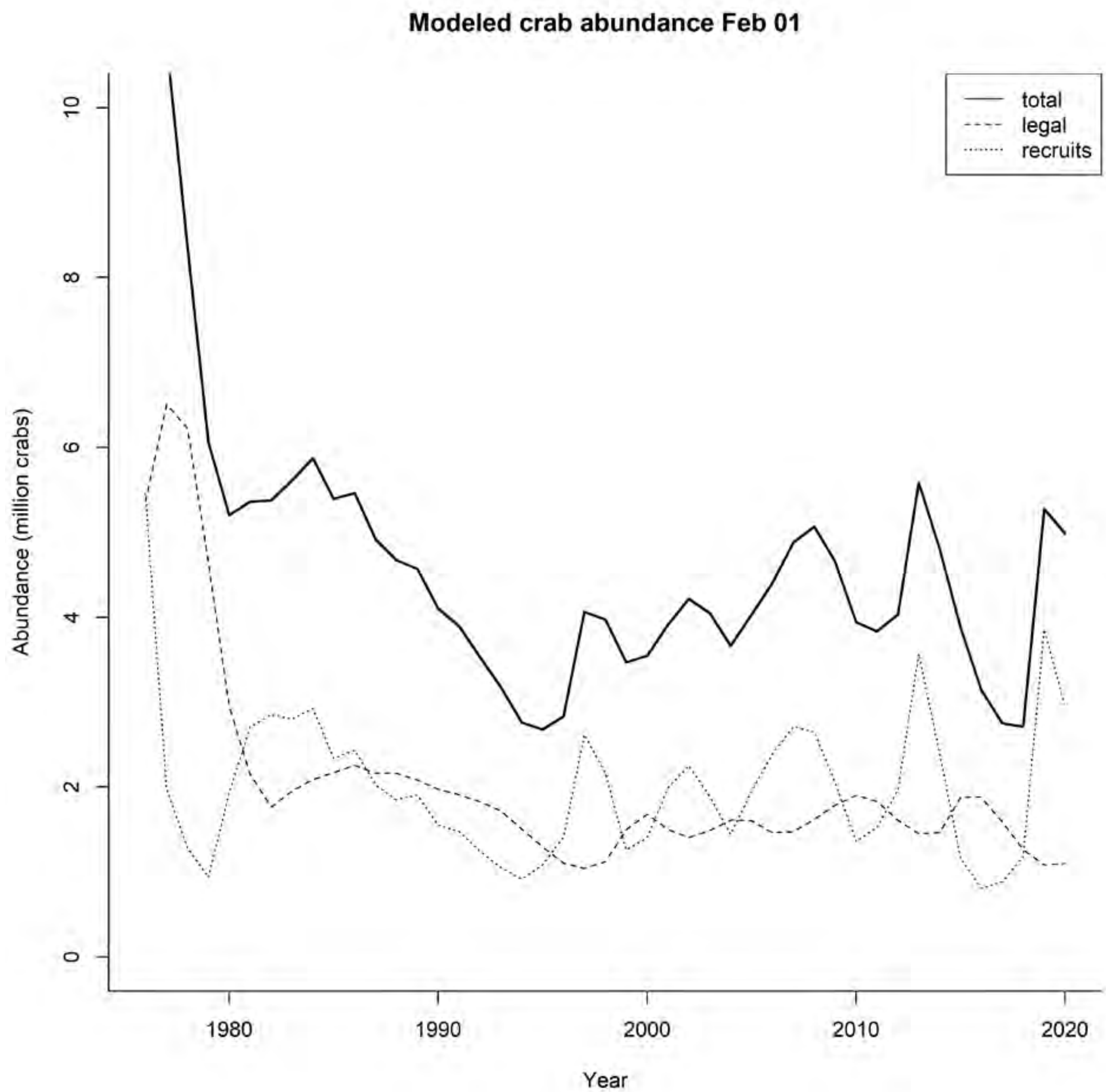


Figure D5-5. Estimated abundance of legal males.

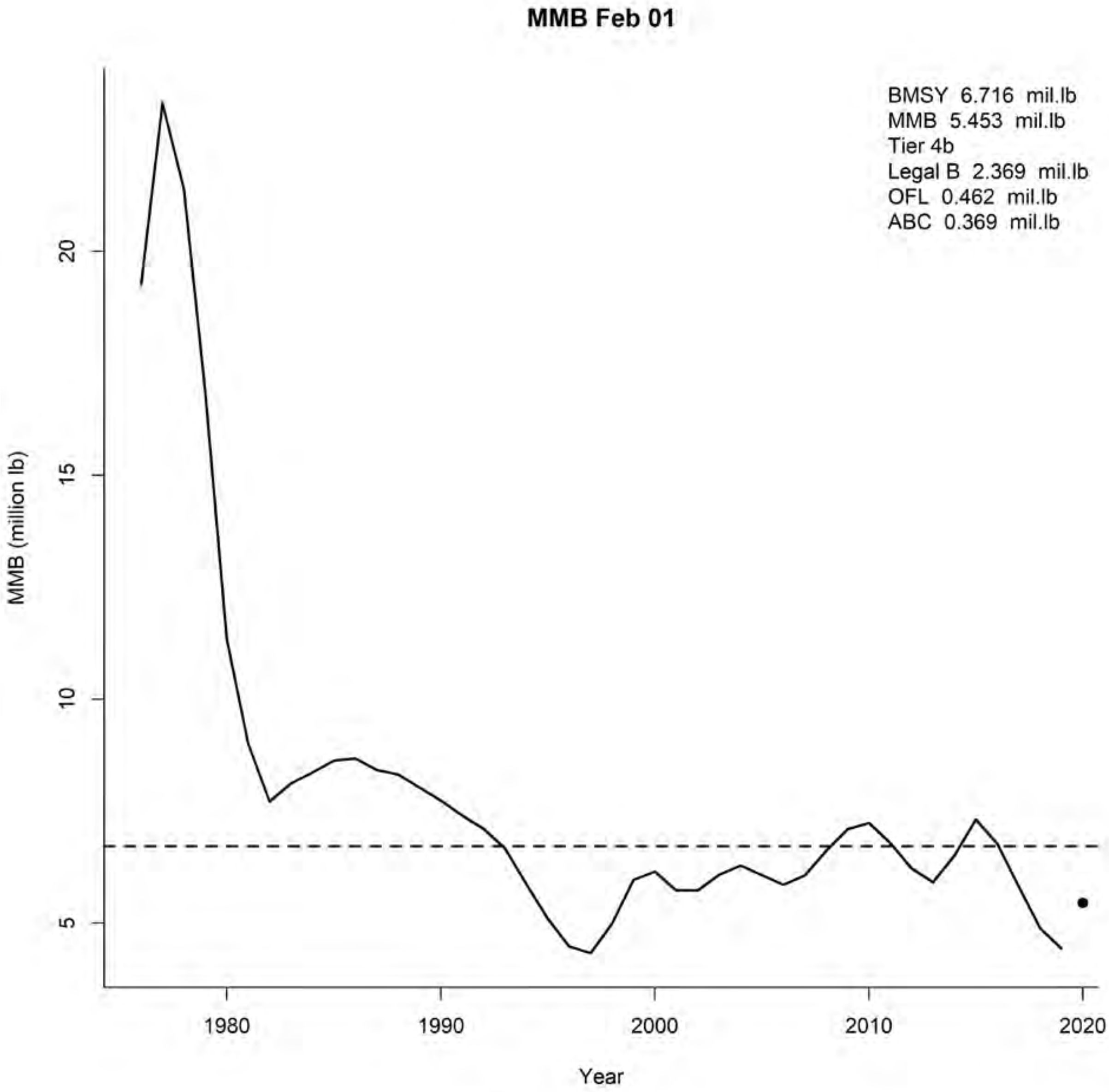


Figure D5-6. Estimated abundance of Mature Male Biomass. Dash line shows Bmsy.

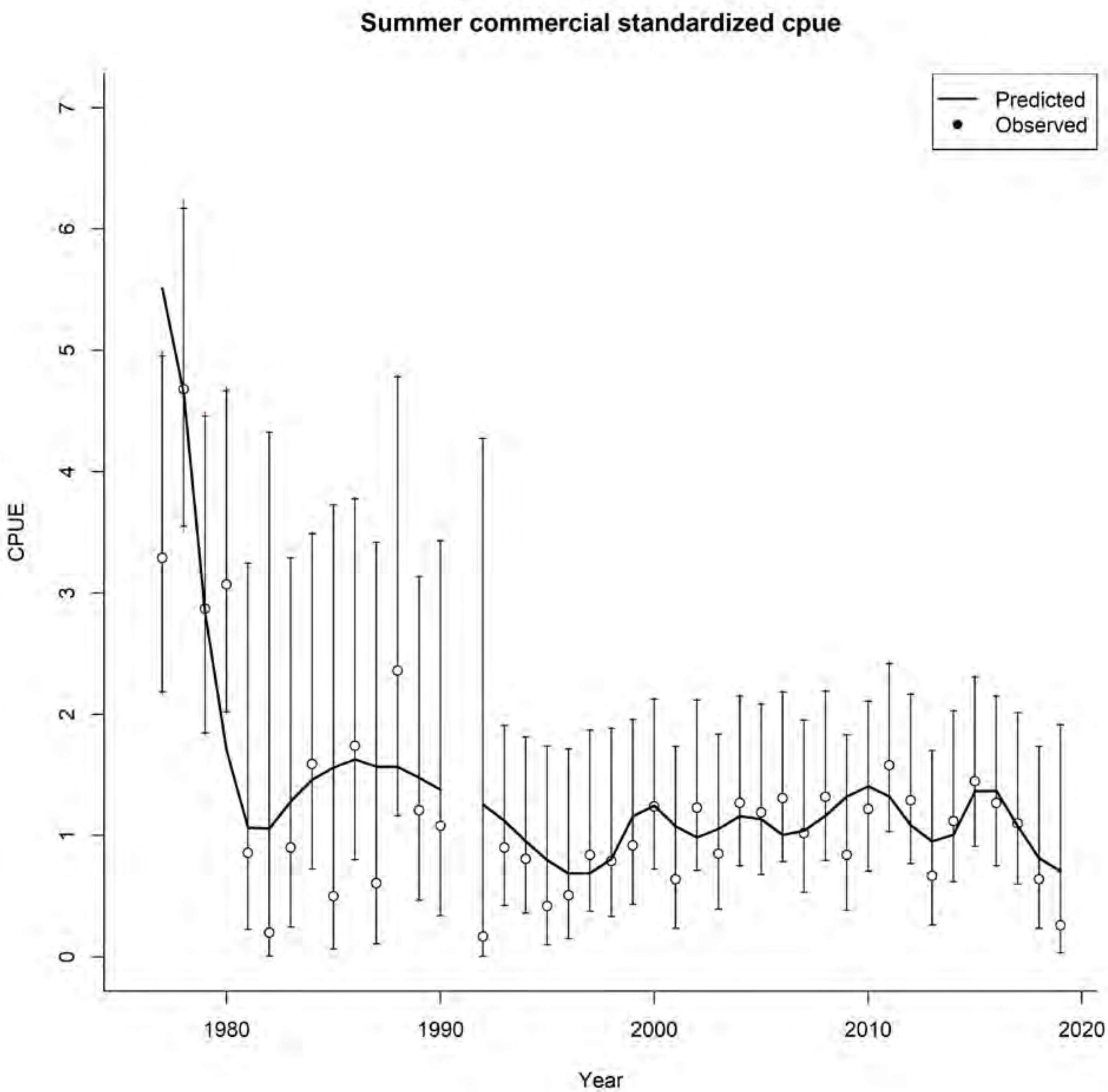


Figure D5-7. Summer commercial standardized cpue.

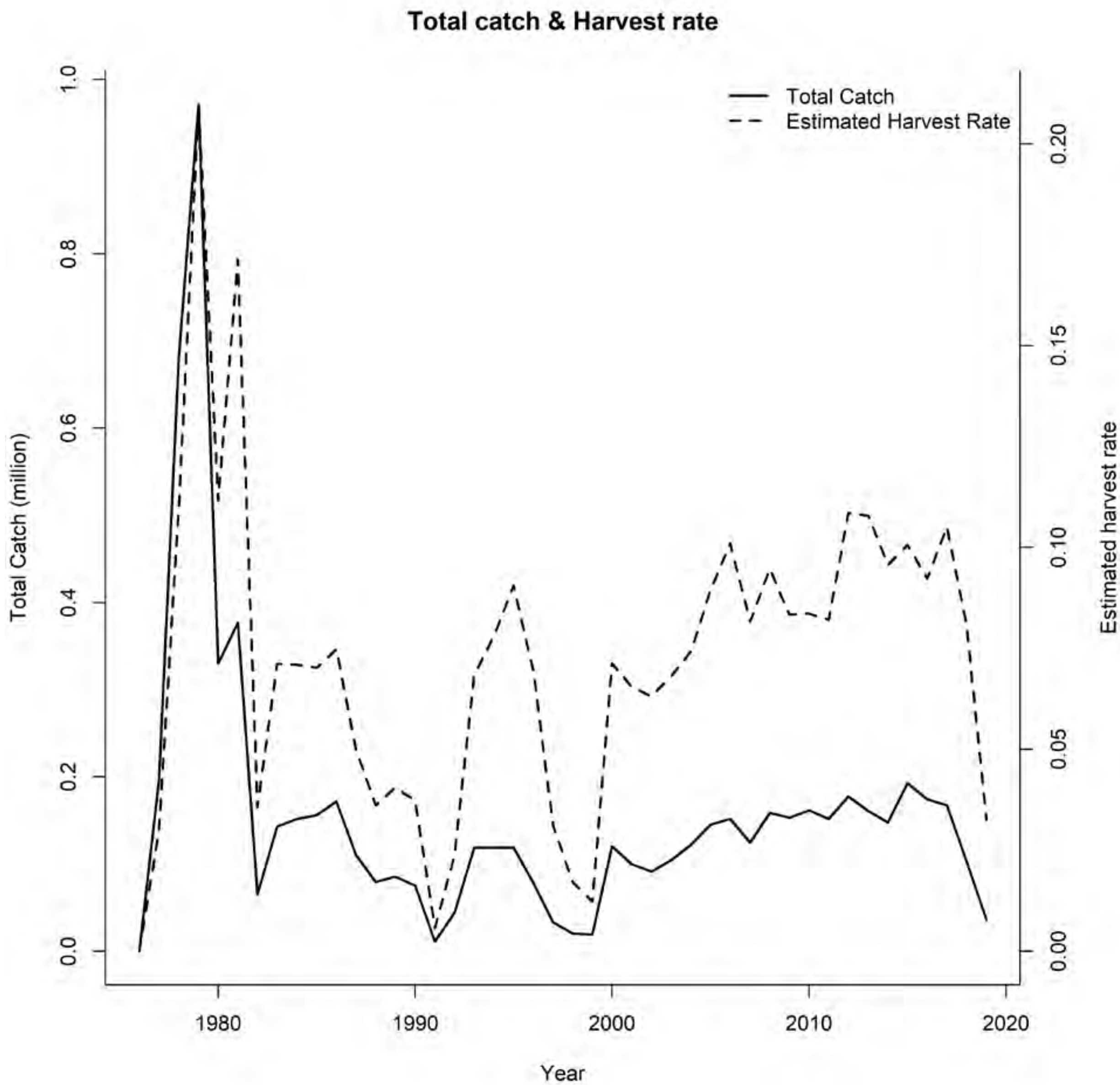


Figure D5-8. Total catch and estimated harvest rate.

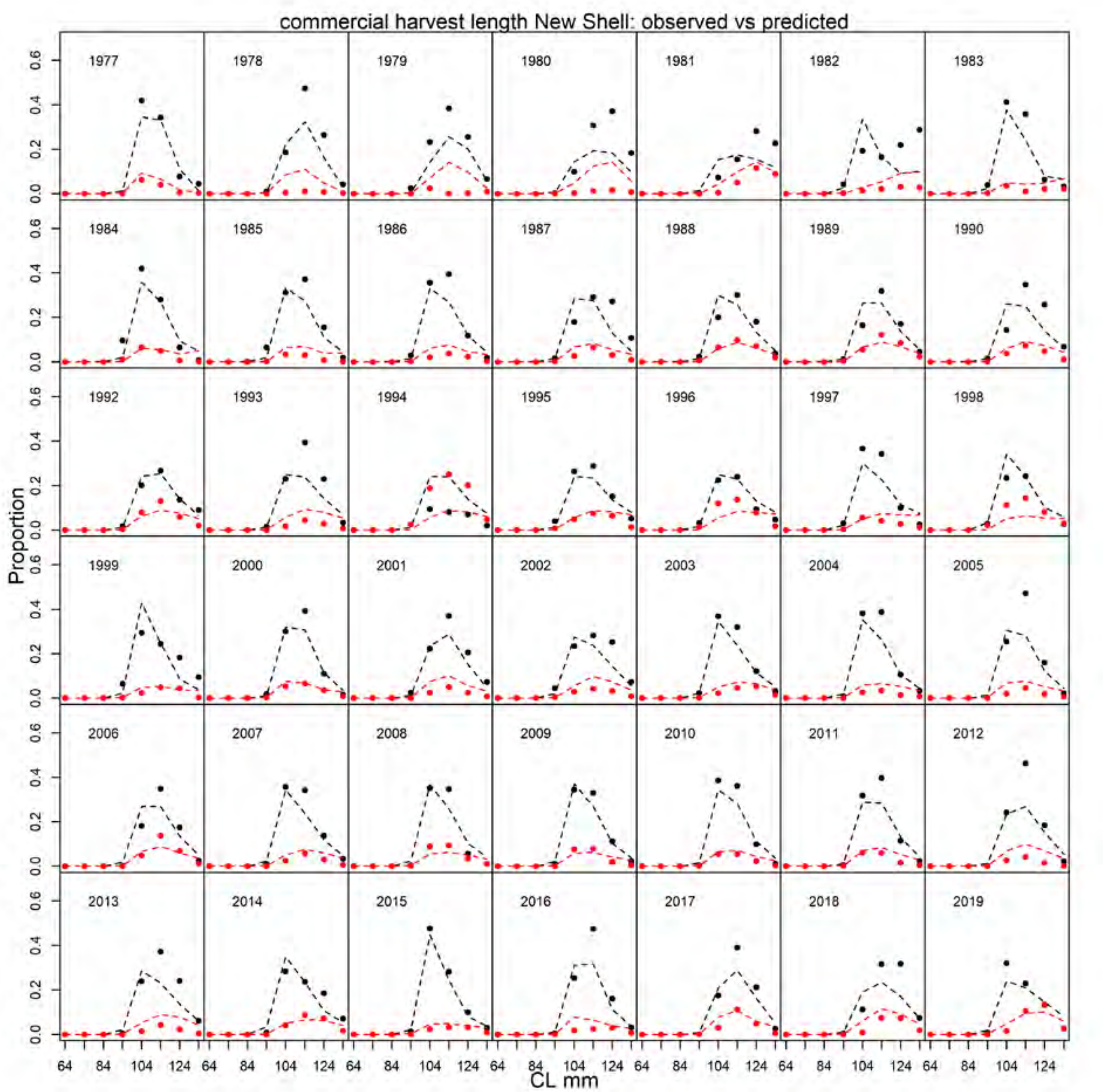


Figure D5-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Black: newshell, Red: oldshell

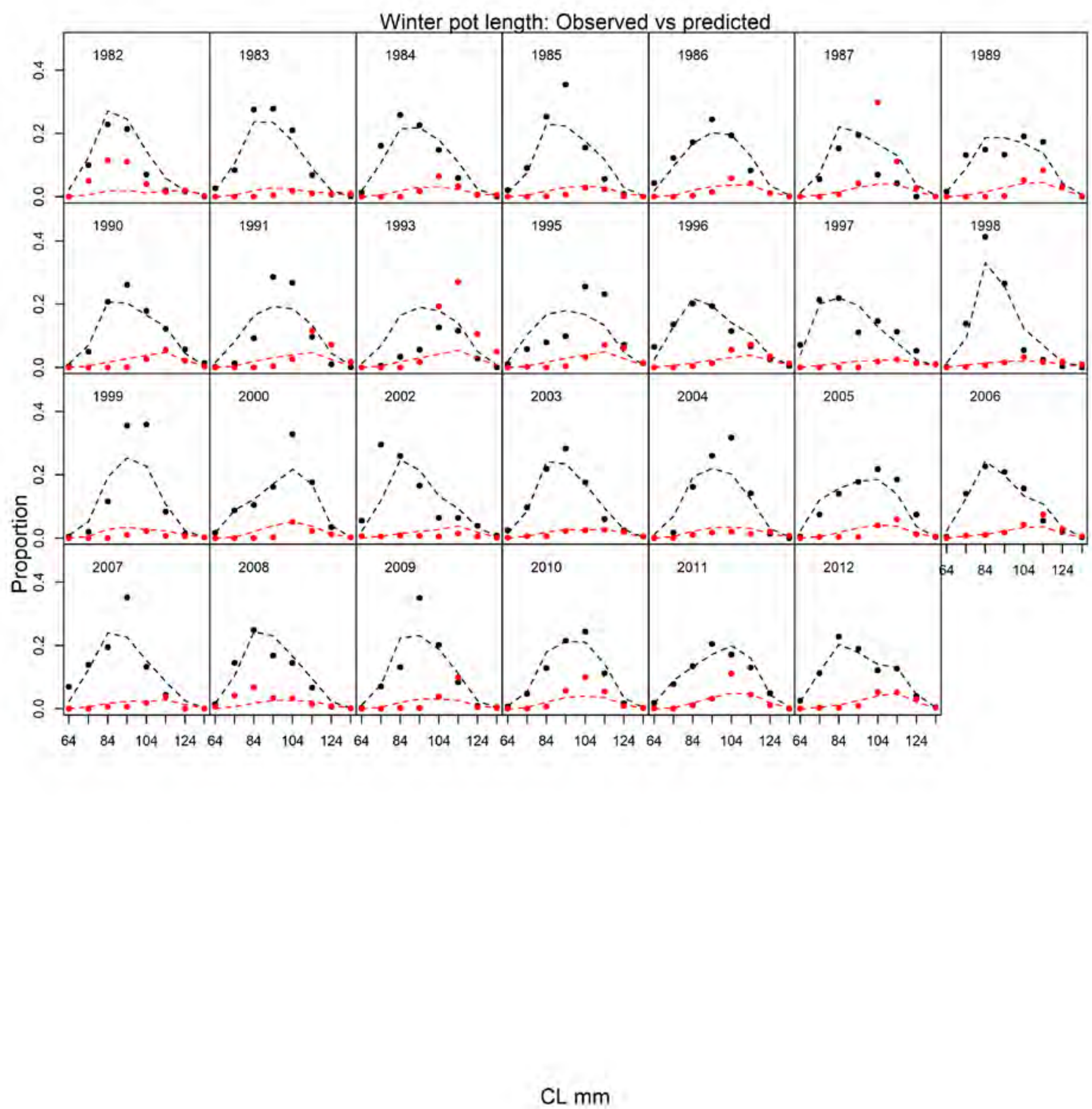


Figure D5-10. Predicted (dashed line) vs. observed (dots) length class proportions for the winter and spring pot survey. Black: newshell, Red: oldshell

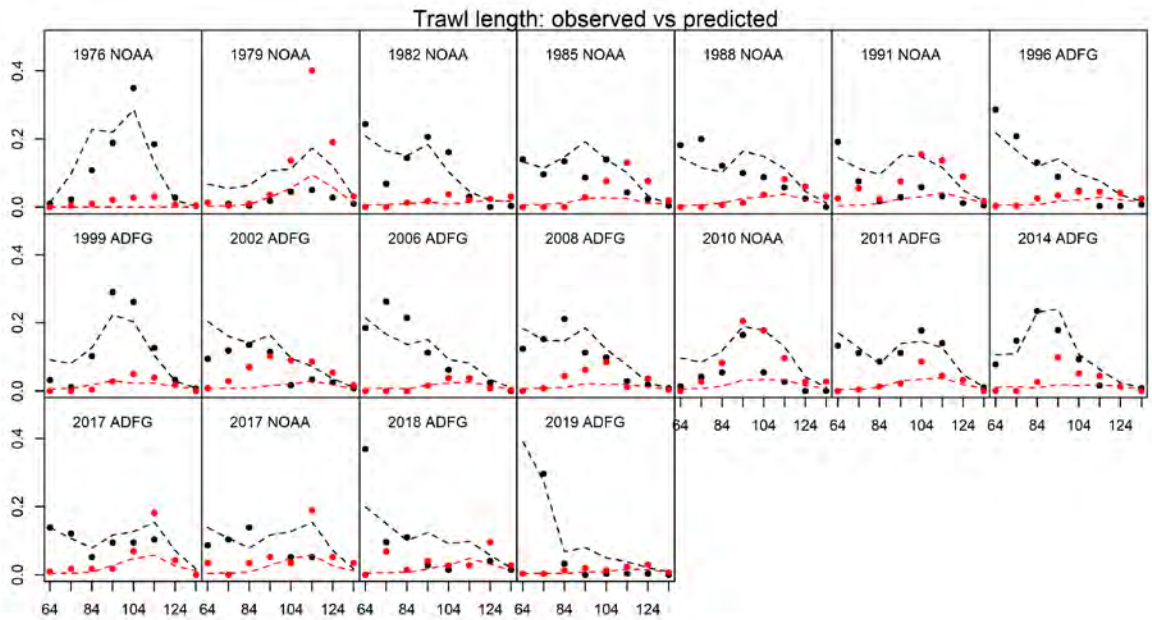


Figure D5-11. Predicted (dashed) vs. observed (dots) length class proportions for trawl survey. Black: newshell, Red: oldshell

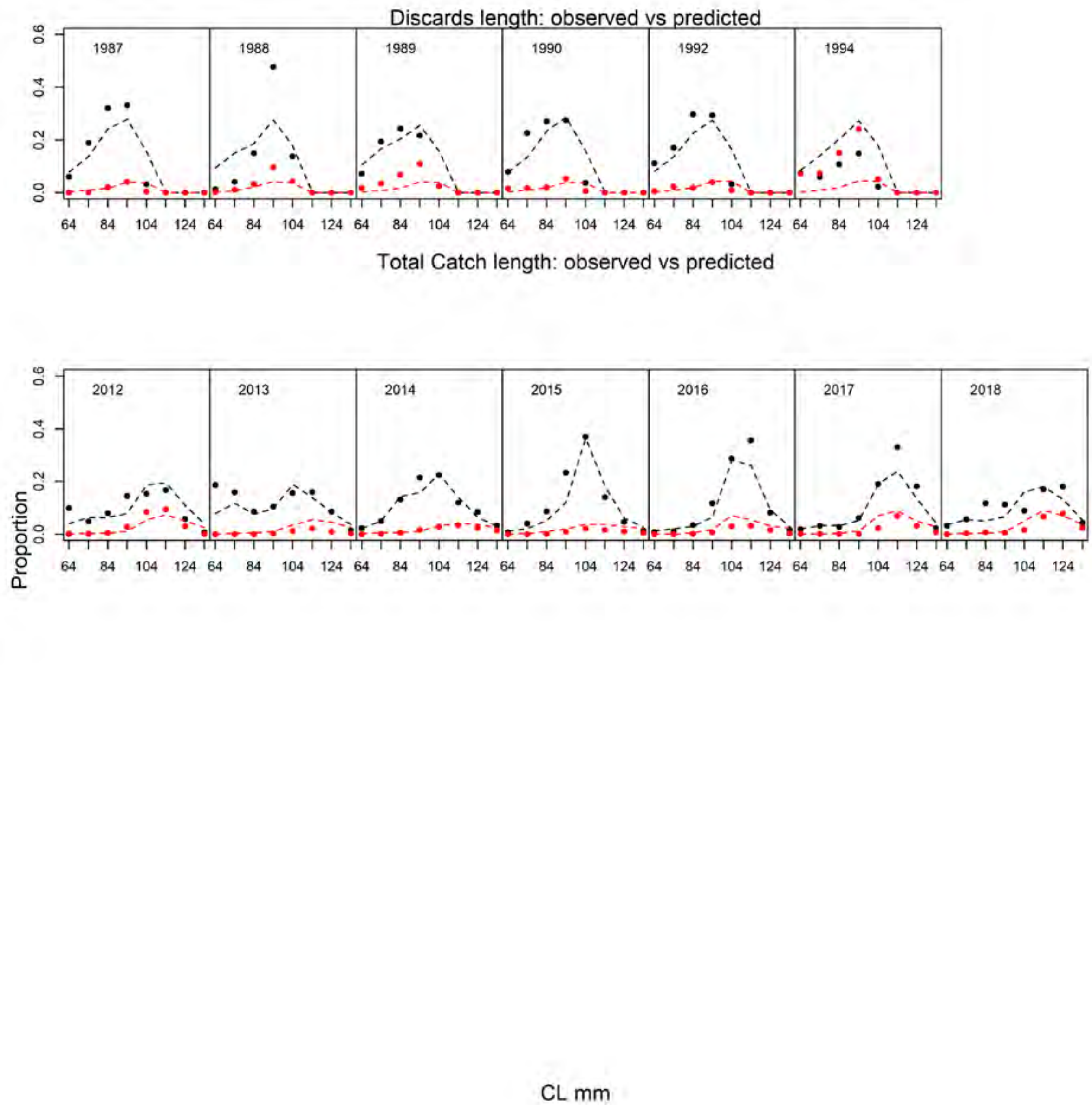


Figure D5-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

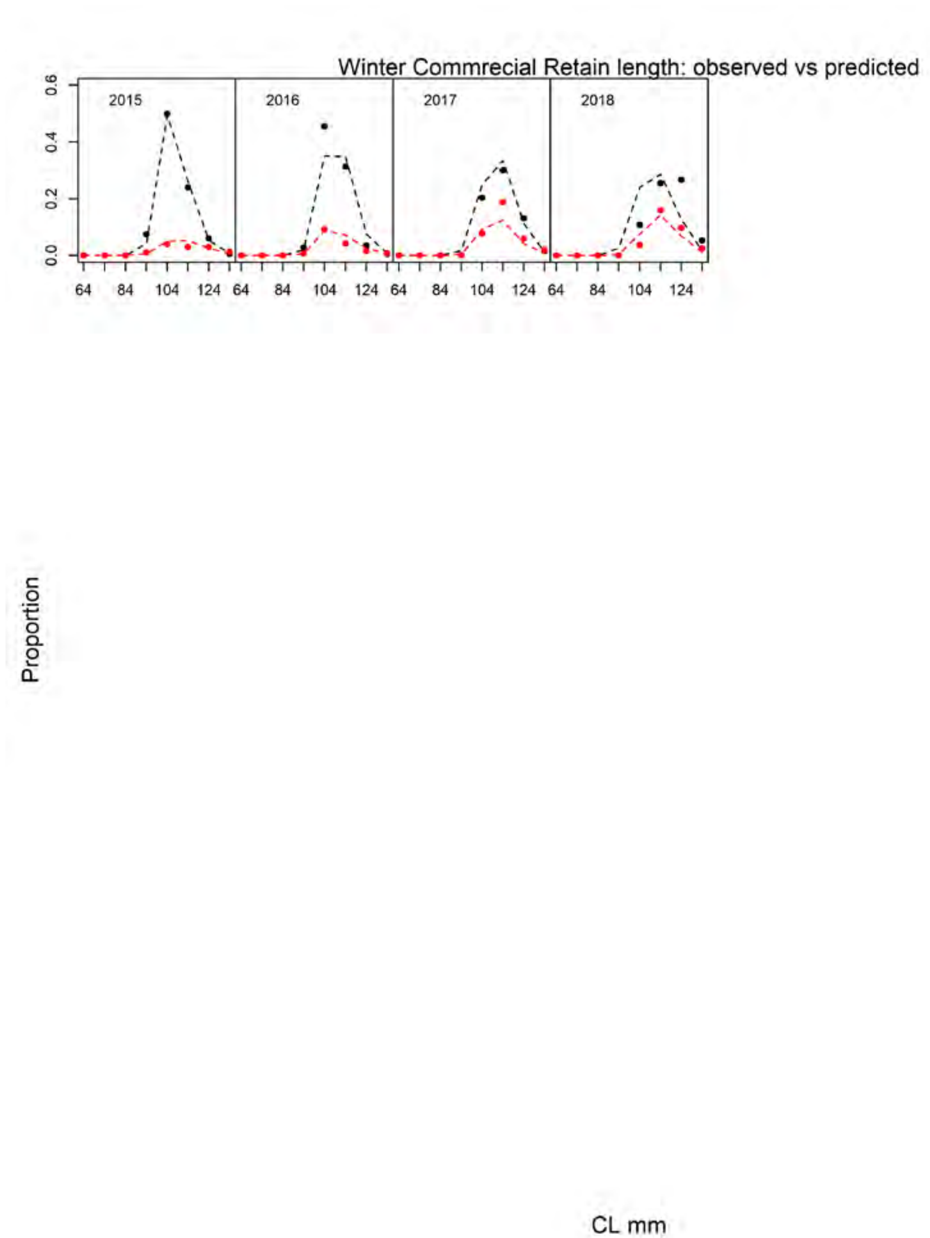


Figure D5-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

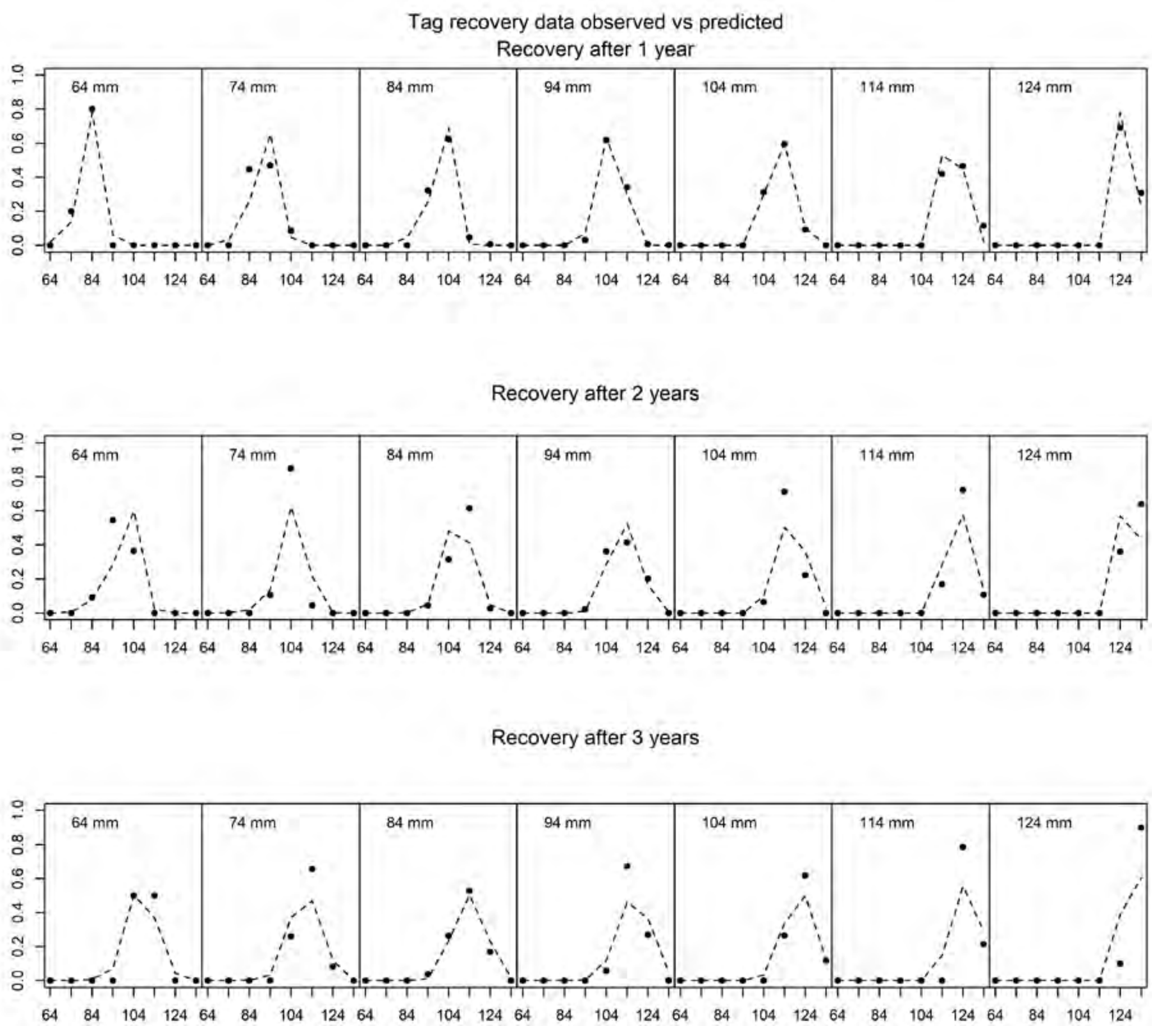


Figure D5-13. Predicted vs. observed length class proportions for tag recovery data.

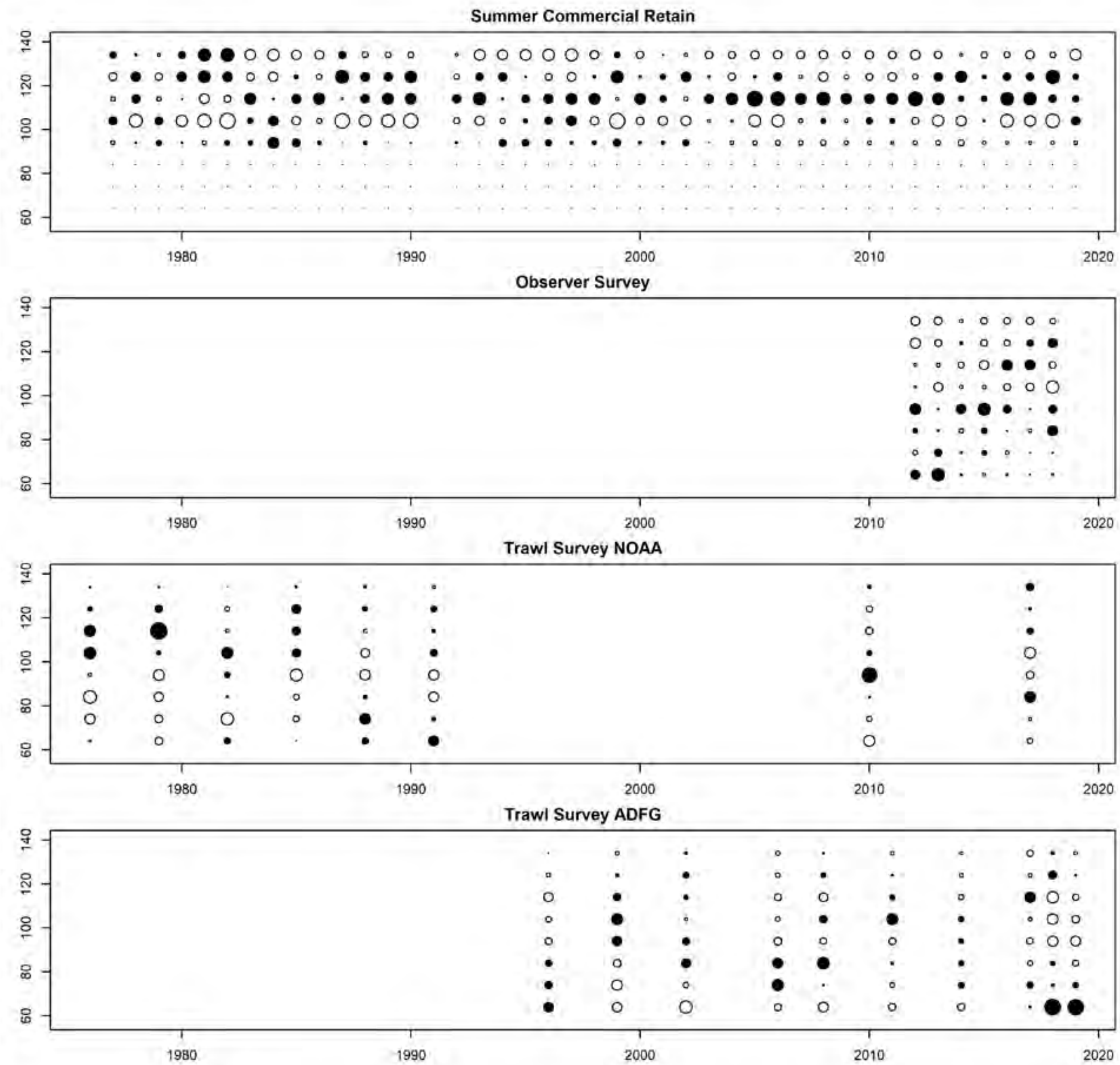


Figure D5-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

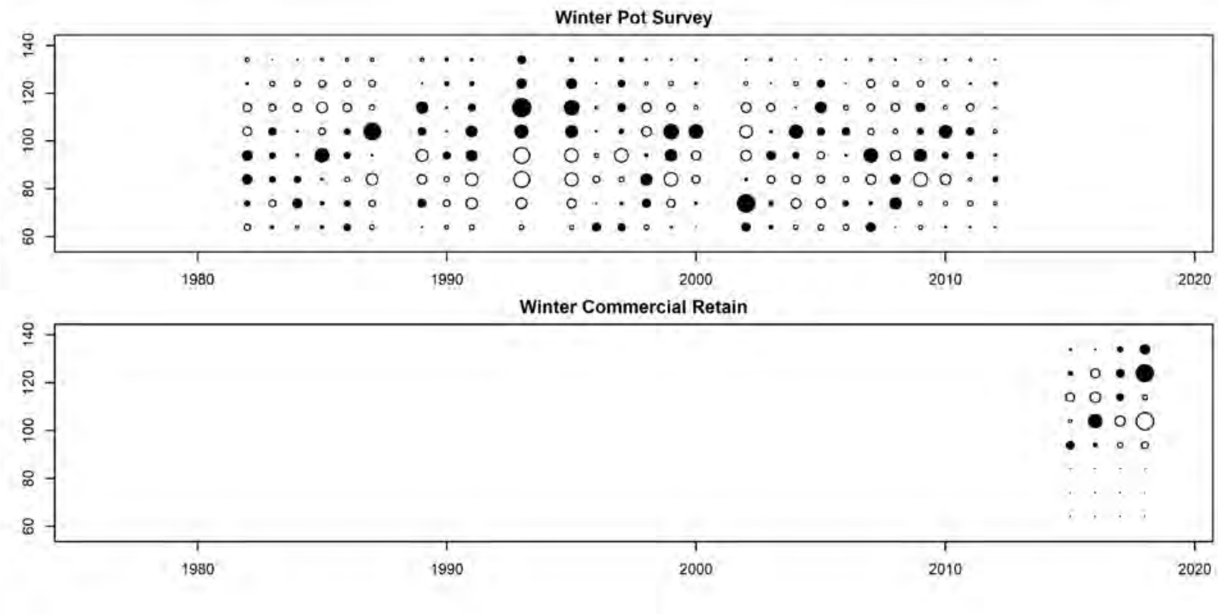


Figure D5-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table D5. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.808	0.138
log_q_2		
log_N_{76}	9.495	0.152
R_0	6.992	0.160
a_1	-0.371	3.653
a_2	1.857	2.993
a_3	2.514	2.818
a_4	2.178	2.818
a_5	2.439	2.803
a_6	1.663	2.856
a_7	0.349	3.350
r1	10.000	0.574
r2	9.895	0.660
log_a	-2.994	0.123
log_b	4.872	0.028
log_ϕ_{st1}		
log_ϕ_{wa}	-1.405	0.272
log_ϕ_{wb}	4.840	0.018
Sw1	0.069	0.034
Sw2	0.356	0.090
log_ϕ_I		
$log\_\phi ra$	-0.852	0.146
$log\_\phi rb$	4.634	0.010
$log\_\phi wra$	-0.883	0.607
$log\_\phi wrb$	4.650	0.040
w^2_t	0.002	0.020
q	0.658	0.109
σ	0.310	0.041
β_1	3.978	0.240
β_2	9.764	1.053

name	Estimate	std.dev
selc 1	0.094	0.039
selc 2	0.143	0.044
selc 3	0.237	0.060
selc 4	0.337	0.055
selc 5	0.653	0.198
selc 6	1.000	0.000
selc 7	0.708	0.099
selc 8	0.292	0.121
selt 1	0.829	0.212
selt 2	0.620	0.129
selt 3	0.741	0.144
selt 4	0.890	0.281
selt 5	1.000	0.000
selt 6	0.973	0.170
selt 7	0.540	0.148
selt 8	0.169	0.092

Appendix D - Model 19.5

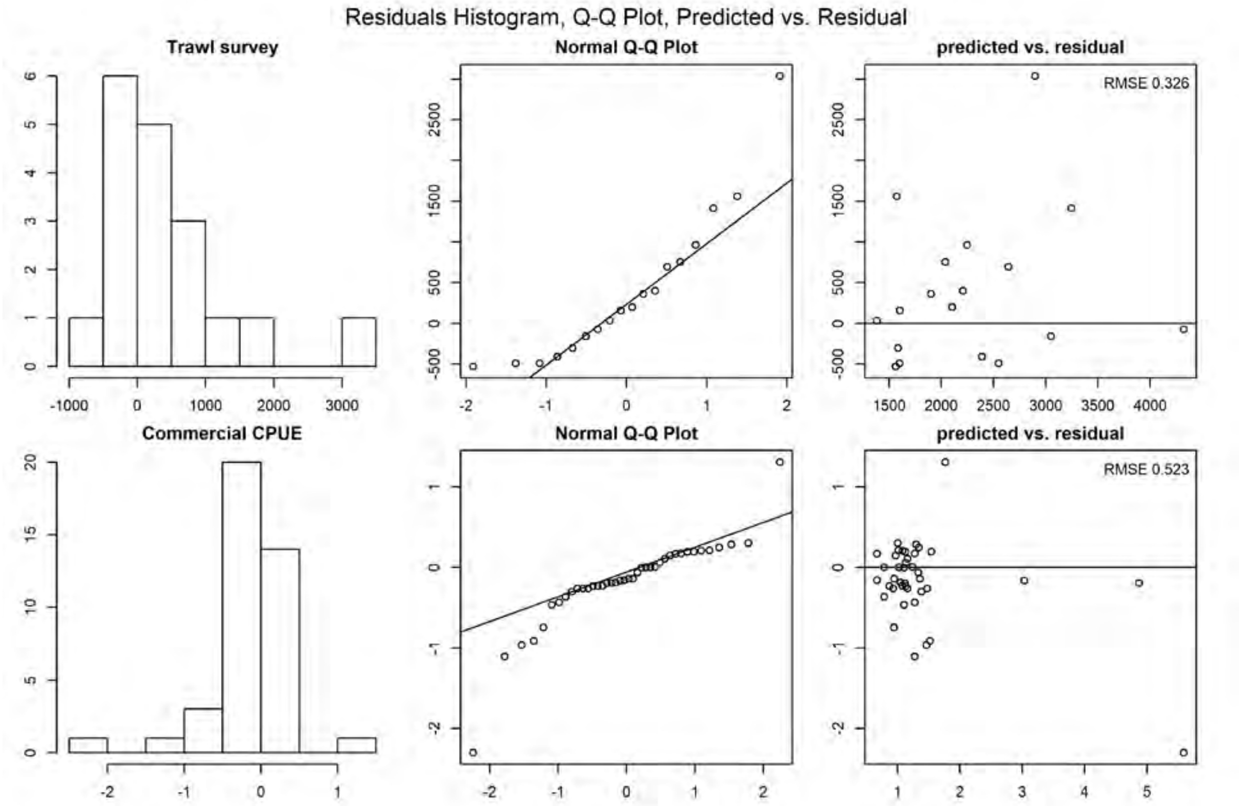


Figure D6-1. QQ Plot of Trawl survey and commercial CPUE.

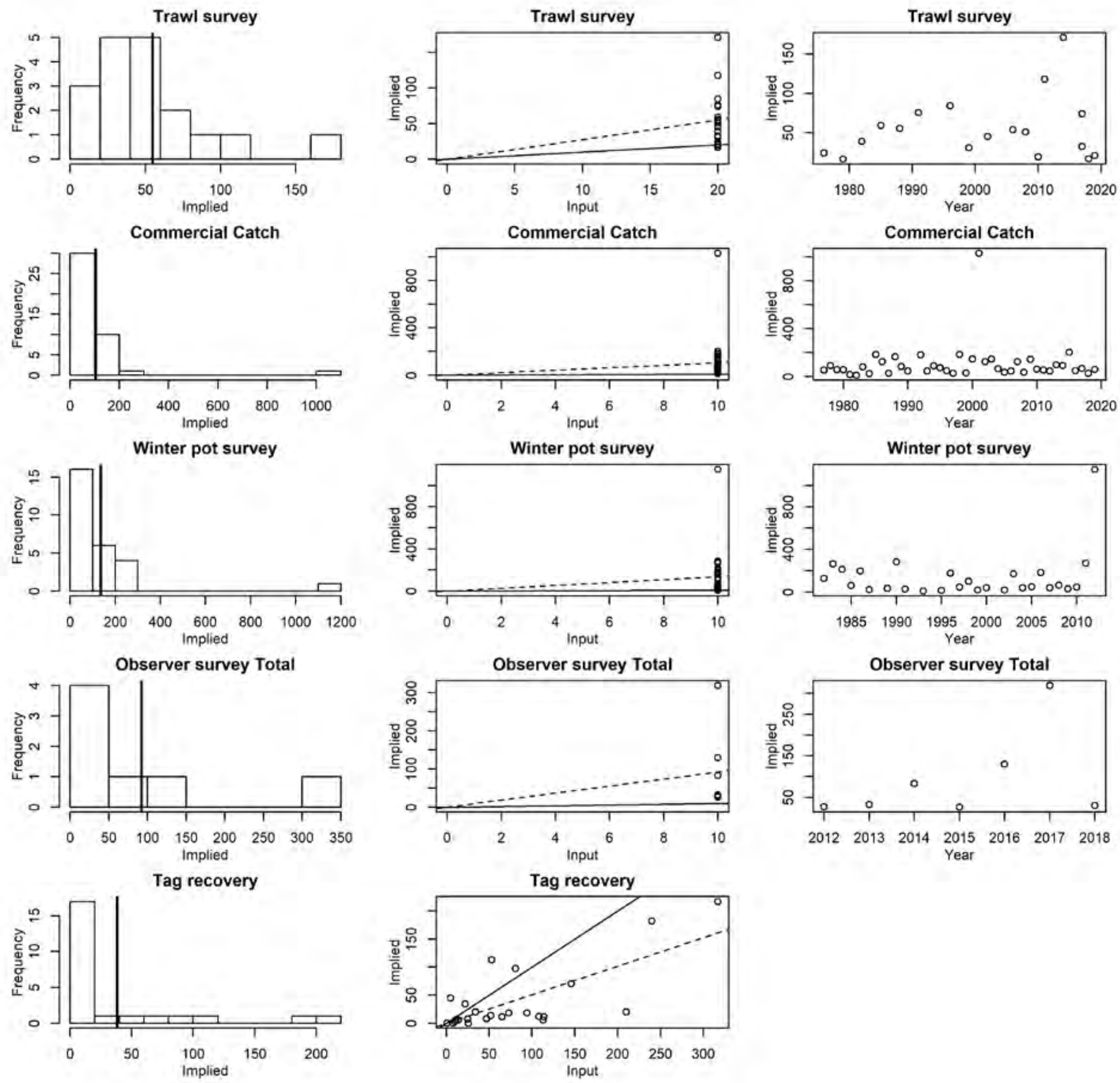


Figure D6-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

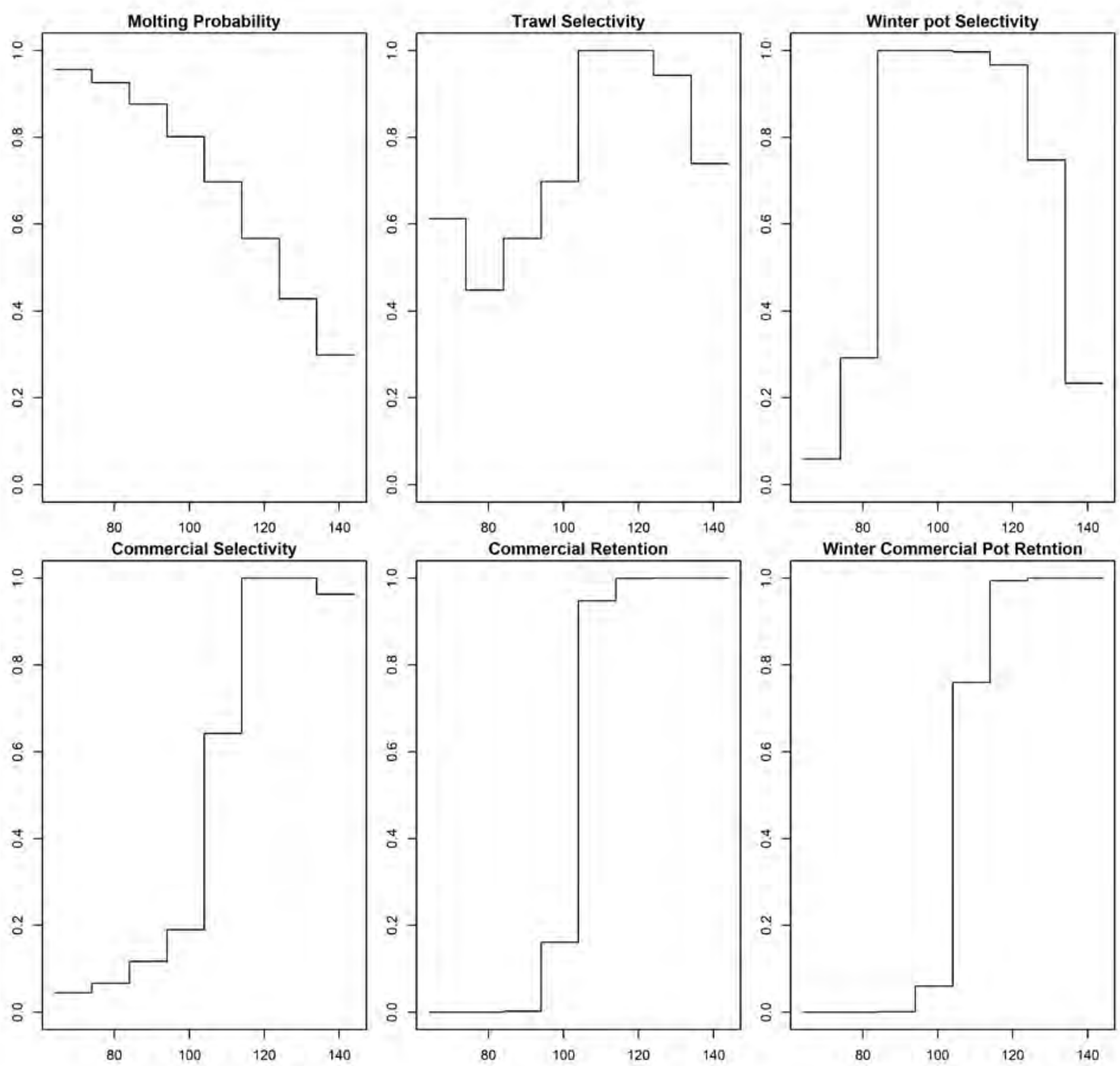


Figure D6-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

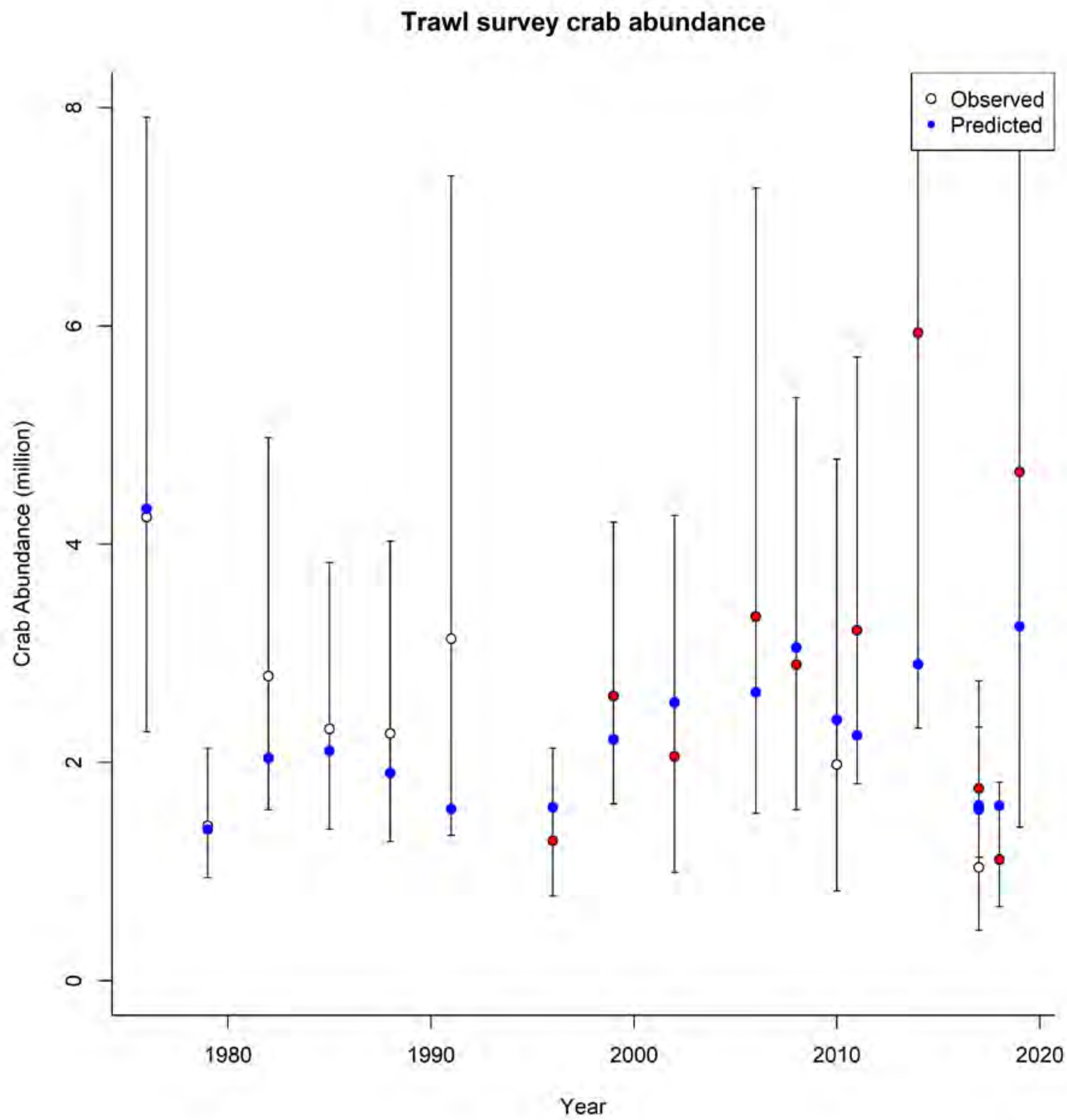


Figure D6-4. Estimated trawl survey male abundance (blue) (crab >= 64 mm CL). Observed: White: NOAA trawl survey, Red: ADG&G trawl survey

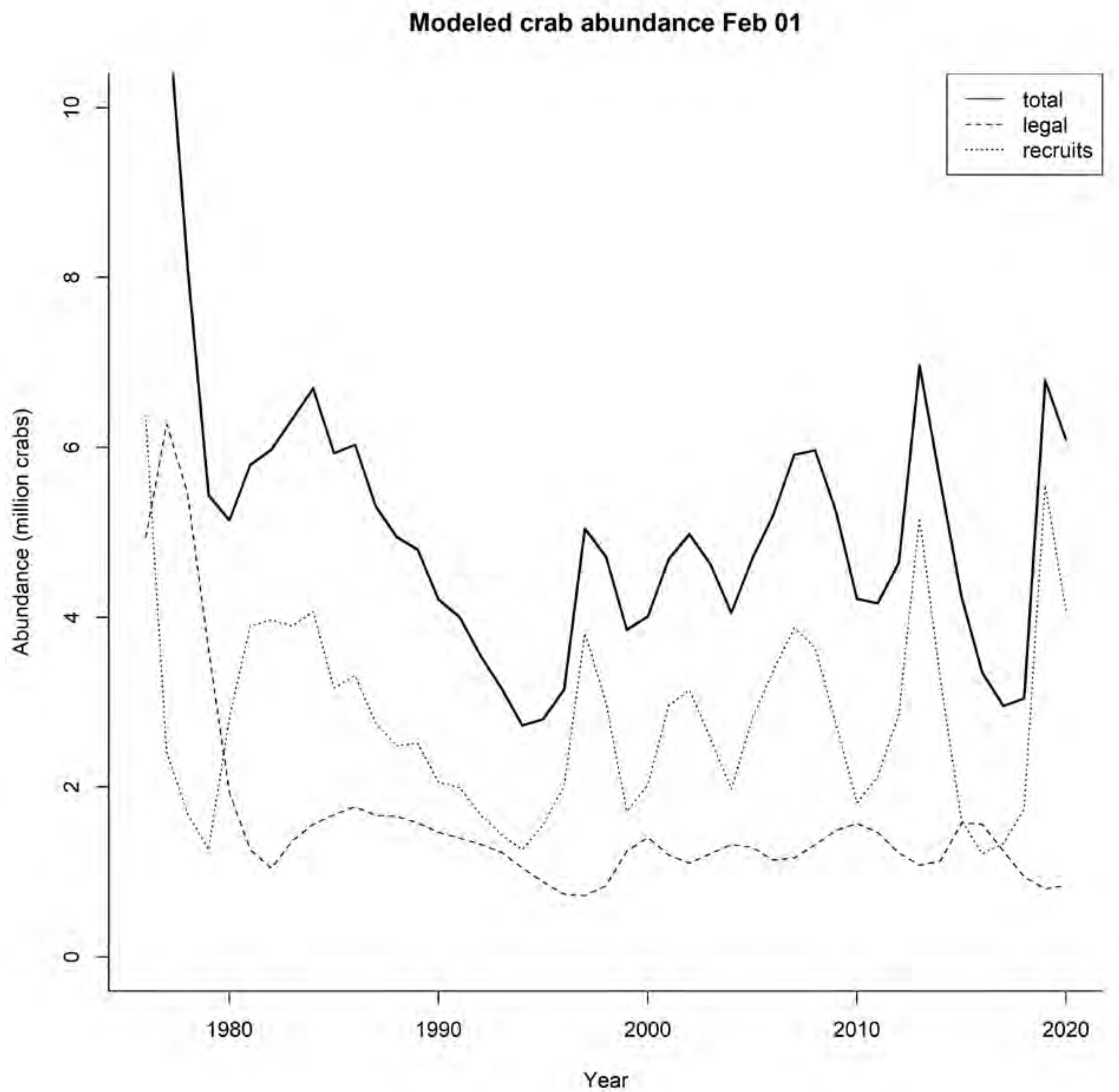


Figure D6-5. Estimated abundance of legal males.

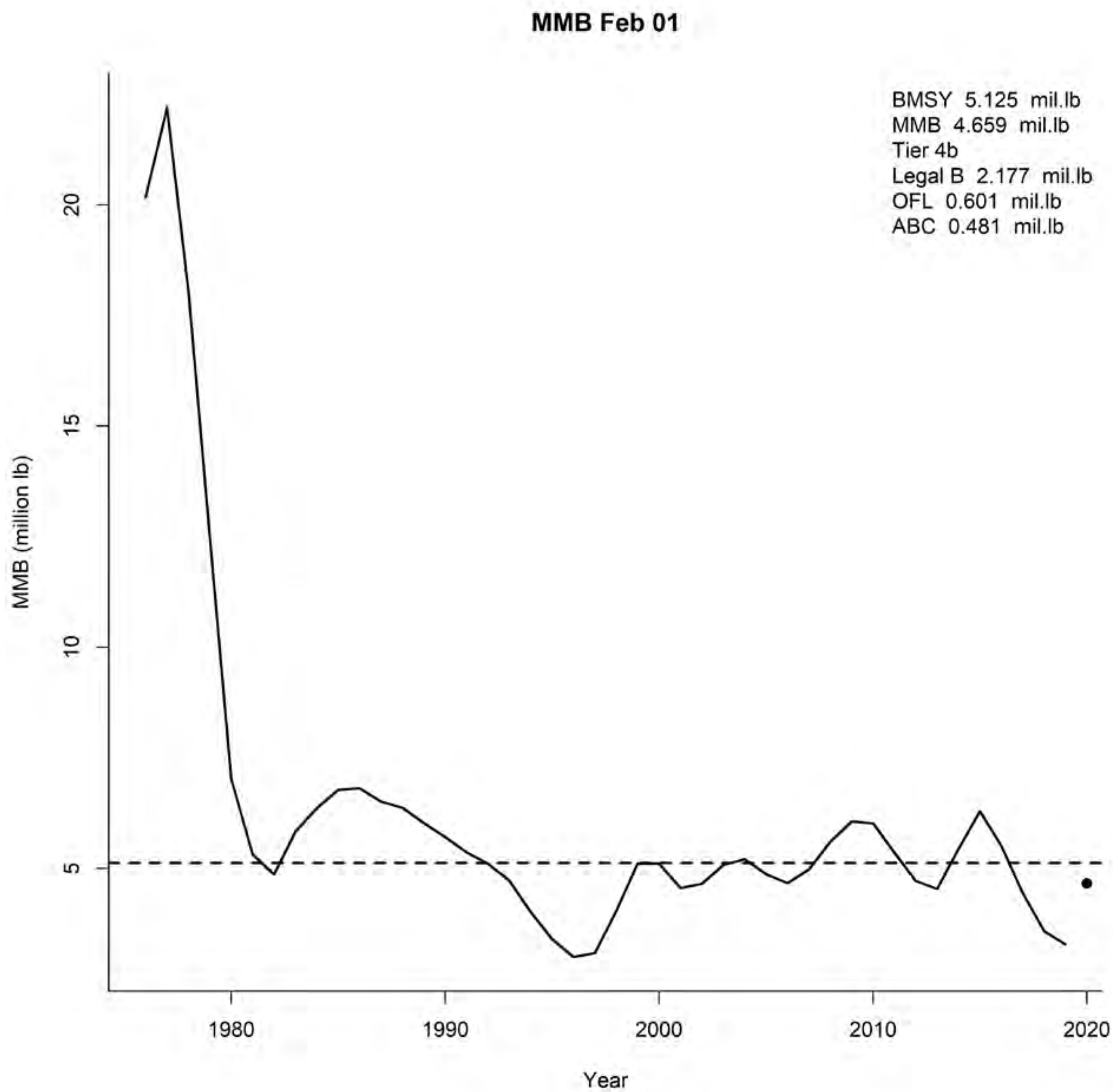


Figure D6-6. Estimated abundance of Mature Male Biomass. Dash line shows Bmsy.

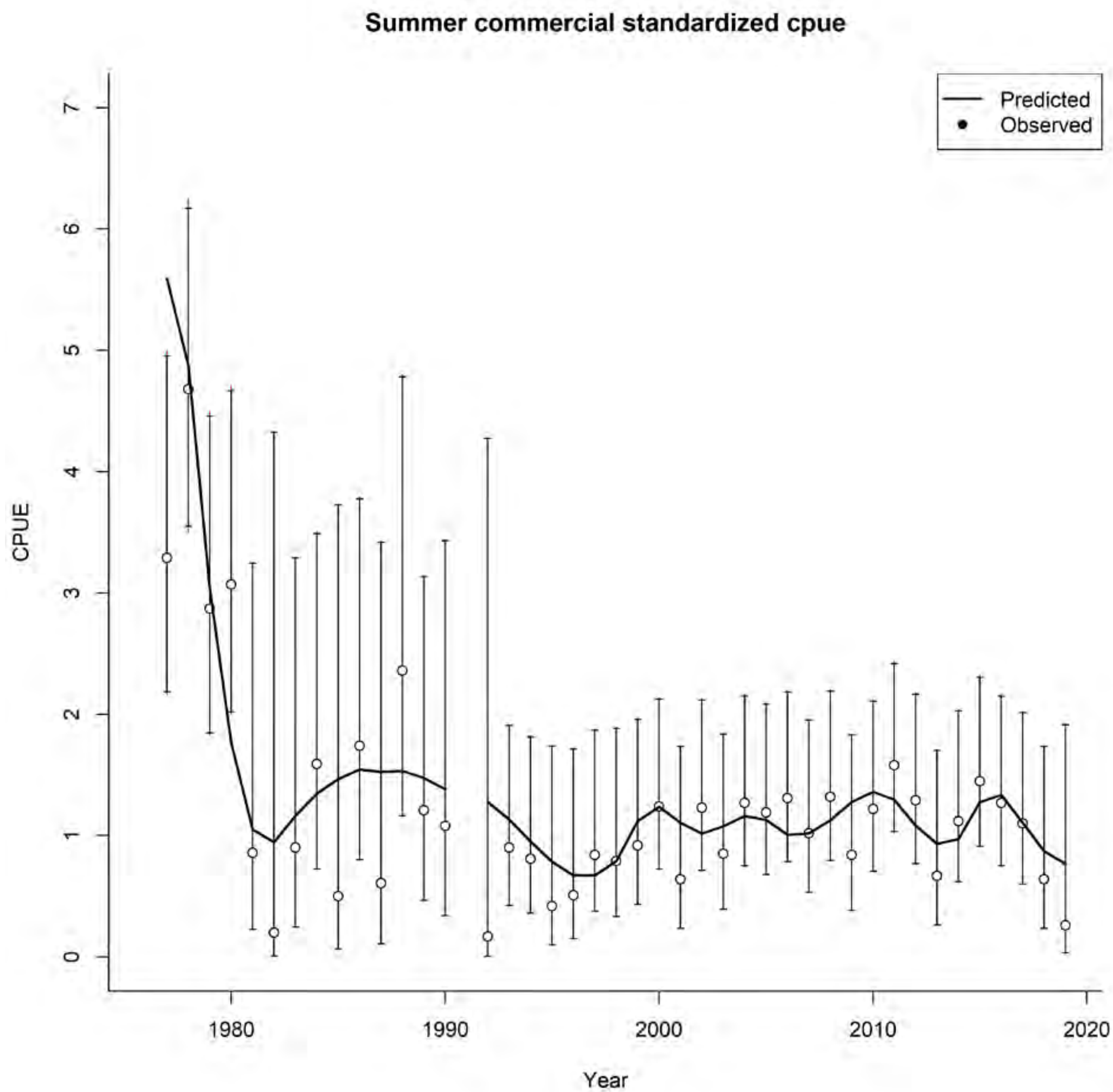


Figure D6-7. Summer commercial standardized cpue.

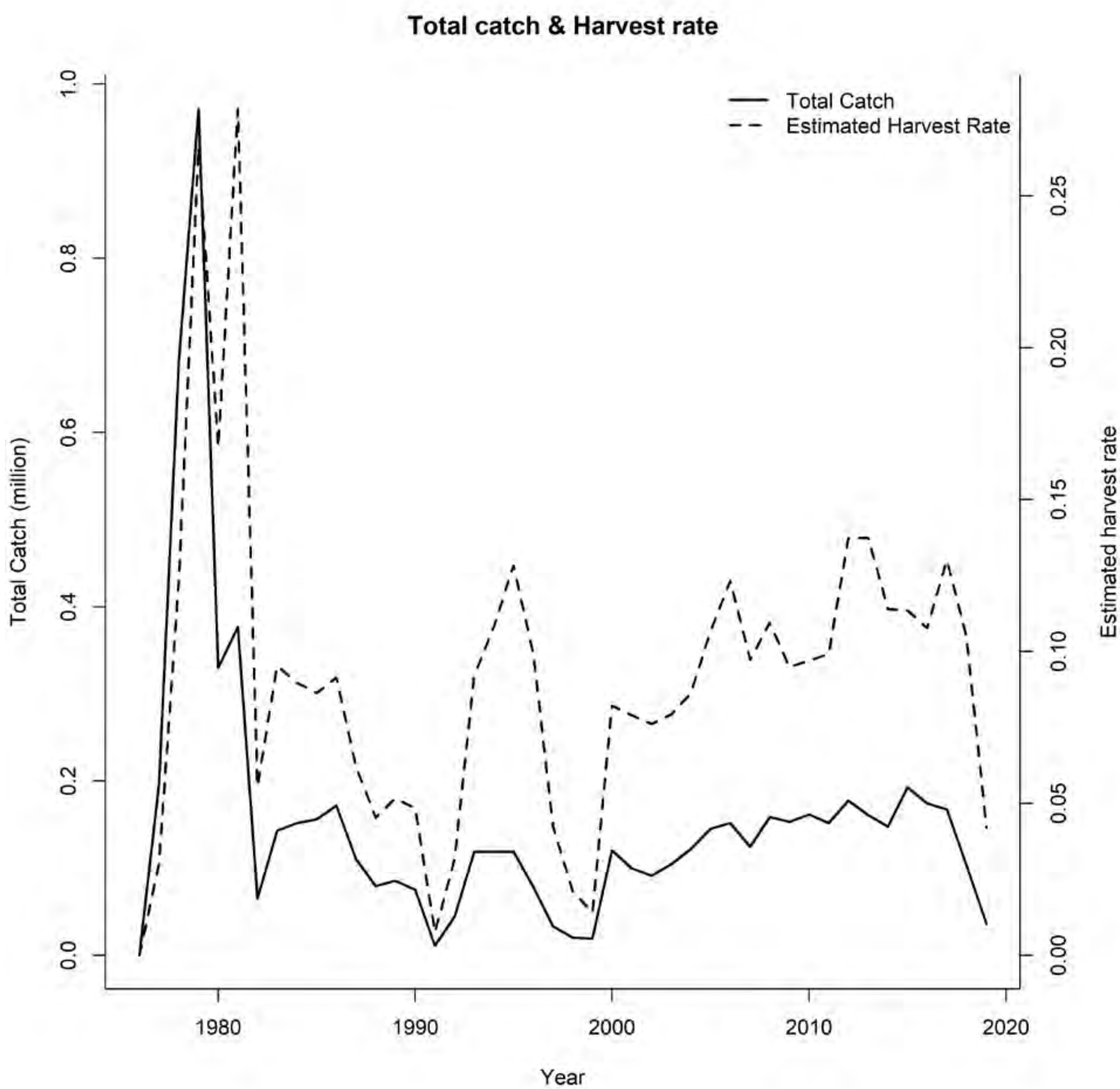


Figure D6-8. Total catch and estimated harvest rate.

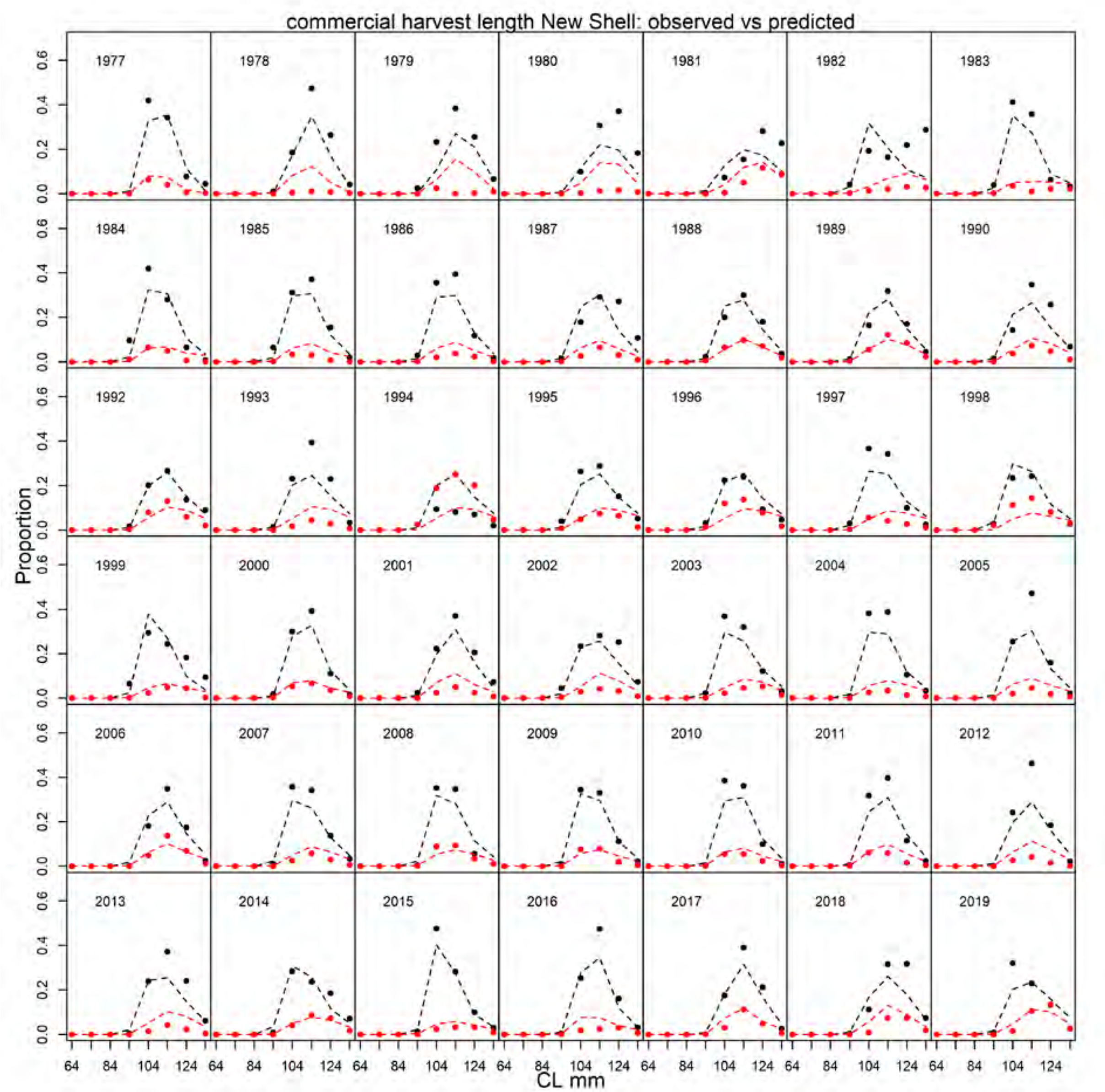


Figure D6-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Black: newshell, Red: oldshell

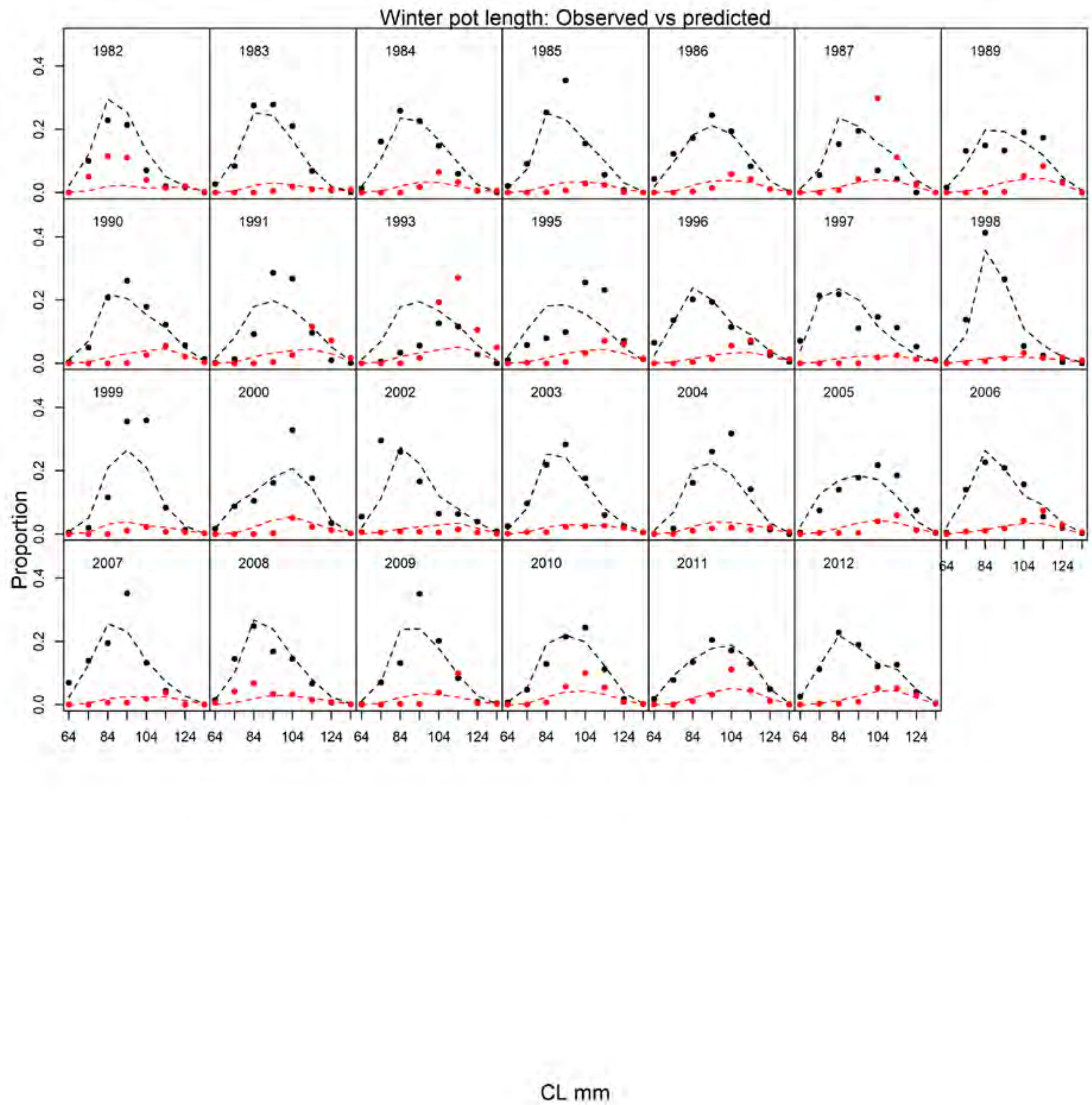


Figure D6-10. Predicted (dashed line) vs. observed (dots) length class proportions for the winter and spring pot survey. Black: newshell, Red: oldshell

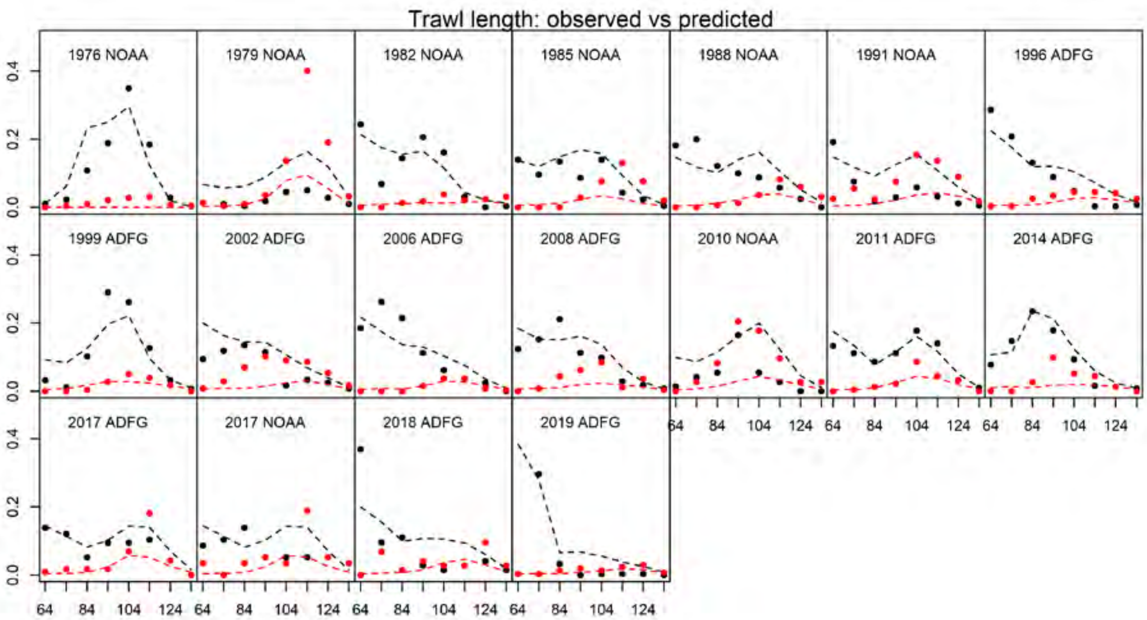


Figure D6-11. Predicted (dashed) vs. observed (dots) length class proportions fo Black: newshell, Red: oldshell r trawl survey.

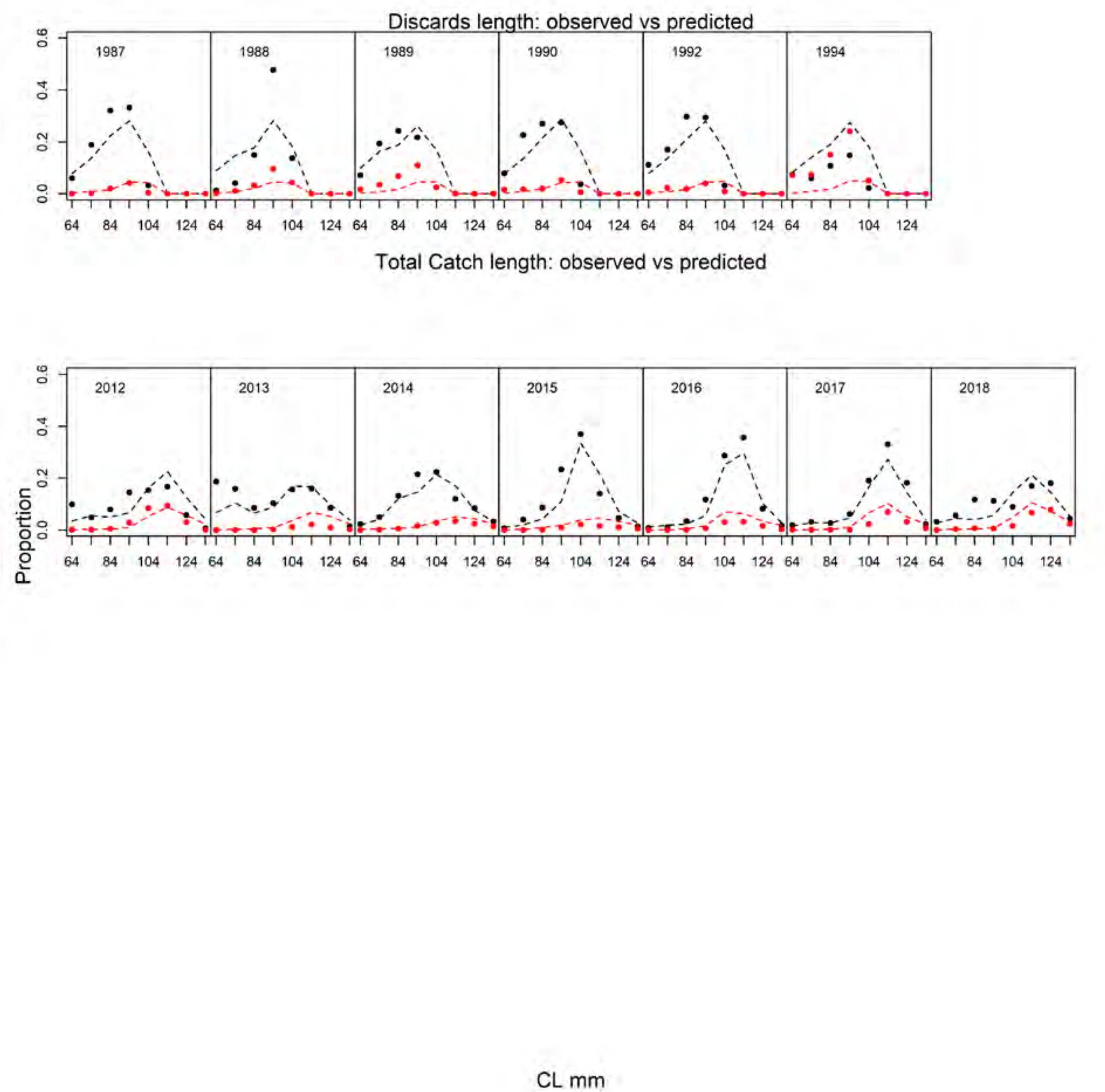


Figure D6-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

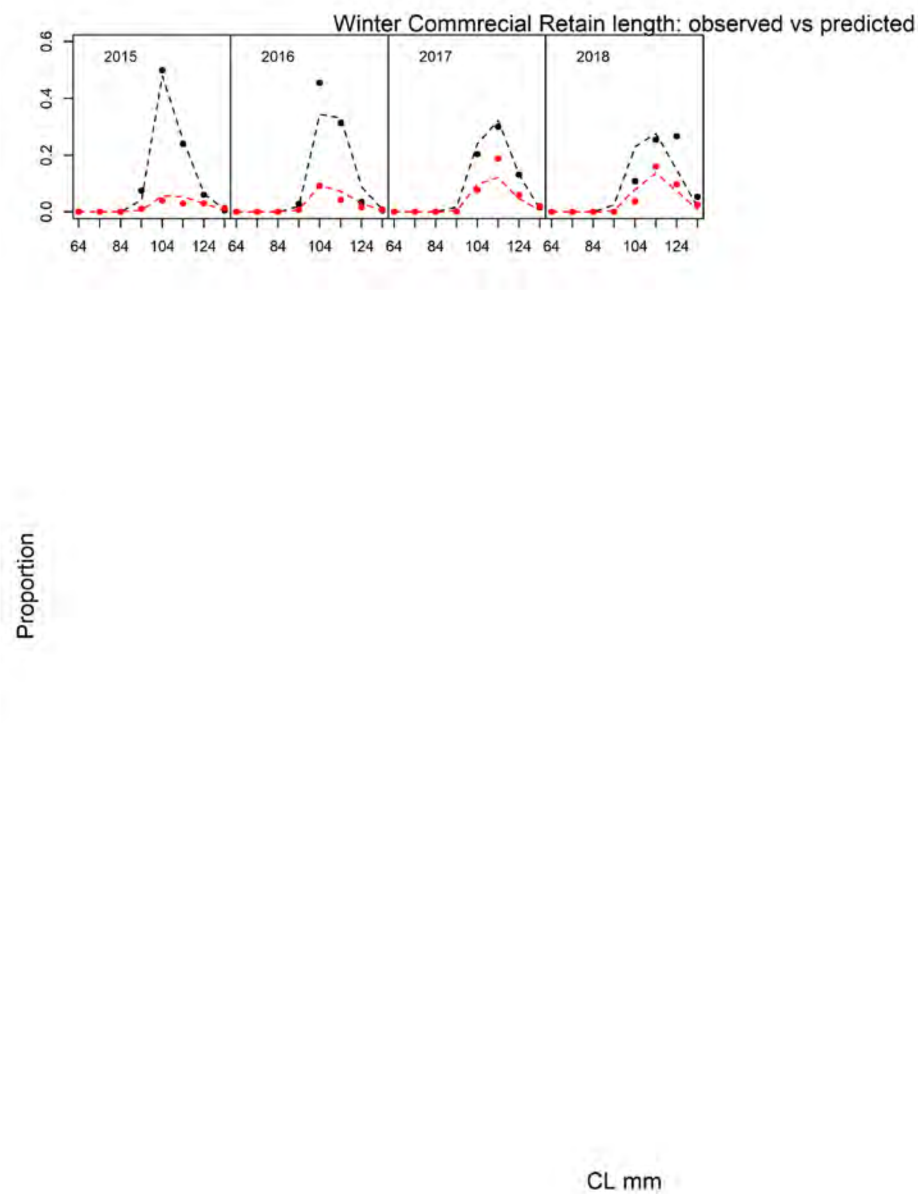


Figure D6-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

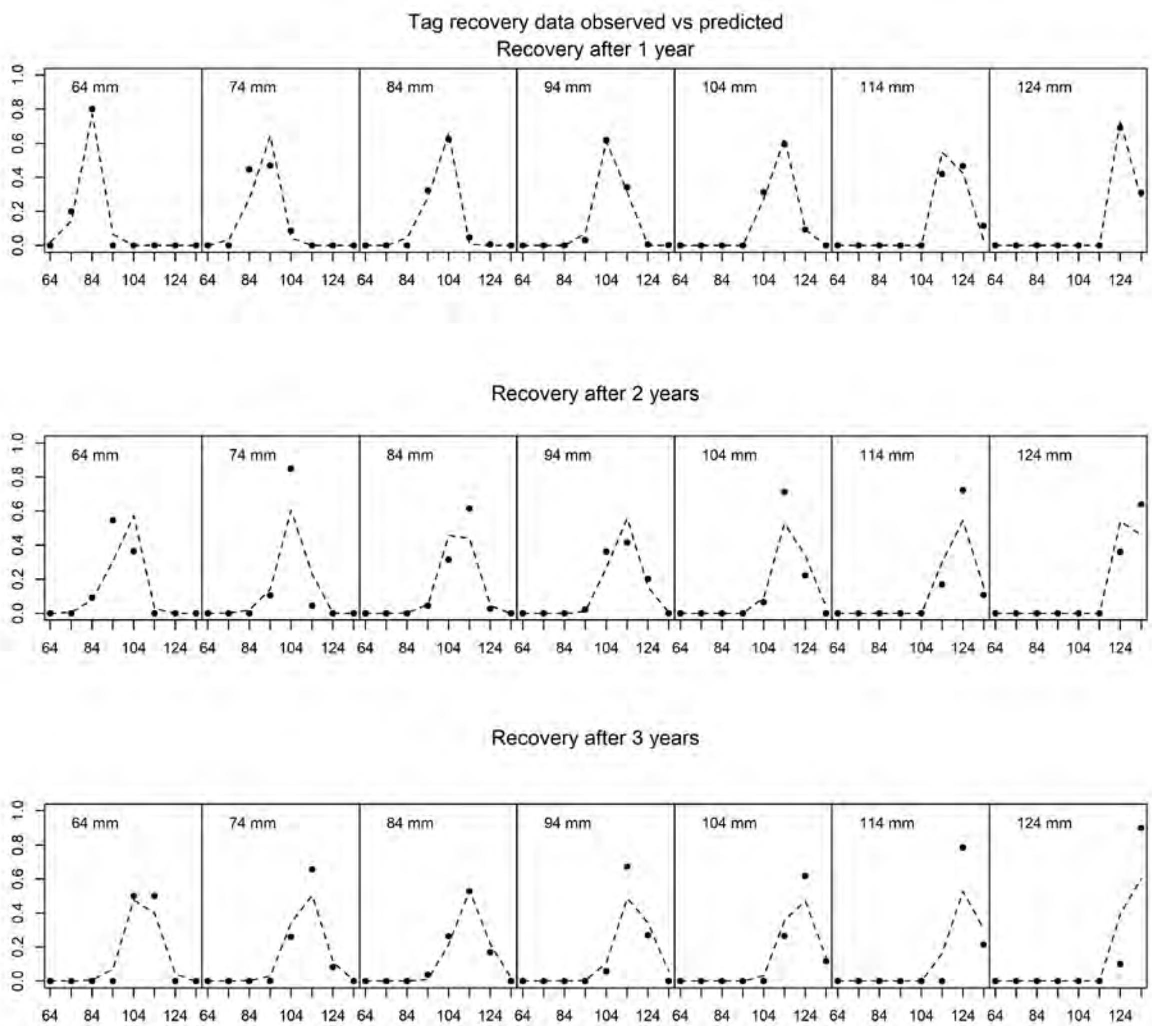


Figure D6-13. Predicted vs. observed length class proportions for tag recovery data.

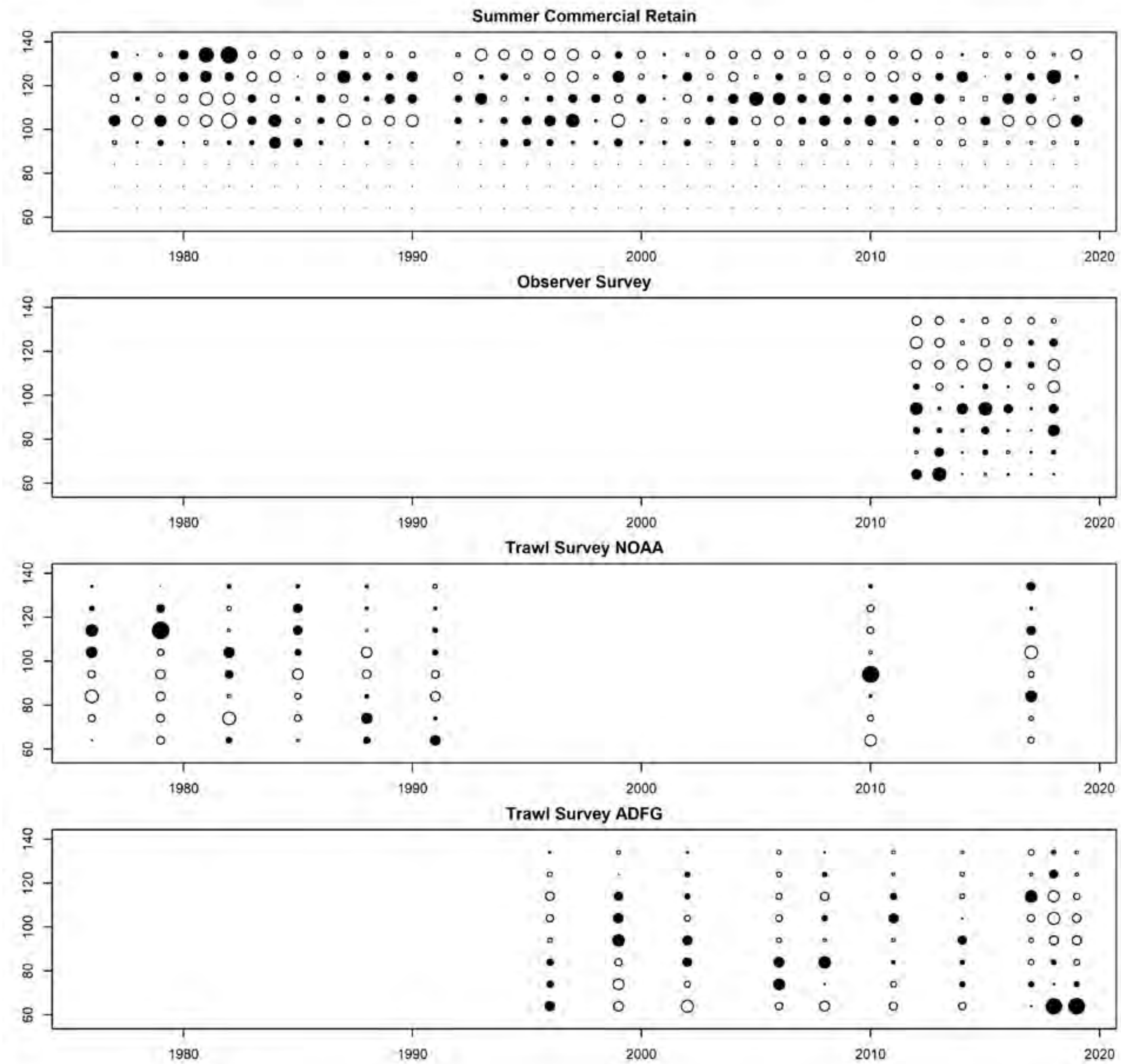


Figure D6-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

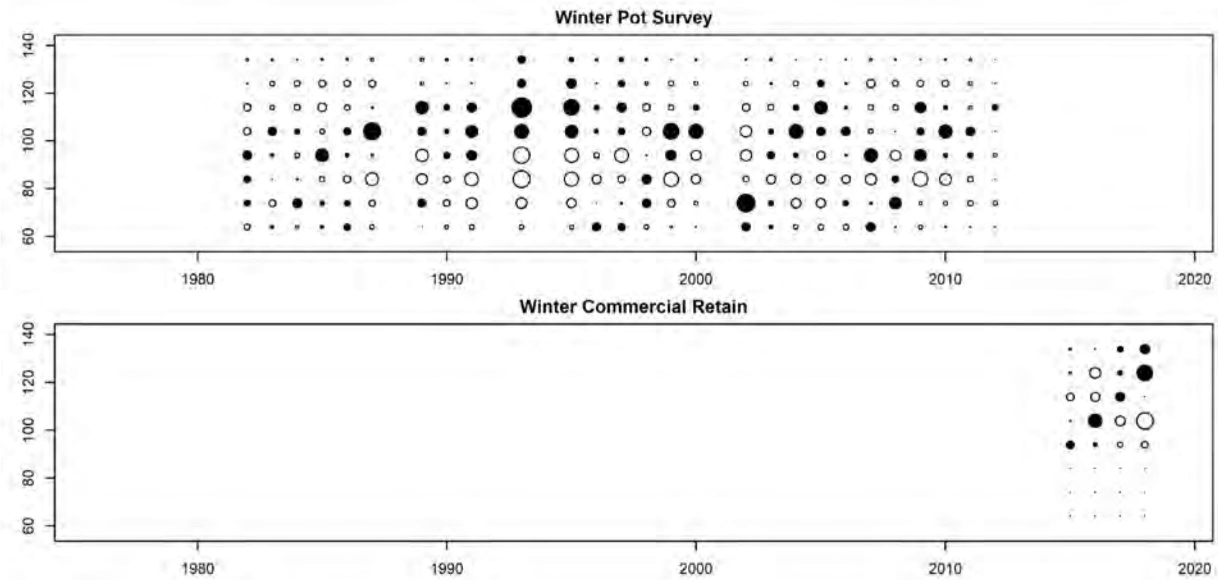


Figure D6-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table D6. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.600	0.133
log_q_2		
log_N_{76}	9.637	0.169
R_0	7.359	0.202
a_1	1.858	4.830
a_2	3.838	4.409
a_3	4.907	4.227
a_4	4.770	4.211
a_5	4.580	4.201
a_6	3.691	4.233
a_7	1.937	4.514
r1	10.000	0.531
r2	9.951	0.630
log_a	-2.879	0.115
log_b	4.815	0.020
log_ϕ_{st1}		
log_ϕ_{wa}	-1.481	0.434
log_ϕ_{wb}	4.892	0.028
Sw1	0.059	0.030
Sw2	0.292	0.075
log_ϕ_l		
$log\_\phi ra$	-0.791	0.138
$log\_\phi rb$	4.626	0.009
$log\_\phi wra$	-0.940	0.470
$log\_\phi wrb$	4.659	0.033
w^2_t	0.002	0.019
q	0.712	0.117
σ	0.433	0.034
β_1	4.010	0.230
β_2	9.762	0.964

name	Estimate	std.dev
selc 1	0.045	0.020
selc 2	0.067	0.023
selc 3	0.117	0.035
selc 4	0.190	0.039
selc 5	0.642	0.062
selc 6	0.988	0.295
selc 7	1.000	0.000
selc 8	0.963	0.252
selt 1	0.613	0.168
selt 2	0.448	0.108
selt 3	0.567	0.118
selt 4	0.698	0.125
selt 5	0.874	0.271
selt 6	1.000	0.000
selt 7	0.943	0.209
selt 8	0.739	0.348