Norton Sound Red King Crab Stock Assessment for the fishing year 2014

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Executive Summary

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

2. Catches. This stock supports three main fisheries: summer commercial, winter commercial, and winter subsistence fisheries. Of those, the summer commercial fishery accounts for more than 90% of total harvest. Summer commercial fishery started in 1977, and its catch quickly reached a peak in the late 1970s with retained catch of over 2.9 million pounds. Since 1982, retained catches have been below 0.5 million pounds, averaging 0.275 million pounds, including several low years in the 1990s. As the crab population rebounds, retained catches have been increasing. For past several years, retained catch is around 0.4 million pounds.

3. Stock Biomass. Estimated mature male biomass (MMB) shows an increasing trend since 1997, and an historic low in 1982 following a crash from the peak in 1977. However, uncertainty in historical biomass is great, which is in part by infrequent trawl surveys (every 3 to 5 years) and limited winter pot survey.

4. Recruitment. Model estimated recruitment was weak during the late 1970s and high during the early 1980s with a slight 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 lbs.)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2010/11	1.56[A]	5.44	0.40	0.42	0.46	0.73[A]	
2011/12	1.56[B]	4.70	0.36	0.40	0.43	0.66[B]	0.59
2012/13	1.78[C]	4.59	0.47	0.47	0.47	0.53[C]	0.48
2013/14	2.06[D]	5.00				0.58[D]	0.52
2014/15							

Status and catch specifications (1000t)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2010/11	0.71[A]	2.47	0.18	0.19	0.21	0.33[A]	
2011/12	0.71[B]	2.13	0.16	0.18	0.20	0.30[B]	0.27
2012/13	0.80[C]	2.08	0.21	0.21	0.21	0.24[C]	0.22
2013/14	0.62[D]	2.16	TBD	TBD	TBD	0.26[D]	0.24
2014/15							

Notes:
MSST was calculated as $B_{MSY}/2$
A-Calculated from the assessment reviewed by the Crab Plan Team in May 2010
B-Calculated from the assessment reviewed by the Crab Plan Team in May 2011
C-Calculated from the assessment reviewed by the Crab Plan Team in May 2012
D-Calculated from the assessment reviewed by the Crab Plan Team in May 2013
E-Calculated from the assessment reviewed by the Crab Plan Team in Sept 2013

Biomass in millions of pounds

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	ABC
2010/11	4a	3.12	5.44	1.7	0.18	1983-2010	0.18		
2011/12	4a	2.97	4.70	1.6	0.18	1983-2011	0.18	0.9	0.59
2012/13	4a	3.51	4.25	1.2	0.18	1980-2012	0.18	0.9	0.48
2013/14	4a	4.12	5.00	1.2	0.18	1980-2013	0.18	0.9	0.52
2014/15	4a								

Biomass in 1000t

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	ABC
2010/11	4a	1.42	2.47	1.7	0.18	1983-2010	0.18		
2011/12	4a	1.35	2.18	1.6	0.18	1983-2011	0.18	0.9	0.27
2012/13	4a	1.59	1.93	1.2	0.18	1980-2012	0.18	0.9	0.22
2013/14	4a	1.86	2.27	1.2	0.18	1980-2013	0.18	0.9	0.24
2014/15	4a								

6. Probability Density Function of the OFL

OFL profile. CV of the OFL was assumed to be 0.2.

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 in 2011.

For 2014 fishery, we chose 90% OFL (10% Buffer) which was million lb

8. A summary of the results of any rebuilding analyses.
   N/A

A. Summary of Major Changes in 2013

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

   In March 2012, the board of fish adopted a revised GHL: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.25 million lbs; (2) ≤ 7% of legal male abundance when the estimated legal biomass falls within the range 1.25-2.0 million lbs; (3) ≤ 13% of legal male abundance when the estimated legal biomass falls within the range 2.0-3.0 million lbs; and (3) ≤ 15% of legal male when estimated legal biomass >3.0 million lbs.

2. Changes to the input data
   a. Data update: 2013 summer commercial fishery, 2012/2013 winter commercial and subsistence catch.
   b. New Data: 2013 summer commercial fishery observer data, standardized commercial catch CPUE and CV.
   c. Revised data: 1976-1991 NMFS survey NSRKC crab abundance estimates were revised based on original survey data.
   d. Inclusion of the historical winter total subsistence catch data. In previous model, only winter retained subsistence catch data were used, in which it was assumed no

discards mortality from winter subsistence catch. This revised model incorporates winter discards mortality.

3. Changes to the assessment methodology: Following model modification were evaluated

   Following major modeling modification was made:

   a. Changing modeling schedule from July 01- June 30 to Feb 01 to Jan 30 schedule
   b. Inclusion of winter commercial and subsistence discards. Winter commercial catch discards were assumed estimated from the model. Discards from the winter subsistence fishery was estimated as total subsistence catch minus total retained subsistence catch. Discards of all winter subsistence catch was assumed to be males of length classes 1 and 2.

4. Changes to the assessment results.

   a. Calculation of OFL and ABC now includes both winter (subsistence + commercial) and summer commercial catches.

B. Response to SSC and CPT Comments

CPT Review April 30 – May 3, 2013

The team had the following comments:
Additional items to be addressed in the future include the following.

- Future model runs should examine variation in M.

- *Future runs should compare the parameter value estimates for NSRKC and those for BBRKC. For example, are molting probabilities similar? Are there tagging data that can be used to inform molting probability?*

  Author response:

  Comparison of parameter value estimates with BBRKC can be valid, assuming that life-history characteristics of NSRKC are similar to the BBRKC. However, we contend that the assumption is wrong. For instance, the maximum CL of male BBRKC reaches > 165 mm (maximum size 227mm), and males are assumed to mature at CL of 120 mm (Zheng and Siddeek 2012). On the other hand, the maximum CL of male NSRKC is around 130mm, and males are assumed to mature at CL of 94mm. By BBRKC standard, NEARLLY ALL NSRKC is considered immature, which obviously is incorrect.

Molting probability of BBRKC from 65 to 125 mm is greater than 60% (Zheng and Siddeek 2012), which is reasonable considering that they are immature. On the other hand, molting probability of BBRKC the older length class (> 155mm) goes down to < 25%. If we assume that CL class of > 120mm of NSRKC corresponds to > 155mm of BBRKC, > 55% molting probability of CL > 120mm NSRKC seems unreasonably high.

- *The stock assessment author should verify that the assessment document follows the terms of reference for crab stock assessment documents.*

  Implemented.

- *Plots of recruitment for the different models should be included.*

  Implemented.

- List the bounds for each parameter and evaluate which parameters might be hitting bounds.

  Implemented.

- When plotting model runs, always include the base model for comparison.

  Implemented.

- Include the discussion of model runs in the main document, not as an appendix.

  Implemented.

- Be sure that the figures are titled consistently. In the current document, “total crab abundance” actually means “total male crab abundance” (figures in Appendix D are very confusing and mislabeled) and “Trawl survey legal abundance” actually means “total legal abundance” (Figure 4b) – correct all throughout,

  Implemented.

- Be sure that data in tables and figures are consistent.

  Implemented.

- Equation 24 is missing the additional variance term.

  Corrected

- Figures all need unique figure numbers.

  This was largely due to the fact that two separate documents (SAFE assessment report, and Standardization of CPUE report) were combined as a single document at the time of publication.

- All pages must be numbered sequentially, and all pages must have page numbers for ease of review and discussion by the team.

  Implemented.

SSC Review on June 3-5, 2013

SSC's agreed with all CPT's reviews, and no further comments were provided.

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 with 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 been made on possible stock separation within the putative stock known as Norton Sound red king crab.
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 migrates between deeper offshore waters during molting/feeding and inshore shallow waters during the mating period. Timing of the inshore mating migration is unknown; but is assumed to be during March-June. Offshore migration is considered to begin in May-July. Trawl surveys show that crab distribution is dynamic. Recent surveys show high abundance on the southeast side of the Sound, offshore of Stebbins and Saint Michael. Timing of molting is unknown; however, is considered to occur in late August – September, based on increase catches of fresh-molted crabs in later fishing season (August- September).

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 in winter (December – May) (Menard et al. 2011). The majority of red king crab are harvested by the summer commercial fisheries, whereas the majority of the winter harvest is in the subsistence fishery occurring near the coast (Table 2).

<u>Summer Commercial Fishery</u>

Summer commercial crab fishery started in 1977 (Table 1). A large-vessel summer commercial crab fishery existed in the Norton Sound Section from 1977 through 1990. No summer commercial fishery occurred in 1991 because there was 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. Regulation changes and location of buyers resulted in harvest distribution moving eastward in Norton Sound in the mid-1990s. In the Norton Sound, a legal crab is defined as ≥ 4-3/4 inch carapace width (CW, Menard et al. 2011; equivalent to ≥ 124 mm carapace length [CL]). Since 2005, commercial buyers started accepting only legal crabs of ≥ 5 inch carapace.

Not all Norton Sound area is open for commercial fisheries. Since beginning of the commercial fisheries in 1977, inland waters near Nome area has been closed for summer commercial crab fishery, possibly to protect crab nursery grounds (Figure 2). Extent of closed water changed throughout history. Appendix E shows historical harvest by Stat area.

<u>CDQ Fishery</u>

The Norton Sound and Lower Yukon CDQ groups divide the CDQ allocation. Only fishers designated by the Norton Sound and Lower Yukon CDQ groups are allowed to participate in this portion of the king crab fishery. Fishers are required to have a CDQ fishing permit from the Commercial Fisheries Entry Commission (CFEC) and register their vessel with the Alaska Department of Fish and Game (ADF&G) before they make their first delivery. Fishers operate under authority of the CDQ group and each CDQ group decides how their crab quota is to be harvested. During the March 2002 BOF meeting, new regulations were adopted that affected the CDQ crab fishery and relaxed closed-water boundaries in eastern Norton Sound and waters west of Sledge Island. At its March 2008, the BOF changed the start date of the Norton Sound open-access portion of the fishery to be opened by emergency order and as early as June 15. The CDQ fishery may open at any time (as soon as ice is out), by emergency order. It is possible that the fishery starts BEFORE determination of OFL and ABC.

Winter Commercial Fishery

Winter commercial crab fishery is a small fishery using hand lines and pots through the nearshore ice. Approximately 10 permit holders participated in this fishery harvesting, on average 2,500 crabs during 1978-2009; however, during 2006-2013 periods the winter commercial catch increased to 3,000 – 23,000 (Table 2). Causes for this increase are unclear. The winter commercial fishery catch is influenced not only by crab abundance, but also by changes in near shore crab distribution, ice conditions, the number of participants, and market condition.

Subsistence Fishery

Subsistence crab fishery has been occurring for a long time; however, its harvest is available since 1977/78 winter period. The majority of subsistence crab fishery mainly occurs during winter using hand lines and pots through the nearshore ice. Average annual winter subsistence harvest was 5,400 crabs (1977-2010). Subsistence harvesters need to obtain a permit before fishing and record daily effort and catch. There is no size limit in the subsistence fishery. The subsistence fishery catch is influenced not only by crab abundance, but also by changes in distribution, changes in gear (e.g., more use of pots instead of hand lines since 1980s), and ice conditions (e.g., reduced catch due to unstable ice conditions: 1987-88, 1988-89, 1992-93, 2000-01, 2003-04, 2004-05, and 2006-07).

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

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

Since 1997 Norton Sound red king crab have been managed based on a guideline harvest limit (GHL). Detailed historical methods of GHL determination are unknown. Since 1999, GHL is 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 lbs; (2) ≤ 5% of legal male abundance when the estimated legal biomass falls within the range 1.5-2.5 million lbs; and (3) ≤ 10% of legal male when estimated legal biomass >2.5 million lbs.

In 2012 the Alaska Board of Fisheries adopted a revised GHL: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.25 million lbs; (2) ≤ 7% of legal male abundance when the estimated legal biomass falls within the range 1.25-2.0 million lbs; (3) ≤ 13% of legal male abundance when the estimated legal biomass falls within the range 2.0-3.0 million lbs; and (3) ≤ 15% of legal male when estimated legal biomass >3.0 million lbs.

Year	Notable historical management changes
1976	The abundance survey started
1977	Large vessel commercial fisheries began
1991	Fishery closed due to staff constraints
1994	Super exclusive designation into effect. The end of large vessel commercial fishery operation. Participation limited to small boats. The majority of commercial fishery subsequently shifted to east of 164°W line.
1998	Community Development Quota (CDQ) allocation into effect
1999	Guideline Harvest Limit (GHL) into effect
2000	North Pacific License Limitation Program (LLP) into effect.
2002	Change in closed water boundaries (Figure 2)
2005	Commercially accepted legal crab size changed from ≥ 4-3/4 inch CW to ≥ 5 inch CW
2006	The Statistical area Q3 section expanded (Figure 1)
2008	Start date of the open access fishery changed from July1 to after June 15 by emergency order. Pot configuration requirement: at least 4 escape rings (>4½ 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 > 6½ inches.
2012	Board of fisheries adopted a revised GHL

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

NSRKC is a Tier4a crab stock. Direct estimation of the B_{MSY} is not possible. B_{MSY} is calculated as mean model estimated mature male biomass (MMB) from 1980 to present. Choice of this period was based on a belief that PDO shift occurred in 1976-77 could have changed the productivity.

D. Data

1. Summary of new information:
    1. Historical total catch of winter subsistence fishery. Data have been available but have not been incorporated into the model.

2. Available survey, catch, and tagging data

Data	Years	Data Types	Tables
Summer trawl survey	76,79,82,85,88,91,96, 99, 02,06,08,10,11	Abundance and proportion by length and shell condition	3,5, Figure 3
Winter pot survey	81-87, 89-91,93,95-00,02-12	Proportion by length and shell condition	6, Figure 3
Summer commercial fishery	76-90,92-13	Harvest, effort, standardized CPUE, and proportion by length and shell condition	1,4, Figure 3
Summer commercial Observer	87-90,92,94, 2012-2013	Proportion by length and shell condition (sub-legal only)	7, Figure 3
Winter commercial and subsistence fishery	76-13	The Number of crab harvested and retained (No length composition was recorded)	2, Figure 3
Tagging	80-13	Used to create a growth increment matrix	8

Data available but not used for assessment

Data	Years	Data Types	Reason for not used
Summer pot survey	80-82,85	Abundance and proportion by length and shell condition	Uncertainties on how estimates were made.
Summer preseason survey	95	Proportion by length and shell condition	Just one year of data

1. Summer commercial fishery and winter commercial and subsistence catch, (ADF&G 1976-2011) (Tables 1 and 2).

2. Length composition of discards of sublegal males (observer data) from the summer fishery (ADF&G 1987-90, 1992, 1994, 2012) (Table 7). The survey was opportunistic, and the number of crab discarded was not recorded. Continuation of summer commercial discards observer data depend upon future funding. No information on winter commercial catch discards. Total number of discards from winter subsistence catch is available (Table 2).

3. In Norton Sound, no other crab, groundfish, or shellfish fisheries exist.

	Fishery	Data availability
Directed pot fishery (males)	Summer commercial Winter commercial/subsistence	summer commercial winter subsistence
Directed pot fishery (females)		Little
Bycatch in other crab fisheries	Does not exist	NA
Bycatch in ground pot	Does not exist	NA
Bycatch in ground fish trawl	Does not exist	NA
Bycatch in the scallop fishery	Does not exist	NA

4. Catch at length data for summer commercial fisheries (Table 4).

5. Survey abundance estimates:

Triennial trawl surveys were conducted by the NMFS (1976-1991, 2010) and by the ADF&G (1996-2011) (Table 3). The NMFS survey was conducted using the 83-112 Eastern Otter Trawl, whereas the ADF&G survey was conducted using the 400 Eastern Otter Trawl. In both surveys, survey design was based on 10×10nm square, except for the NMFS survey in 2010 where survey grid was 20×20nm. Abundance of crabs were estimated by area-swept methods (Alverson and Pereyra 1969). Historical NMFS trawl survey abundance was re-estimated from the original raw data in 2013.

Summer pot survey was conducted in 1980-82 and 1985. However, the data were dropped out of the assessment model by a recommendation of the CPT in 2013. The main reason was the lack of original data to verify the abundance estimates.

3. Other miscellaneous data: None.

4. Growth-per-molt (Table 8), estimated from tagging data (1991-2007).

5. Proportion of legal size crab, estimated from trawl survey data (Table 5).

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).

In 2010 the model was modified with 1) M =0.18, 2) include summer commercial discards mortality, 3) weight of fishing effort = 20, 4) the maximum effective sample size for commercial catch and winter surveys = 100, and 5) M of the last length class = 0.288.

In 2012, the model was modified with 1) M of the last length class = 0.648, 2) the maximum effective sample size for commercial catch and winter surveys = 50, and 3) weight of fishing effort = 50.

In 2013, after the modeling workshop, the model was modified with 1) replace likelifhood 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, and 4) reduce the maximum effective sample size for commercial catch and winter surveys = 20.

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).

b-f. See Appendix A.

g. Critical assumptions of the model:

i. Male crab mature at CL length 94mm.

Bases for this assumption have not been located. No formal study has been conducted to test this assumption.

ii. Instantaneous natural mortality *M* is 0.18 for all length classes, except for the last length group (> 123mm) where M =0.648 (0.18 × 3.6) (Zheng et al. 1998). M is constant over time.

This mortality is based on Bristol Bay red king crab, estimated with a maximum age 25 and the 1% rule (Zheng 2005), and was adopted for NSRKC by CPT. The assumption of the higher M for the last length group is based not on biological data, but rather a working hypothesis attempting to explain the lower than model predicted proportion of this group in summer commercial fisheries (Figures 10, 13). It is possible, that the last length group moved into areas inaccessible to commercial fisheries (CPT review 2010). However, this does not explain the low proportion observed in the summer trawl survey, when all of the Norton Sound Area was surveyed. In addition, lowering the catch selectivity did not result in lower log likelihood than increasing the mortality (CPT 2010).

iii. Trawl survey selectivity is a logistic function with 1.0 for length classes 5-6.

This assumption was not based on biological/mechanistic data and reasoning, but rather an attempt to improve model fit.

iv. Winter pot survey selectivity is a dome shaped function: logistic function for length classes 1-4, 1.0 for length class 5, and model estimate for the last length group.

This assumption is based on a belief (but no empirical data) that very large crab less representative in near shore area where the winter surveys occur. This assumption improves the model fit and reduces the bias in the bubble plot.

v. Summer commercial fisheries selectivity is an asymptotic logistic function of 1.0 at the length class 5 and 6. It has two curves: before 1993, and 1993-present, reflecting changes in fishing vessel composition and pot configuration.

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

Winter commercial king crab pots can be any dimension (5AAC 34.925(d)). No data exists about crab pot configuration of commercial or subsistence crab fishery gears. However, because commercial fishers are also subsistence fishers, it is reasonable to assume that the commercial fishers used crab pots that they also used for subsistence harvest, and hence both fisheries have the same selectivity.

vii. Growth increments are is a function of length and are constant over time.

viii. Molting probabilities are an inverse logistic function of length for males.

ix. A summer fishing season for the directed fishery is short.

x. Discards handling mortality is assumed to be 20%. No empirical estimate is available.

xi. Annual retained catch is measured without error.

xii. All legal size crabs (≥ 4-3/4 inch CW) are taken to the commercial dock.

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 for length class 4. However, model was not sensitive to this change.

xiii. All sublegal size crab or commercially unacceptable size crab (< 5 inch CW, since 2005) are discarded.

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

h. Changes of assumptions since last assessment:

Discards mortality of the winter commercial and subsistence fisheries is 20%.

i. Code validation. Model code is reviewed at CPT modeling workshop in 2013, and is available from the authors.

3. Model Selection and Evaluation

a. Description of alternative model configurations.

Following model modifications were made:

1. Shift modeling time period from July 1st - June 30th to Feb 1st - Jan 31st. This modeling configuration considers that winter fisheries occur prior to summer fisheries.
2. Inclusion of winter commercial and subsistence discards mortality.

We did not evaluate various model configurations, but evaluated the influence of observer data. For this, we evaluated

a. Full data
b. without observer data

b. Evaluation of alternative models results

Log-likelihood

	Total	Trawl survey abundance	Standardized CPUE	Trawl Length Composition	Winter Pot Length Composition	Commercial Catch Length Composition	Recruitment	Observer Length Composition
Full Data	28.86	5.85	-22.35	9.79	14.36	14.45	0.34	6.24
Without Observer	26.70	5.84	-22.62	9.89	14.26	13.83	0.30	5.18

c. Selection of the best model:

Selection of the best model in this case, depends on reliability of data obtained in 2013.

In 2013, commercial fishery opened on July 3 because of low meat fill observed in crabs collected during the spring tagging survey. Once opened, very low catch rates persisted for the first three weeks. Considering that crabs have not moved to offshore, the ADF&G opened waters normally closed to commercial fishing (3 nmiles inward of the closure line) in order to increase harvest efficiency. However, this did not increase the catch rates. The season was extended by emergency order when it became apparent the GHL would not be met by the regulatory closure date of September 3. As of this writing (September 9 2013), fishery has not been closed yet.

Observer data were collected from as many as fishermen as possible. However, the observer data are limited to fishermen who 1) have a boat large enough to have an observer safely, 2) are willing to have an observer on board, and 3) are accessible by the observers. However, the estimates seem reliable because the estimates did not differ from systematic survey conducted by the ADF&G.

d. Parameter estimates:

e. Model selection criteria.

NA

f. Residual analysis.

RMSE was calculated as

$$RMSE = \sqrt{\tfrac{1}{n}\sum(\ln(obs) - \ln(pred))^2}$$

QQ plots, histograms of residuals, and plot of predicted vs. residual were provided for trawl abundance and commercial catch standardized CPUE.

a. Model evaluation:

4. Results

1. Effective sample sizes and weighting factors (Figure 4a b)

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 overtime.

Following weights were used

Data	Weighting Factor
Recruitment	0.01

Maximum sample size for length proportion:

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

2. Tables of estimates.

a. Model Parameter estimates (Table 10, 11, Figure 5).

Most of parameters were estimated with CV of around 30%. Notable exception was recruitment parameter for 1977-1979, 1998, 2003, 2012, 2013 (log_R_{77}, log_R_{78}, log_R_{79}, log_R_{98}, log_R_{03}, log_R_{12}, log_R_{13}), trawl selectivity parameter (log_ϕ_{st} and log_ω_{st}), and winter pot survey selectivity (log_ω_{sw}). For 1978 and 1979, estimates were close to zero reflecting extremely low proportion of < 94mm crab observed in 1979 trawl survey (Table 5, Figure 3,4). The high CVs for those selectivity parameters are an artifact because the estimated selectivity was 1.0 for those cases. In asymptotic logistic function, multitudes of parameter combinations can result in 1.0, so that model was not able to converge into single parameter.

b. Abundance and biomass time series (Figure 6, 7, 8).

Fits of the both scenarios to trawl survey data are similar. Exception is 2013.

c. Recruitment time series (Table 12 and Figure 6).

d. Time series of catch/biomass (Table 3, Figure 9, 10)

e. Selectivities, molting probabilities, and proportions of legal crabs by length are provided in Table 10.

3. Graphs of estimates.

a. Molting probability and trawl/pot selectivity (Figure 5)

b. Trawl survey abundance and model abundance (Figure 6)

c. Estimated male abundances (recruits, legal, and total) (Figure 7)

d. Estimated mature male biomass (Figure 8)

e. Time series of catch standardized cpue (Figure 9).

f. Time series of catch and estimated harvest rate (Figure 10).

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; however fits of cpue are available (Figure 9, 11)

b. Model fits to survey numbers (Figure 6, 11).

The majority of model estimated abundances of total crabs were within the 95% confidence interval of the survey observed abundance, except for 1976 and 1979, where model estimates was higher than the observed abundance.

c. Model fits to catch and survey proportions by length (Figure 12, 13, 14, 15, 16).

d. Marginal distribution for the fits to the composition data: (Figure 13).

e. Plots of implied versus input effective sample sizes and time-series of implied effective sample size (Figure 4)

f. Tables of RMSEs for the indices:

Indices	Full data	without observer data
Trawl survey	0.268	0.267
CPUE	0.464	0.461

b. QQ plots and histograms of residuals (Figure 11).

5. Retrospective and prospective analyses.

Not provided

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 currently placed in Tier 4 (NPFMC 2007). 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 capture the essential population dynamics. Whereas tier 4 stocks are assumed to have reliable estimates of current survey biomass and instantaneous M, the estimates for the Norton Sound red king crab stock uncertain. Survey biomass is based on triennial trawl surveys with CVs ranging 15-42% (Table 4). The natural mortality of 18% adopted by the CPT (2010) is based on Bristol Bay red king crab with the maximum age 25 and the 1% rule (Zheng 2005); however, no data are available to support the assumption of a maximum age 25 for the Norton Sound red king crab.

The OFL is estimated by the F_{MSY} proxy, B_{MSY} proxy, and estimated legal male abundance and biomass:

$$F_{OFL} = \gamma M, \quad when\ B / B_{MSY^{prox}} > 1, \qquad (1)$$

$$F_{OFL} = \gamma M\ (B / B_{MSY^{prox}} - 0.1) / 0.9, \quad when \quad 0.25 < B / B_{MSY^{prox}} \le 1, \qquad (2)$$

$$F_{OFL} = bycatch\ mortality\ \&\ directed\ \ fishery\ F = 0, \quad when\ B / B_{MSY^{prox}} \le 0.25, \qquad (3)$$

where B is a mature male biomass (MMB), B_{MSY} proxy is average mature male biomass over a specified time period. $M = 0.18$ and $\gamma = 1$.

For Norton Sound red king crab, MMB is defined as CL > 94 mm.

OFL was calculated for retained catch and total male catch. The retained OFL is based on legal crab biomass catchable to summer commercial pot fisheries (*Legal_B*):

$$Legal\_B = \sum_l (N_{s,l,} + O_{s,l,}) S_{s,l} L_l wm_l$$

$$OFL_{retained} = (1 - \exp(-F_{OFL})) Legal\_B$$

The total male OFL is

$$OFL_{totalmales} = OFL_{retained} + (1 - \exp(-F_{OFL})) \sum_l (N_{s,l,} + O_{s,l,}) S_{s,l} (1 - L_l) wm_l\ hm$$

where $N_{s,l}$ and $O_{s,l}$ are summer abundances of newshell and oldshell crabs in length class l in the terminal year, L_l is the proportion of legal males in length class l, $S_{s,l}$ is summer commercial catch selectivity, wm_l is average weight in length class l and hm is handling mortality rate

For the selection of the B_{MSY} proxy, default data used are survey MMB. However, for the Norton Sound red king crab stock, only available survey MMB data are triennial trawl surveys, 11 years of data during 37 years period. Instead, we used the <u>*model estimated*</u> MMB for calculation of B_{MSY} proxy from 1980 to present.

Predicted legal male and mature male biomass in 2014 are:

Legal male biomass:
Full data: 3.75 million lb with a standard deviation of 1.55 million lb.
Without Observer data: 2.83 million lb with a standard deviation of 1.18 million lb.

Mature male biomass:

Full data: 7.93 million lb with a standard deviation of 5.82 million lb.
Without Observer data: 3.72 million lb with a standard deviation of 4.37 million lb.

Note: Projection of legal male biomass and mature male biomass for July 01 2014, is based on model estimates of February 01 2014 population projected forward, with natural mortality but **without winter harvests**. Hence, OFL is for both winter and summer catch combined.

Candidate OFL and ABC million lb. Parenthesis indicates standard deviation

scenario	B_{2014}	B_{MSY}	Legal male biomass	M	F_{OFL}	OFL	ABC (0.9×OFL)
Full	7.93 (5.82)	4.46	3.75 (1.55)	0.18	0.18	0.619	0.556
without observer	3.72 (4.37)	4.36	2.83 (1.18)	0.18	0.15	0.394	0.355

B_{MSY} proxy was calculated as an average MMB during 1980-2014 periods.

Full data: 4.46 million lb
Without Observer data: 4.36 million lb

Based on the calculation of F_{OFL} listed above, F_{OFL} for the

Retained OFL for legal male crab is
Full data: 0.619 million lb.
Without Observer data: 0.394 million lb.

G. Calculation of the ABC

1. Specification of the probability distribution of the OFL.

Probability distribution of the OFL was determined based on the CPT recommendation in January 2013 as follows:

Tier 4 crab stocks

Calculation of a distribution for the OFL for Tier 4 stocks involves repeating four steps (detailed below). The aim is to have the median of the distribution for the OFL equal the point estimate (so that P*=0.5 implies that the ABC equals to the point estimate of the OFL). The proposed steps are: (a) Sample current MMB from a normal distribution with mean given by the point estimate of current MMB and CV equal to the sampling CV. (b)The B_{MSY} proxy is the average MMB over a pre-specified set of years. Uncertainty in the B_{MSY} proxy only accounts for uncertainty in MMB for the years for which it is assumed the stock was "at B_{MSY}" and not uncertainty in the years concerned. For each of the years used when defining the B_{MSY} proxy, sample MMB from a distribution with mean given by its point estimate and CV equal to the sampling CV. The pseudo B_{MSY} proxy is then the average of the samples values. (c)Sample M from a normal distribution with mean equal to the assumed M and CV equal to an assumed CV (e.g. 0.2). (d)Compute the OFL. Form a cumulative distribution for the OFL from the sampled values. Find the median of this distribution. Using normal quantiles to rescale the distribution so that the median equals the OFL (similar to a bias-corrected bootstrap).

For the Norton Sound red king crab, calculation of OFL was based on summer commercial retained legal male biomass. For calculation of the ABC, default percentile is P* = 49; however, for the Norton Sound Stock the NPFMC adopted 10% buffer of OFL (i.e., ABC = 0.9×OFL) in 2012.

Retained ABC for legal male crab is

Full data: 0.556 million lb.

Without observer data: 0.355 million lb.

H. Rebuilding Analyses

Not applicable

I. Data Gaps and Research Priorities

The major data gaps of the Norton Sound red king crab are: spatially and temporarily consistent estimate of abundance, length frequency of discards from fisheries, and estimates of the instantaneous natural mortality. In addition, life-history of the Norton Sound red king crab stock is poorly understood. This includes size at maturity, natural mortality rate, timing and locations of reproduction, location of females during summer.

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Table 1. Historical summer commercial red king crab fishery economic performance, Norton Sound Section, eastern Bering Sea, 1977-2013. Bold type shows data used for assessment model.

Year	Guideline Harvest Level (lbs) [b]	Commercial Harvest (lb) [a, b] Open Access	CDQ	Total Number Harvest	Vessels	Permits	Landings	Total Pots Registered	Pulls	ST CPUE	SD	Season Length Days	Dates	Mid-day from July 1
1977	[c]	0.52		**195,877**	7	7	13		5,457	**NA**	**NA**	60	[c]	**0.03**
1978	3.00	2.09		**660,829**	8	8	54		10,817	**1.55**	**0.36**	60	6/07-8/15	**0.03**
1979	3.00	2.93		**970,962**	34	34	76		34,773	**3.01**	**0.23**	16	7/15-7/31	**0.063**
1980	1.00	1.19		**329,778**	9	9	50		11,199	**1.60**	**0.22**	16	7/15-7/31	**0.063**
1981	2.50	1.38		**376,313**	36	36	108		33,745	**1.97**	**0.27**	38	7/15-8/22	**0.093**
1982	0.50	0.23		**63,949**	11	11	33		11,230	**0.66**	**0.19**	23	8/09-9/01	**0.14**
1983	0.30	0.37		**132,205**	23	23	26	3,583	11,195	**0.12**	**0.26**	3.8	8/01-8/05	**0.093**
1984	0.40	0.39		**139,759**	8	8	21	1,245	9,706	**1.10**	**0.23**	13.6	8/01-8/15	**0.107**
1985	0.45	0.43		**146,669**	6	6	72	1,116	13,209	**1.17**	**0.24**	21.7	8/01-8/23	**0.132**
1986	0.42	0.48		**162,438**	3	3		578	4,284	**0.42**	**0.22**	13	8/01-8/25	**0.153**
1987	0.40	0.33		**103,338**	9	9		1,430	10,258	**1.28**	**0.44**	11	8/01-8/12	**0.118**
1988	0.20	0.24		**76,148**	2	2		360	2,350	**0.74**	**0.33**	9.9	8/01-8/11	**0.115**
1989	0.20	0.25		**79,116**	10	10		2,555	5,149	**1.76**	**0.72**	3	8/01-8/04	**0.096**
1990	0.20	0.19		**59,132**	4	4		1,388	3,172	**2.02**	**0.34**	4	8/01-8/05	**0.099**
1991	0.34			**0**	No Summer Fishery									
1992	0.34	0.07		**24,902**	27	27		2,635	5,746	**0.31**	**0.33**	2	8/01-8/03	**0.093**
1993	0.34	0.33		**115,913**	14	20	208	560	7,063	**1.01**	**0.10**	52	7/01-8/28	**0.09**
1994	0.34	0.32		**108,824**	34	52	407	1,360	11,729	**0.89**	**0.06**	31	7/01-7/31	**0.044**
1995	0.34	0.32		**105,967**	48	81	665	1,900	18,782	**0.47**	**0.05**	67	7/01-9/05	**0.066**
1996	0.34	0.22		**74,752**	41	50	264	1,640	10,453	**0.54**	**0.08**	57	7/01-9/03	**0.096**
1997	0.08	0.09		**32,606**	13	15	100	520	2,982	**0.92**	**0.10**	44	7/01-8/13	**0.101**
1998	0.08	0.03	0.00	**10,661**	8	11	50	360	1,639	**0.87**	**0.13**	65	7/01-9/03	**0.088**
1999	0.08	0.02	0.00	**8,734**	10	9	53	360	1,630	**0.89**	**0.12**	66	7/01-9/04	**0.101**
2000	0.33	0.29	0.01	**111,728**	15	22	201	560	6,345	**1.29**	**0.06**	91	7/01- 9/29	**0.11**
2001	0.30	0.28	0.00	**98,321**	30	37	319	1,200	11,918	**0.67**	**0.05**	97	7/01- 9/09	**0.085**
2002	0.24	0.24	0.01	**86,666**	32	49	201	1,120	6,491	**1.27**	**0.06**	77	6/15-9/03	**0.074**
2003	0.25	0.25	0.01	**93,638**	25	43	236	960	8,494	**0.92**	**0.05**	68	6/15-8/24	**0.079**
2004	0.35	0.31	0.03	**120,289**	26	39	227	1,120	8,066	**1.35**	**0.05**	51	6/15-8/08	**0.063**
2005	0.37	0.37	0.03	**138,926**	31	42	255	1,320	8,867	**1.28**	**0.05**	73	6/15-8/27	**0.071**
2006	0.45	0.42	0.03	**150,358**	28	40	249	1,120	8,867	**1.36**	**0.05**	68	6/15-8/22	**0.09**
2007	0.32	0.29	0.02	**110,344**	38	30	251	1,200	9,118	**1.08**	**0.05**	52	6/15-8/17	**0.063**
2008	0.41	0.36	0.03	**143,337**	23	30	248	920	8,721	**1.41**	**0.05**	73	6/23-9/03	**0.063**
2009	0.38	0.37	0.03	**143,485**	22	27	359	920	11,934	**0.89**	**0.04**	98	6/15-9/20	**0.1**
2010	0.40	0.39	0.03	**149,822**	23	32	286	1,040	9,698	**1.26**	**0.05**	58	6/28-8/24	**0.096**
2011	0.36	0.37	0.03	**141,626**	24	25	173	1,040	6,808	**1.68**	**0.06**	33	6/28-7/30	**0.038**
2012	0.47	0.44	0.03	**161,113**	29	29	289	1,200	10,041	**1.34**	**0.05**	72	6/29-9/08	**0.077**
2013[d]	0.50	0.33	0.02	**117,733**	36	33			12,738	**0.70**	**0.04**	69	7/3-9/08	**0.077**

[a] Deadloss included in total. [b] Millions of pounds. [c] Information not available. [d] Preliminary as of 9/08 fishery has not been closed.

Table 2. Historical winter commercial and subsistence red king crab fishery, Norton Sound Section, eastern Bering Sea, 1977-2013. Bold typed were used for assessment model.

		Commercial			Subsistence				
Model Year	Year[a]	# of Fishers	# of Crab Harvested	Winter[b]	Permits			Total Crab	
					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	1999/2000	10	**3,045**	1999/2000	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	30	**22,641**	2012/13	149	140	67	**21,524**	**7,622**

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. Trawl survey abundance estimate is based on 10×10 $nmil^2$ grid, except for 2010 (20×20 $nmil^2$).

				Survey coverage			Abundance ≥74 mm	
Year	Dates	Survey Agency	Survey method	surveyed stations	Stations w/ NSRKC	n $mile^2$ covered		CV
1976	9/02 - 9/05	NMFS	Trawl	103	62	10260	**4247.5**	**0.31**
1979	7/26 - 8/05	NMFS	Trawl	85	22	8421	**1417.2**	**0.20**
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	58	37	5721	**2791.7**	**0.29**
1985	7/01 - 7/14	ADFG	Pots				2320.4	0.083
1985	9/16 -10/01	NMFS	Trawl	78	49	7688	**2306.3**	**0.25**
1988	8/16 - 8/30	NMFS	Trawl	78	41	7721	**2263.4**	**0.29**
1991	8/22 - 8/30	NMFS	Trawl	52	38	5183	**3132.5**	**0.43**
1996	8/07 - 8/18	ADFG	Trawl	50	30	4938	**1264.7**	**0.317**
1999	7/28 - 8/07	ADFG	Trawl	53	31	5221	**2276.1**	**0.194**
2002	7/27 - 8/06	ADFG	Trawl	57	37	5621	**1747.6**	**0.125**
2006	7/25 - 8/08	ADFG	Trawl	101	45	10008	**2549.7**	**0.288**
2008	7/24 - 8/11	ADFG	Trawl	74	44	7330	**2707.1**	**0.164**
2010[a]	7/27 - 8/09	NMFS	Trawl	35	15	13749	**2041.0**	**0.455**
2011	7/18 - 8/15	ADFG	Trawl	65	34	6447	**2701.7**	**0.133**

Table 4. Summer commercial catch size/shell composition. Sizes in this and Tables 5-10 and 12 are mm carapace length. Legal size (4.75 inch carapace width is approximately equal to 124 mm carapace length.

		New Shell						Old Shell					
Year	Sample	74-83	84-93	94-103	104-113	114-123	124+	74-83	84-93	94-103	104-113	114-123	124+
1977	1549	0	0	0.0032	0.4196	0.3422	0.1220	0	0	0	0.0626	0.040	0.0103
1978	389	0	0	0.0103	0.1851	0.473	0.3059	0	0	0	0.0051	0.0103	0.0103
1979	1660	0	0	0.0253	0.2325	0.3831	0.3217	0	0	0	0.0253	0.0006	0.0114
1980	1068	0	0	0.0037	0.0983	0.3062	0.5543	0	0	0	0.0028	0.0112	0.0234
1981	1748	0	0	0.0039	0.0734	0.1541	0.5090	0	0	0	0.0045	0.0504	0.2046
1982	1093	0	0	0.0421	0.1921	0.1647	0.5050	0	0	0.0037	0.0128	0.022	0.0576
1983	802	0	0	0.0387	0.4127	0.3579	0.0973	0	0	0.0037	0.0362	0.010	0.0436
1984	963	0	0	0.0966	0.4195	0.2804	0.0717	0	0	0.0104	0.0654	0.0488	0.0073
1985	2691	0	0.0004	0.0643	0.3122	0.3716	0.1747	0	0	0.0026	0.0334	0.0312	0.0097
1986	1138	0	0	0.029	0.3559	0.3937	0.1353	0	0	0.0018	0.0202	0.0378	0.0264
1987	1542	0	0	0.0166	0.1788	0.2912	0.3798	0	0	0.0025	0.0267	0.0650	0.0393
1988	1522	0.0007	0	0.0237	0.2004	0.3003	0.2181	0	0	0.0059	0.0644	0.0972	0.0894
1989	2595	0	0	0.0127	0.1643	0.3185	0.2148	0	0	0.0042	0.0555	0.1215	0.1084
1990	1289	0	0	0.0147	0.1435	0.3468	0.3251	0	0	0.0008	0.0372	0.0737	0.0582
1991													
1992	2566	0	0	0.0172	0.201	0.2662	0.2244	0	0	0.0027	0.0792	0.1292	0.080
1993	1813	0	0	0.0142	0.2312	0.3939	0.263	0	0	0.0004	0.0173	0.0437	0.0362
1994	404	0	0	0.0248	0.0941	0.0817	0.0891	0	0	0.0248	0.1881	0.25	0.2475
1995	1174	0	0	0.0392	0.2615	0.2853	0.207	0	0	0.0077	0.0486	0.0741	0.0767
1996	787	0	0	0.0318	0.2236	0.2389	0.141	0	0	0.014	0.1194	0.136	0.0953
1997	1198	0	0	0.0292	0.3656	0.3414	0.1244	0	0	0.0033	0.0559	0.0417	0.0384
1998	1055	0	0	0.0284	0.2332	0.2427	0.1071	0	0	0.0218	0.1118	0.1431	0.1118
1999	561	0	0	0.0026	0.2434	0.2698	0.3836	0	0	0	0	0.0423	0.0582
2000	17213	0	0	0.0194	0.2991	0.3917	0.1249	0	0	0.0028	0.0531	0.0654	0.0436
2001	20030	0	0	0.0243	0.2232	0.3691	0.2781	0	0	0.0008	0.0241	0.0497	0.0304
2002	5198	0	0	0.0442	0.2341	0.2814	0.3253	0	0	0.0046	0.0282	0.0419	0.0402
2003	5220	0	0	0.0232	0.3680	0.3197	0.1523	0	0	0.0011	0.0218	0.0465	0.0674
2004	9605	0	0	0.0087	0.3811	0.3880	0.1395	0	0	0.0004	0.0255	0.0347	0.0221
2005	5360	0	0	0.0022	0.2539	0.4709	0.1823	0	0	0	0.0205	0.0451	0.025
2006	6707	0	0	0.0021	0.1822	0.3484	0.199	0	0	0.0003	0.0498	0.1375	0.0807
2007	6125	0	0	0.0111	0.3574	0.3407	0.1714	0	0	0.0008	0.0247	0.0573	0.0366
2008	5766	0	0	0.0047	0.3512	0.3476	0.0668	0	0	0.0014	0.0895	0.0928	0.0461
2009	6026	0	0	0.0105	0.3445	0.3294	0.1339	0	0	0.0012	0.0768	0.0795	0.0242
2010	5902	0	0	0.0053	0.3855	0.3617	0.1095	0	0	0.0019	0.0546	0.0546	0.0271
2011	2552	0	0	0.0043	0.3170	0.3969	0.1387	0	0	0.0020	0.0611	0.0588	0.0212
2012	5056	0	0	0.0026	0.2421	0.4620	0.2067	0	0	0.0002	0.0259	0.0423	0.0182
2013[a]	4203	0	0	0.0052	0.2427	0.3624	0.3084	0	0	0.0005	0.0159	0.0402	0.0247

[a]: Fishery has not been closed yet, preliminary as of Sept 08 2013

Table 5. Summer Trawl Survey size/shell composition

		New Shell						Old Shell					
Year	Sample	74-83	84-93	94-103	104-113	114-123	124+	74-83	84-93	94-103	104-113	114-123	124+
1976	1311	0.0214	0.1053	0.1915	0.3455	0.1831	0.0290	0.0046	0.0114	0.0252	0.032	0.0366	0.0145
1979	133	0.0151	0.0075	0.0301	0.0752	0.0827	0.0602	0	0.0075	0.0301	0.1203	0.3835	0.188
1982	256	0.0898	0.2031	0.2891	0.2109	0.0352	0.0078	0	0.0156	0.0195	0.043	0.0234	0.0625
1985	311	0.1190	0.2122	0.1865	0.1768	0.0643	0.0193	0	0	0.0193	0.0514	0.0868	0.0643
1988	306	0.2255	0.1405	0.1536	0.1275	0.0686	0.0392	0	0.0065	0.0131	0.0392	0.0882	0.0980
1991	250	0.0967	0.0223	0.0372	0.0743	0.0409	0.0223	0.0706	0.0297	0.0967	0.197	0.1747	0.1375
1996	196	0.2959	0.1786	0.1224	0.0816	0.0051	0.0153	0.0051	0.0357	0.0459	0.0612	0.0612	0.0918
1999	274	0.0109	0.1058	0.2993	0.2701	0.1314	0.0401	0	0.0036	0.0292	0.0511	0.0401	0.0182
2002	230	0.1261	0.1435	0.1565	0.0304	0.0348	0.0348	0.0304	0.0739	0.1087	0.0957	0.0913	0.0739
2006	208	0.3235	0.2614	0.1405	0.0752	0.0458	0.0294	0	0	0.0196	0.0458	0.0458	0.0131
2008	242	0.1743	0.2407	0.1286	0.112	0.0332	0.029	0.0083	0.0498	0.0705	0.0954	0.0125	0.0456
2010	68	0.1202	0.1366	0.2077	0.1257	0.1093	0.0437	0.0109	0.0328	0.082	0.071	0.0383	0.0219
2011	320	0.1282	0.0989	0.1282	0.2051	0.1612	0.0476	0.0037	0.0147	0.0256	0.0989	0.0513	0.0366

Table 6. Winter pot survey size/shell composition

		New Shell						Old Shell					
Year	Sample	74-83	84-93	94-103	104-113	114-123	124+	74-83	84-93	94-103	104-113	114-123	124+
1981/82	243	0.1481	0.3374	0.3169	0.1029	0.0288	0.0247	0	0	0.0041	0.0082	0.0082	0.0206
1982/83	2520	0.0855	0.2824	0.2854	0.2155	0.0706	0.0085	0	0	0.004	0.0194	0.0097	0.0189
1983/84	1655	0.1638	0.2626	0.2291	0.1502	0.0601	0.0057	0	0	0.0178	0.065	0.0329	0.0127
1984/85	773	0.0932	0.2589	0.3618	0.1586	0.057	0.0097	0	0	0.0065	0.0291	0.0239	0.0013
1985/86	568	0.1276	0.1831	0.2553	0.2025	0.0863	0.0132	0	0	0.015	0.0607	0.044	0.0123
1986/87	144	0.0556	0.1597	0.1944	0.0694	0.0417	0	0	0	0.0417	0.2986	0.1111	0.0278
1987/88													
1988/89	492	0.1341	0.1514	0.1352	0.1941	0.1758	0.0346	0	0	0.002	0.0528	0.0854	0.0346
1989/90	2072	0.0495	0.2075	0.2616	0.1795	0.1221	0.0726	0	0	0.001	0.0263	0.056	0.0239
1990/91	1281	0.0125	0.0921	0.2857	0.2678	0.096	0.0109	0	0	0.0039	0.0265	0.1163	0.0882
1992/93	181	0.0055	0.0331	0.0552	0.1271	0.116	0.0276	0	0	0.0166	0.1934	0.2707	0.1547
1993/94													
1994/95	850	0.0588	0.08	0.0988	0.2576	0.2341	0.0847	0	0	0.0035	0.0329	0.0718	0.0776
1995/96	776	0.1214	0.1835	0.1733	0.1022	0.0599	0.0265	0	0	0.0181	0.1214	0.1242	0.0695
1996/97	1582	0.2297	0.2351	0.1189	0.1568	0.1216	0.0676	0	0	0	0.0189	0.027	0.0243
1997/98	399	0.1395	0.4136	0.2653	0.0544	0.0236	0.0034	0	0	0.0238	0.0317	0.017	0.0272
1998/99	882	0.0192	0.1168	0.3566	0.3605	0.0838	0.0154	0	0	0.01	0.0223	0.0069	0.0085
1999/00	1308	0.0885	0.1062	0.1646	0.3345	0.1788	0.0372	0	0	0.0018	0.0513	0.023	0.0142
2000/01													
2001/02	832	0.3136	0.2763	0.1761	0.0681	0.0668	0.0501	0	0	0.0077	0.0051	0.0154	0.0064
2002/03	826	0.0994	0.2236	0.2994	0.1801	0.0559	0.0261	0	0	0.0224	0.0273	0.0261	0.0273
2003/04	286	0.0175	0.1643	0.2622	0.3462	0.1119	0.0105	0	0	0.0175	0.021	0.014	0.0245
2004/05	406	0.0741	0.1407	0.1827	0.2173	0.1852	0.0765	0	0	0.0025	0.0395	0.0593	0.0173
2005/06	512	0.1406	0.2266	0.209	0.1563	0.0547	0.0215	0	0	0.0176	0.043	0.0742	0.0352
2006/07	160	0.1486	0.2095	0.3784	0.1419	0.0473	0	0	0	0.0068	0.0203	0.0405	0
2007/08	3482	0.1898	0.3219	0.1703	0.1479	0.0672	0.0083	0	0	0.0359	0.0339	0.0155	0.0092
2008/09	526	0.0706	0.1336	0.3511	0.2023	0.084	0.0134	0	0	0.0019	0.0382	0.0992	0.0057
2009/10	581	0.047	0.1357	0.2157	0.2452	0.113	0.0191	0	0	0.0591	0.1009	0.0539	0.0104
2010/11	597	0.0786	0.1368	0.2103	0.1744	0.1333	0.0513	0	0.0120	0.0325	0.1128	0.0462	0.0120
2011/12	676	0.1155	0.2340	0.1945	0.1246	0.1292	0.0456	0.0030	0.0030	0.0912	0.0532	0.0532	0.0350

Table 7. Summer commercial1987-1994, 2012-2013 observer survey (Sub legal crab only)

		New Shell						Old Shell					
Year	Sample	74-83	84-93	94-103	104-113	114-123	124+	74-83	84-93	94-103	104-113	114-123	124+
1987	1076	0.2026	0.3625	0.3522	0.0344	0	0	0	0	0.0437	0.0046	0	0
1988	712	0.052	0.184	0.4831	0.139	0	0	0	0	0.0969	0.0449	0	0
1989	911	0.2492	0.3392	0.2371	0.0274	0	0	0	0	0.1196	0.0274	0	0
1990	459	0.2702	0.3203	0.3028	0.0414	0	0	0	0	0.0588	0.0065	0	0
1992	515	0.2175	0.3592	0.332	0.0369	0	0	0	0	0.0447	0.0097	0	0
1994	726	0.1556	0.303	0.1736	0.0262	0	0	0	0	0.2824	0.0592	0	0
2012	738	0.1396	0.2398	0.4106	0.1314	0.0122	0	0.0027	0.0027	0.0298	0.0285	0.0014	0.0014
2013[a]	1457	0.5148	0.2711	0.1997	0.0110	0	0	0.0007	0.0007	0.0021	0	0	0

[a]: Fishery has not been closed yet, preliminary as of Sept 08 2013

Table 8. Growth matrix (proportion of crabs molting from a given pre-molt carapace length range into post-molt length ranges) for Norton Sound male red king crab. Length is measured as mm CL. Results are derived from mark-recapture and winter tagging data from 1980 to 2007.

Pre-molt Length Class	Post-molt Length Class					
	74-83	84-93	94-103	104-113	114-123	124+
74-83	0	0.33	0.67	0	0	0
84-93	0	0	0.56	0.44	0	0
94-103	0	0	0	0.76	0.24	0
104-113	0	0	0	0.18	0.61	0.21
114-123	0	0	0	0	0.33	0.67
124+	0	0	0	0	0	1.00

Table 9. Estimated selectivities, molting probabilities, and proportions of legal crabs by length (mm CL) class for Norton Sound male red king crab

Full data

Length Class	Legal Proportion	Mean weight (lb)	Selectivity				Molting Probability
			Summer Trawl	Winter Pot	Summer Fishery		
					77-92	93-13	
74 - 83	0.00	0.854	0.70	0.56	0.15	0.06	1.00
84 - 93	0.00	1.210	0.77	1.00	0.25	0.15	0.93
94 - 103	0.26	1.652	0.84	1.00	0.40	0.35	0.87
104 - 113	0.97	2.187	0.91	1.00	0.63	0.67	0.81
114 - 123	0.99	2.825	1.00	1.00	1.00	1.00	0.75
124+	1.00	3.697	1.00	0.36	1.00	1.00	0.70

Without Observer data

Length Class	Legal Proportion	Mean weight (lb)	Selectivity				Molting Probability
			Summer Trawl	Winter Pot	Summer Fishery		
					77-92	93-13	
74 - 83	0.00	0.854	1.00	0.60	0.14	0.03	1.00
84 - 93	0.00	1.210	1.00	1.00	0.22	0.10	0.93
94 - 103	0.26	1.652	1.00	1.00	0.37	0.31	0.87
104 - 113	0.97	2.187	1.00	1.00	0.61	0.69	0.81
114 - 123	0.99	2.825	1.00	1.00	1.00	1.00	0.75
124+	1.00	3.697	1.00	0.36	1.00	1.00	0.70

Table 10. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

Parameter	Lower	Upper
log_q_1	-32.5	8.5
log_q_2	-32.5	10.0
log_N_{76}	2.0	15.0
R_0	2.0	12.0
$log\_\sigma_R^2$	-20.0	20.0
a_1	-5.0	5.0
a_2	-5.0	5.0
a_3	-5.0	5.0
a_4	-5.0	5.0
a_5	-5.0	5.0
r	0.5	0.9
log_α	-5.5	-2.0
log_β	0.55	10.0
log_ϕ_{st}	-10.0	-1.0
log_ω_{st}	0.51	10.0
log_ϕ_{sw}	-10.0	10.0
log_ω_{sw}	3.9	5.5
Sw_6	0.1	1.0
log_ϕ_1	-5.0	-1.0
log_ω_1	3.9	7.5
log_ϕ_2	-5.0	-1.0
log_ω_2	3.9	7.5
w_t	0.0	6.0
q	0.1	1.0

Table 11. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

	Full data		Without Observer	
name	Estimate	std.dev	Estimate	std.dev
log_q_1	-7.137	0.220	-7.128	0.222
log_q_2	-6.769	0.118	-6.781	0.118
log_N_{76}	9.050	0.204	9.045	0.206
R_0	6.393	0.233	6.332	0.304
$log\_\sigma_R^2$	1.112	0.541	1.181	0.583
log_R_{77}	-2.740	3.385	-2.696	3.428
log_R_{78}	-2.440	1.629	-2.357	1.630
log_R_{79}	-0.583	1.267	-0.695	1.518
log_R_{80}	1.168	0.401	1.242	0.452
log_R_{81}	0.448	0.461	0.523	0.494
log_R_{82}	0.594	0.498	0.648	0.535
log_R_{83}	1.036	0.397	1.084	0.444
log_R_{84}	0.532	0.461	0.616	0.493
log_R_{85}	0.745	0.443	0.827	0.503
log_R_{86}	0.465	0.420	0.527	0.463
log_R_{87}	0.068	0.421	0.143	0.461
log_R_{88}	0.336	0.393	0.392	0.438
log_R_{89}	0.046	0.419	0.097	0.473
log_R_{90}	-0.456	0.477	-0.366	0.535
log_R_{91}	-0.518	0.560	-0.507	0.654
log_R_{92}	-1.120	0.839	-1.280	0.953
log_R_{93}	-0.337	0.483	-0.122	0.489
log_R_{94}	-0.437	0.506	-0.461	0.565
log_R_{95}	-0.084	0.376	-0.006	0.420
log_R_{96}	0.298	0.405	0.332	0.453
log_R_{97}	0.625	0.337	0.702	0.387
log_R_{98}	-2.204	1.398	-2.105	1.398
log_R_{99}	-0.602	0.657	-0.567	0.694
log_R_{00}	0.336	0.399	0.390	0.445
log_R_{01}	0.280	0.354	0.350	0.401
log_R_{02}	0.525	0.431	0.592	0.472
log_R_{03}	-0.962	1.162	-0.882	1.157
log_R_{04}	-0.004	0.461	0.033	0.503
log_R_{05}	0.657	0.324	0.725	0.377
log_R_{06}	0.106	0.474	0.141	0.515
log_R_{07}	0.714	0.332	0.785	0.382
log_R_{08}	0.542	0.383	0.598	0.431
log_R_{09}	-0.087	0.451	-0.011	0.486
log_R_{10}	-0.157	0.435	-0.133	0.481
log_R_{11}	0.027	0.609	0.259	0.626
log_R_{12}	2.068	1.091	0.000	6.977
log_R_{13}	2.068	1.091	0.000	6.977
a_1	-0.339	1.779	-0.342	1.780
a_2	1.291	1.235	1.296	1.235
a_3	1.837	1.145	1.843	1.145
a_4	2.119	1.130	2.118	1.129
a_5	1.397	1.190	1.393	1.190
r1	0.613	0.055	0.578	0.058

log_ α	-4.626	0.320	-4.616	0.326
log_ β	0.739	17.991	0.550	0.420
log_ ϕ_{st}	-4.721	70.665	0.507	2208.300
log_ ω_{st}	9.755	42.960	3.707	9236.400
log_ ϕ_{sw}	0.640	79.778	0.626	465.420
log_ ω_{sw}	4.361	0.132	4.360	1.344
Sw_6	0.359	0.103	0.362	0.104
log_ ϕ_1	-3.071	0.250	-2.995	0.359
log_ ω_1	7.211	711.440	7.163	0.321
log_ ϕ_2	-2.260	0.358	-1.981	0.284
log_ ω_2	4.689	0.068	4.663	0.038
log_ w^2_t	0.061	0.024	0.060	0.023
q	0.659	0.129	0.658	0.129

Table 12. Annual abundance estimates (million crabs) and mature male biomass (MMB, million lbs) for Norton Sound red king crab estimated by length-based analysis from 1976-2014 (Full data)

Full data

	Abundance			Legal (≥ 104 mm)				MMB	
Year	Recruits	Total (≥ 74 mm)	Mature (≥ 94 mm)	Abundance	S.D	Biomass	S.D	Biomass	S.D.
1976	1.432	7.842	6.410	4.805	1.245	11.460	3.106	14.171	3.418
1977	1.816	7.795	5.979	5.250	1.076	13.762	2.872	15.028	3.060
1978	0.361	5.719	5.357	4.561	0.756	12.669	2.236	14.028	2.114
1979	0.073	3.670	3.597	3.361	0.467	9.665	1.449	10.087	1.459
1980	0.320	2.160	1.840	1.776	0.320	5.342	0.993	5.462	1.008
1981	1.841	3.033	1.192	1.060	0.224	3.241	0.683	3.466	0.769
1982	1.205	2.922	1.717	1.016	0.263	2.532	0.683	3.698	0.914
1983	1.186	3.270	2.085	1.555	0.356	3.814	0.888	4.708	1.069
1984	1.761	4.025	2.264	1.753	0.394	4.474	1.013	5.338	1.202
1985	1.250	3.990	2.740	2.015	0.448	5.158	1.156	6.377	1.396
1986	1.362	4.148	2.786	2.229	0.493	5.811	1.291	6.755	1.475
1987	1.114	3.952	2.838	2.253	0.482	5.989	1.302	6.977	1.470
1988	0.773	3.522	2.749	2.255	0.457	6.087	1.253	6.926	1.376
1989	0.898	3.347	2.450	2.094	0.403	5.797	1.132	6.405	1.220
1990	0.733	2.993	2.260	1.875	0.340	5.242	0.971	5.894	1.052
1991	0.469	2.510	2.041	1.716	0.289	4.801	0.824	5.353	0.883
1992	0.403	2.134	1.731	1.513	0.234	4.297	0.673	4.672	0.707
1993	0.247	1.699	1.452	1.270	0.181	3.667	0.527	3.979	0.556
1994	0.433	1.511	1.078	0.962	0.141	2.804	0.411	3.005	0.428
1995	0.434	1.365	0.931	0.754	0.109	2.148	0.314	2.447	0.346
1996	0.581	1.448	0.867	0.683	0.102	1.857	0.276	2.168	0.310
1997	0.847	1.804	0.957	0.715	0.106	1.875	0.276	2.281	0.328
1998	1.180	2.416	1.236	0.889	0.123	2.264	0.309	2.846	0.404
1999	0.265	1.958	1.694	1.208	0.146	3.031	0.372	3.846	0.428
2000	0.325	1.793	1.467	1.309	0.147	3.484	0.389	3.761	0.414
2001	0.835	2.023	1.188	1.041	0.123	2.936	0.343	3.190	0.384
2002	0.883	2.185	1.302	0.968	0.117	2.636	0.311	3.195	0.368
2003	1.083	2.547	1.464	1.094	0.122	2.843	0.315	3.465	0.348
2004	0.397	2.133	1.735	1.282	0.137	3.275	0.340	4.038	0.473
2005	0.602	2.088	1.487	1.282	0.174	3.403	0.443	3.755	0.480
2006	1.176	2.545	1.369	1.113	0.153	3.036	0.416	3.470	0.459
2007	0.823	2.459	1.636	1.165	0.149	3.026	0.397	3.816	0.466
2008	1.258	2.942	1.684	1.321	0.156	3.410	0.406	4.023	0.474
2009	1.174	3.135	1.961	1.443	0.157	3.704	0.410	4.575	0.467
2010	0.700	2.839	2.138	1.636	0.159	4.201	0.415	5.049	0.495
2011	0.580	2.532	1.952	1.627	0.172	4.318	0.451	4.873	0.497
2012	0.663	2.351	1.687	1.427	0.152	3.913	0.418	4.357	0.448
2013	4.485	5.985	1.501	1.220	0.175	3.359	0.436	3.833	0.593
2014						3.745	1.548	7.934	5.824

Without Observer

Year	Abundance			Legal (≥ 104 mm)				MMB	
	Recruits	Total (≥ 74 mm)	Mature (≥ 94 mm)	Abundance	S.D	Biomass	S.D	Biomass	S.D.
1976	1.428	7.801	6.373	4.770	1.240	11.371	3.088	14.079	3.406
1977	1.830	7.780	5.951	5.221	1.077	13.675	2.866	14.941	3.062
1978	0.351	5.713	5.362	4.565	0.754	12.653	2.226	14.015	2.104
1979	0.073	3.672	3.599	3.364	0.467	9.665	1.445	10.084	1.456
1980	0.271	2.116	1.845	1.781	0.320	5.349	0.994	5.470	1.009
1981	1.854	3.021	1.167	1.054	0.224	3.233	0.681	3.427	0.765
1982	1.208	2.925	1.717	1.019	0.263	2.535	0.683	3.696	0.918
1983	1.175	3.267	2.092	1.562	0.359	3.830	0.894	4.724	1.078
1984	1.733	4.003	2.270	1.765	0.399	4.504	1.023	5.358	1.213
1985	1.257	3.994	2.737	2.027	0.453	5.190	1.167	6.386	1.404
1986	1.384	4.176	2.793	2.236	0.496	5.830	1.299	6.774	1.484
1987	1.111	3.976	2.865	2.275	0.493	6.038	1.322	7.035	1.511
1988	0.775	3.550	2.775	2.283	0.477	6.157	1.295	6.992	1.420
1989	0.891	3.365	2.474	2.118	0.418	5.864	1.170	6.472	1.259
1990	0.721	3.000	2.279	1.898	0.351	5.305	0.999	5.952	1.079
1991	0.474	2.524	2.049	1.730	0.292	4.846	0.836	5.389	0.890
1992	0.386	2.127	1.741	1.522	0.234	4.325	0.676	4.702	0.712
1993	0.206	1.656	1.450	1.274	0.180	3.684	0.526	3.985	0.552
1994	0.491	1.541	1.050	0.949	0.140	2.783	0.408	2.957	0.423
1995	0.414	1.361	0.947	0.751	0.108	2.134	0.310	2.464	0.347
1996	0.583	1.456	0.873	0.695	0.104	1.882	0.279	2.182	0.312
1997	0.825	1.792	0.966	0.725	0.107	1.901	0.278	2.306	0.331
1998	1.189	2.423	1.234	0.897	0.125	2.288	0.312	2.854	0.406
1999	0.262	1.965	1.703	1.217	0.147	3.056	0.373	3.871	0.430
2000	0.318	1.790	1.472	1.314	0.148	3.499	0.391	3.776	0.415
2001	0.826	2.015	1.189	1.045	0.124	2.949	0.344	3.197	0.385
2002	0.883	2.186	1.302	0.974	0.117	2.651	0.311	3.202	0.368
2003	1.084	2.554	1.470	1.101	0.122	2.860	0.315	3.480	0.349
2004	0.396	2.143	1.747	1.295	0.139	3.307	0.344	4.068	0.479
2005	0.588	2.084	1.496	1.292	0.175	3.429	0.445	3.780	0.483
2006	1.179	2.549	1.371	1.121	0.154	3.060	0.419	3.484	0.461
2007	0.801	2.447	1.647	1.177	0.150	3.057	0.399	3.844	0.469
2008	1.262	2.944	1.682	1.328	0.157	3.431	0.408	4.030	0.474
2009	1.163	3.133	1.970	1.453	0.157	3.729	0.410	4.598	0.469
2010	0.700	2.845	2.144	1.647	0.160	4.232	0.417	5.071	0.498
2011	0.560	2.520	1.960	1.635	0.172	4.341	0.453	4.895	0.498
2012	0.764	2.447	1.683	1.431	0.152	3.927	0.418	4.359	0.449
2013	0.646	2.212	1.566	1.250	0.185	3.420	0.453	3.953	0.635
2014						2.835	1.180	3.719	4.369

Table 13. Summary of catch and estimated bycatch/discards (million lbs) for Norton Sound red king crab. Assumed average crab weight is 2.5 lbs for the winter commercial catch and 2.0 lbs for the subsistence catch (Full data)

Full data

Year	*Summer com*	*Winter com*	*Winter Sub*	*discards Summer*	*discards Winter Sub*	*discards Winter com*	*Total*	*Catch/ MMB*
1977	0.52	0.000	ND	0.0071	ND	0.0000		
1978	2.09	0.024	0.025	0.0202	0.0153	0.0001	2.175	0.155
1979	2.93	0.001	0.000	0.0128	0.0003	0.0000	2.944	0.292
1980	1.19	0.000	0.000	0.0048	0.0003	0.0000	1.195	0.219
1981	1.38	0.000	0.001	0.0333	0.0004	0.0000	1.415	0.408
1982	0.23	0.000	0.003	0.0094	0.0016	0.0000	0.244	0.066
1983	0.37	0.001	0.021	0.0107	0.0128	0.0000	0.416	0.088
1984	0.39	0.002	0.022	0.0117	0.0094	0.0000	0.435	0.082
1985	0.43	0.003	0.017	0.0114	0.0048	0.0000	0.466	0.073
1986	0.48	0.005	0.014	0.0101	0.0074	0.0001	0.517	0.076
1987	0.33	0.003	0.012	0.0061	0.0033	0.0000	0.354	0.051
1988	0.24	0.001	0.005	0.0036	0.0017	0.0000	0.251	0.036
1989	0.25	0.001	0.012	0.0034	0.0036	0.0000	0.270	0.042
1990	0.19	0.009	0.024	0.0028	0.0090	0.0001	0.235	0.040
1991	0	0.010	0.015	0.0000	0.0039	0.0001	0.029	0.005
1992	0.07	0.019	0.023	0.0008	0.0066	0.0001	0.120	0.026
1993	0.33	0.004	0.002	0.0028	0.0002	0.0000	0.339	0.085
1994	0.32	0.014	0.008	0.0029	0.0016	0.0001	0.347	0.115
1995	0.32	0.019	0.011	0.0045	0.0047	0.0001	0.359	0.147
1996	0.22	0.004	0.003	0.0039	0.0025	0.0000	0.233	0.108
1997	0.09	0.000	0.001	0.0022	0.0017	0.0000	0.095	0.042
1998	0.03	0.002	0.017	0.0008	0.0234	0.0000	0.073	0.026
1999	0.02	0.007	0.015	0.0005	0.0062	0.0001	0.049	0.013
2000	0.3	0.008	0.011	0.0026	0.0082	0.0001	0.330	0.088
2001	0.28	0.003	0.001	0.0036	0.0002	0.0000	0.288	0.090
2002	0.25	0.006	0.004	0.0055	0.0059	0.0000	0.271	0.085
2003	0.26	0.017	0.008	0.0060	0.0098	0.0002	0.301	0.087
2004	0.34	0.001	0.002	0.0063	0.0012	0.0000	0.351	0.087
2005	0.4	0.005	0.008	0.0044	0.0050	0.0001	0.423	0.113
2006	0.45	0.000	0.002	0.0078	0.0017	0.0000	0.462	0.133
2007	0.31	0.008	0.021	0.0073	0.0215	0.0001	0.368	0.096
2008	0.39	0.014	0.019	0.0079	0.0183	0.0002	0.449	0.112
2009	0.4	0.012	0.010	0.0091	0.0044	0.0001	0.436	0.095
2010	0.42	0.012	0.014	0.0074	0.0039	0.0001	0.457	0.091
2011	0.4	0.008	0.013	0.0049	0.0051	0.0001	0.431	0.088
2012	0.47	0.023	0.018	0.0056	0.0081	0.0002	0.525	0.120
2013	0.35	0.057	0.018	0.0121	0.0278	0.0004	0.465	0.121

Without Observer data

Year	*Summer com*	*Winter com*	*Winter Sub*	*discards Summer*	*discards Winter Sub*	*discards Winter com*	*Total*	*Catch/ MMB*
1977	0.52	0.000	ND	0.0069	ND			
1978	2.09	0.024	0.025	0.0188	0.0153	0.0013	2.174	0.155
1979	2.93	0.001	0.000	0.0121	0.0003	0.0000	2.943	0.292
1980	1.19	0.000	0.000	0.0044	0.0003	0.0000	1.195	0.218
1981	1.38	0.000	0.001	0.0332	0.0004	0.0000	1.415	0.413
1982	0.23	0.000	0.003	0.0089	0.0016	0.0000	0.244	0.066
1983	0.37	0.001	0.021	0.0102	0.0128	0.0002	0.415	0.088
1984	0.39	0.002	0.022	0.0112	0.0094	0.0002	0.435	0.081
1985	0.43	0.003	0.017	0.0107	0.0048	0.0003	0.466	0.073
1986	0.48	0.005	0.014	0.0098	0.0074	0.0005	0.517	0.076
1987	0.33	0.003	0.012	0.0058	0.0033	0.0002	0.354	0.050
1988	0.24	0.001	0.005	0.0034	0.0017	0.0001	0.251	0.036
1989	0.25	0.001	0.012	0.0033	0.0036	0.0001	0.270	0.042
1990	0.19	0.009	0.024	0.0026	0.0090	0.0006	0.235	0.039
1991	0	0.010	0.015	0.0000	0.0039	0.0007	0.030	0.006
1992	0.07	0.019	0.023	0.0008	0.0066	0.0012	0.121	0.026
1993	0.33	0.004	0.002	0.0023	0.0002	0.0002	0.339	0.085
1994	0.32	0.014	0.008	0.0023	0.0016	0.0007	0.347	0.117
1995	0.32	0.019	0.011	0.0040	0.0047	0.0011	0.360	0.146
1996	0.22	0.004	0.003	0.0031	0.0025	0.0004	0.233	0.107
1997	0.09	0.000	0.001	0.0017	0.0017	0.0000	0.094	0.041
1998	0.03	0.002	0.017	0.0006	0.0234	0.0003	0.073	0.026
1999	0.02	0.007	0.015	0.0004	0.0062	0.0007	0.049	0.013
2000	0.3	0.008	0.011	0.0022	0.0082	0.0007	0.330	0.087
2001	0.28	0.003	0.001	0.0028	0.0002	0.0001	0.287	0.090
2002	0.25	0.006	0.004	0.0044	0.0059	0.0005	0.271	0.085
2003	0.26	0.017	0.008	0.0048	0.0098	0.0018	0.301	0.086
2004	0.34	0.001	0.002	0.0054	0.0012	0.0001	0.350	0.086
2005	0.4	0.005	0.008	0.0037	0.0050	0.0005	0.422	0.112
2006	0.45	0.000	0.002	0.0061	0.0017	0.0000	0.460	0.132
2007	0.31	0.008	0.021	0.0060	0.0215	0.0008	0.367	0.095
2008	0.39	0.014	0.019	0.0063	0.0183	0.0016	0.449	0.111
2009	0.4	0.012	0.010	0.0074	0.0044	0.0012	0.435	0.095
2010	0.42	0.012	0.014	0.0062	0.0039	0.0013	0.457	0.090
2011	0.4	0.008	0.013	0.0042	0.0051	0.0008	0.431	0.088
2012	0.47	0.023	0.018	0.0047	0.0081	0.0016	0.525	0.120
2013	0.35	0.057	0.018	0.0043	0.0278	0.0041	0.461	0.117

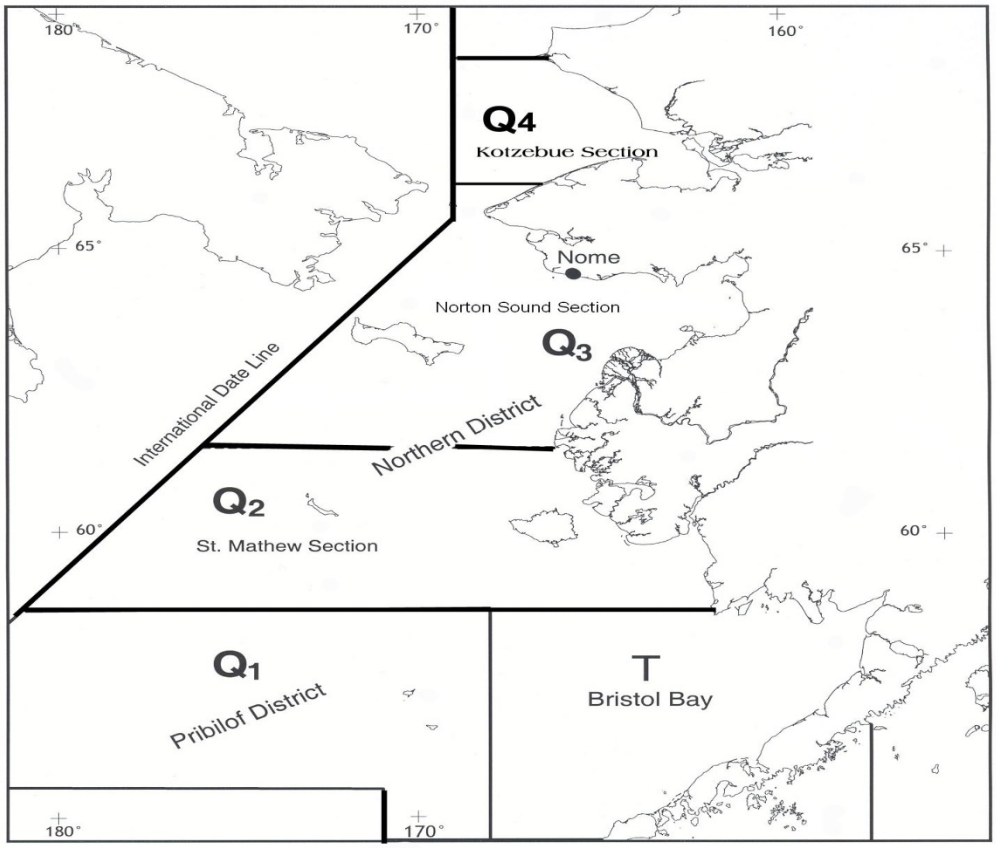


Figure 1. King crab fishing districts and sections of Statistical Area Q.

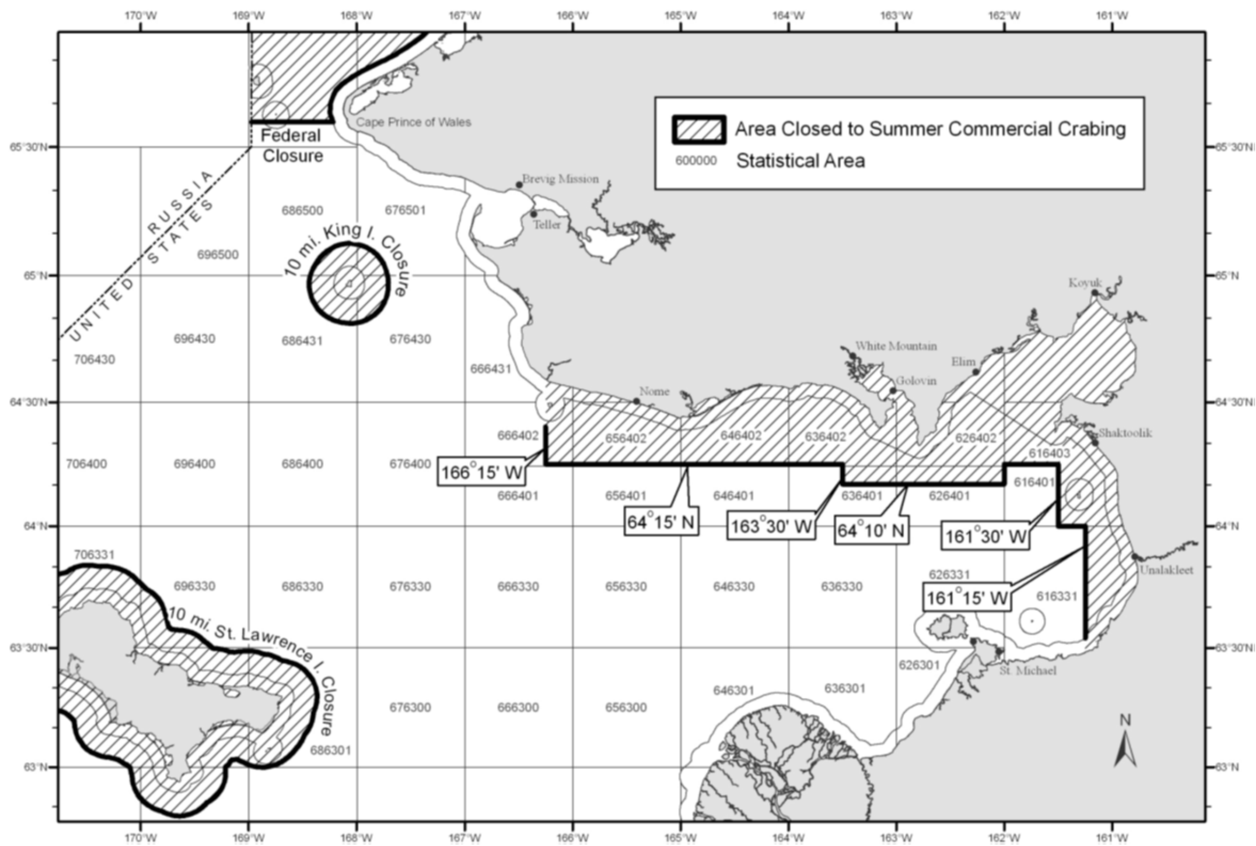
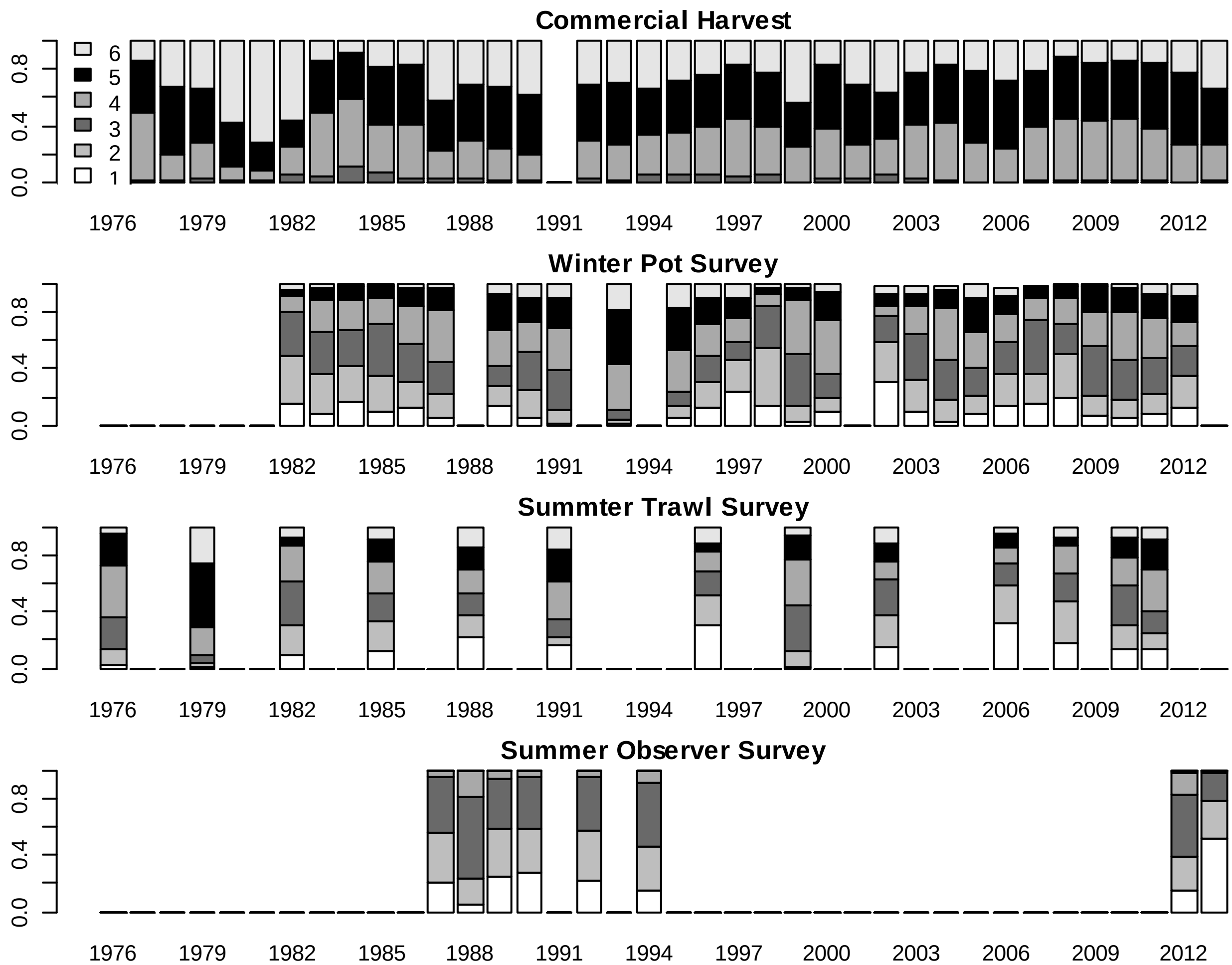


Figure 2. Closed water regulations in effect for the Norton Sound commercial crab fishery.



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure 3. Observed length compositions 1976-2013.

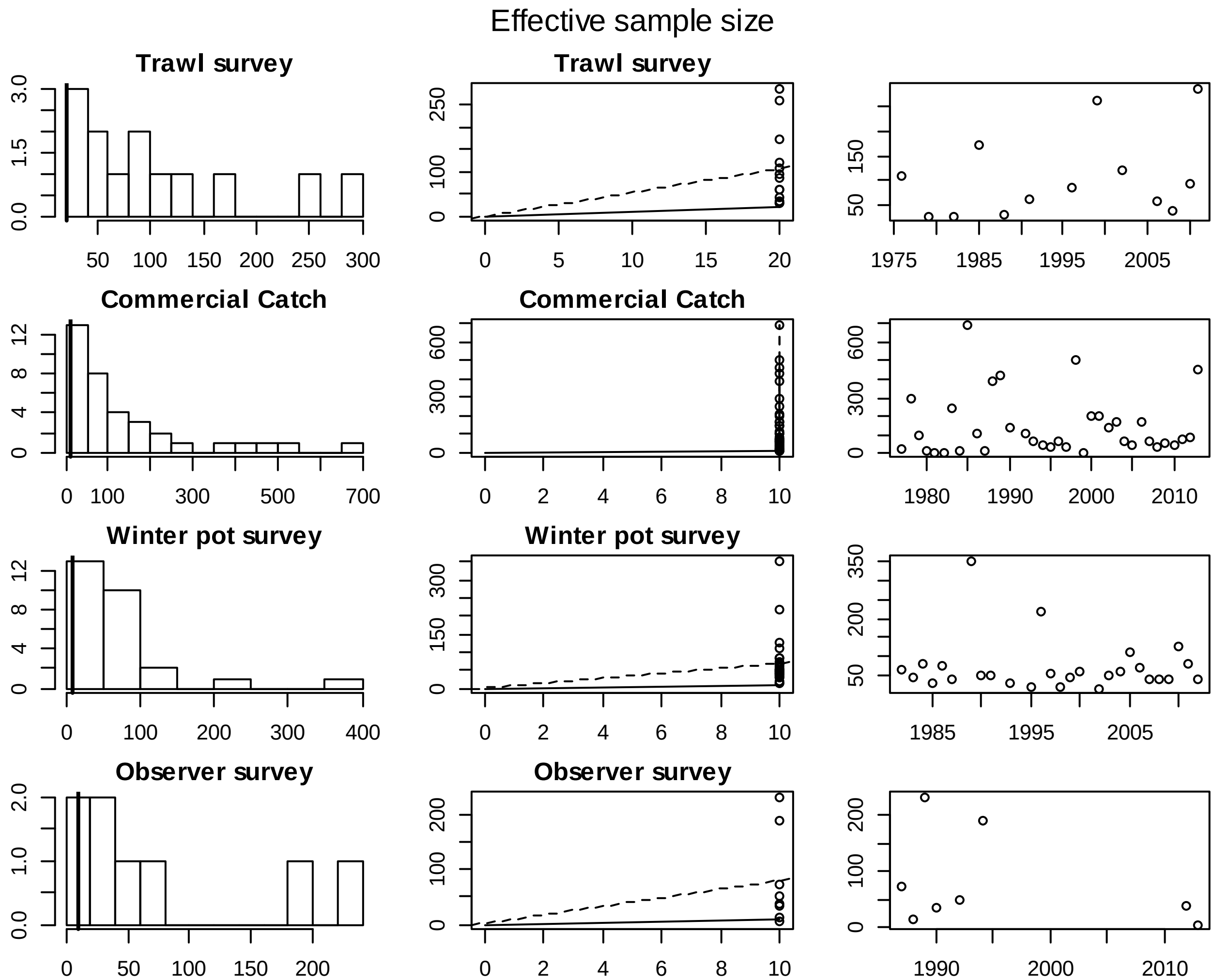


Figure 4a: Effective sample size vs. implied sample size (without Observer data)

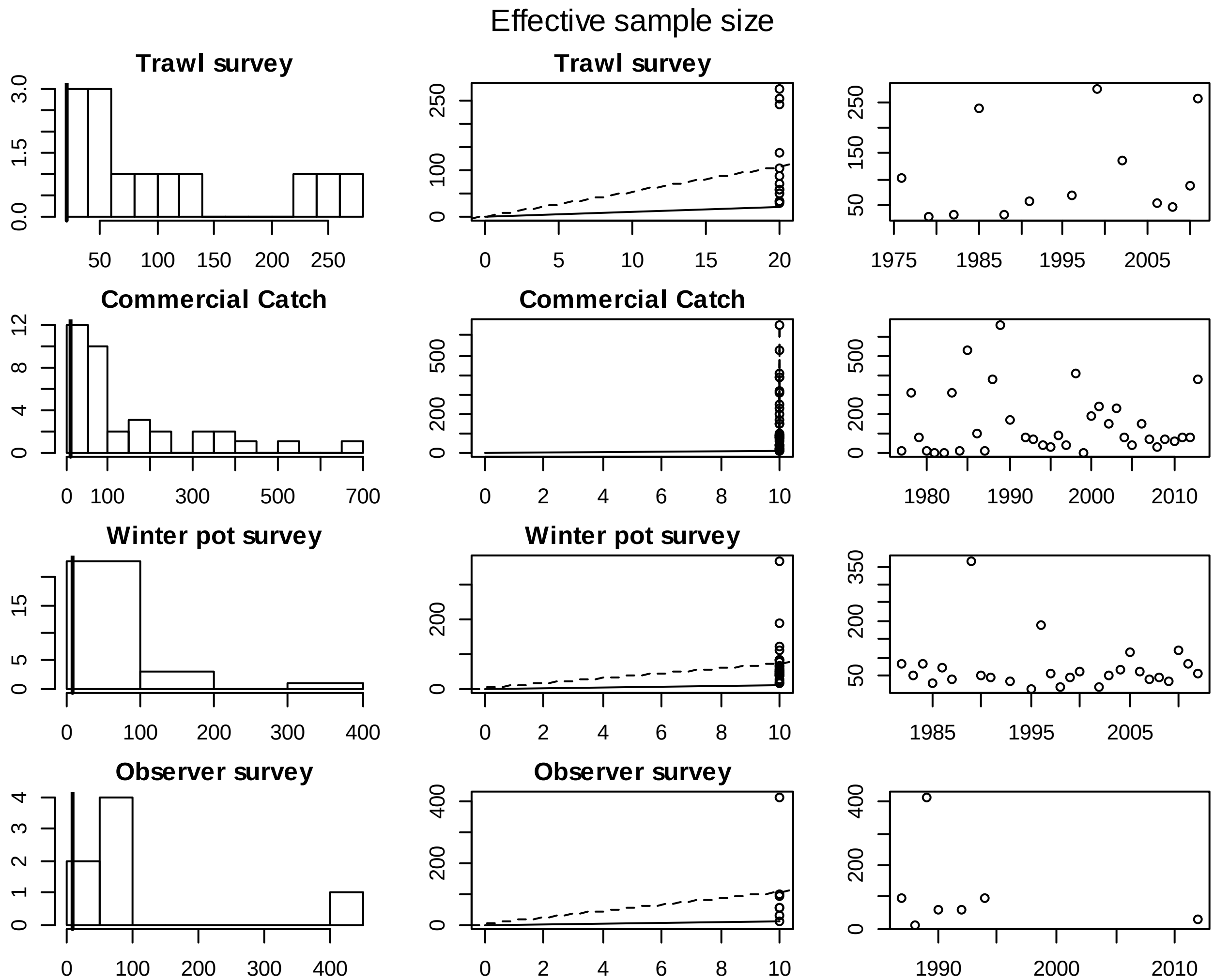


Figure 4b: Effective sample size vs. implied sample size (without Observer data)

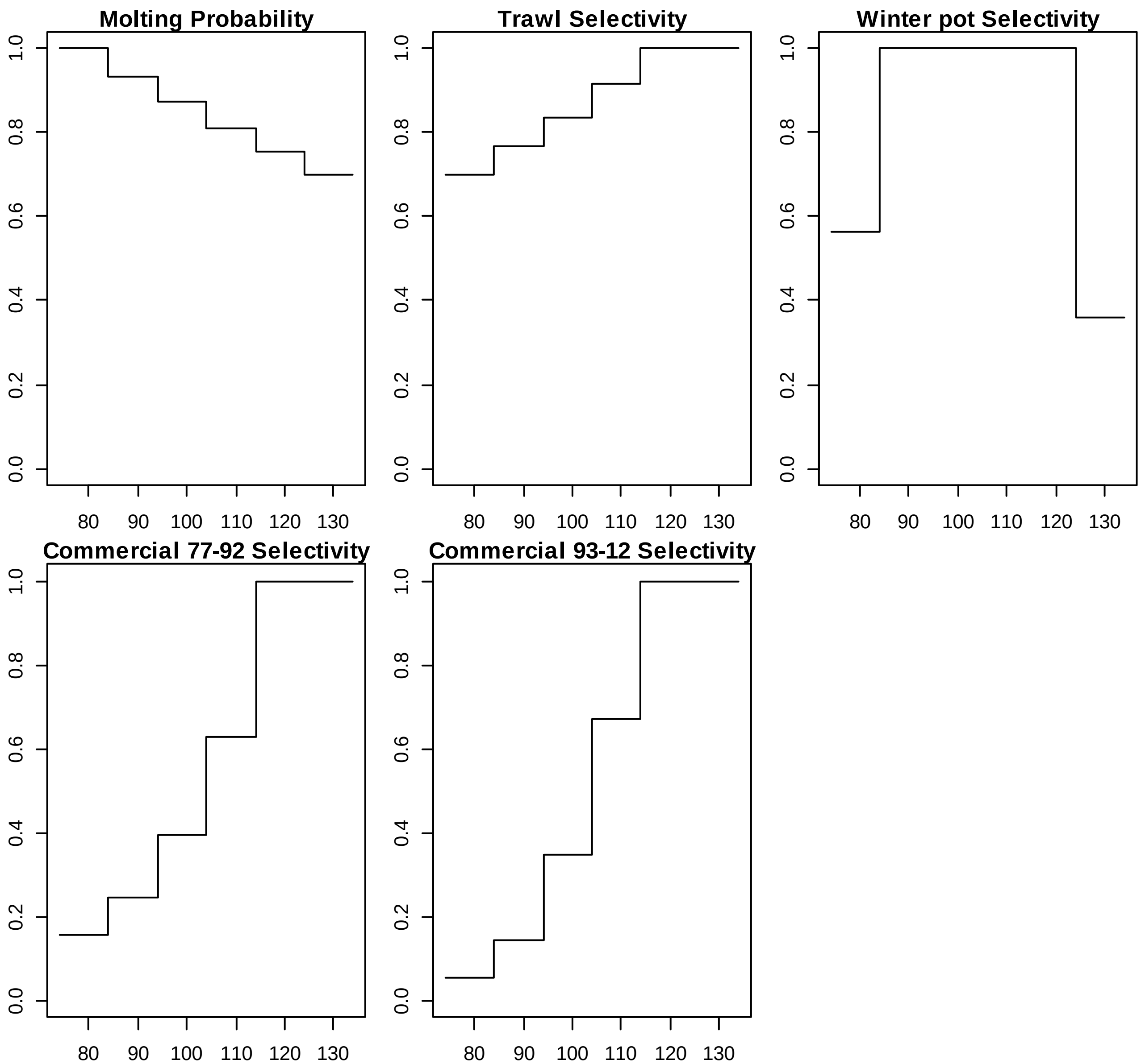


Figure 5a. Molting probability and trawl/pot selectivity (Full data).

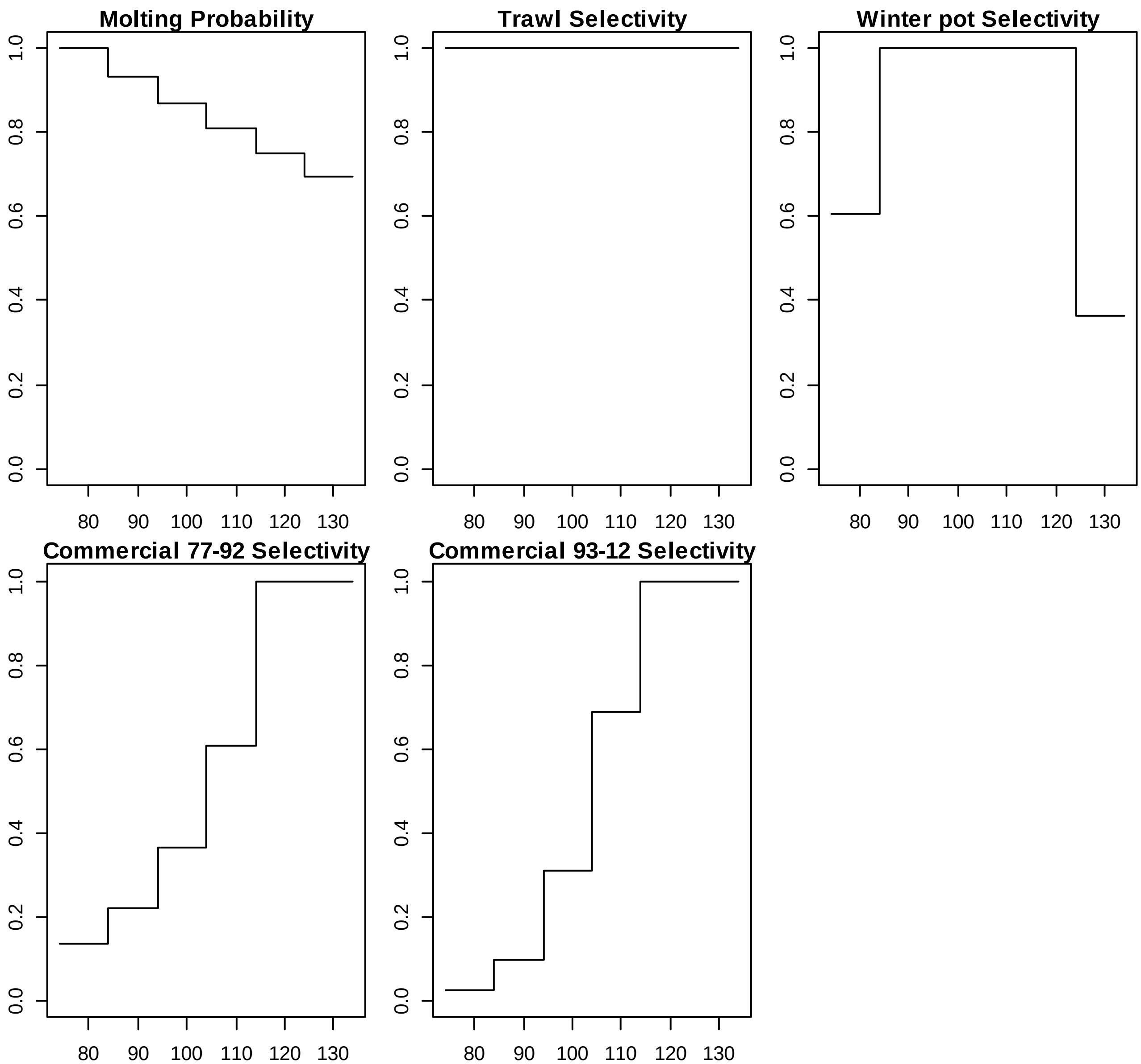


Figure 5b. Molting probability and trawl/pot selectivity (without Observer data).

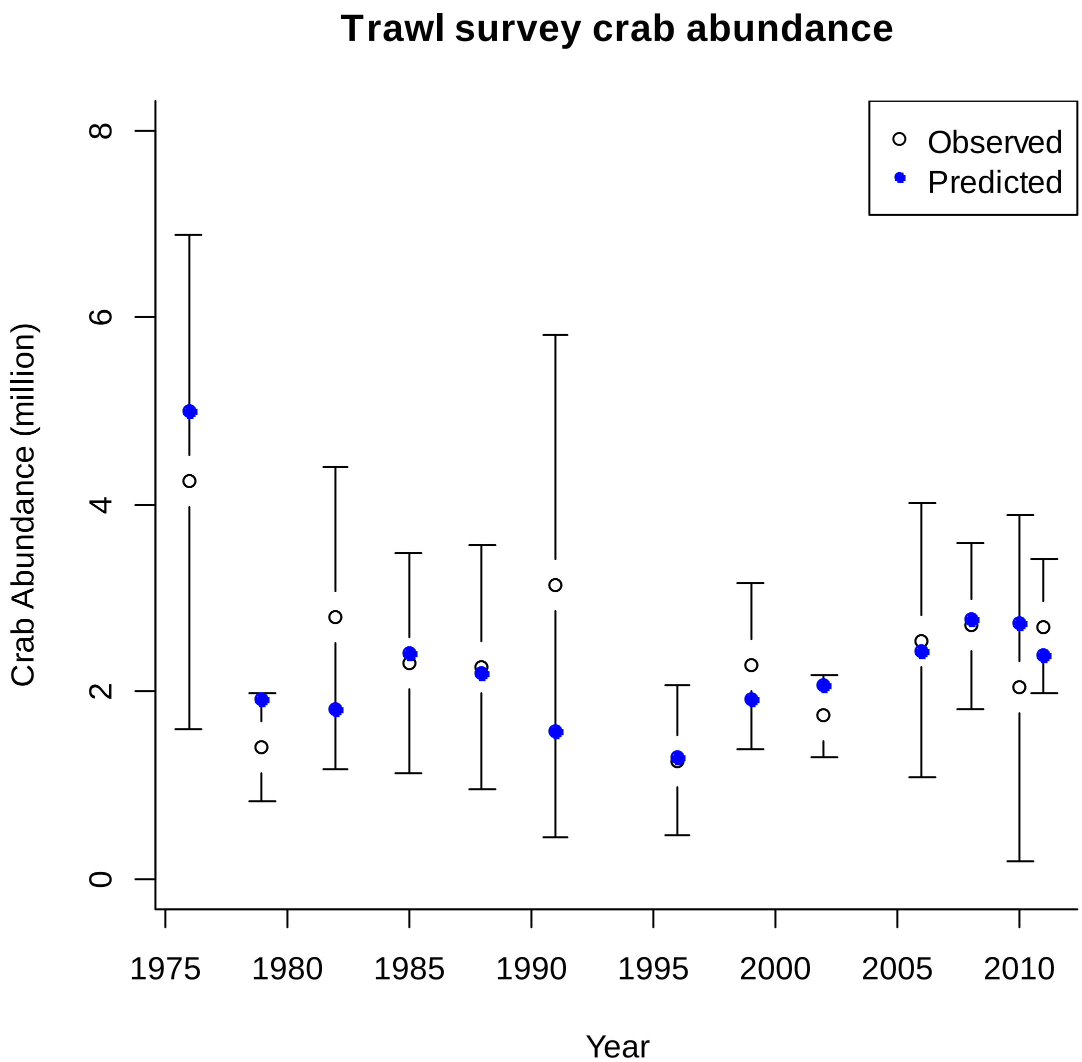


Figure 6a. Estimated trawl survey abundance (crabs ≥ 74 mm CL) male. (Full data)

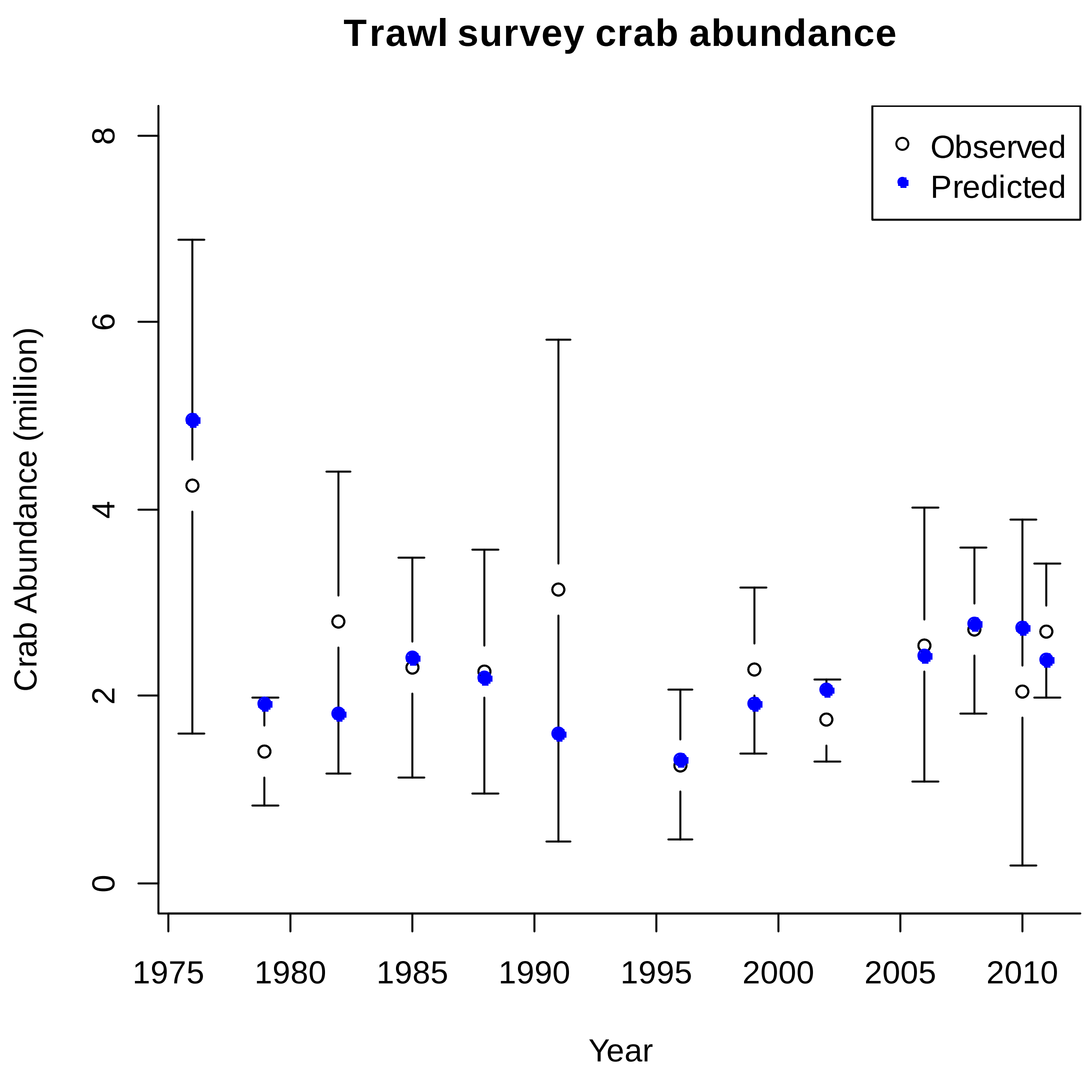


Figure 6b. Estimated trawl survey abundance (crabs ≥ 74 mm CL) male (Without Observer data)

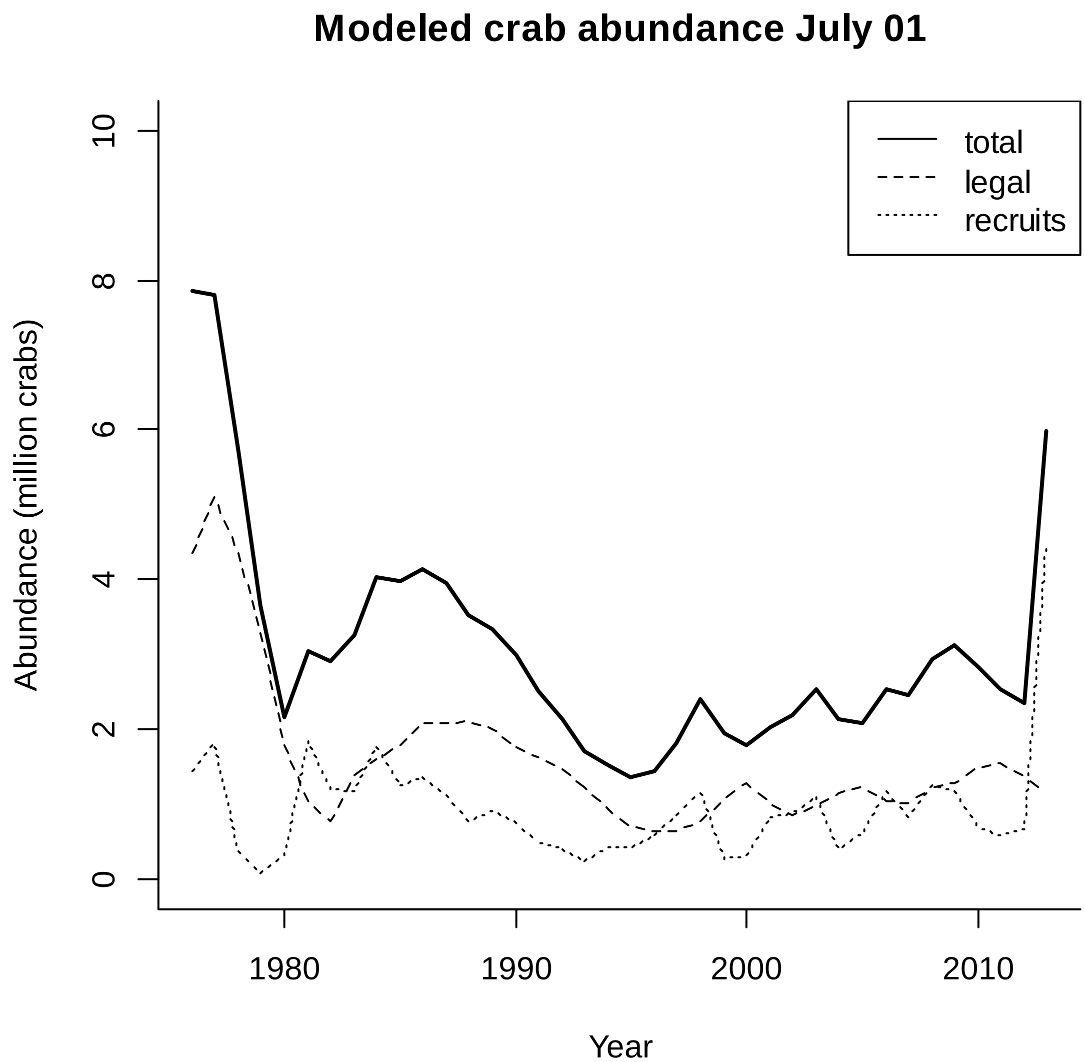


Figure 7a. Estimated abundance of legal male from 1976-2013 (Full data)

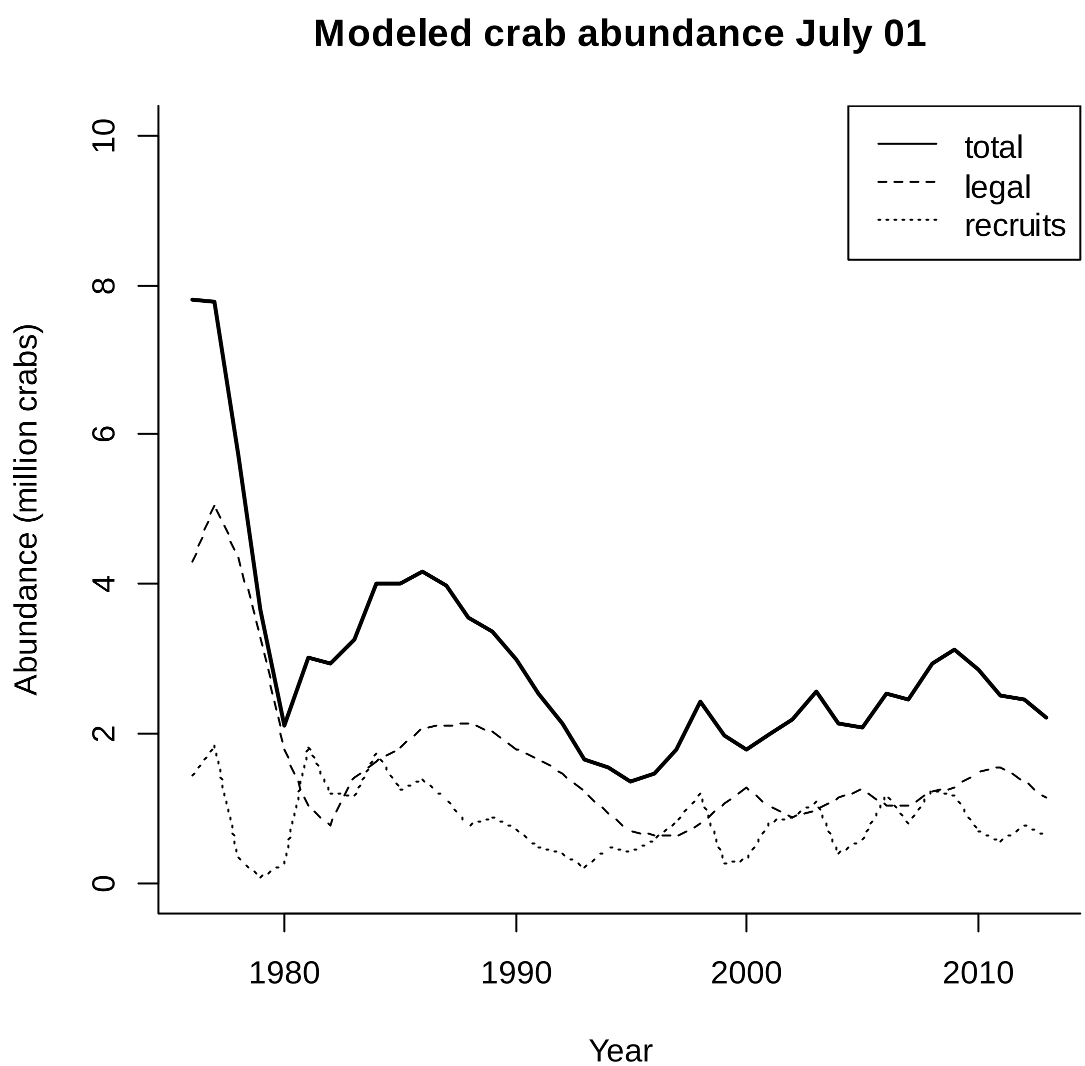


Figure 7b. Estimated abundance of legal male from 1976-2013 (without Observer data)

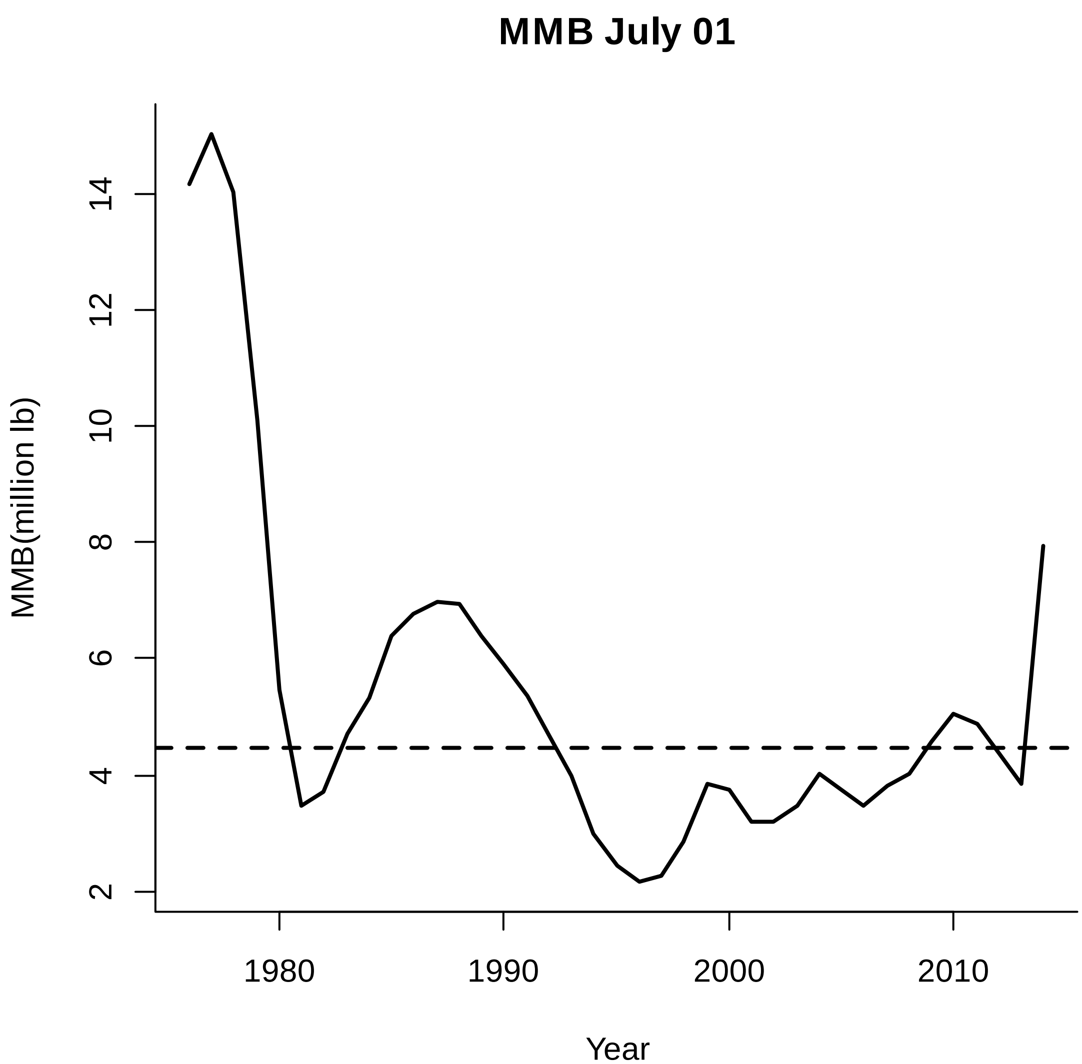


Figure 8a. Estimated abundance of leg recruits from 1976-2014 (Full data). Dash line shows Bmsy (Average MMB of 1980-2014)

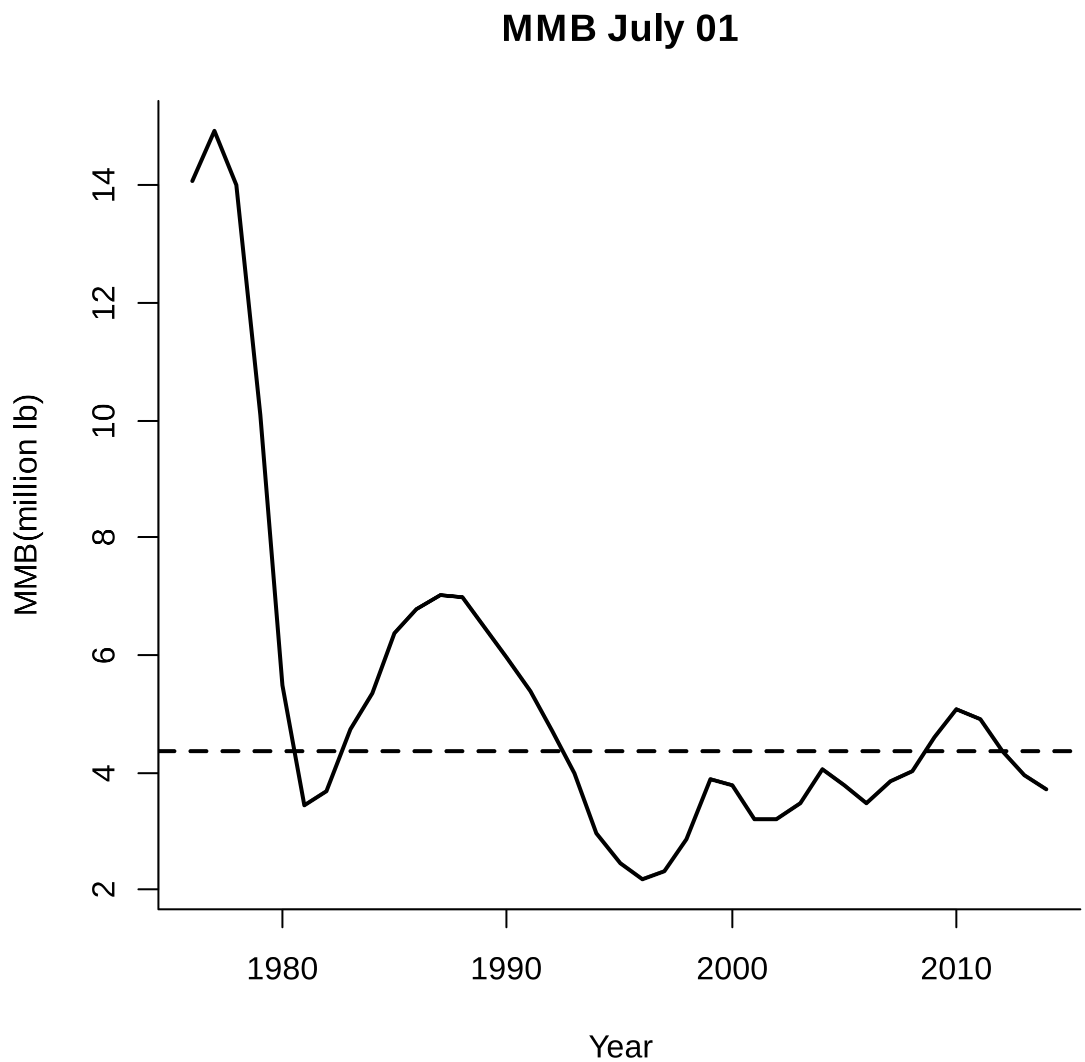


Figure 8b. Estimated abundance of leg recruits from 1976-2014 (without Observer data). Dash line shows Bmsy (Average MMB of 1980-2014)

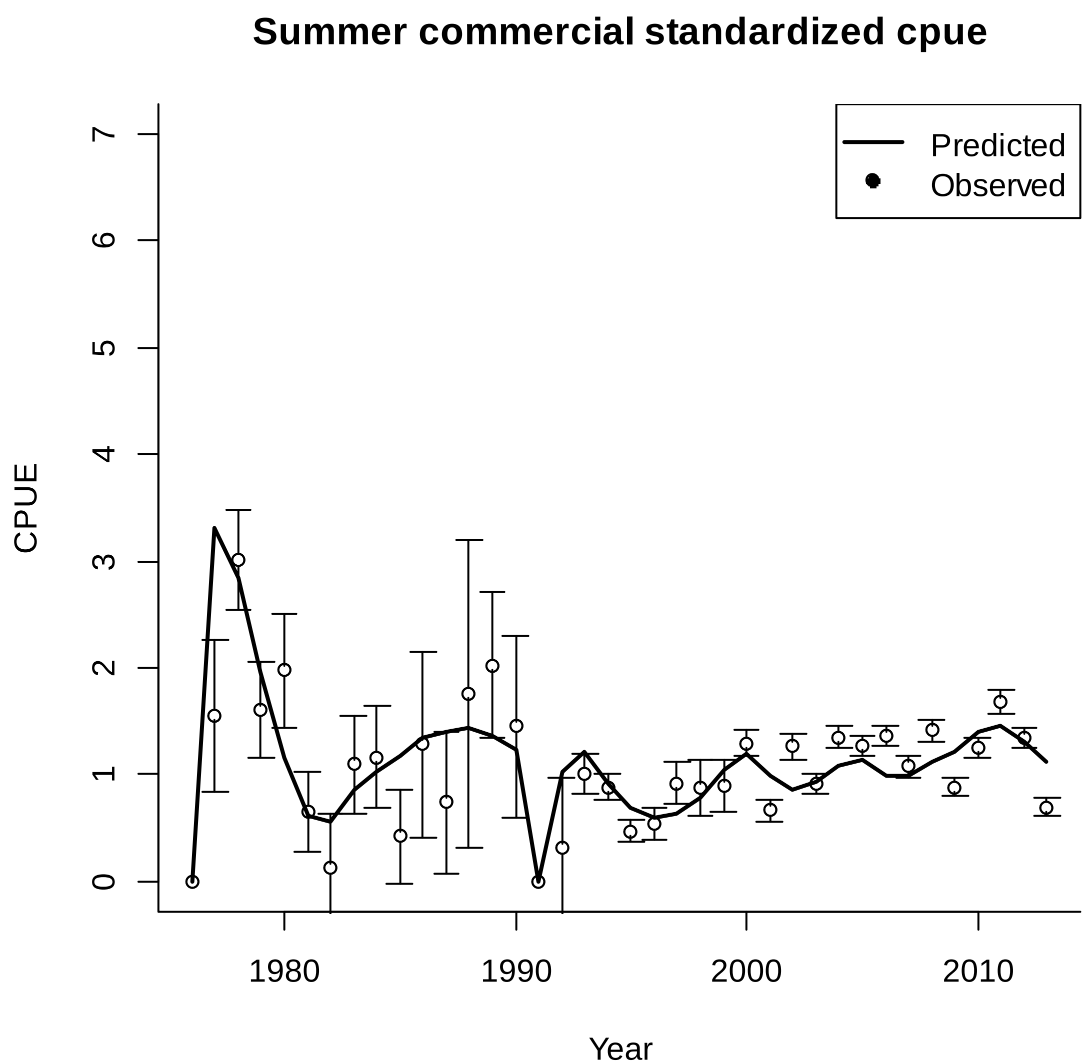


Figure 9a. Summer commercial standardized cpue (1977-2013) (Full data)

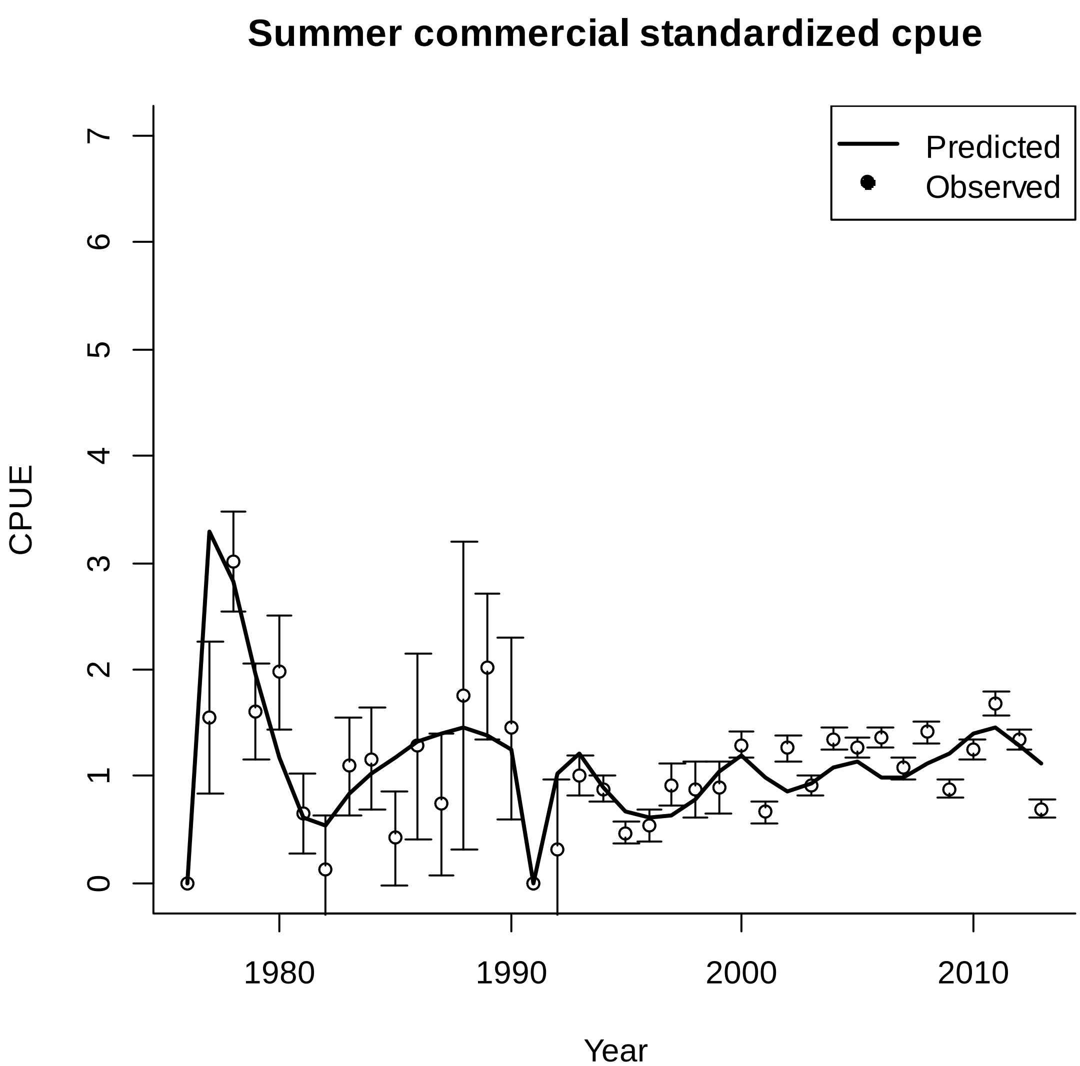


Figure 9b. Summer commercial standardized cpue (1977-2013) (without Observer data)

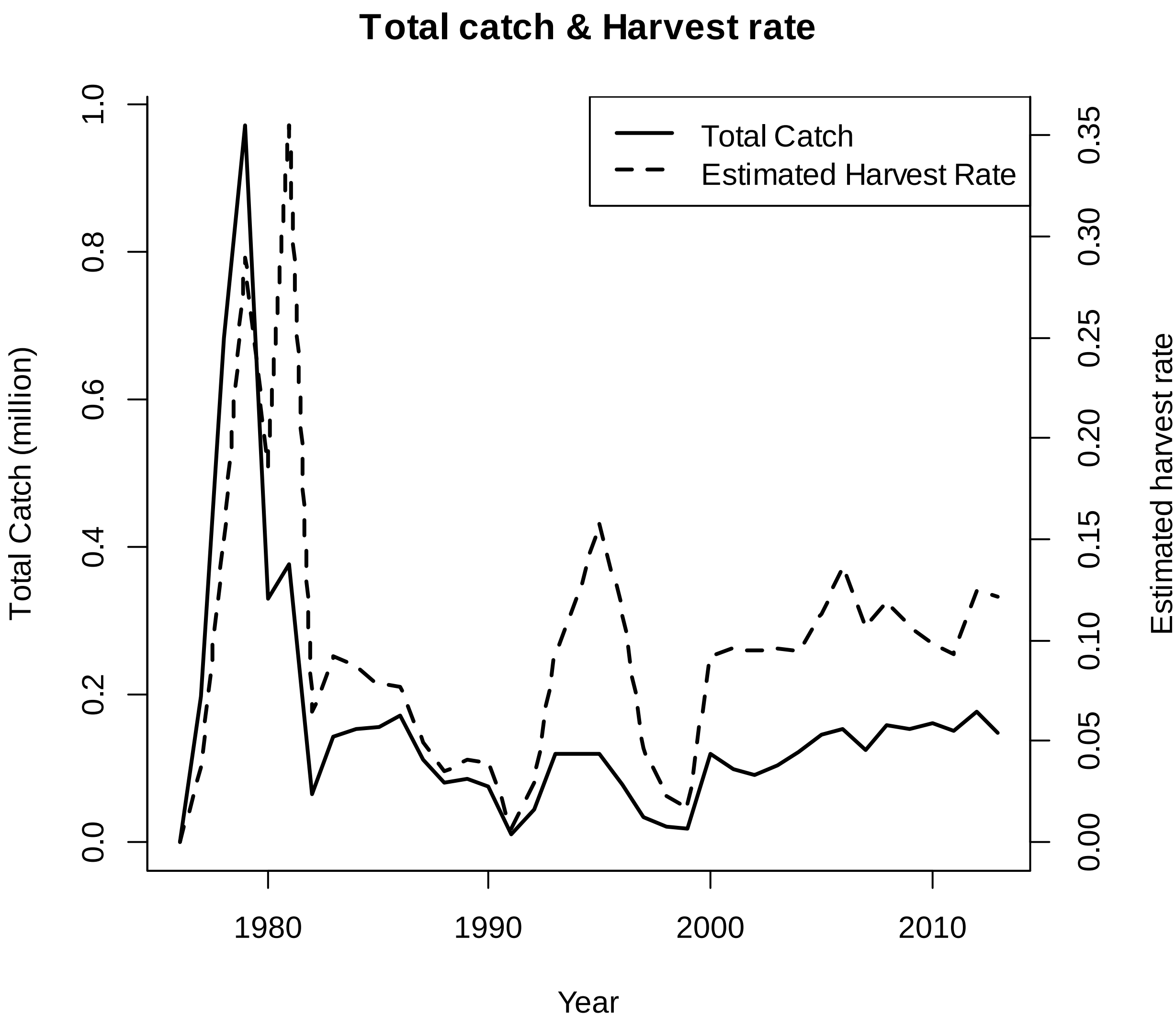


Figure 10a: Total catch and estimated harvest rate 1976-2013 (Full data)

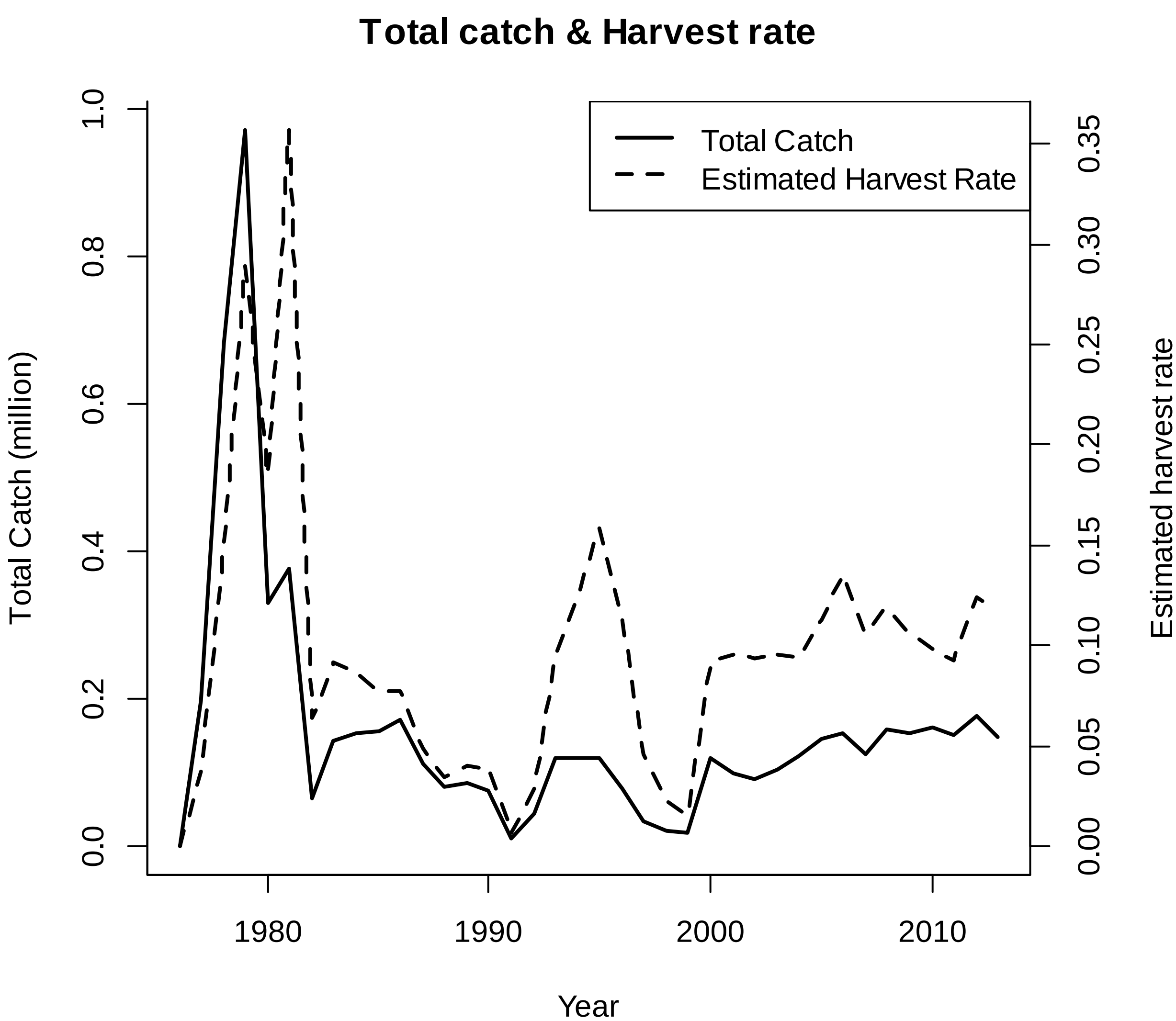


Figure 10b: Total catch and estimated harvest rate 1976-2013 (without Observer data)

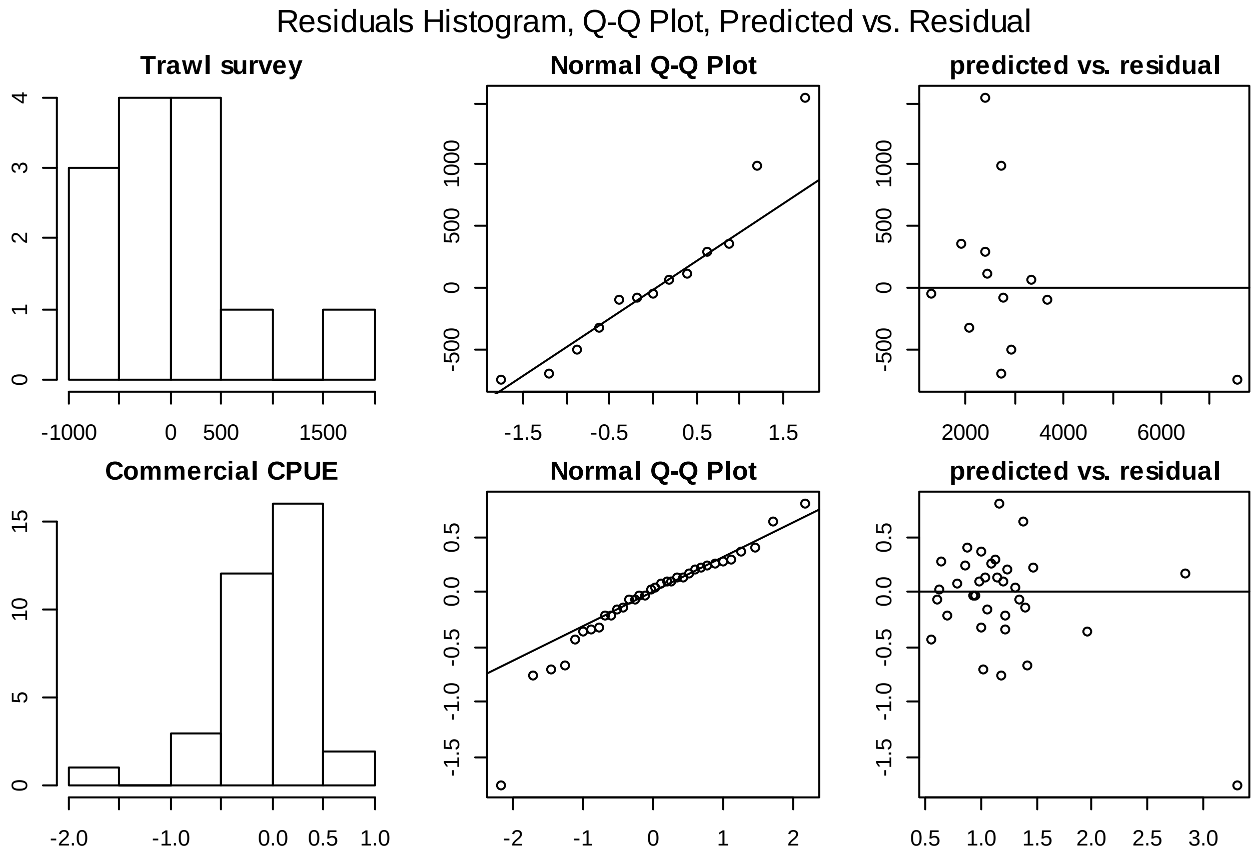


Figure 11a: Residual and QQ plot (Full data)

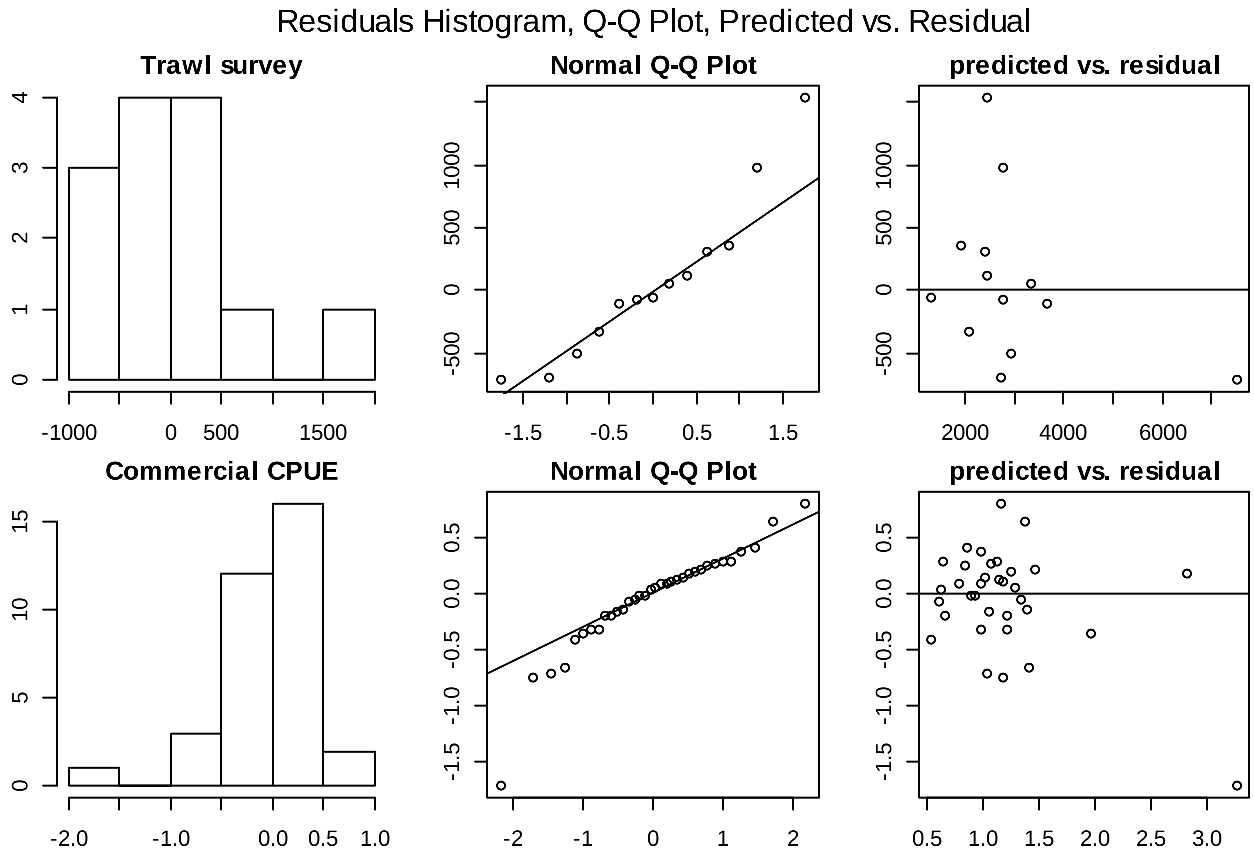
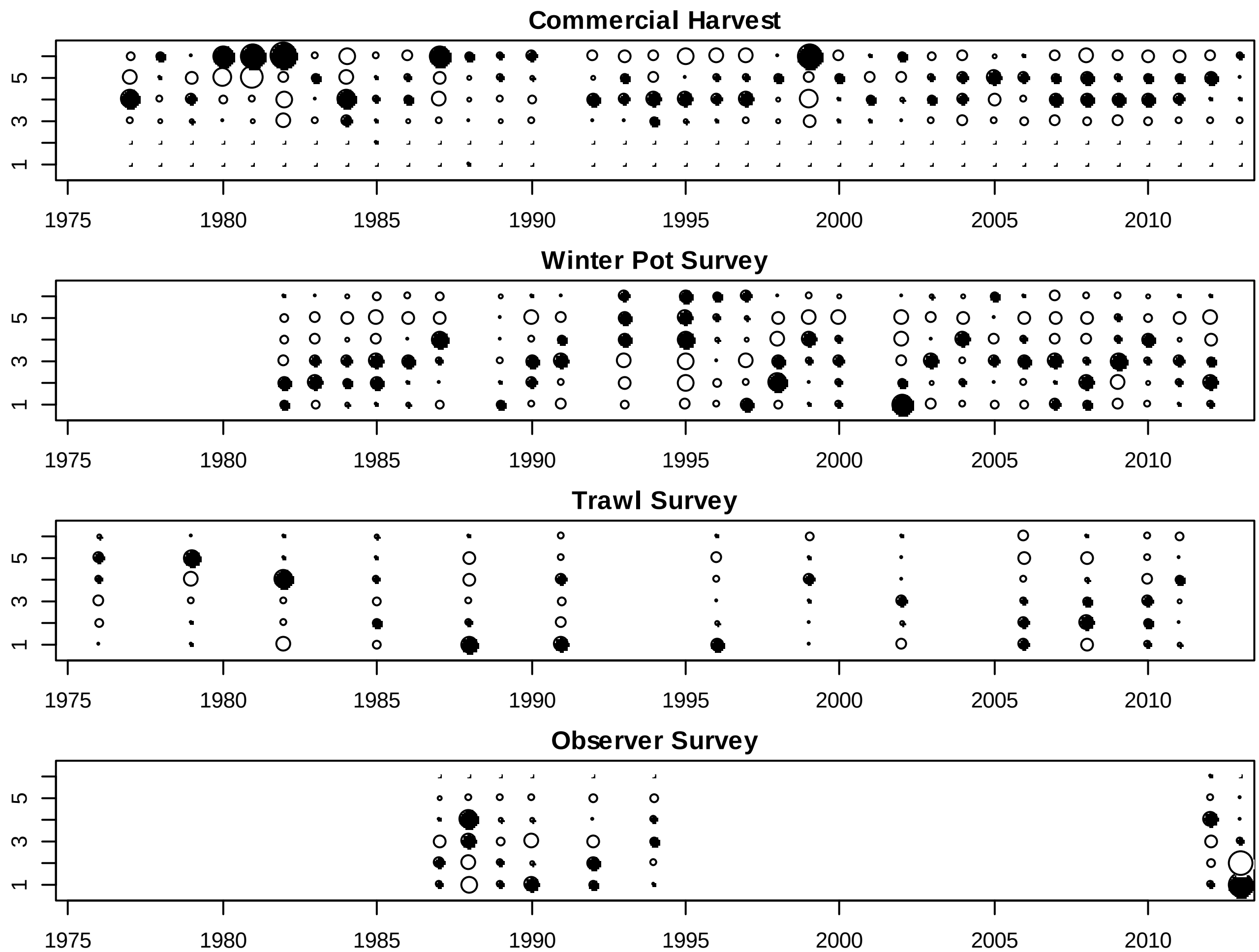
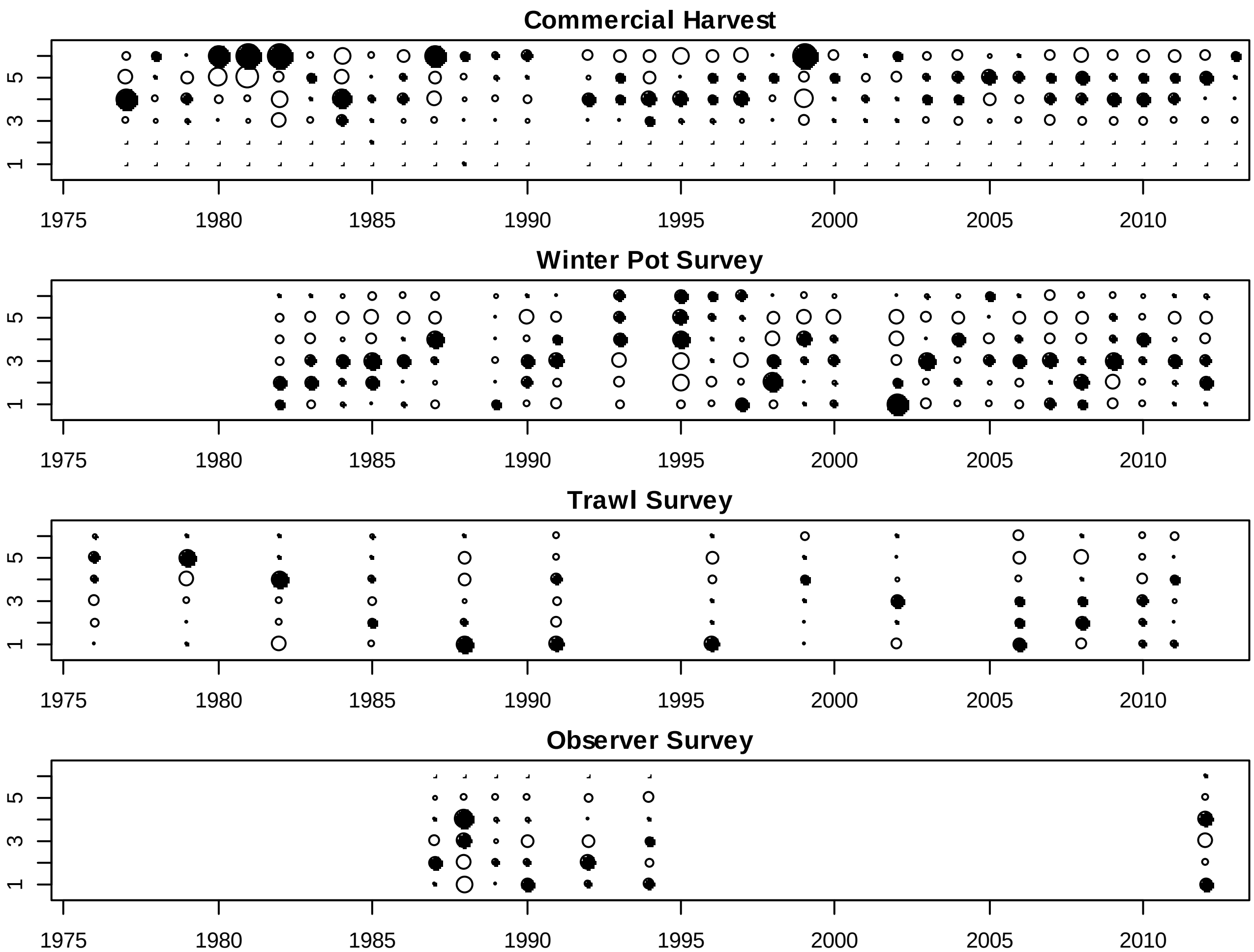


Figure 11b: Residual and QQ plot (without Observer data)



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure 12a: Bubble plot of predicted and observed length proportion (Full data).



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure 12b: Bubble plot of predicted and observed length proportion (without Observer data).

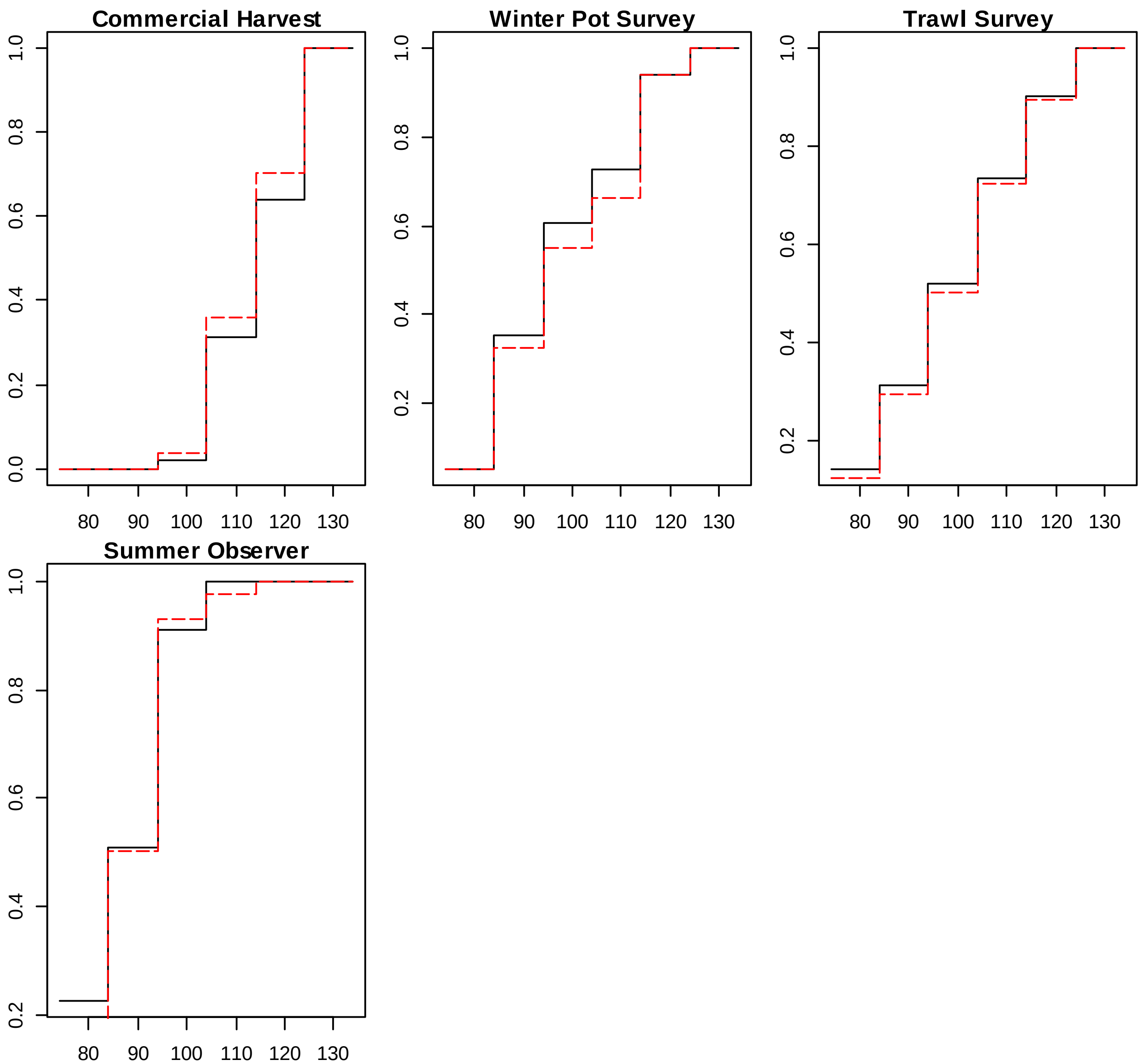


Figure 13a:. Cumulative frequency of length classes between observed and modeled (Full data)

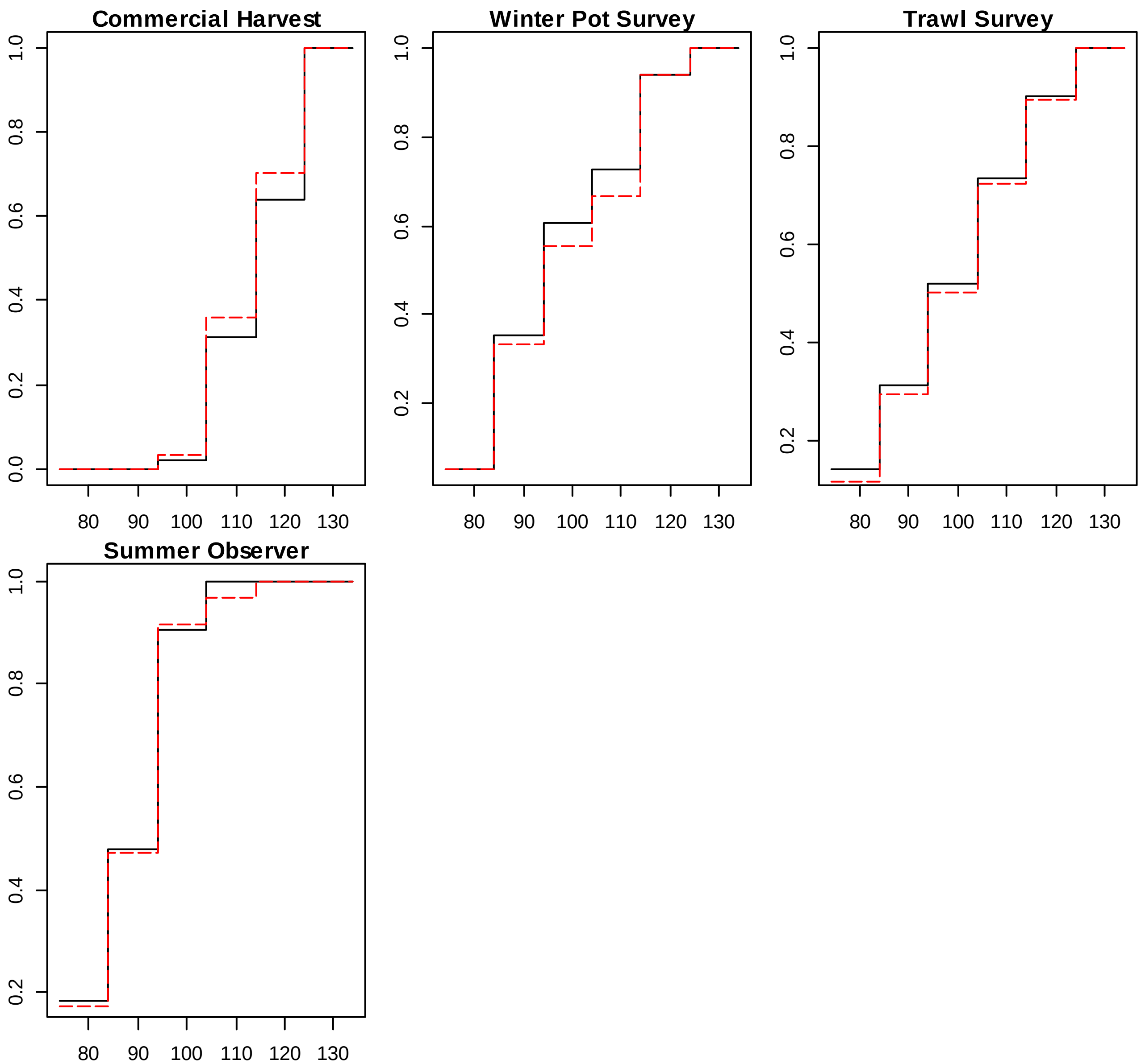


Figure 13b: Cumulative frequency of length classes between observed and modeled (without observer data)

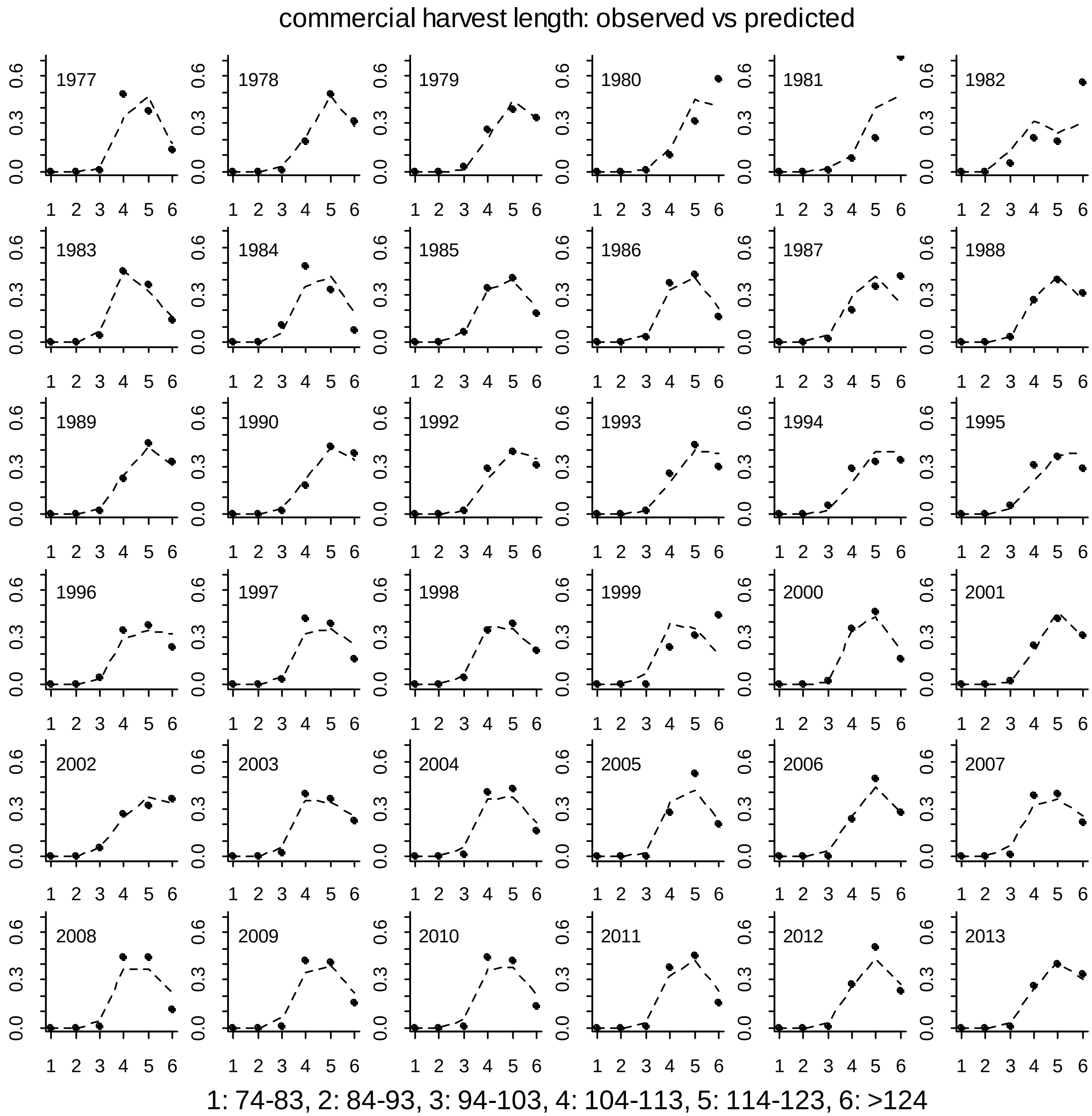


Figure 14a: Predicted vs. observed length class proportion for commercial catch (Full data)

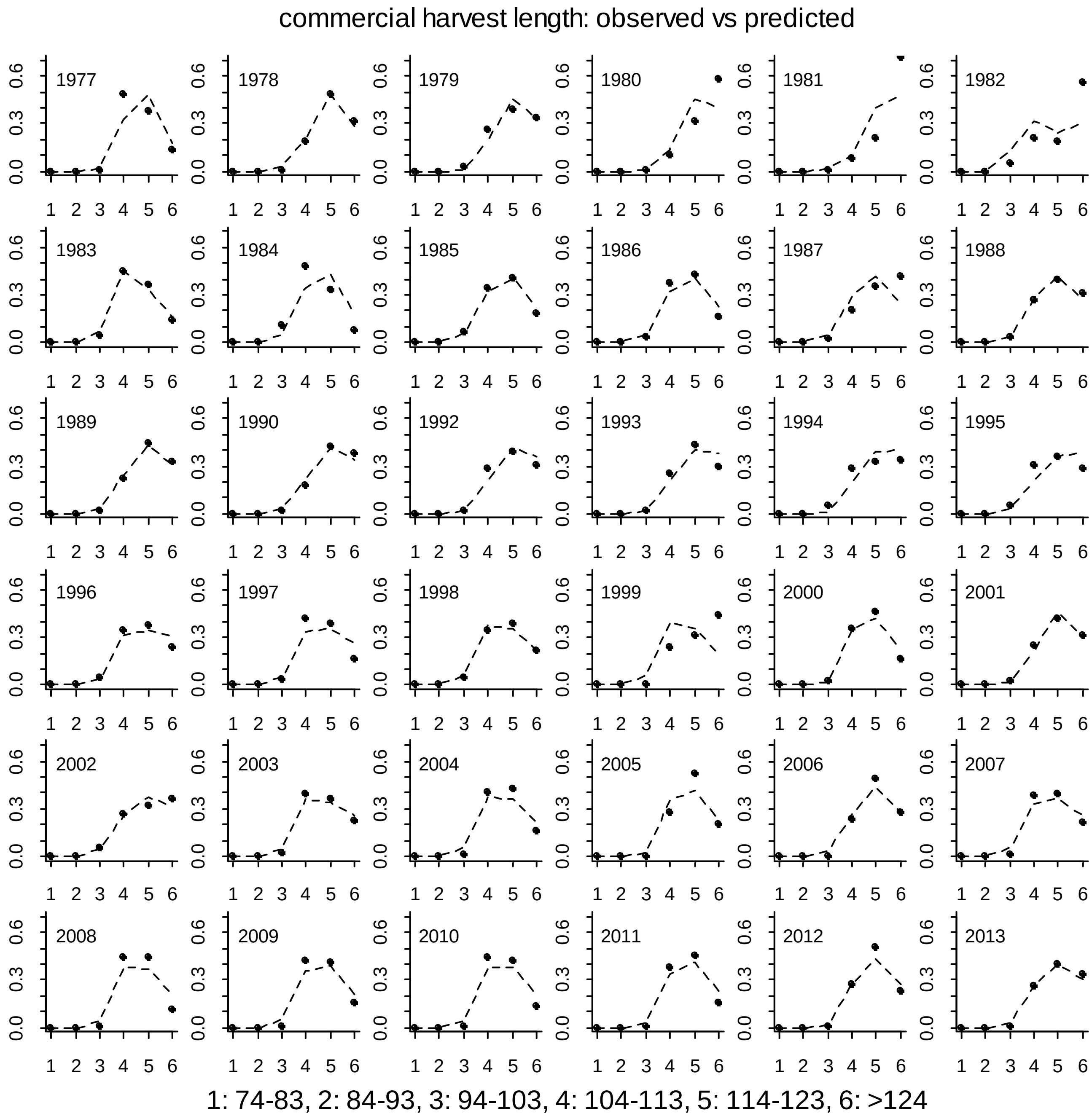


Figure 14b: Predicted vs. observed length class proportion for commercial catch (without Observer data)

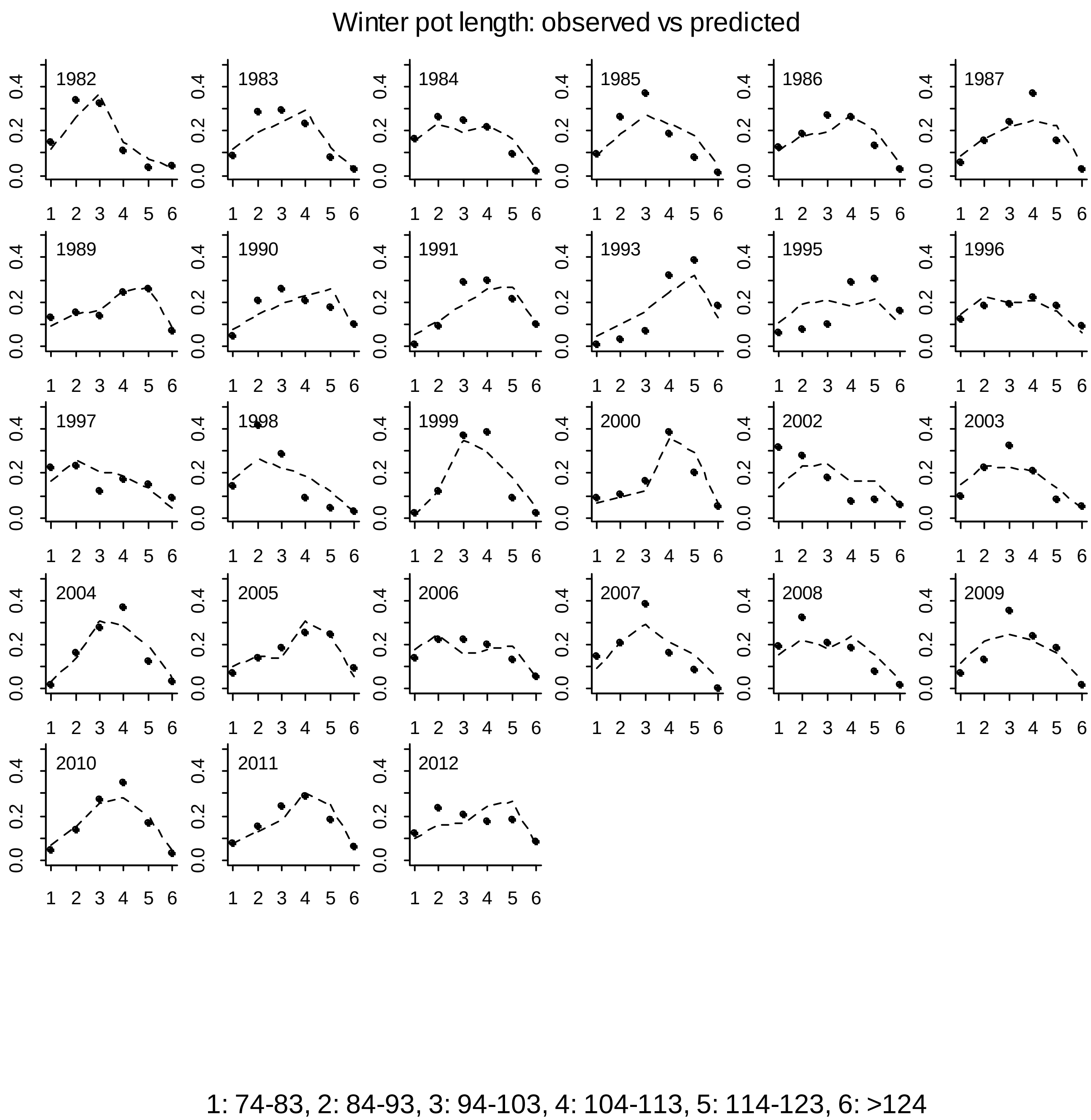


Figure 15a: Predicted vs. observed length class proportion for winter pot survey (Full data)

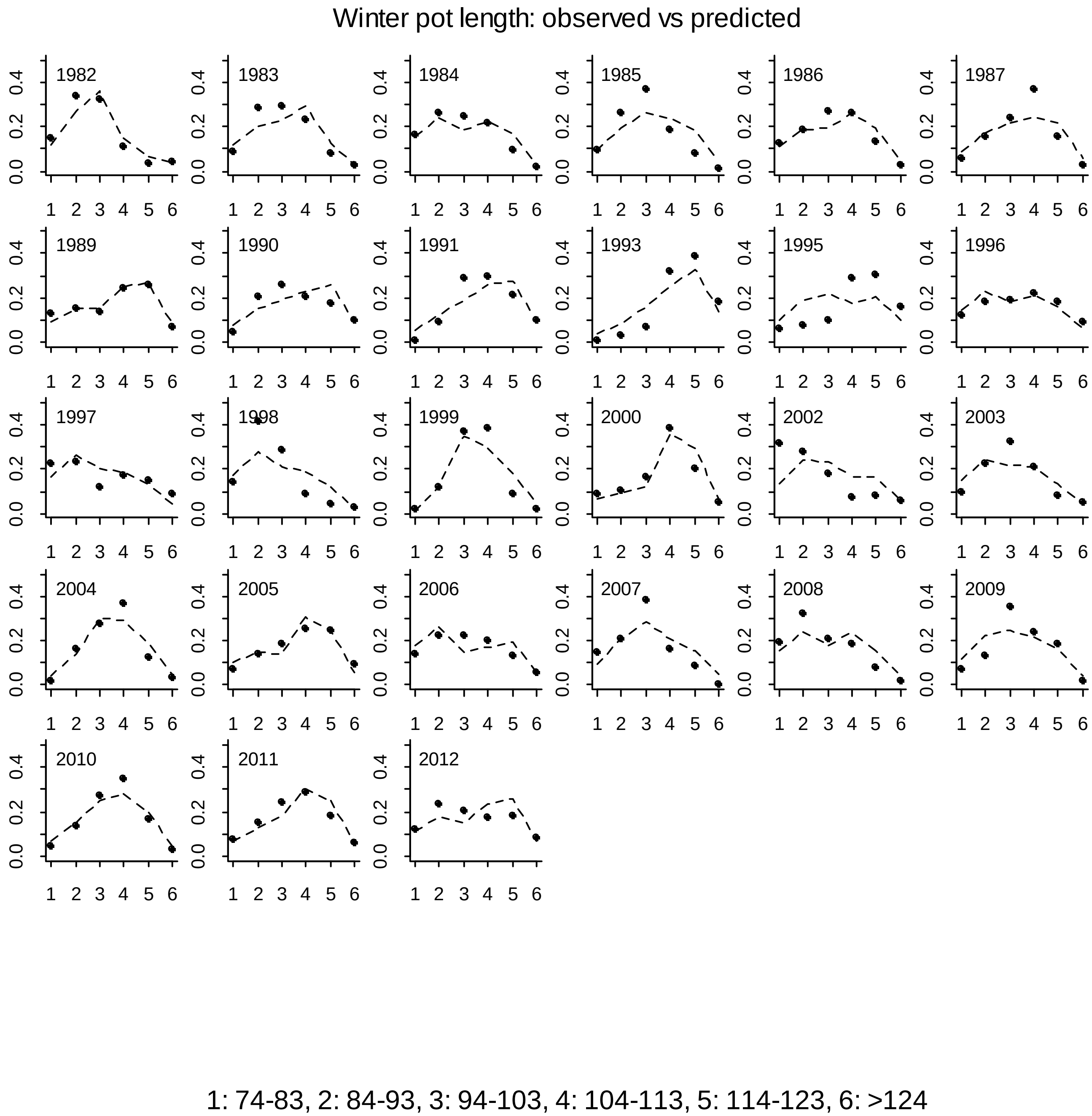


Figure 15b: Predicted vs. observed length class proportion for winter pot survey (without Observer data)

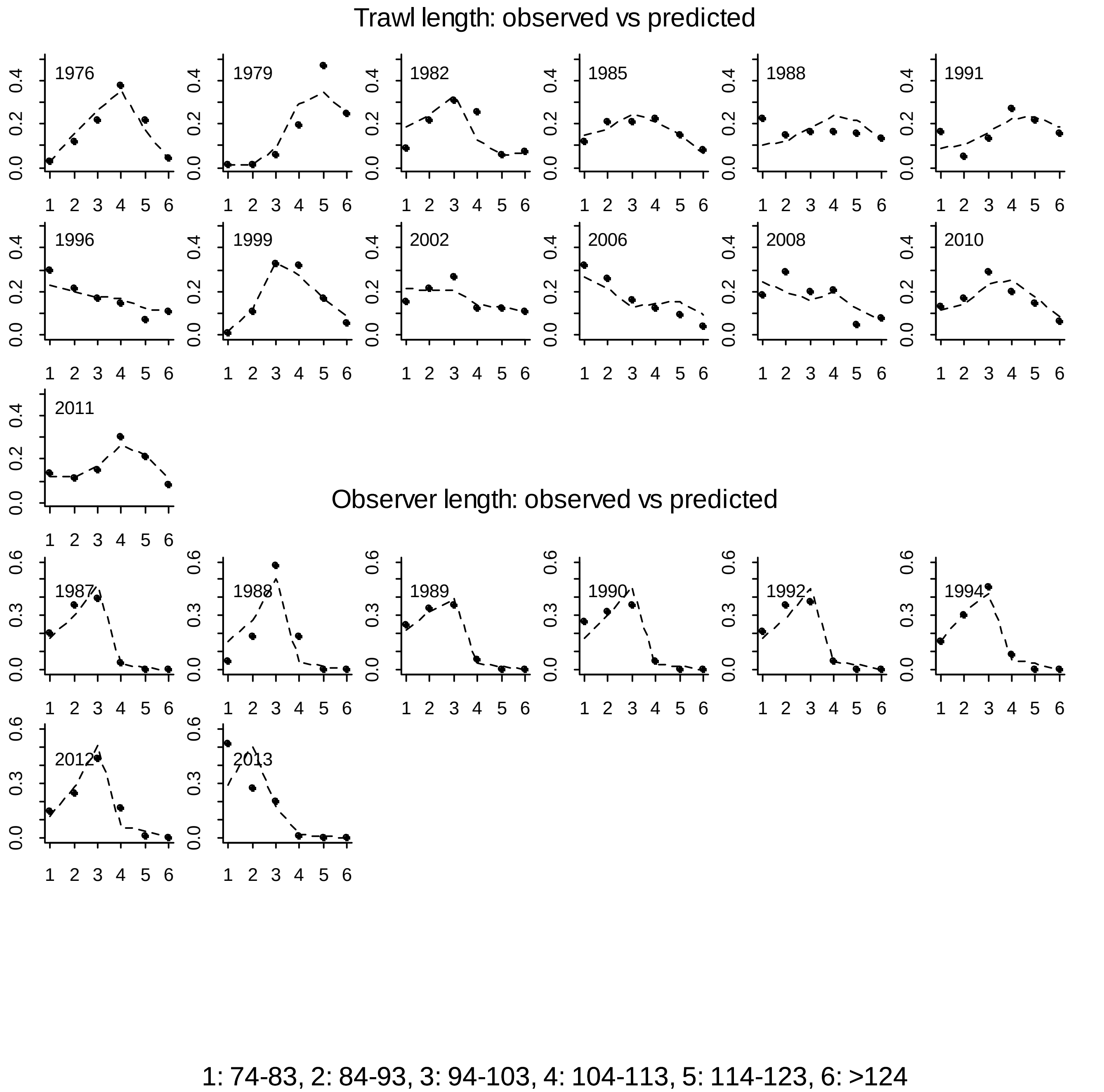
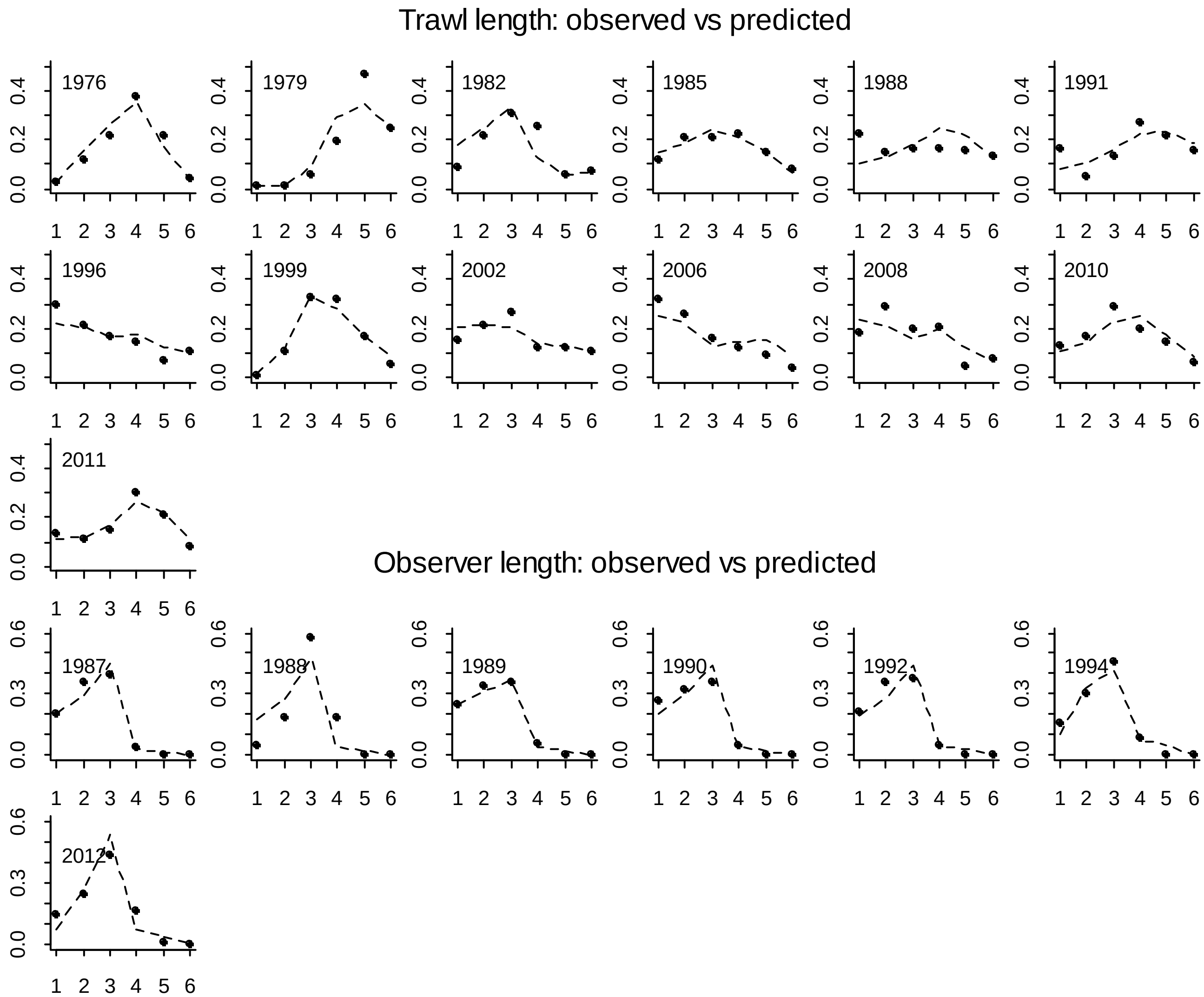


Figure 16a: Predicted vs. observed length class proportion for trawl survey and commercial observer (Full data).



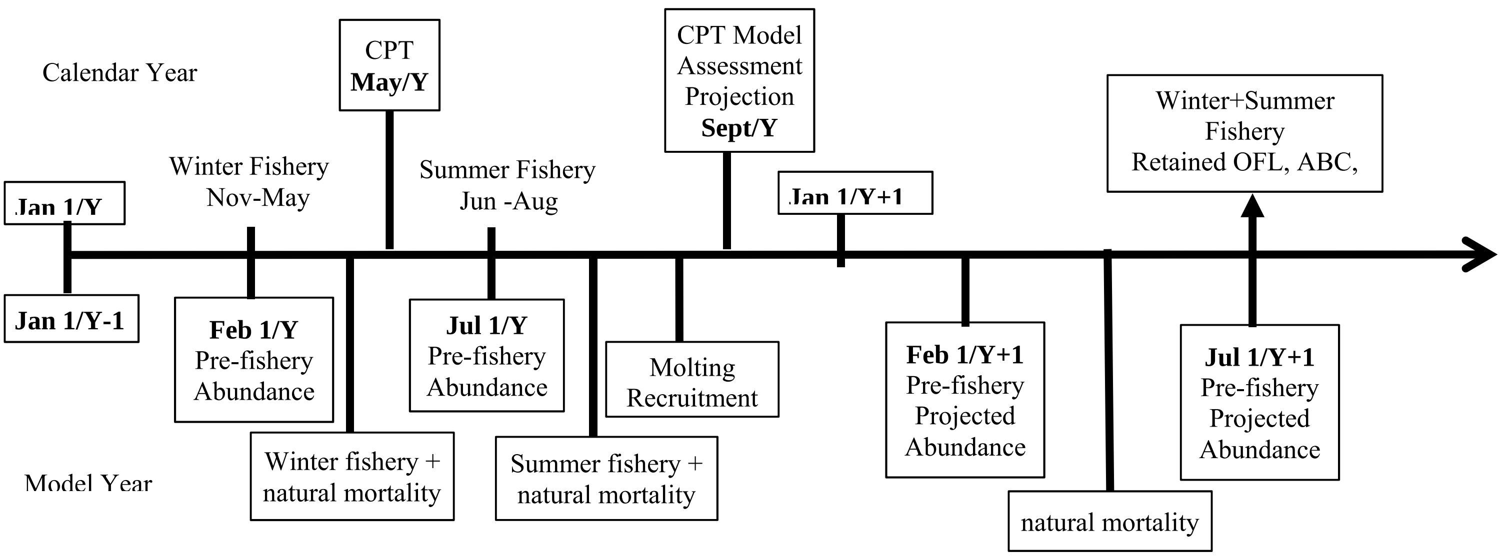
1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure 16b: Predicted vs. observed length class proportion for trawl survey and commercial observer. (without Observer data)

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 6 length classes with model parameters estimated by the maximum likelihood method. The model estimates abundances of crabs with CL ≥74 mm and with 10-mm length intervals because few crabs with CL <74 mm were caught during surveys or fisheries and there were relatively small sample sizes for trawl and winter pot surveys. The model was made for newshell and oldshell male crabs separately, but assumed they have the same molting probability and natural mortality.



Timeline of calendar events and crab modeling events.

In this assessment model, model year starts February1st to January 31st of the following year. Model year starts in February 1st 1976.

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

Abundance of the initial pre-fishery population was defined as

$$B_1 = e^{\log\_N_{76}} \tag{1}$$

The length proportion of the first year was calculated as

$$p_i = \frac{\exp(a_i)}{1+\sum_{i=1}^{n-1}\exp(a_i)} \text{ for } i = 1,..,n\text{-}1$$
$$p_n = 1 - \frac{\sum_{i=1}^{n-1}\exp(a_i)}{1+\sum_{i=1}^{n-1}\exp(a_i)} \quad (2)$$

Abundance of crab length class was is a multiplication of the first year abundance. In this it was assumed no oldshell crab exist for the first year.

$$N_{w,l,1} = p_i \cdot B_1 \quad (3)$$

Where

$N_{s,l,1}$, $O_{s,l,1}$: summer abundances of newshell and oldshell crabs in length class l in the first year.

p_n : proportion of the neswshell crab

$p_{n,l}$: conditional proportion of l-th length neswshell crab, $p_{n,0}$ =0

$p_{o,l}$: conditional proportion of l-th length oldwshell crab, $p_{o,0} = p_{o,1}$ =0

Crab abundance on July 1st

Summer crab abundance of new and oldshells is survivors of winter commercial and subsistence crab fishery and natural mortality

$$N_{s,l,t} = (N_{wl,t} - C_{w,t}\hat{P}_{w,n,l,t} - C_{p,t}\hat{P}_{p,n,l,t} - D_{w,n,l,t} - D_{p,n,l,t})e^{-0.42M_l}$$
$$O_{s,l,t} = (O_{w,l,t} - C_{w,t}\hat{P}_{w,o,l,t} - C_{p,t}\hat{P}_{p,o,l,t} - D_{w,o,l,t} - D_{p,o,l,t})e^{-0.42M_l} \quad (4)$$

where

$N_{s,l,t}$, $O_{s,l,t}$: summer abundances of newshell and oldshell crabs in length class l in year t
$N_{w,l,t}$, $O_{w,l,t}$:winter abundances of newshell and oldshell crabs in length class l in year t
$C_{w,t}$, $C_{p,t}$: total winter commercial and subsistence catches in year t,
$P_{w,n,l,t}$, $P_{p,n,l,t}$: Length proportion of winter commercial and subsistence catches for newshell crabs for length class l in year t
$P_{w,o,l,t}$, $P_{p,o,l,t}$: length compositions of winter commercial and subsistence catches for oldshell crabs in length class l in year t

$D_{w,n,l,t}$, $D_{p,n,l,t}$: Discards of winter commercial and subsistence catches for newshell crabs in length class *l* in year *t*
$D_{w,o,l,t}$, $D_{p,o,l,t}$: Discards of winter commercial and subsistence catches for oldshell crabs in length class *l* in year *t*
M_l : instantaneous natural mortality in length class *l*, constant for all sizes and shell conditions
0.42 : proportion of the year from Feb 1 to July 1 is 5 months, or 0.42 year

Crab abundance on Feb 1st

Abundance of newshell crab of the *t*-th year and *l*-th length class ($N_{w,l,t}$), is a newshell and oldshell population of previous (*t-1*th) year that survived from summer commercial fishery and molted plus recruitment.

$$N_{w,l,t} = \sum_{l'=1}^{l'=l} G_{l',l} [(N_{s,l',t-1} + O_{s,l',t-1})e^{-y_c M_l} - C_{s,t}(\hat{P}_{s,n,l',t-1} + \hat{P}_{s,o,l',t-1}) - D_{l',t-1}] m_{l'} e^{-(0.58-y_c)M_l} + R_{l,t-1} \qquad (5)$$

Abundance of oldshell crabs $O_{w,l,t}$ is the non-molting portion of survivors of crabs from summer fishery:

$$O_{w,l,t} = [(N_{s,l,t-1} + O_{s,l,t-1})e^{-y_c M_l} - C_{s,t}(\hat{P}_{s,n,l,t-1} + \hat{P}_{s,o,l,t-1}) - D_{l,t-1}](1 - m_l) e^{-(0.58-y_c)M_l} \qquad (6)$$

where

$G_{l',l}$: a growth matrix representing the expected proportion of crabs molting from length class l' to length class *l* (independently estimated outside of the assessment model frame),
$C_{s,t}$: total summer catch in year *t* (assumed to be accurate without error),
$P_{s,n,l,t}$, $P_{s,o,l,t}$: Compositions of summer catch for newshell and oldshell crabs in length class *l* in year *t*,
$D_{l,t}$: discards of length class *l* in year *t*,
m_l : molting probability in 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
$R_{l,t}$: recruitment into length class *l* in year *t*.

Discards

In summer and winter commercial fisheries, sublegal males (<4.75 inch CW and <5.0 inch CW since 2005) are not retained, but are sorted and discarded. Those discarded crabs are subject to handling mortality.

For winter subsistence fisheries, we assumed that all unretained crabs consist of

Discards of length class *l* in year *t* from the commercial pot fishery were estimated as:

$$D_{l,t} = (N_{s,l,t} + O_{s,l,t})\, S_{s,l}\, (1 - L_l)\, hm_s\, [C_{s,t} / \sum_l (N_{s,l,t} + O_{s,l,t})\, L_l] \quad (7)$$

$$D_{w,n,l,t} = (N_{w,l,t})\, S_{w,l}\, (1 - L_l)\, hm_w\, [C_{w,t} / \sum_l (N_{w,l,t} + O_{w,l,t})\, L_l] \quad (8)$$

$$D_{w,o,l,t} = (O_{w,l,t})\, S_{w,l}\, (1 - L_l)\, hm_w\, [C_{w,t} / \sum_l (N_{w,l,t} + O_{w,l,t})\, L_l] \quad (9)$$

$$D_{p,n,l,t} = C_{d,t} P_{d,n,l,t} hm_w \quad (10)$$

$$D_{p,o,l,t} = C_{d,t} P_{d,o,l,t} hm_w \quad (11)$$

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
L_l : the proportion of legal males in length class *l*.
Reflecting the change of commercial acceptable crab size since 2005, proportion of legal males in the length class 4, was calculated as $p_4 L_4$. Where p_4 is the proportion of commercially acceptable crab among legal crab of the length class 4. p_4 was estimated from the model. (This was removed because the estimate of p_4 was 1.0).
$S_{s,l}$: Selectivity of the summer commercial fishery.
$P_{d,n,l,t}$, $P_{d,o,l,t}$: Compositions of discards for newshell and oldshell crabs in length class *l* in year *t*,

Molting Probability

Molting probability for length class *l*, m_l, was calculated using a reverse logistic function fitted as a function of length and time (Balsiger's 1974)

$$m_l = 1 - \frac{1}{1 + e^{-\alpha(i-\beta)}} \quad (12)$$

where
α and β are parameters, and *i* is the mid-length of length class *l*.
m_l was re-scaled such that $m_1 = 1$.

Trawl net and pot selectivity

Selectivity of length class *l* for summer commercial fishery ($S_{s,l}$), summer trawl survey ($S_{st,l}$), summer pot survey ($S_{p,l}$), winter pot survey ($S_{w,l}$), and summer trawl survey were assumed to be an asymptotic logistic function with parameters ϕ and ω, where *i* is the mid-length of the length class *l*.

$$S_l = \frac{1}{1 + e^{-\phi(i-\omega)}} \tag{13}$$

Selectivity of $S_{1\text{-}4}$ were re-scaled such that $S_5 = S_6 = 1$.

For summer commercial fisheries, two sets of parameters (ϕ_1, ω_1), (ϕ_2, ω_2) were estimated: 1) before 1993, and 2) 1933 to present reflecting changes in fisheries, and crab pot configurations.

For winter pot survey and winter harvest, selectivity ($S_{w,l}$) was assumed to be dome shaped, with $S_{w,5} = 1$, and $S_{w,6}$ was directly estimated from the model.

Estimation of Recruitment

We modeled recruitment of year *t*, R_t, as a stochastic process around the mean, R_0:

$$R_t = R_0 e^{\tau_t}, \tau_t \sim N(0, \sigma_R^2) \tag{14}$$

R_t was assumed to come from only length classes 1 ($R_{1,t}$) and 2 ($R_{2,t}$) , and was calculated as

$$\begin{aligned} R_{1,t} &= r\, R_t \\ R_{2,t} &= (1 - r)\, R_t \end{aligned} \tag{15}$$

where *r* is a parameter with a value less than or equal to 1. $R_{l,t} = 0$ when $l \geq 3$.

Observation model

Estimates of survey abundances

Summer trawl survey abundance

Abundance of *t*-th year trawl survey was estimated by subtracting population of July 1st abundance minus summer commercial fisheries harvested by before trawl survey, multiplied by selectivity of trawl.

$$\hat{B}_{st,t} = \sum_l [(N_{s,l,t} + O_{s,l,t})\, e^{-y_c M_l} - C_{s,t}(\hat{P}_{s,n,l',t} + \hat{P}_{s,o,l',t}) P_{c,t}] e^{-(y_{st}-y_c)M_l} S_{st,l}$$
$$\hat{B}_{st,1} = \sum_l (N_{s,l,1} + O_{s,l,1}) e^{-(y_{st})M_l}\, S_{st,l} \tag{16}$$

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

Summer pot survey abundance (Removed from likelihood components)

Abundance of *t*-th year pot survey was estimated as

$$\hat{B}_{p,t} = \sum_l [(N_{s,l,t} + O_{s,l,t})\, e^{-y_p M_l}] S_{p,l} \tag{17}$$

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

Estimation of 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, C_t.

$$\hat{f}_t = q_i (A_t - 0.5C_t) \tag{18}$$

Because fishing fleet and pot limit configuration changed in 1993 and 2008, q_1 is for fishing efforts before 1993, q_2 is from 1994 to present.

Estimates of length composition

Winter commercial catch

Length compositions of winter commercial catch ($P_{w,n,l,t}$, $P_{w,o,l,t}$) for length *l* in year *t* were estimated from the winter population, winter pot selectivity, and proportion of legal crabs for each length class as:

$$\hat{P}_{w,n,l,t} = N_{w,l,t} S_{w,l} L_l / \sum_{l=1} [(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l]$$
$$\hat{P}_{w,o,l,t} = O_{w,l,t} S_{w,l} L_l / \sum_{l=1} [(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l] \quad (19)$$

Winter subsistence catch

Subsistence fishery does not have a size limit; however, crabs 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

$$\hat{P}_{p,n,l,t} = N_{w,l,t} S_{w,l} / \sum_{l=3} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}]$$
$$\hat{P}_{p,o,l,t} = O_{w,l,t} S_{w,l} / \sum_{l=3} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \quad (20)$$

Winter subsistence discards

Subsistence fishery discards proportion was assumed to be length composition $l = 1$ and 2 only, and was estimated as follows

$$\hat{P}_{pd,n,l,t} = N_{w,l,t} S_{w,l} / \sum_{l=1}^{2} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}]$$
$$\hat{P}_{pd,o,l,t} = O_{w,l,t} S_{w,l} / \sum_{l=1}^{2} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \quad (21)$$

Winter pot survey

The above equations were also used to calculate length compositions of winter pot survey for newshell and oldshell crabs, $P_{sw,n,l,t}$ and $P_{sw,o,l,t}$ ($l \geq 1$).

$$\hat{P}_{sw,n,l,t} = N_{w,l,t} S_{w,l} / \sum_{l} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}]$$
$$\hat{P}_{sw,o,l,t} = O_{w,l,t} S_{w,l} / \sum_{l} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \quad (22)$$

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 calculated based on summer population, selectivity, and legal abundance;

$$\hat{P}_{s,n,l,t} = N_{s,l,t} S_{s,l} L_l / A_t$$
$$\hat{P}_{s,o,l,t} = O_{s,l,t} S_{s,l} L_l / A_t \tag{23}$$

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

$$A_t = \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} L_l] \tag{24}$$

Observer discards

Length/shell compositions of Observer discards in 87-90, 92, 94, and 2012 were estimated as

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

Summer trawl survey

Some trawl surveys occurred during the molting period, and thus we combined the length compositions of newshell and oldshell crabs as one single shell condition, $P_{st,l,t}$, and were estimated as

$$\hat{P}_{st,,l,t} = \frac{[(N_{s,l,t} + O_{s,l,t}) e^{-y_c M_l} - C_{s,t} (\hat{P}_{s,n,l',t} + \hat{P}_{s,o,l',t}) P_{c,t}] e^{-(y_{st} - y_c) M_l} S_{st,l}}{\sum_l [(N_{s,l,t} + O_{s,l,t}) e^{-y_c M_l} - C_{s,t} (\hat{P}_{s,n,l',t} + \hat{P}_{s,o,l',t}) P_{c,t}] e^{-(y_{st} - y_c) M_l} S_{st,l}} \tag{26}$$

Summer pre-season survey (1976) (Removed from likelihood due to only 1 year of survey)

The same selectivity for the summer commercial fishery was applied to the summer pre-season survey, resulting in estimated length compositions for both newshell and oldshell crabs as:

$$\hat{P}_{sf,n,l,t} = N_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}]$$
$$\hat{P}_{sf,o,l,t} = O_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}] \tag{27}$$

This was not incorporated into likelihood calculation because of one year data.

Summer pot survey (1980-82, 85) (Removed from likelihood due to failure to locate original data)

The length/shell condition compositions of summer pot survey were estimated as

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

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

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:

$$\begin{aligned}
&\sum_{i=1}^{i=5}\sum_{t=1}^{t=n_i} K_{i,t}\left[\sum_{l=1}^{l=5} P_{i,l,t}\ln(\hat{P}_{i,l,t}+\kappa)) - \sum_{l=1}^{l=5} P_{i,l,t}\ln(P_{i,l,t}+\kappa)\right] \\
&-\sum_{t=1}^{t=n_i}\frac{[\ln(q\cdot\hat{B}_{i,t}+\kappa)-\ln(B_{i,t}+\kappa)]^2}{2\cdot ln(CV_{i,t}^2+1)} \\
&-\sum_{t=1}^{t=n_i}\left[\frac{\ln\left[\ln(CV_t^2+1)+w_t\right]}{2} - \frac{[\ln(\hat{f}_t+\kappa)-\ln(f_t+\kappa)]^2}{2\cdot\left[\ln(CV_t^2+1)+w_t\right]}\right] \\
&-W_R\sum_{t=1}\tau_t^2
\end{aligned} \qquad (29)$$

1where

i: length/shell compositions of :

1 triennial summer trawl survey

2 summer pot survey (1980-82, 85): Removed

3 annual winter pot survey

4 summer commercial fishery

5 observer bycatch during the summer fishery

n_i: the number of years in which data set *i* is available

$K_{i,t}$: 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*

In this, while observation and estimation were made for oldshell and newshell separately, both were combined for likelihood calculations.

κ : a constant equal to 0.001

CV : coefficient of variation for the survey abundance. CV for summer pot survey was assumed 0.34

$B_{i,k,t}$: observed and estimated annual total abundances for data set *i* and year *t*
W_f : the weighting factor of the summer fishing effort
f_t : observed and estimated summer fishing cpue
w^2_t: extra variance factor
W_R : the weighting factor of recruitment.

It is generally believed that total annual commercial crab catches in Alaska are fairly accurately reported. Thus, no measurement error was imposed on total annual catch.

e. 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, and the growth matrix.

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 (NPFMC 2007) 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 8).

Mean growth increment per molt, standard deviation for each pre-molt length class, and the growth matrix (Table 8), were estimated from tagging surveys conducted in summer 1981-1985, and winter 1981-present. In summer 1981-1985 study legal and sublegal males captured by the survey pots were tagged, and in the1981-present winter survey, sublegal males were tagged. All tagged crabs were recaptured by summer and winter commercial/subsistence fisheries.

ii. Parameters Estimated Conditionally

Estimated parameters are listed in Table 5. Selectivity and molting probabilities based on these estimated parameters are summarized in Table 4.

A likelihood approach was used to estimate parameters, which include fishing catchability, parameters for selectivity of survey and fishing gears and for molting probabilities, recruits each year (except the first and the last years), and total abundance in the first year (Table 5).

f. Definition of model outputs.

i. Mature Male Biomass (MMB) on July 1st was defined as size classes 3 to 6

$$MMB = \sum_{l=3} (N_{s,l,} + O_{s,l,}) wm_l$$

For the projected year's MMB we used projected Feb 1st crab abundance, reduced by

$$MMB = \sum_{l=3} (N_{w,l,} + O_{w,l,}) e^{-0.42 M_l} wm_l$$

ii. Projected Legal Male Biomass for winter+summer fishery OFL calculation was calculated as the projected number of crab on Feb 1st of size class greater than 94mm (N_{wl}+O_{wl}) multiplied by 1) mortality from Feb 1st to July 1st, 2) commercial pot selectivity(S_{sl}), 3) proportion of legal crab (L_l), and 4) mean weight lb (w_{ml})

$$Legal\_B = \sum_{l} (N_{w,l,} + O_{w,l,}) e^{-0.42 M_l} S_{s,l} L_l wm_l$$

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