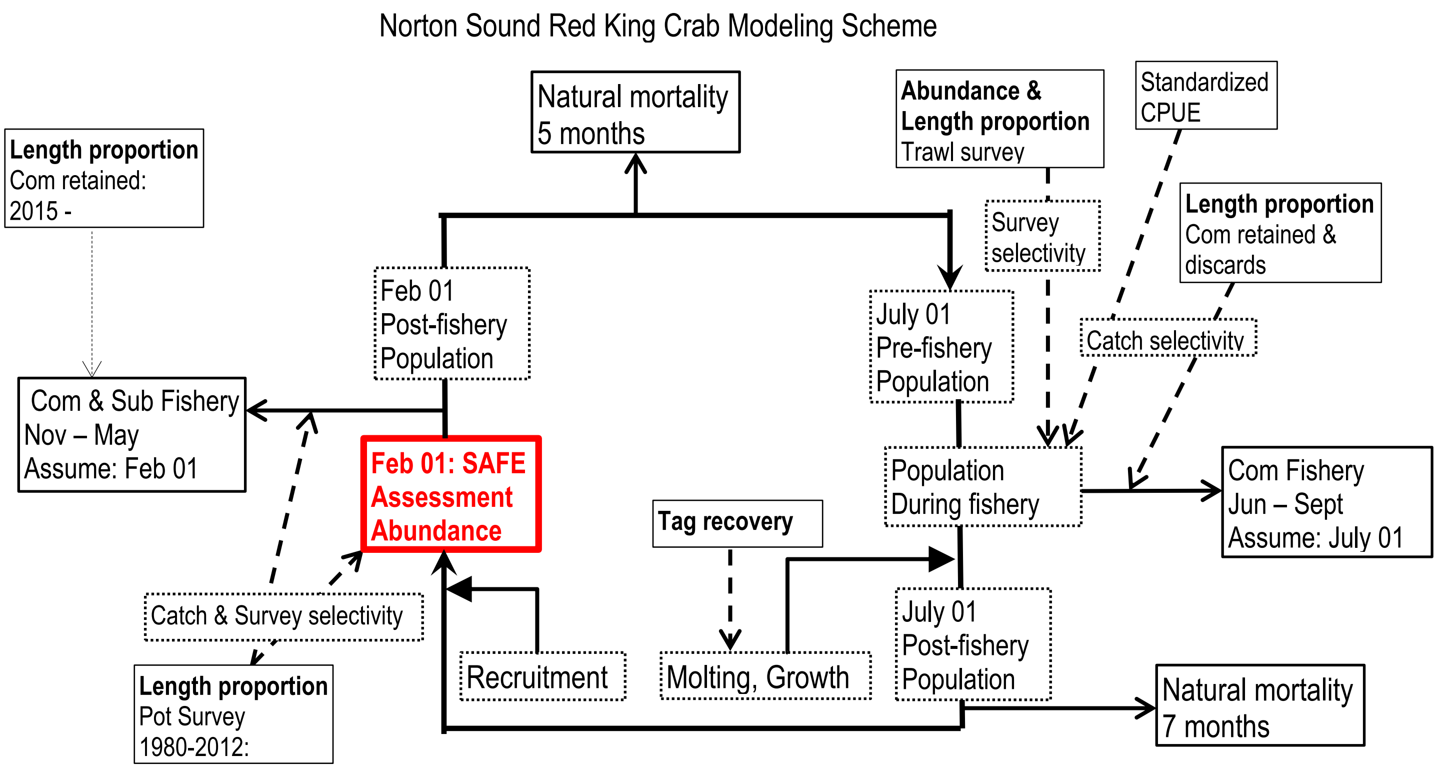
## Appendix A. Description of the Norton Sound Red King Crab Model

### a. Model description.

The model is an extension of the length-based model developed by Zheng et al. (1998) for Norton Sound red king crab. The model has 8 male length classes with model parameters estimated by the maximum likelihood method. The model estimates abundances of crab with CL ≥64 mm and with 10-mm length intervals (8 length classes, ≥134mm) because few crab measuring less than 64 mm CL were caught during surveys or fisheries and there were relatively small sample sizes for trawl and winter pot surveys. The model treats newshell and oldshell male crab separately but assumes they have the same molting probability and natural mortality.




Timeline of calendar events and crab modeling events:

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

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

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

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

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

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

for model estimated parameters $a_l$.

*Crab abundance on July 1st*

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

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

where

$N_{s,l,t}$ , $O_{s,l,t}$ : summer abundances of newshell and oldshell crab in length class *l* in year *t* ,
$N_{w,l,t-1}$, $O_{w,l,t-1}$ : winter abundances of newshell and oldshell crab in length class *l* in year *t-1* ,
$C_{w,t-1}$, $C_{p,t-1}$ : total winter commercial and subsistence catches in year *t-1*,
$P_{w,n,l,t-1}$, $P_{w,o,l,t-1}$ : Proportion of newshell and oldshell length class *l* crab in year *t-1*, harvested by winter commercial fishery,
$P_{p,n,l,t-1}$ , $P_{p,o,l,t-1}$ : Proportion of newshell and oldshell length class *l* crab in year *t-1*, harvested by winter subsistence fishery,
$D_{w,n,l,t-1}$, $D_{w,o,l,t-1}$: Discard mortality of newshell and oldshell length class *l* crab in winter commercial fishery in year *t-1* ,

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

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

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

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

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

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

*Crab abundance on Feb 1st*

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

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

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

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

where

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

*Discards*

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

Summer and winter commercial discards

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

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

$$D_{l,t} = C_{s,t}\frac{(N_{s,l,t}+O_{s,l,t})\,S_{s,l}\,(1-P_{lg,l})}{\sum_l (N_{s,l,t}+O_{s,l,t})\,S_{s,l}\,P_{lg,l}}hm_s \quad \text{(Baseline model)}$$

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

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

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

where

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

$S_{w,l}$ : Selectivity of the winter commercial fishery,
$S_{r,l}$ : Retention selectivity of the summer commercial fishery,

Winter subsistence Discards

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

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

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

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

*Recruitment*

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

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

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

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

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

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

*Molting Probability*

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

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

*Trawl net, summer commercial pot, retention selectivity*

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

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

*Alternative Summer commercial pot, retention selectivity*

Summer pot selectivity was assumed to be a logistic function of length-class mid carapace length ($L$) and parameters ($\alpha$, $\beta$) where $\beta$ corresponds to $L_{50}$.

$$S_{c,l} = \frac{1}{1+e^{-\alpha(L-\beta)}} \tag{16'}$$

*Winter pot selectivity*

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

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

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

*Growth transition matrix*

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

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

Where

$$N(x \mid \mu_{l'}, \sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left( -\frac{(L-\mu_{l'})^2}{\sigma^2} \right)$$

$$lm_l = L_1 + st \cdot l$$

$$\mu_l = L_1 + \beta_0 + \beta_1 \cdot l$$

## Observation model

*Summer trawl survey abundance*

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

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

where

$y_{st}$ : the time in year from July 1 to the mid-point of the summer trawl survey,

$y_c$: the time in year from July 1 to the mid-point for the catch before the survey, ($y_{st} > y_c$: Trawl survey starts after opening of commercial fisheries),

$P_{c,t}$ : the proportion of summer commercial crab harvested before the mid-point of trawl survey date.

$S_{st,l}$ : Selectivity of the trawl survey.

Winter pot survey CPUE

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

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

Summer commercial CPUE

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

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

Because the fishing fleet and pot limit configuration changed in 1993, $q_1$ is for fishing efforts before

1993, $q_2$ is from 1994 to present.

**Baseline model**

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

$$\begin{aligned} A_t &= \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} P_{\lg,l}] \text{ (Baseline model)} \\ A_t &= \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} S_{r,l}] \text{ (Alternative model)} \end{aligned} \tag{22}$$

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

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

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

*Summer commercial catch*

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

$$\begin{aligned} &\hat{P}_{s,n,l,t} = N_{s,l,t} S_{s,l} P_{\lg,l} / A_t \\ &\hat{P}_{s,o,l,t} = O_{s,l,t} S_{s,l} P_{\lg,l} / A_t \quad \text{(Baseline model)} \\ &\hat{P}_{s,n,l,t} = N_{s,l,t} S_{s,l} S_{r,l} / A_t \\ &\hat{P}_{s,o,l,t} = O_{s,l,t} S_{s,l} S_{r,l} / A_t \quad \text{(Alternative model)} \end{aligned} \tag{24}$$

*Summer commercial fishery discards (Base model)*

Length/shell compositions of observer discards were modeled as

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

*Summer commercial fishery total catch (Alternative model)*

Length/shell compositions of observer discards were modeled as

$$\hat{P}_{t,n,l,t} = N_{s,l,t} S_{s,l} / \sum_{l} [(N_{s,l,t} + O_{s,l,t}) S_{s,l}]$$
$$\hat{P}_{t,o,l,t} = O_{s,l,t} S_{s,l} / \sum_{l} [(N_{s,l,t} + O_{s,l,t}) S_{s,l}] \qquad (25')$$

*Summer trawl survey*

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

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

*Winter pot survey*

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

$$\hat{P}_{sw,n,l,t} = N_{w,l,t} S_{w,l} / \sum_{l} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}]$$
$$\hat{P}_{sw,o,l,t} = O_{w,l,t} S_{w,l} / \sum_{l} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \qquad (27)$$

*Spring Pot survey 2012-2015*

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

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

*Estimates of tag recovery*

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

$$\hat{P}_{l',l,t,s} = \frac{S_l \cdot [X^t]_{l',l}}{\sum_{l=1}^{n} S_l \cdot [X^t]_{l',l}} \tag{29}$$

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

$$X_{l',l} = \begin{cases} m_{l'} \cdot G_{l',l} & \text{when } l' \neq l \\ m_l \cdot G_{l',l} + (1\text{-}m_i) & \text{when } l' = l \end{cases} \tag{30}$$

**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

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

where

$i$: length/shell compositions of :

1 triennial summer trawl survey,

2 annual winter pot survey,

3 summer commercial fishery retained catch,

4 observer discards or total catch during the summer fishery

5 spring pot survey.

$K_{i,t}$: the effective sample size of length/shell compositions for data set $i$ in year $t$,

$P_{i,l,t}$ : observed and estimated length compositions for data set $i$, length class $l$, and year $t$.

$\kappa$ : a constant equal to 0.0001,

$CV$ : coefficient of variation for the survey abundance,

$B_{i,k,t}$: observed and estimated annual total abundances for data set $i$ and year $t$,

$f_t$ : observed and estimated summer fishing CPUE,

$w^2_t$: extra variance factor,

$SDR$ : Standard deviation of recruitment = 0.5,

$K_{l',t}$: sample size of length class $l'$ released and recovered after $t$-$th$ in year,

$P_{l',l,t,s}$ : observed and estimated proportion of tagged crab released at length $l'$ and recaptured at length $l$, after $t$-$th$ year by commercial fishy pot selectivity $s$,

$W$: weighting for the tagging survey likelihood

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

**d. Parameter estimation framework:**

i. Parameters Estimated Independently

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

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

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

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

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

ii. Parameters Estimated Conditionally

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

A likelihood approach was used to estimate parameters

**e. Definition of model outputs.**

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

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

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

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

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

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

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

iv.

**f. OFL**

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

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

And

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

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

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

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

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

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

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

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

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

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

Thus, OFL is

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

Combining (2) and (7),

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

Solving (8) for x

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

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

revised retained OFL is

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

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

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

Summer fishery harvest rate (Fs) is

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

# Appendix B

# Norton Sound Red King Crab CPUE Standardization

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

# Methods

## Data Source & Cleaning

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

Following data cleaning and combining methods were conducted.

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

## Data Censoring

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

## Analyses

A GLM was constructed as

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

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

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

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

The analyses were conducted for both censored and full data.
Generally, censoring had little effects on standardized CPUE.

Table B-1. List of variables in the fish ticket database. Variables in bold face were used for generalized linear modeling.

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

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

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

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

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

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

| Data | Explanatory variables | Null dev. | Null df | Resid. dev. | Resid. df | AIC |
|---|---|---|---|---|---|---|
| 1977-1992 | YR+VSL+MOY+MSA | 703.7 | 483 | 247.6 | 418 | 1183 |
| 1993-2018 | YR+VSL+WOY+MSA+PF | 4024.0 | 5638 | 2626.6 | 5538 | 11899 |

Table B-5. Standardized (Censored/full data), and scaled arithmetic observed CPUE indices from 1977–1992.

| Year | Censored | | Full data | | Observed |
|---|---|---|---|---|---|
| | **CPUE** | **SE** | **CPUE** | **SE** | **CPUE** |
| 1977 | 2.31 | 0.24 | 3.11 | 0.35 | 2.05 |
| 1978 | 4.15 | 0.13 | 2.51 | 0.23 | 4.77 |
| 1979 | 1.72 | 0.11 | 1.92 | 0.25 | 1.88 |
| 1980 | 2.14 | 0.16 | 2.15 | 0.28 | 1.90 |
| 1981 | 0.65 | 0.09 | 0.67 | 0.21 | 0.71 |
| 1982 | 0.25 | 0.12 | 0.11 | 0.25 | 0.30 |
| 1983 | 0.55 | 0.17 | 1.19 | 0.22 | 0.67 |
| 1984 | 1.10 | 0.18 | 1.02 | 0.23 | 0.97 |
| 1985 | 0.44 | 0.14 | 0.38 | 0.20 | 0.56 |
| 1986 | 1.63 | 0.33 | 0.85 | 0.41 | 1.75 |
| 1987 | 0.80 | 0.29 | 0.66 | 0.32 | 0.66 |
| 1988 | 2.09 | 0.33 | 1.63 | 0.67 | 1.72 |
| 1989 | 0.90 | 0.29 | 2.10 | 0.33 | 0.79 |
| 1990 | 1.60 | 0.41 | 1.31 | 0.40 | 1.31 |
| 1991 | | | | | |
| 1992 | 0.17 | 0.25 | 0.35 | 0.31 | 0.18 |
| 1993 | 0.96 | 0.09 | 1.03 | 0.10 | 1.04 |
| 1994 | 0.63 | 0.05 | 0.82 | 0.07 | 0.67 |
| 1995 | 0.40 | 0.05 | 0.44 | 0.06 | 0.42 |
| 1996 | 0.54 | 0.08 | 0.52 | 0.08 | 0.55 |
| 1997 | 0.76 | 0.10 | 0.81 | 0.10 | 0.88 |
| 1998 | 0.67 | 0.13 | 0.76 | 0.13 | 0.63 |
| 1999 | 0.47 | 0.13 | 0.96 | 0.14 | 0.53 |
| 2000 | 1.35 | 0.06 | 1.25 | 0.06 | 1.36 |
| 2001 | 0.74 | 0.05 | 0.64 | 0.05 | 0.67 |
| 2002 | 1.10 | 0.06 | 1.32 | 0.06 | 1.05 |
| 2003 | 0.90 | 0.05 | 0.86 | 0.05 | 0.87 |
| 2004 | 1.35 | 0.05 | 1.31 | 0.05 | 1.37 |
| 2005 | 1.24 | 0.05 | 1.23 | 0.05 | 1.26 |
| 2006 | 1.45 | 0.05 | 1.33 | 0.05 | 1.38 |
| 2007 | 1.10 | 0.05 | 1.06 | 0.05 | 1.00 |
| 2008 | 1.54 | 0.05 | 1.35 | 0.05 | 1.40 |
| 2009 | 1.04 | 0.04 | 0.87 | 0.04 | 1.00 |
| 2010 | 1.40 | 0.04 | 1.25 | 0.04 | 1.29 |
| 2011 | 1.69 | 0.05 | 1.64 | 0.05 | 1.66 |
| 2012 | 1.58 | 0.04 | 1.33 | 0.04 | 1.51 |
| 2013 | 0.74 | 0.04 | 0.70 | 0.04 | 0.82 |
| 2014 | 1.18 | 0.04 | 1.18 | 0.04 | 1.19 |
| 2015 | 1.55 | 0.05 | 1.52 | 0.05 | 1.47 |
| 2016 | 1.46 | 0.05 | 1.33 | 0.05 | 1.50 |
| 2017 | 1.27 | 0.05 | 1.16 | 0.05 | 1.28 |
| 2018 | 0.81 | 0.05 | 0.68 | 0.05 | 0.85 |

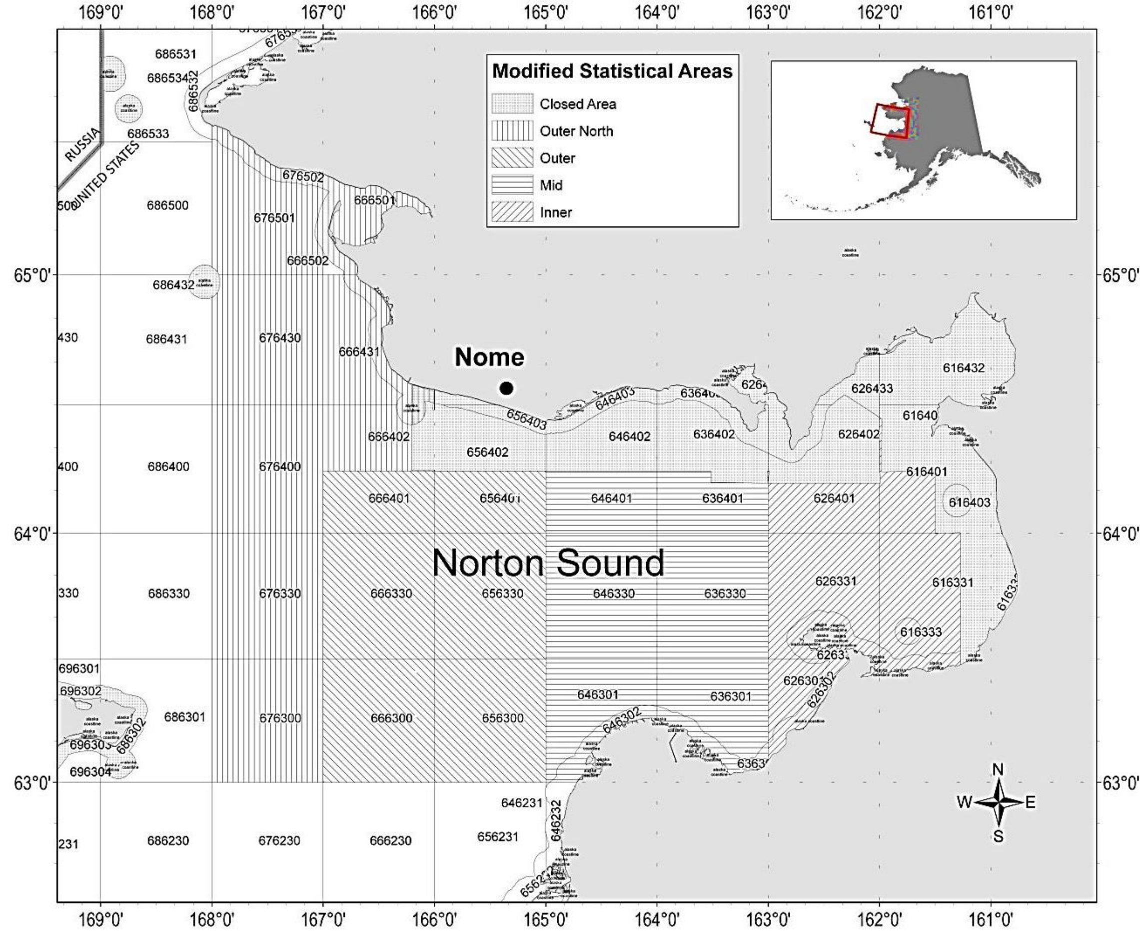



Figure A2-1. Closed area and statistical area boundaries used for reporting commercial harvest information for red king crab in Registration Area Q, Northern District, Norton Sound Section and boundaries of the new *Modified Statistical Areas* used in this analysis.

# Appendix C1: Model 0 Results

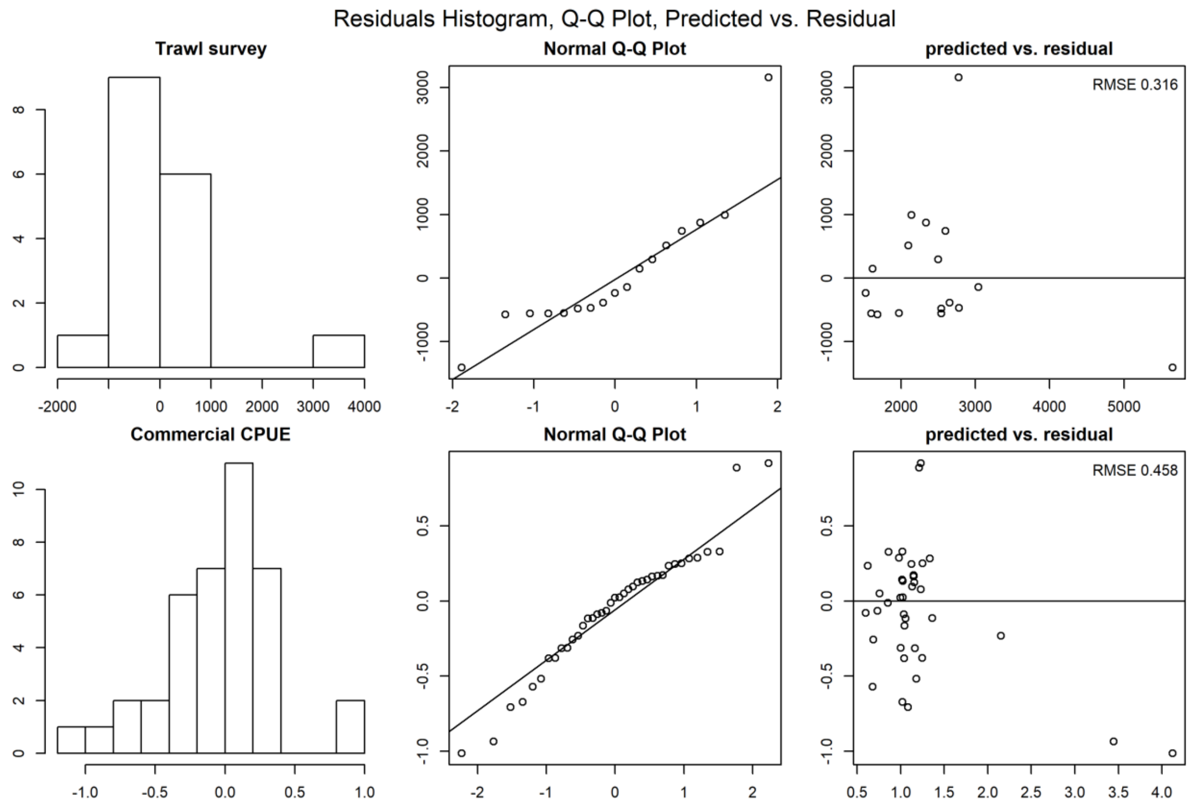



Figure C1-1. QQ Plot of Trawl survey and Commercial CPUE.

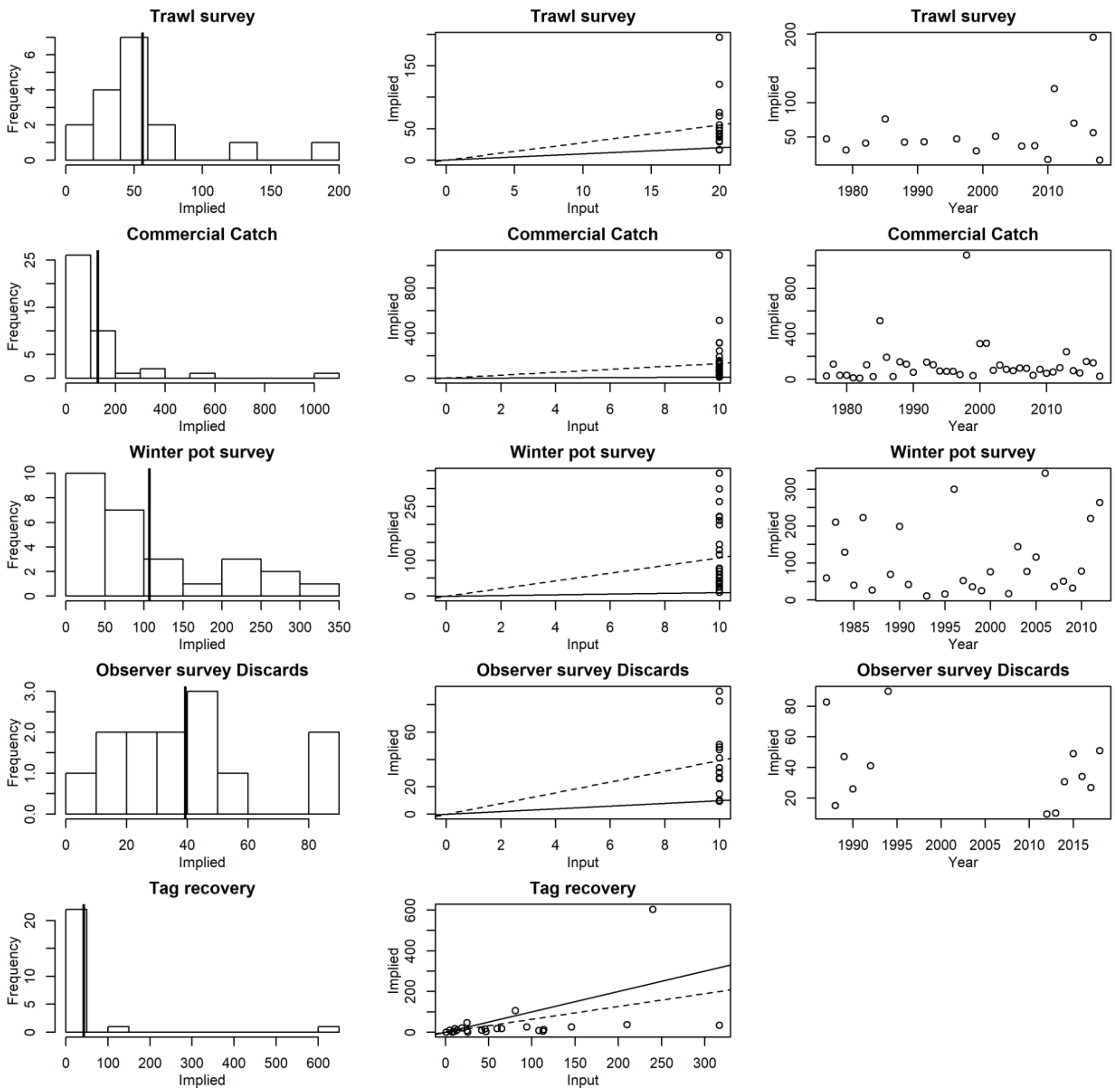



Figure C1-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column show input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

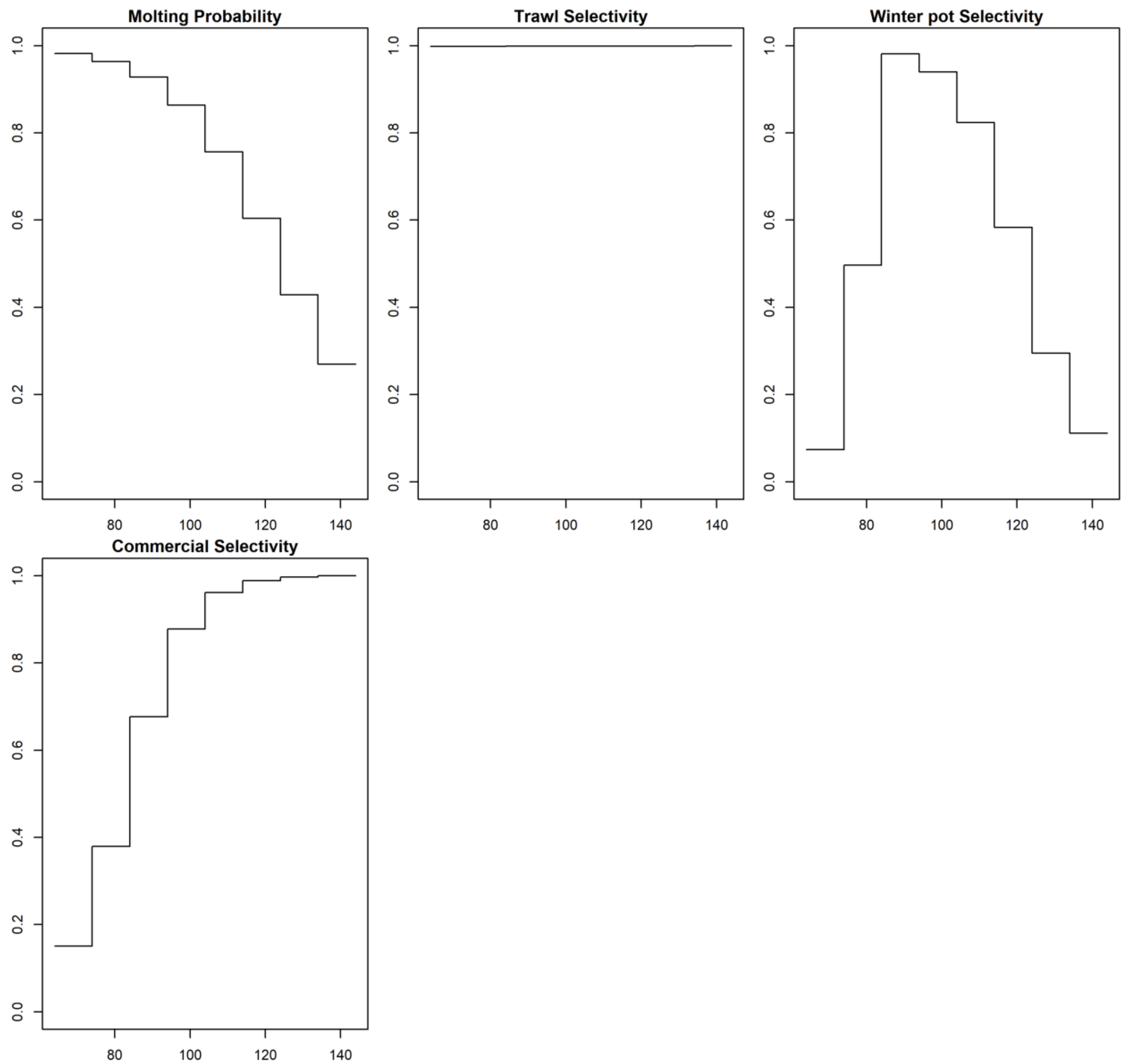



Figure C1-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

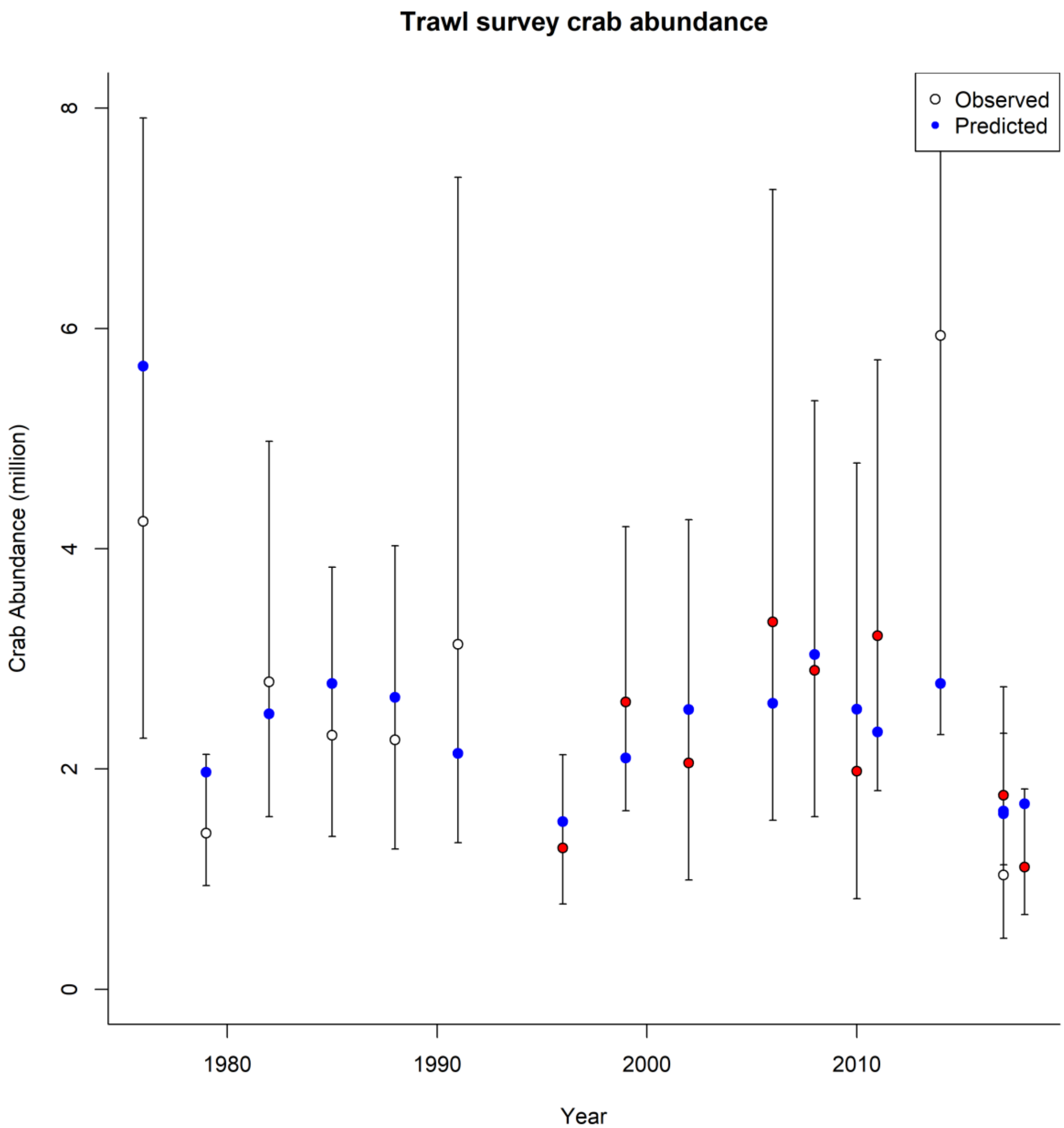



Figure C1-4. Estimated trawl survey male abundance (crab >= 64 mm CL). Observed: White: NOAA Trawl Survey, Red: ADG&G Trawl Survey

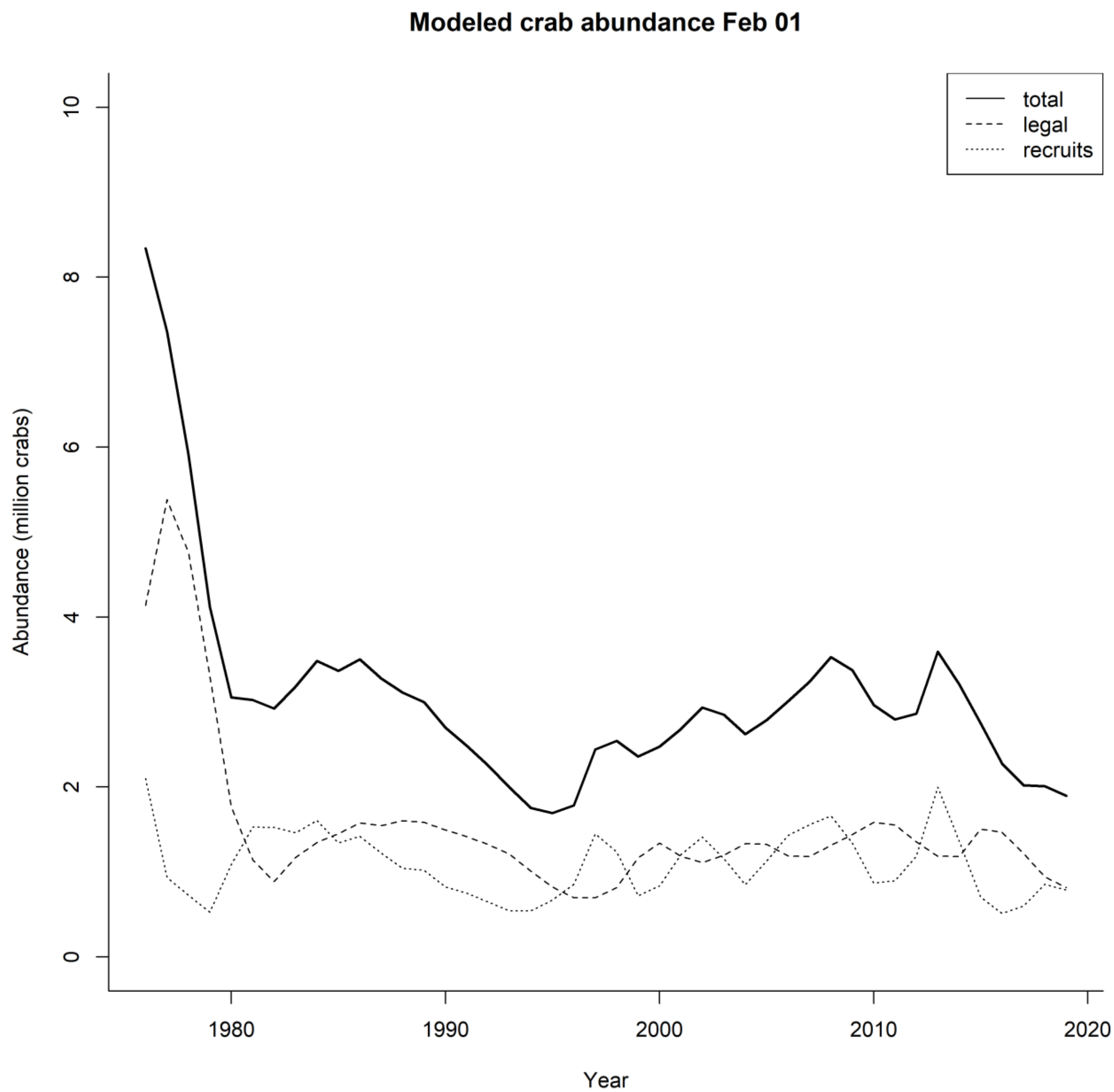



Figure C1-5. Estimated abundance of legal males from 1976-2015.

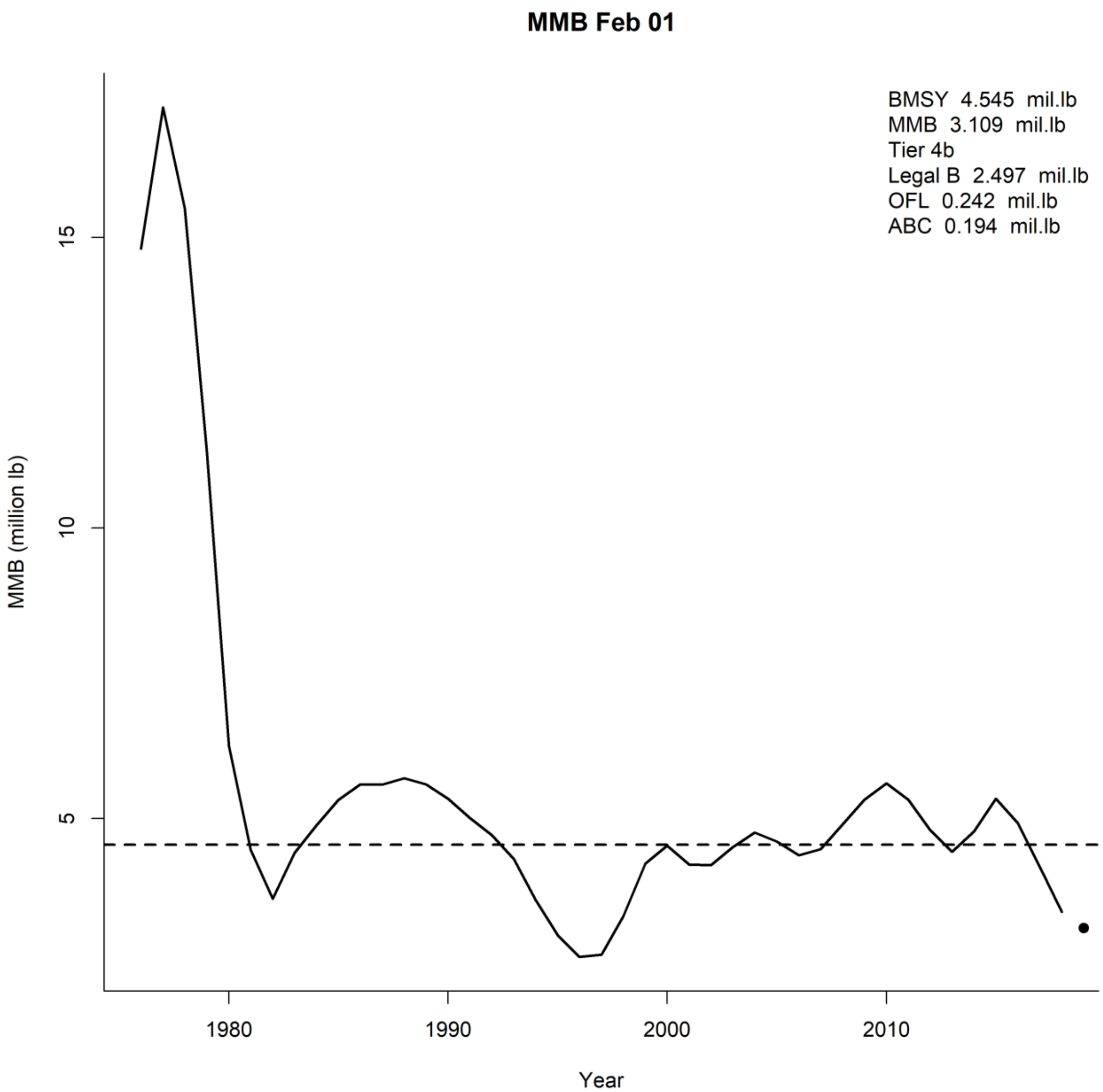



Figure C1-6. Estimated abundance of Mature Male Biomass from 1976-2019. Dash line shows Bmsy (Average MMB of 1980-2019).

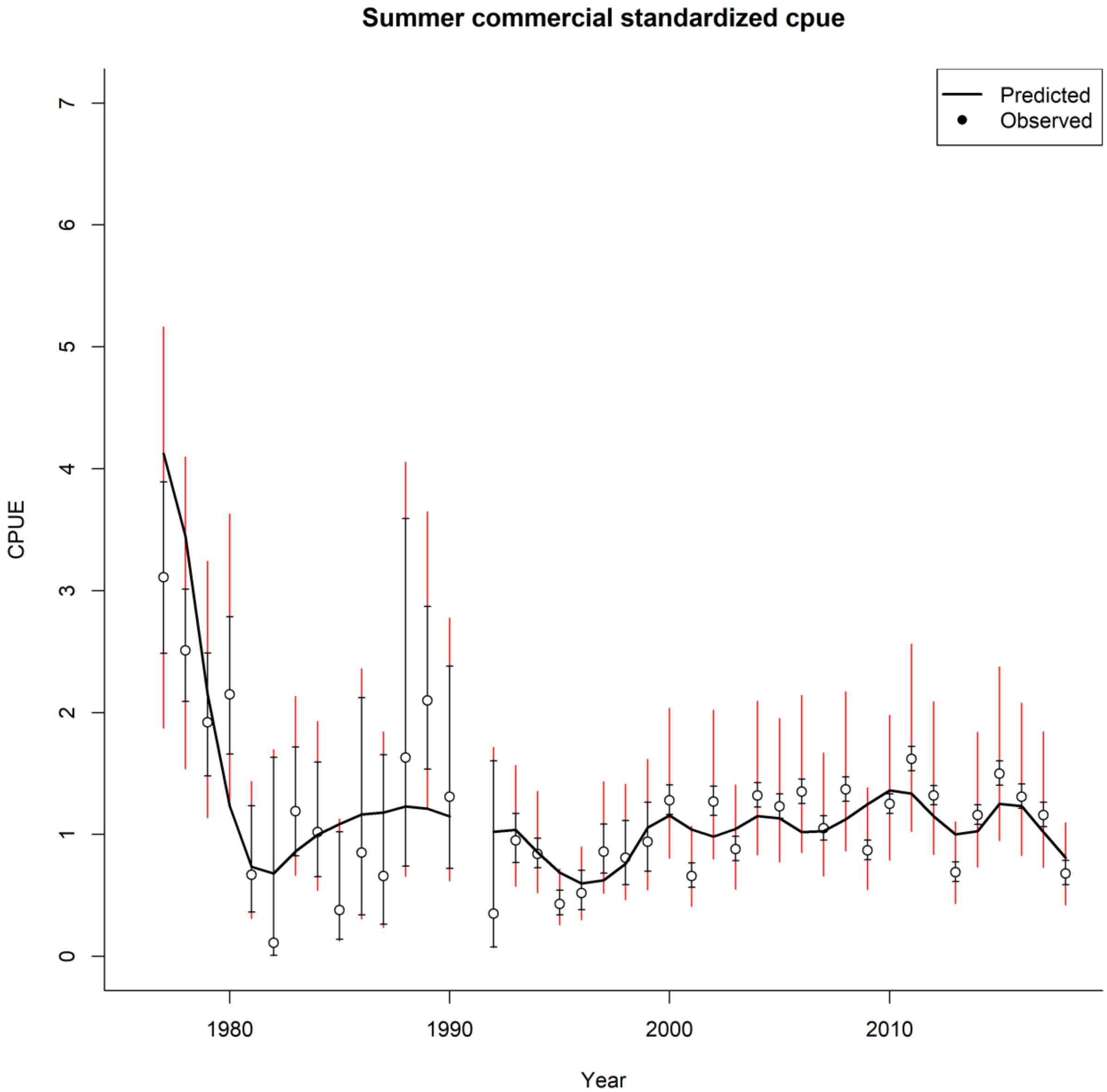



Figure C1-7. Summer commercial standardized cpue 1977-2018.

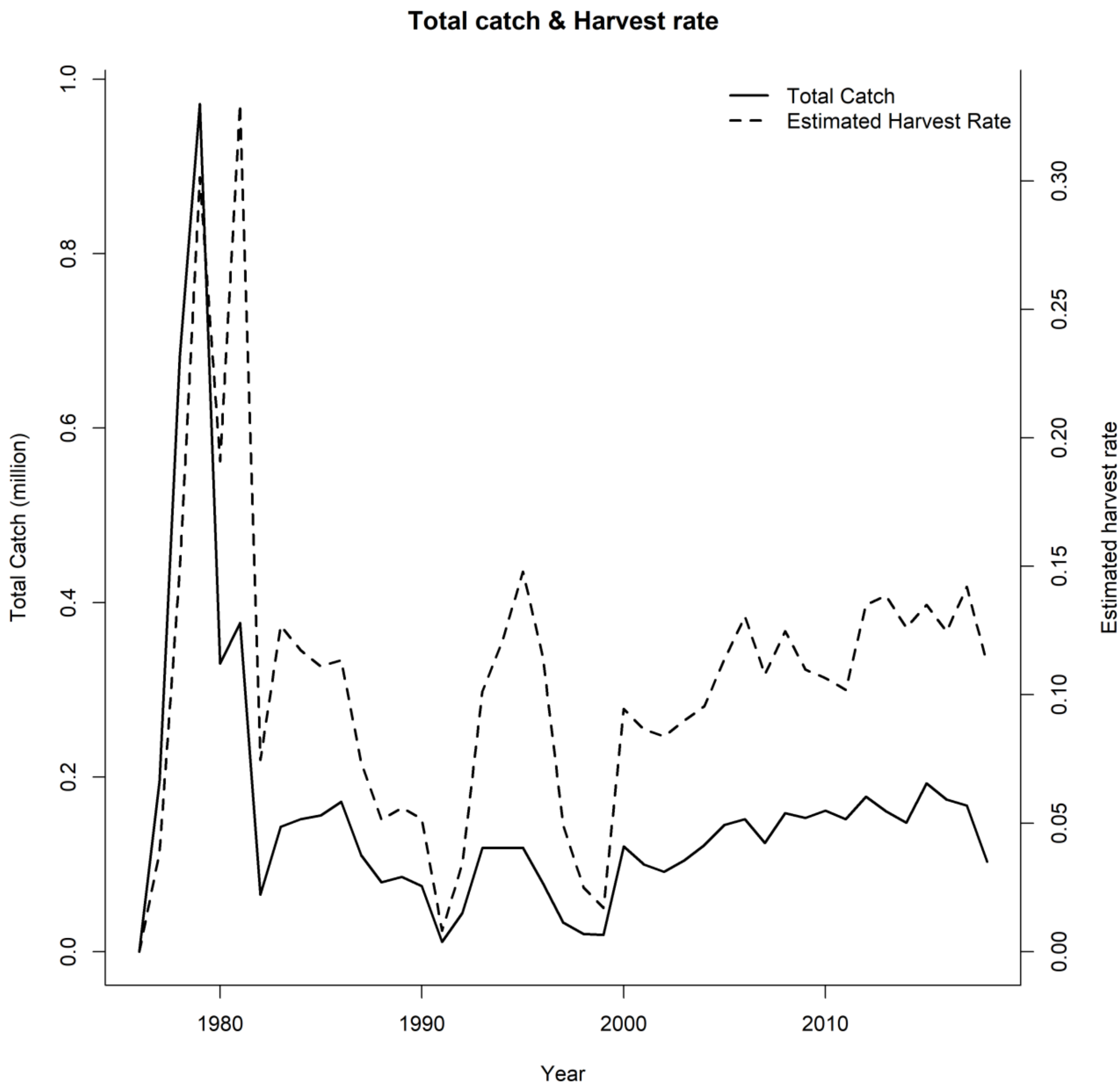



Figure C1-8. Total catch and estimated harvest rate 1976-2018.

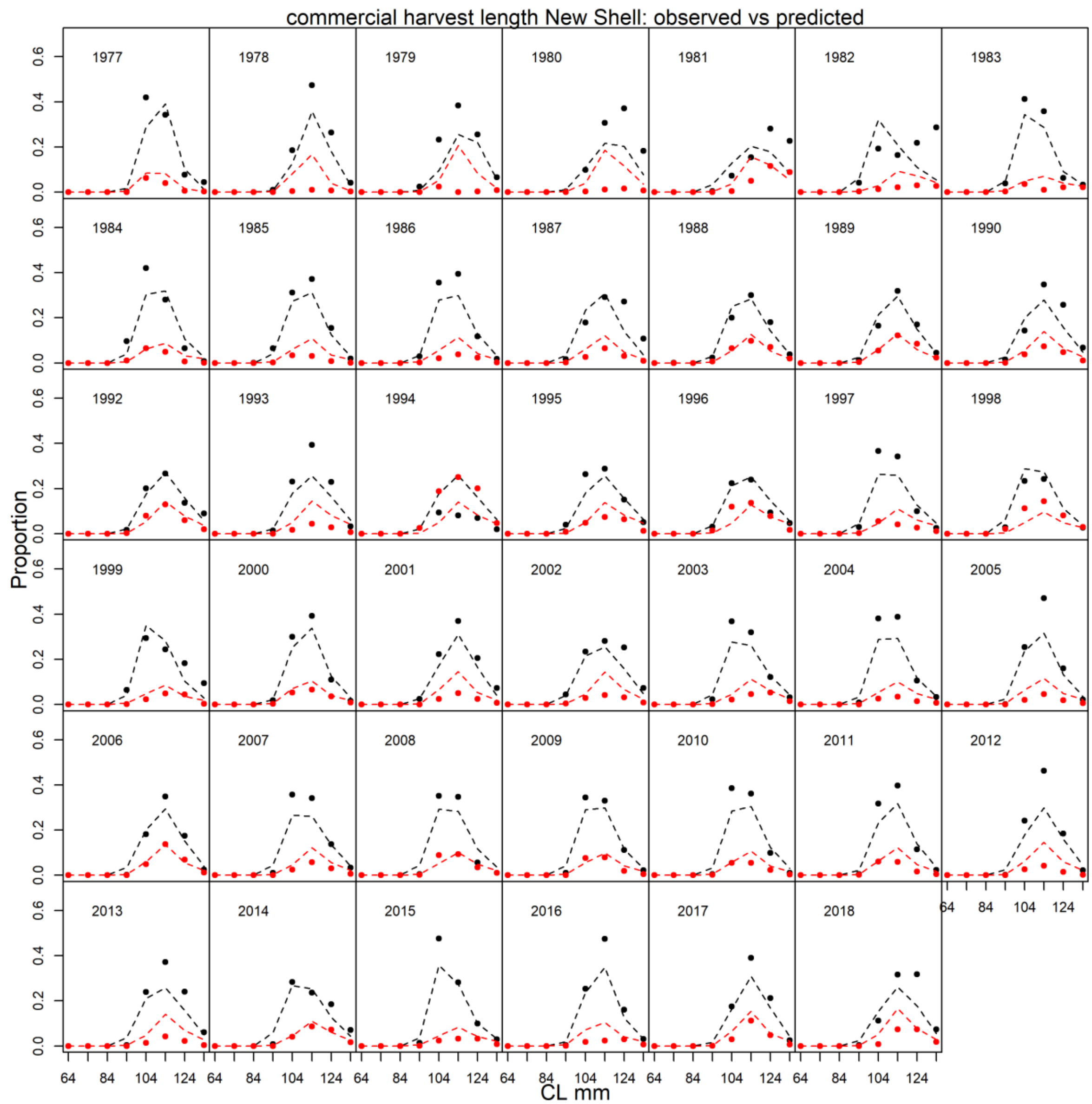



Figure C1-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Bladk: New Shell, Red: Old Shell

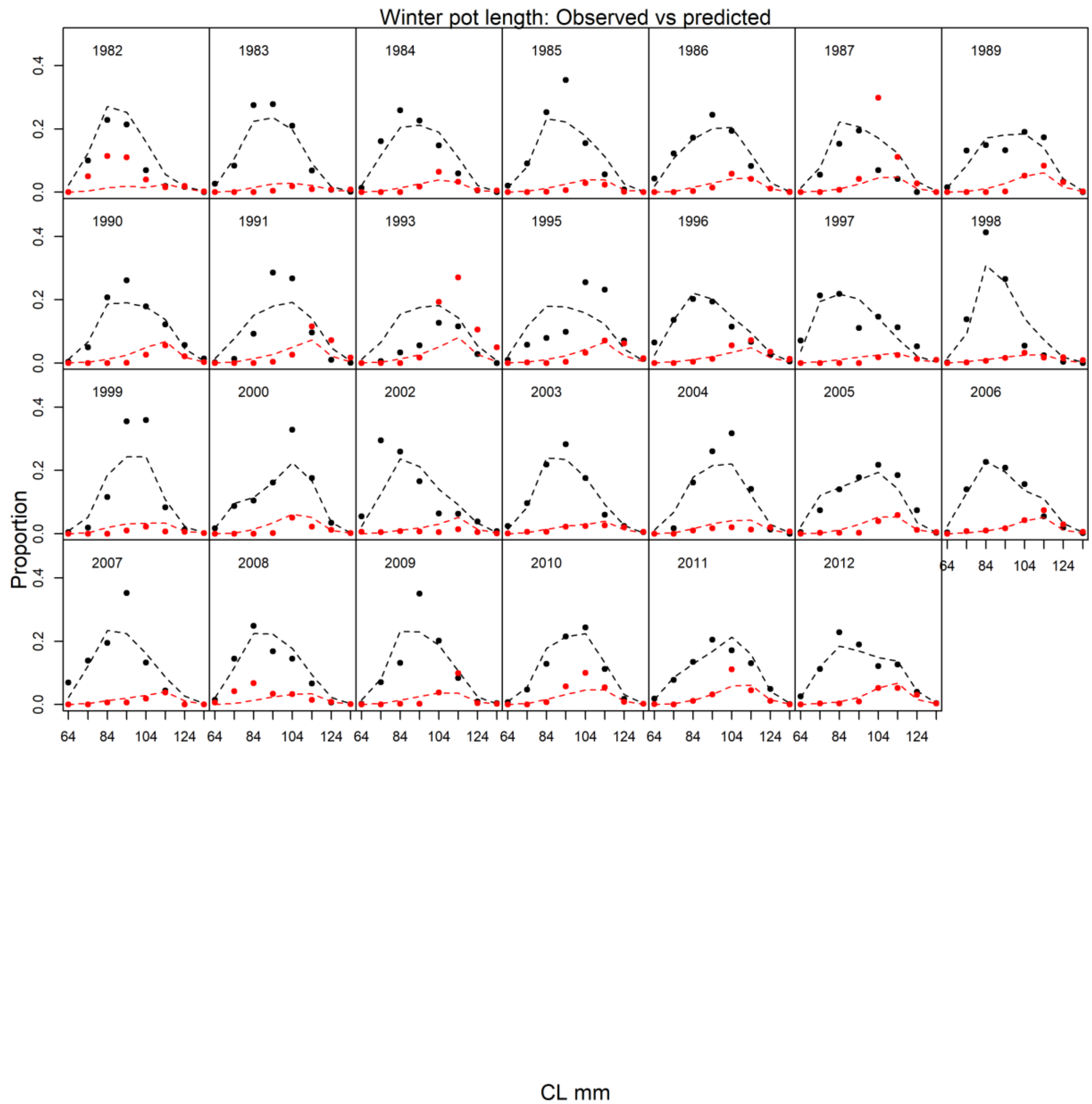
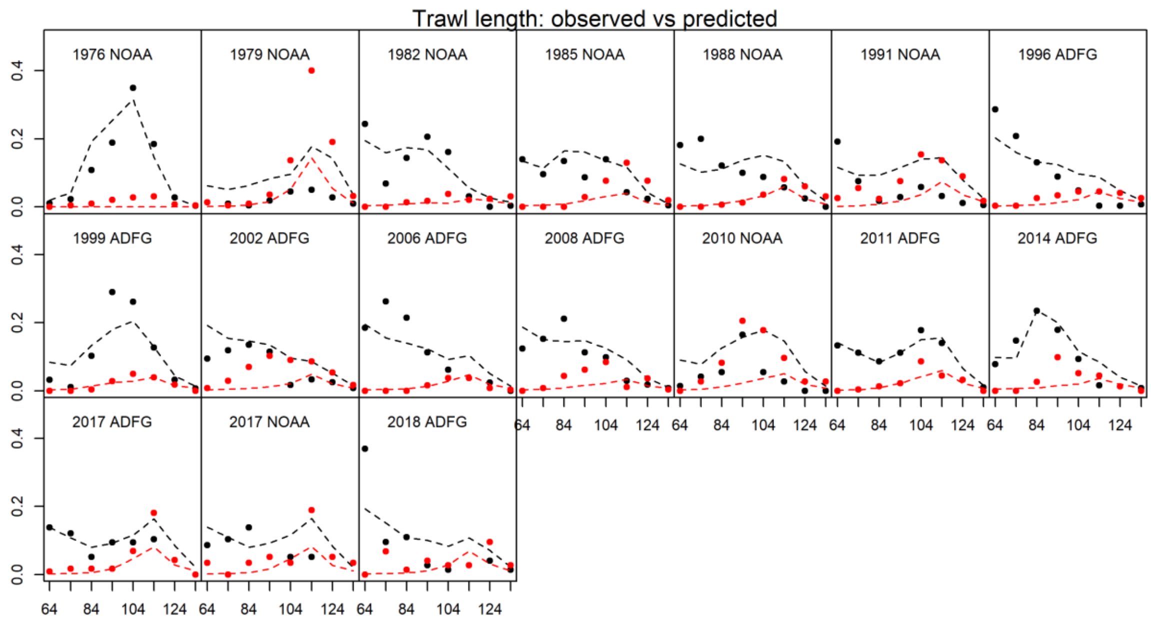



Figure C1-10. Predicted (dashed line) vs. observed (black dots) length class proportions for the winter and spring pot survey.


Trawl length: observed vs predicted
1976 NOAA
1979 NOAA
1982 NOAA
1985 NOAA
1988 NOAA
1991 NOAA
1996 ADFG
1999 ADFG
2002 ADFG
2006 ADFG
2008 ADFG
2010 NOAA
2011 ADFG
2014 ADFG
2017 ADFG
2017 NOAA
2018 ADFG
0.0
0.2
0.4
64
84
104
124

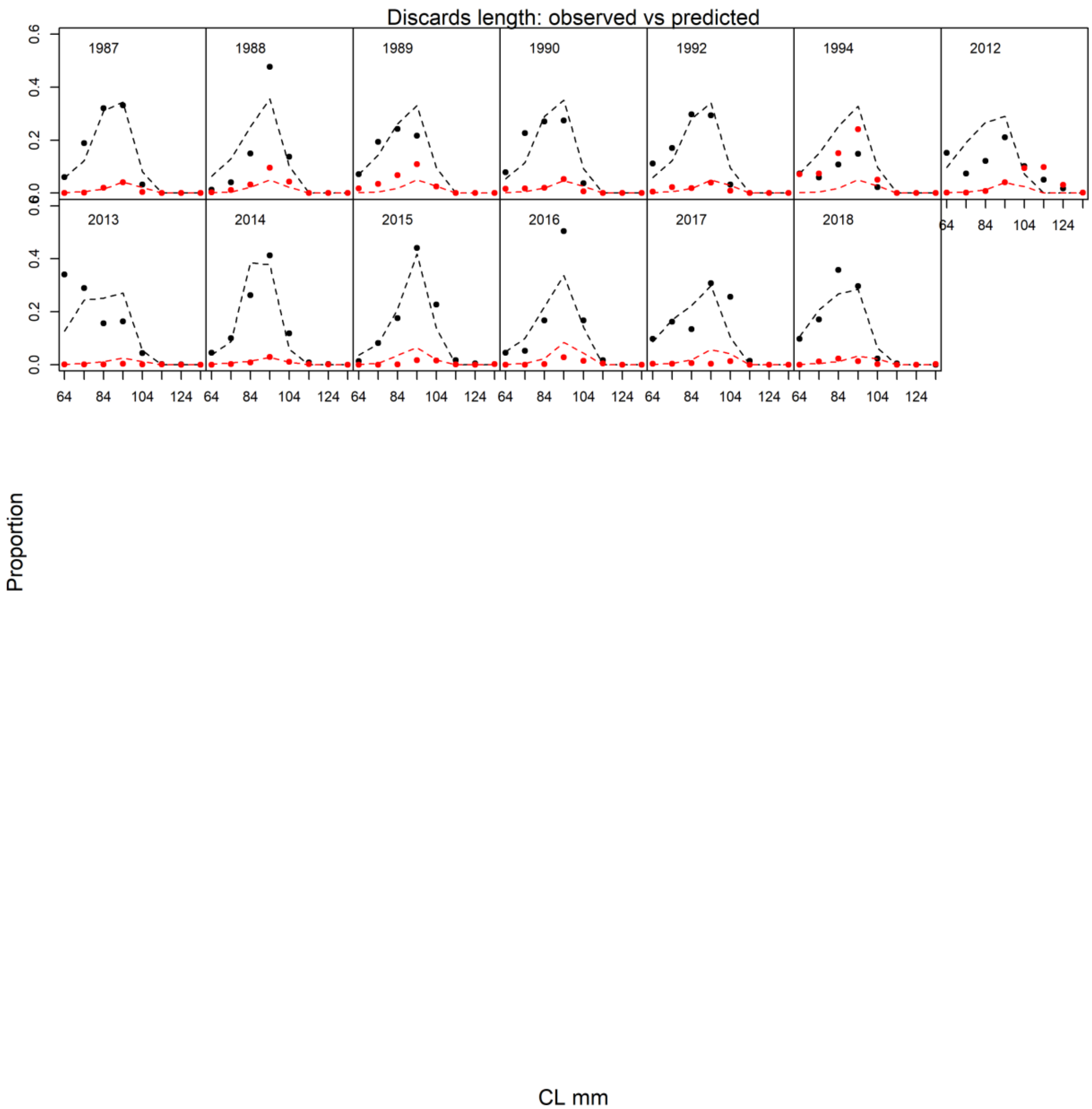



Figure C1-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey.

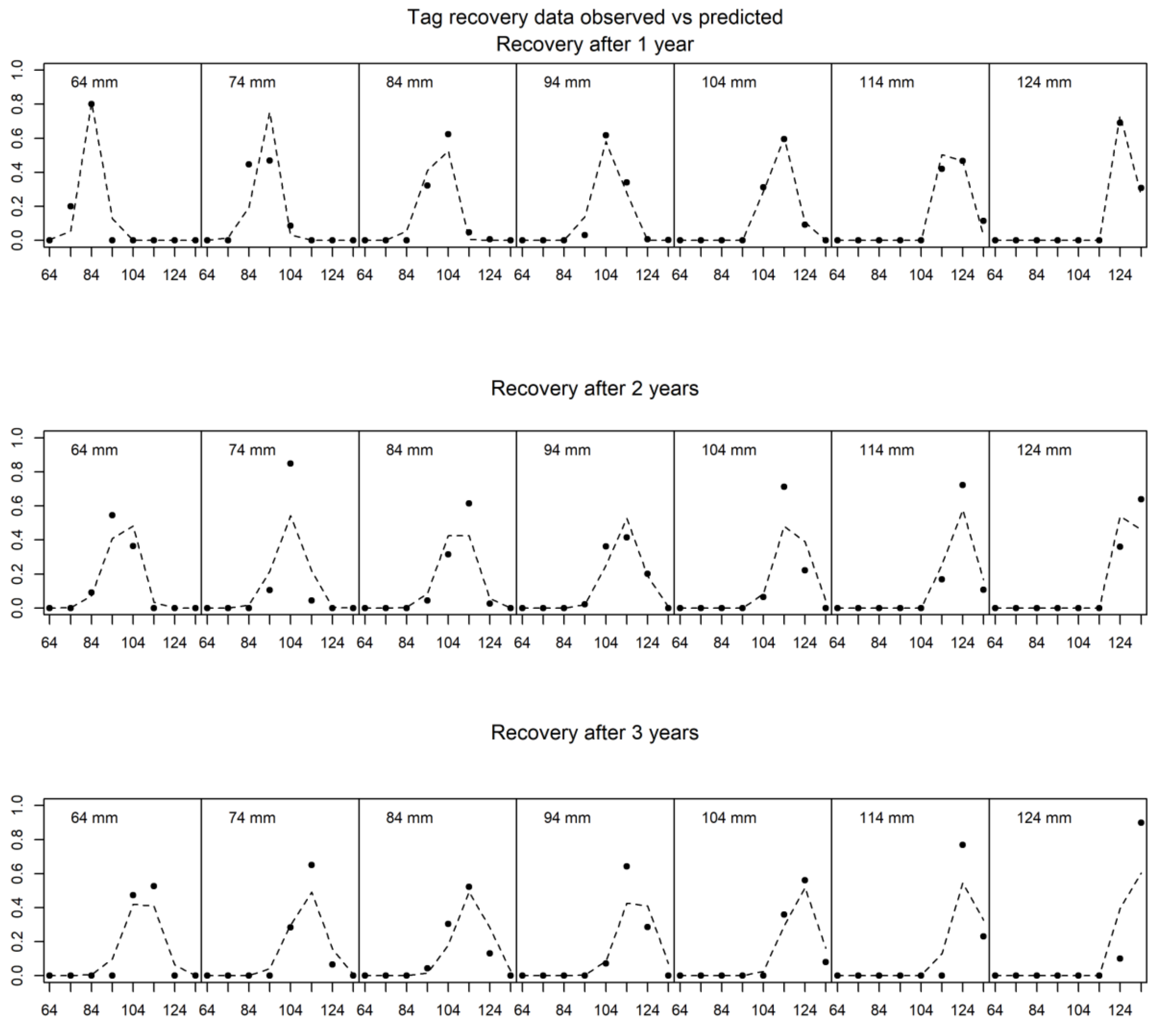



Figure C1-13. Predicted vs. observed length class proportions for tag recovery data.

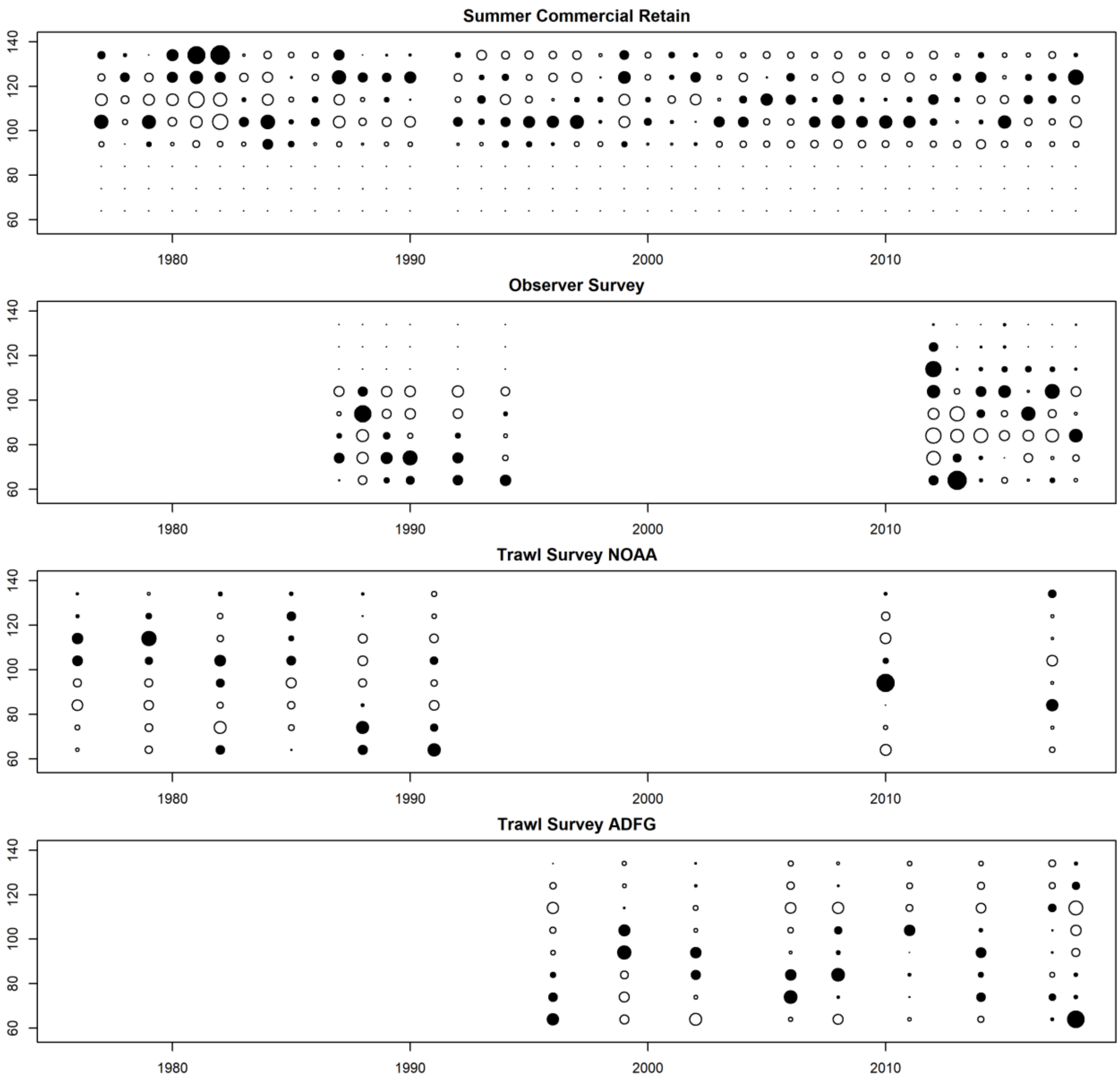



Figure C1-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

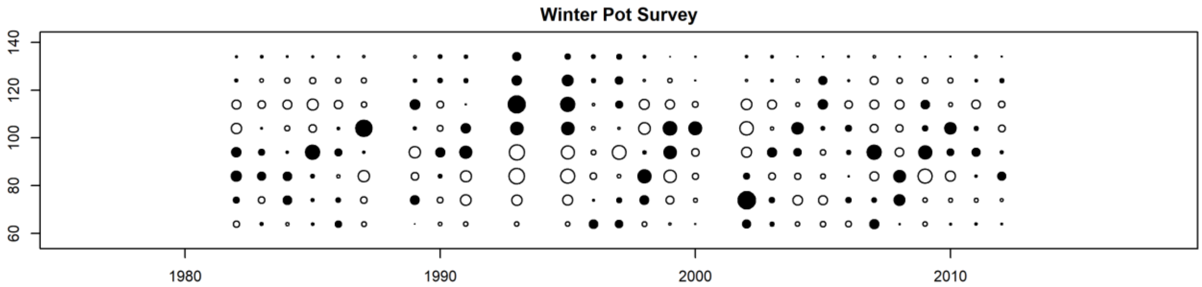



Figure C1-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table C1 . Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

| name | Estimate | std.dev |
|---|---|---|
| log_$q_1$ | -6.965 | 0.168 |
| log_$q_2$ | -6.816 | 0.109 |
| log_$N_{76}$ | 9.029 | 0.130 |
| $R_0$ | 6.440 | 0.081 |
| log_$R_{76}$ | 0.013 | 0.416 |
| log_$R_{77}$ | -0.541 | 0.370 |
| log_$R_{78}$ | -0.725 | 0.353 |
| log_$R_{79}$ | 0.373 | 0.315 |
| log_$R_{80}$ | 0.500 | 0.283 |
| log_$R_{81}$ | 0.404 | 0.263 |
| log_$R_{82}$ | 0.372 | 0.314 |
| log_$R_{83}$ | 0.540 | 0.275 |
| log_$R_{84}$ | 0.147 | 0.291 |
| log_$R_{85}$ | 0.447 | 0.276 |
| log_$R_{86}$ | 0.061 | 0.286 |
| log_$R_{87}$ | 0.021 | 0.246 |
| log_$R_{88}$ | 0.025 | 0.258 |
| log_$R_{89}$ | -0.329 | 0.280 |
| log_$R_{90}$ | -0.276 | 0.253 |
| log_$R_{91}$ | -0.526 | 0.285 |
| log_$R_{92}$ | -0.673 | 0.302 |
| log_$R_{93}$ | -0.577 | 0.289 |
| log_$R_{94}$ | -0.292 | 0.257 |
| log_$R_{95}$ | -0.063 | 0.225 |
| log_$R_{96}$ | 0.576 | 0.217 |
| log_$R_{97}$ | -0.016 | 0.293 |
| log_$R_{98}$ | -0.624 | 0.320 |
| log_$R_{99}$ | -0.008 | 0.310 |
| log_$R_{00}$ | 0.311 | 0.263 |
| log_$R_{01}$ | 0.390 | 0.241 |
| log_$R_{02}$ | -0.005 | 0.314 |
| log_$R_{03}$ | -0.280 | 0.330 |
| log_$R_{04}$ | 0.300 | 0.241 |
| log_$R_{05}$ | 0.425 | 0.222 |
| log_$R_{06}$ | 0.477 | 0.243 |

| name | Estimate | std.dev |
|---|---|---|
| log_$R_{07}$ | 0.540 | 0.231 |
| log_$R_{08}$ | 0.134 | 0.287 |
| log_$R_{09}$ | -0.367 | 0.294 |
| log_$R_{10}$ | -0.002 | 0.253 |
| log_$R_{11}$ | 0.282 | 0.274 |
| log_$R_{12}$ | 0.890 | 0.185 |
| log_$R_{13}$ | -0.196 | 0.284 |
| log_$R_{14}$ | -0.568 | 0.294 |
| log_$R_{15}$ | -0.751 | 0.269 |
| log_$R_{16}$ | -0.389 | 0.226 |
| log_$R_{17}$ | -0.018 | 0.275 |
| $a_1$ | 1.543 | 4.575 |
| $a_2$ | 2.316 | 4.264 |
| $a_3$ | 3.826 | 4.069 |
| $a_4$ | 4.106 | 4.055 |
| $a_5$ | 4.325 | 4.046 |
| $a_6$ | 3.550 | 4.075 |
| $a_7$ | 2.117 | 4.335 |
| r1 | 10.000 | 0.845 |
| r2 | 9.680 | 0.863 |
| log_a | -2.645 | 0.087 |
| log_b | 4.824 | 0.014553 |
| log_$\phi_{st1}$ | 3.145 | 5183.900 |
| log_$\phi_{wa}$ | -2.115 | 0.317 |
| log_$\phi_{wb}$ | 4.798 | 0.028 |
| Sw1 | 0.073 | 0.035 |
| Sw2 | 0.500 | 353.550 |
| log_$\phi_1$ | 3.795 | 6501.300 |
| $w^2_t$ | 0.052 | 0.016 |
| q | 0.766 | 0.131 |
| $\sigma$ | 3.876 | 0.216 |
| $\beta_1$ | 12.301 | 0.705 |
| $\beta_2$ | 7.700 | 0.175 |
| *ms78* | 3.189 | 0.272 |

# Appendix C2: Model 1 Results

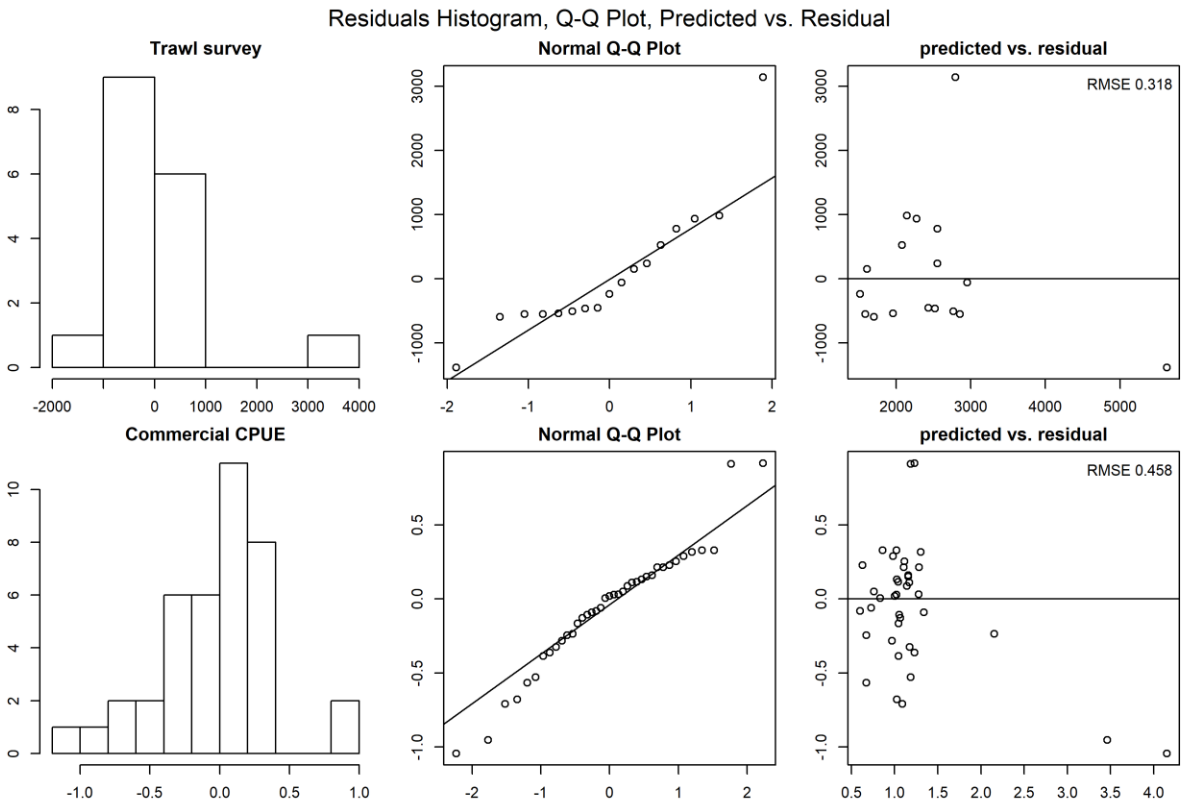



Figure C2-1. QQ Plot of Trawl survey and Commercial CPUE.

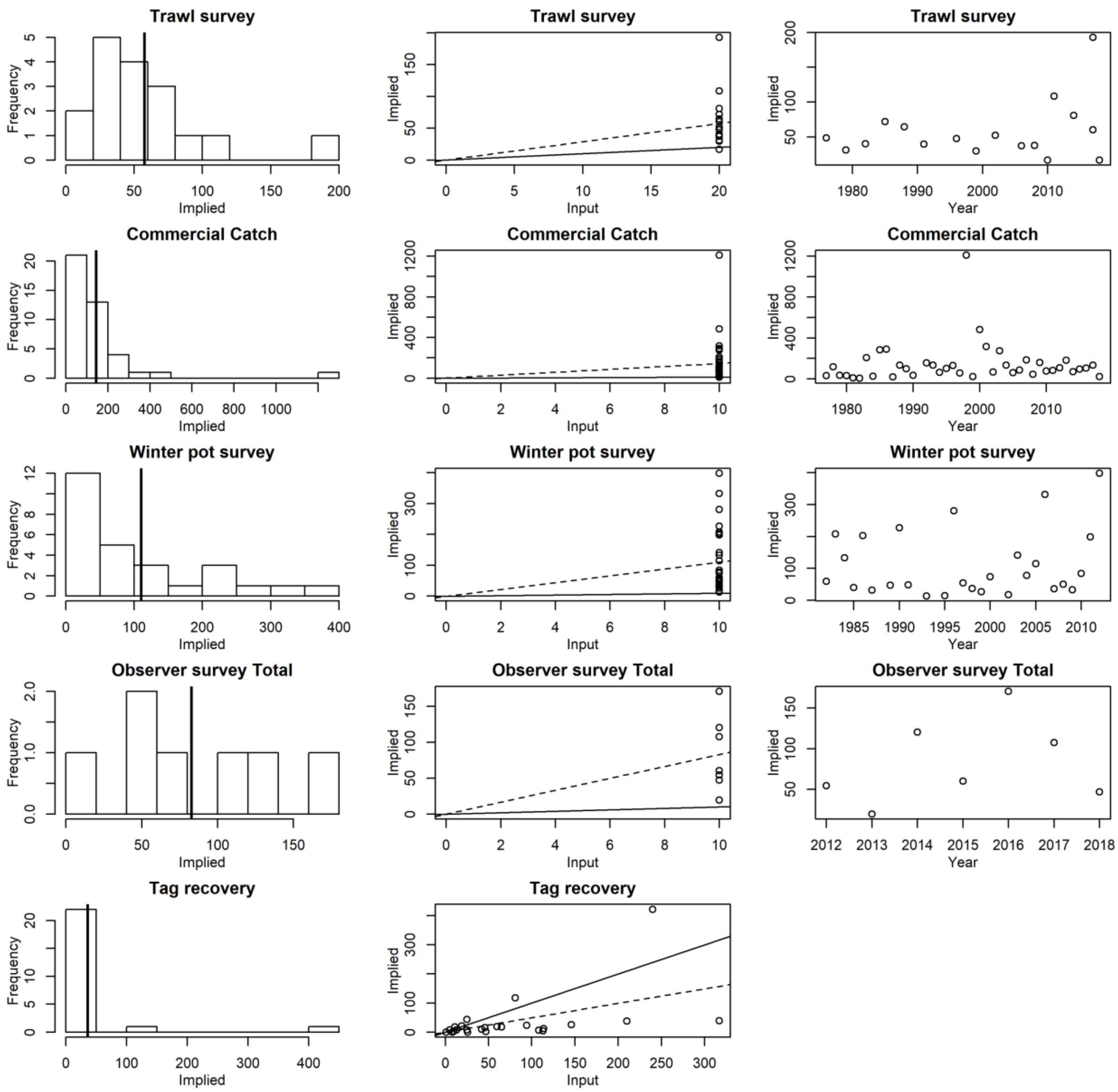



Figure C2-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column show input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

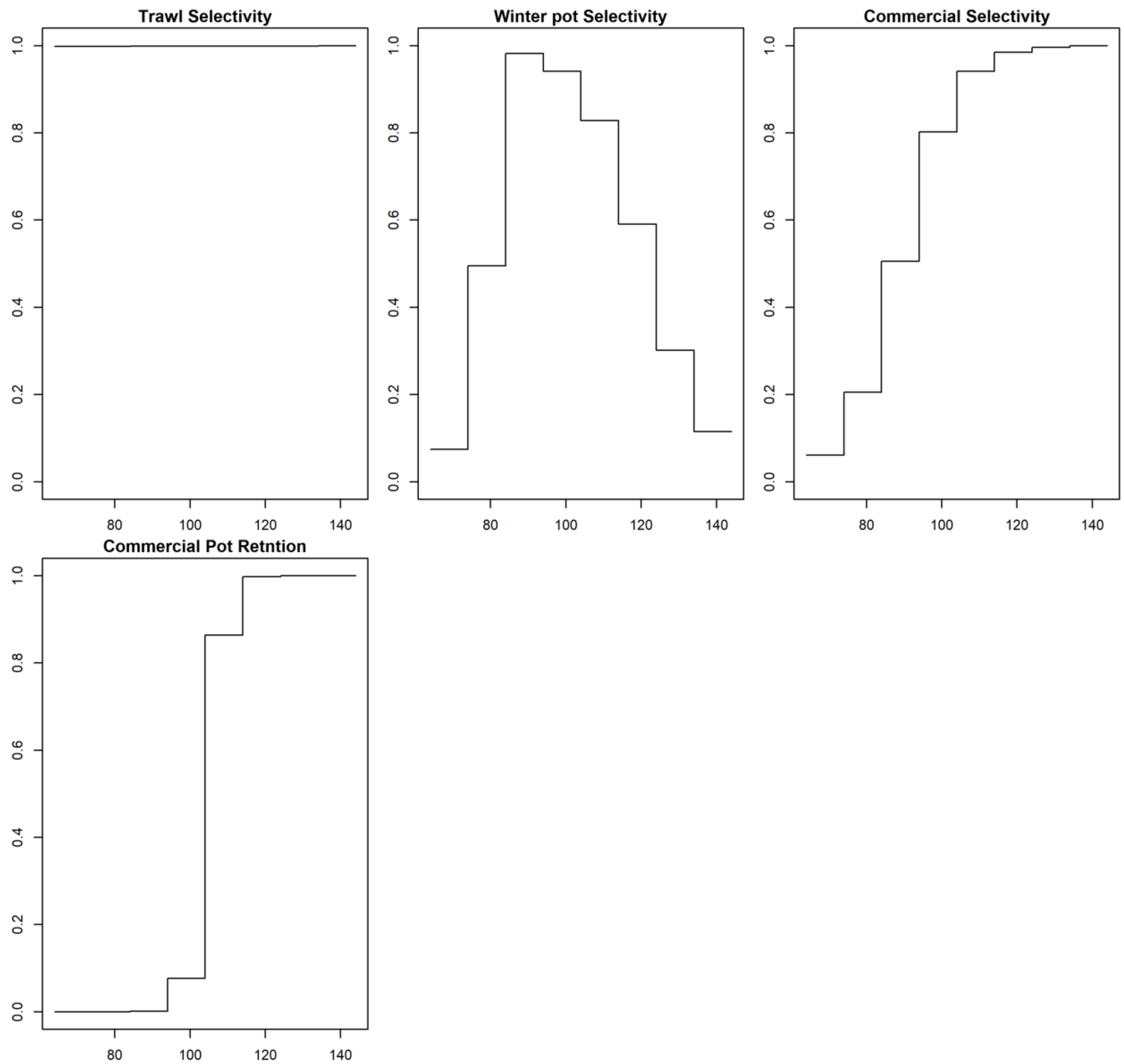



Figure C2-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

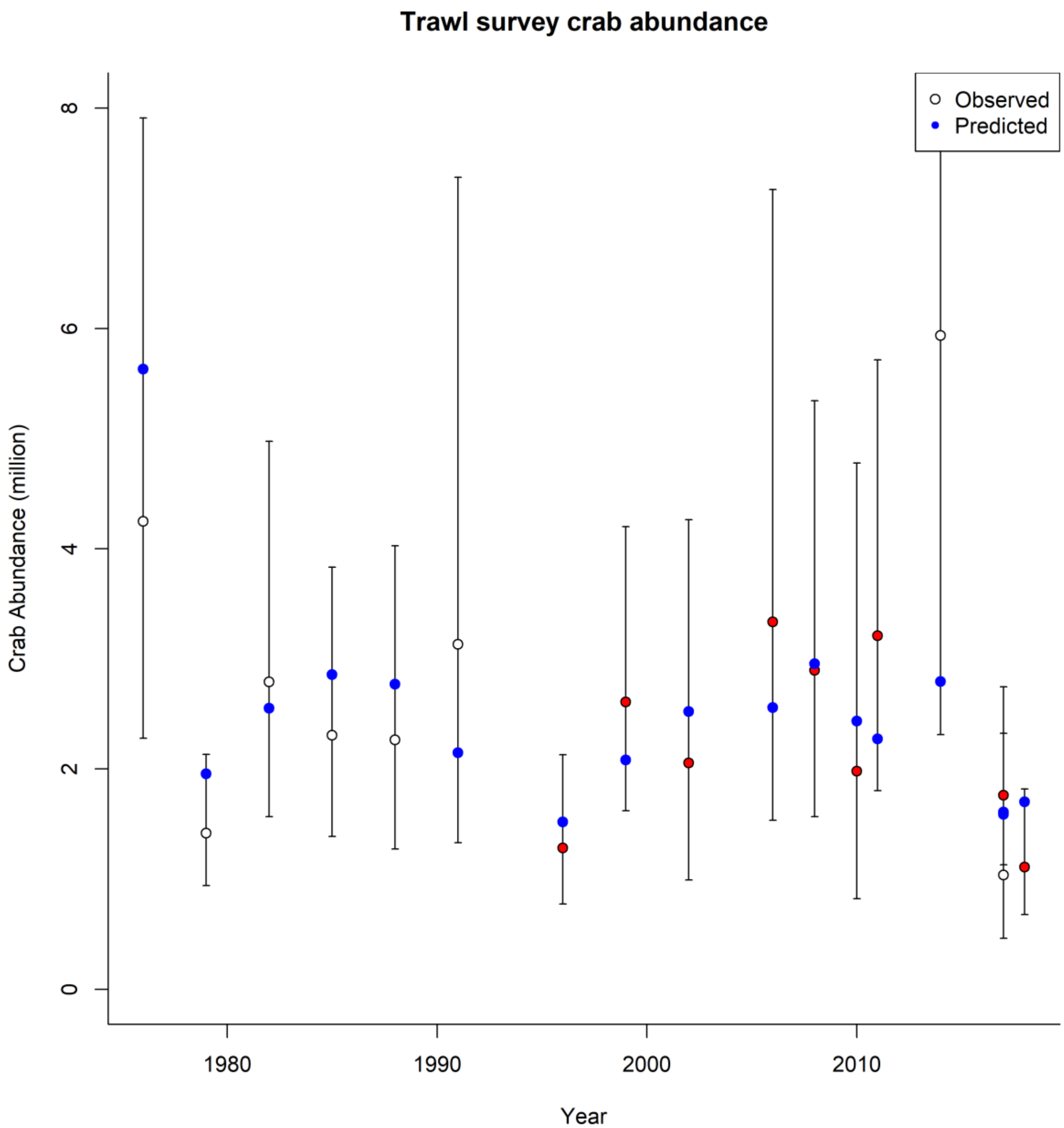



Figure C2-4. Estimated trawl survey male abundance (crab >= 64 mm CL). Observed: White: NOAA Trawl Survey, Red: ADG&G Trawl Survey

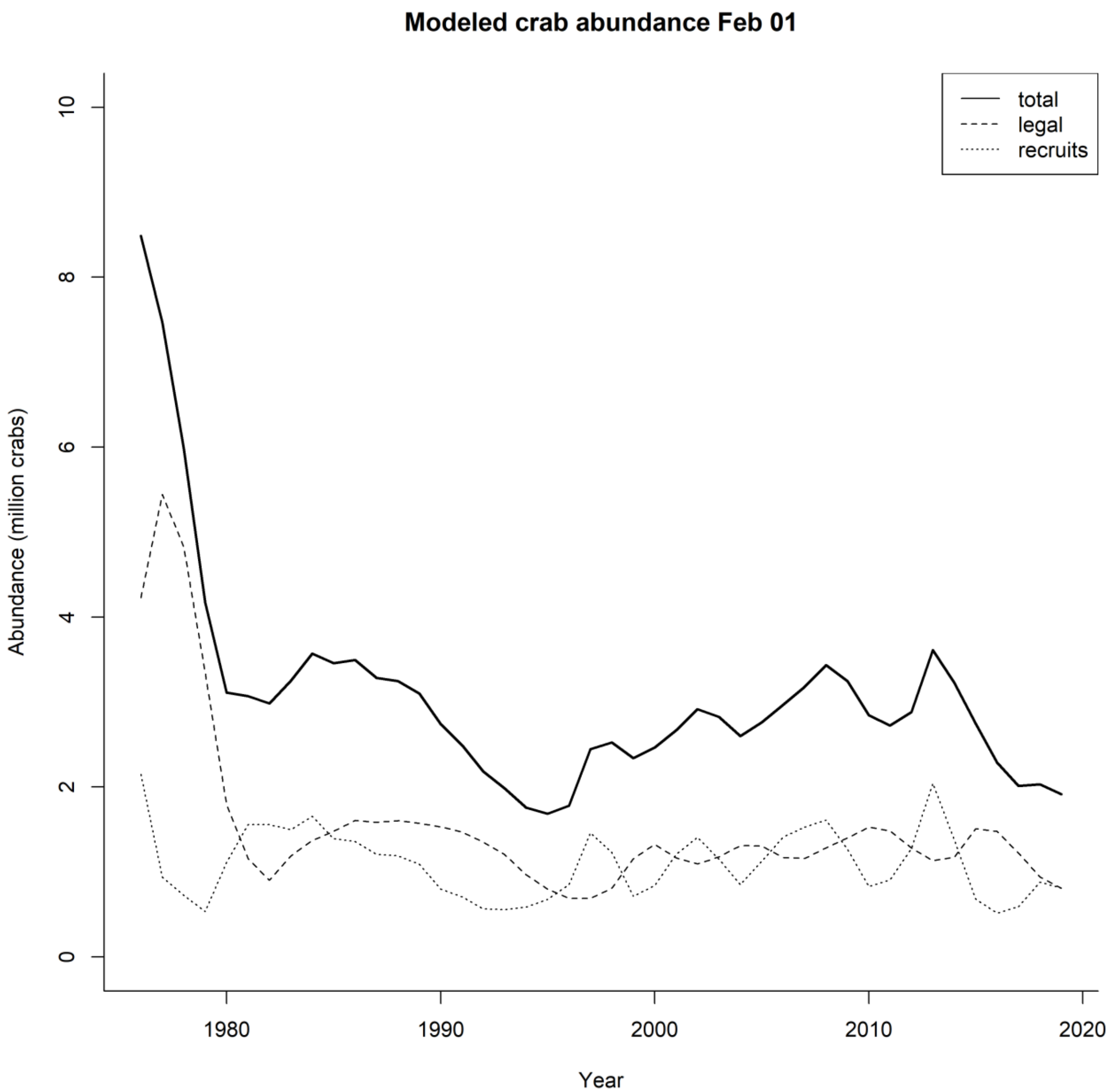



Figure C2-5. Estimated abundance of legal males from 1976-2015.

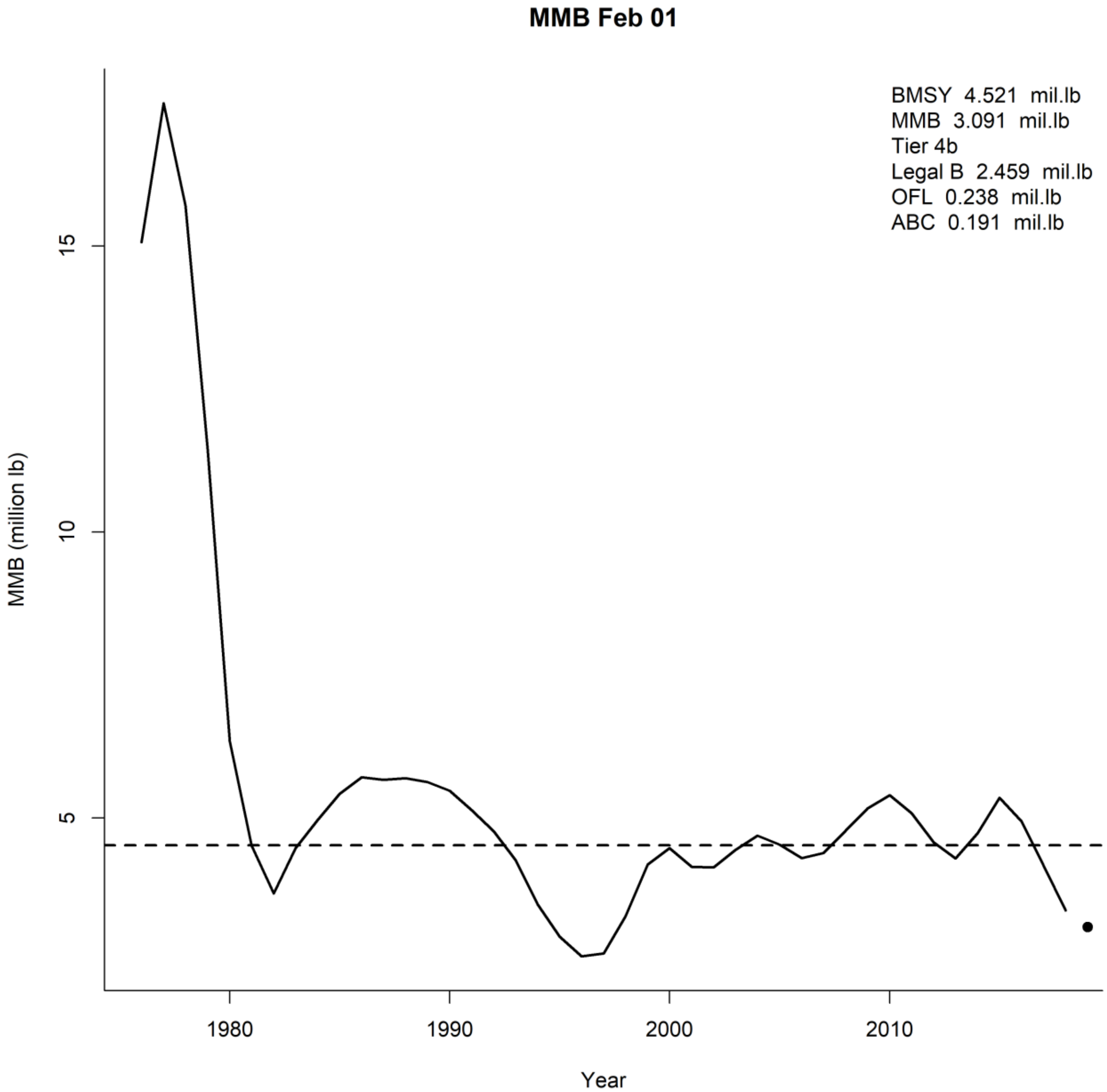



Figure C2-6. Estimated abundance of Mature Male Biomass from 1976-2019. Dash line shows Bmsy (Average MMB of 1980-2019).

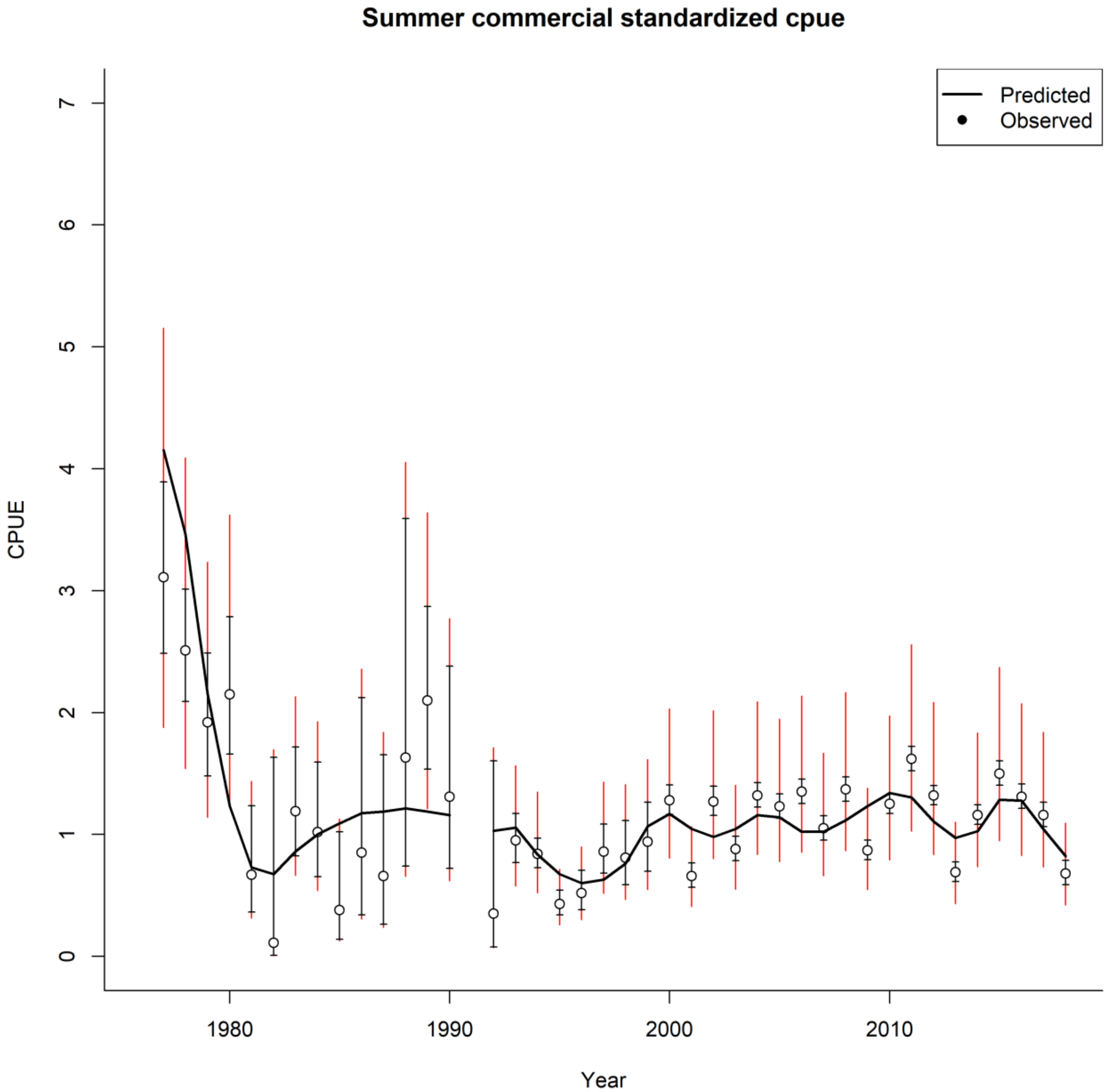



Figure C2-7. Summer commercial standardized cpue 1977-2018.

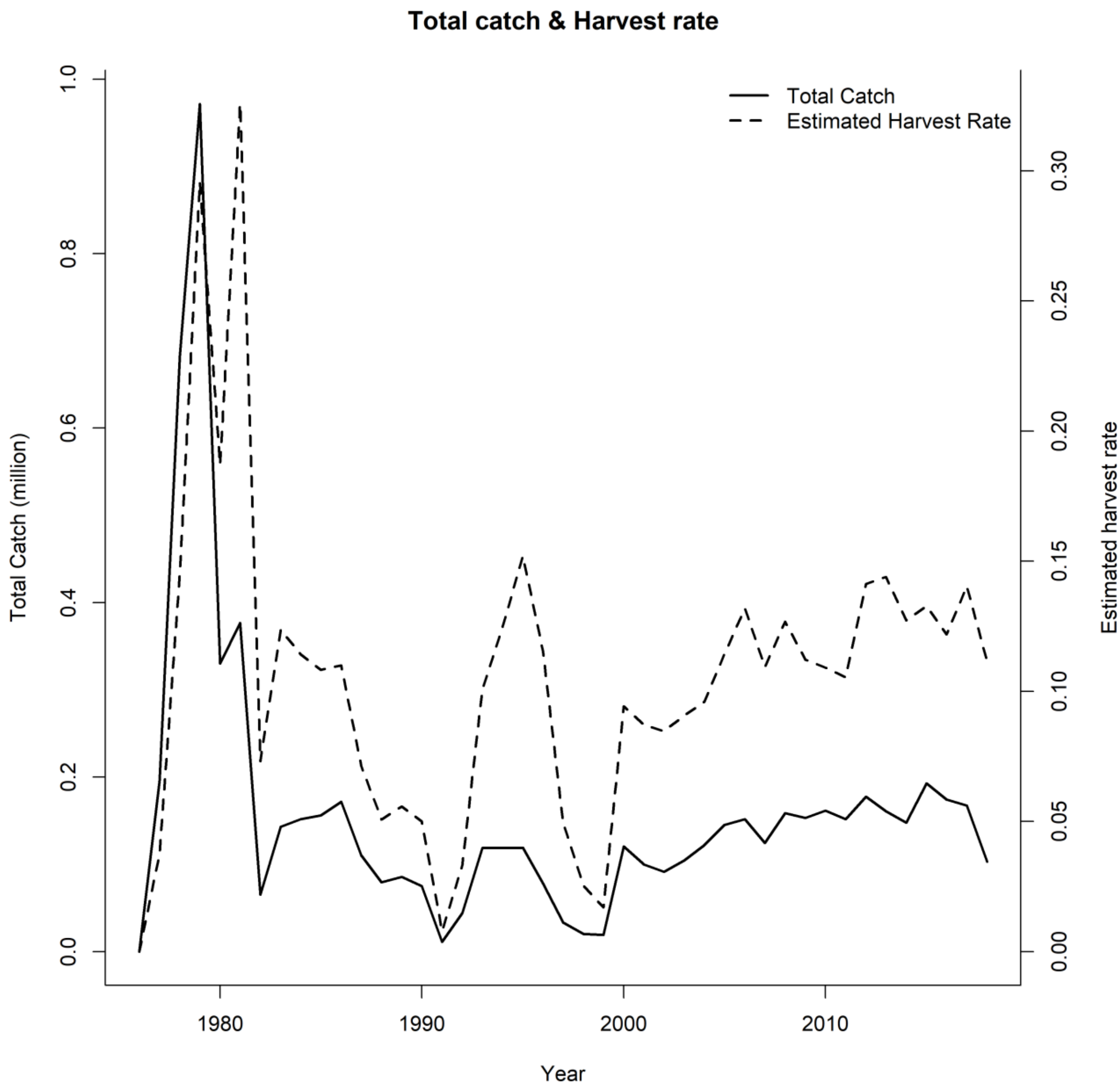



Figure C2-8. Total catch and estimated harvest rate 1976-2018.

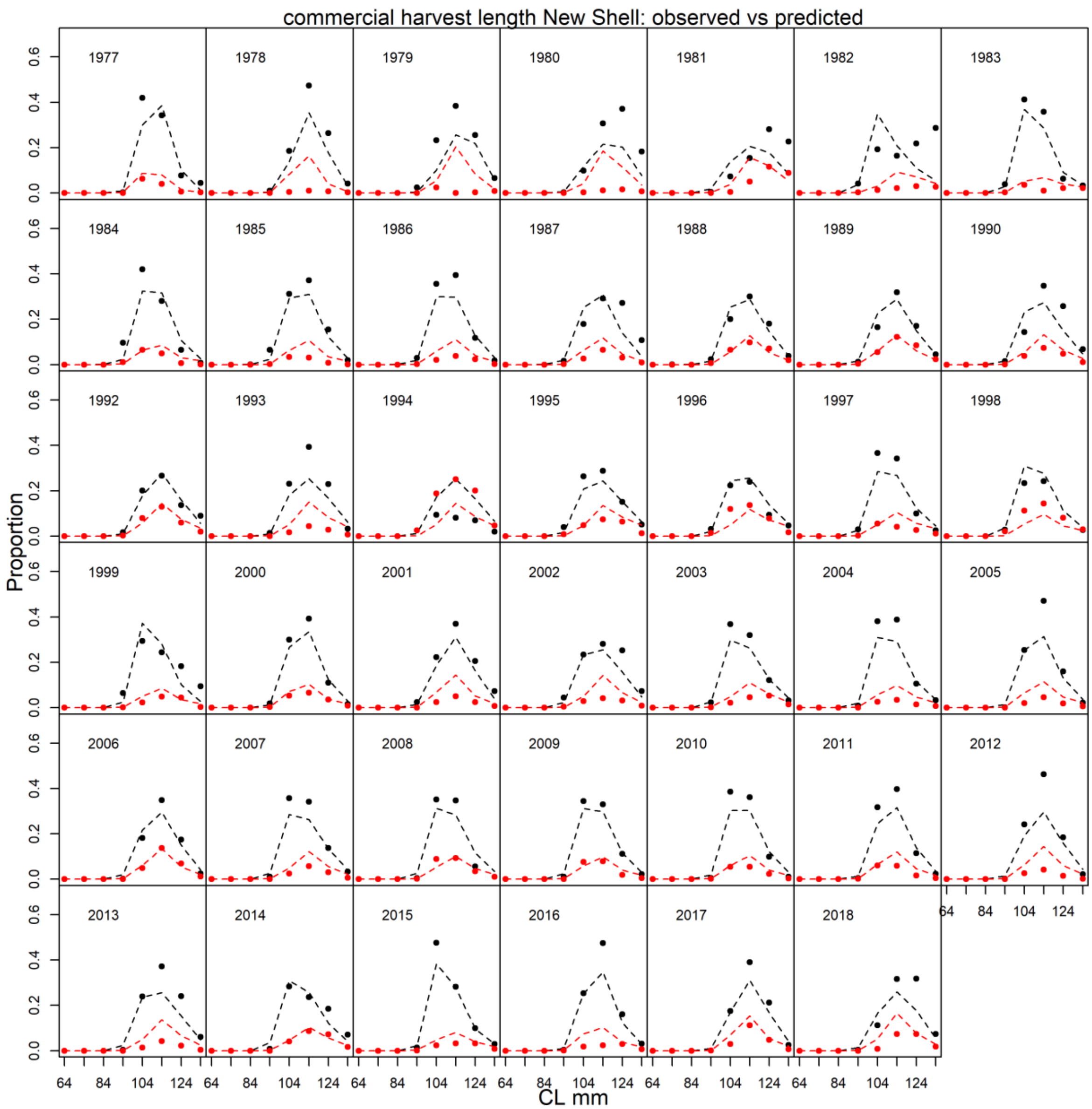



Figure C2-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Bladk: New Shell, Red: Old Shell

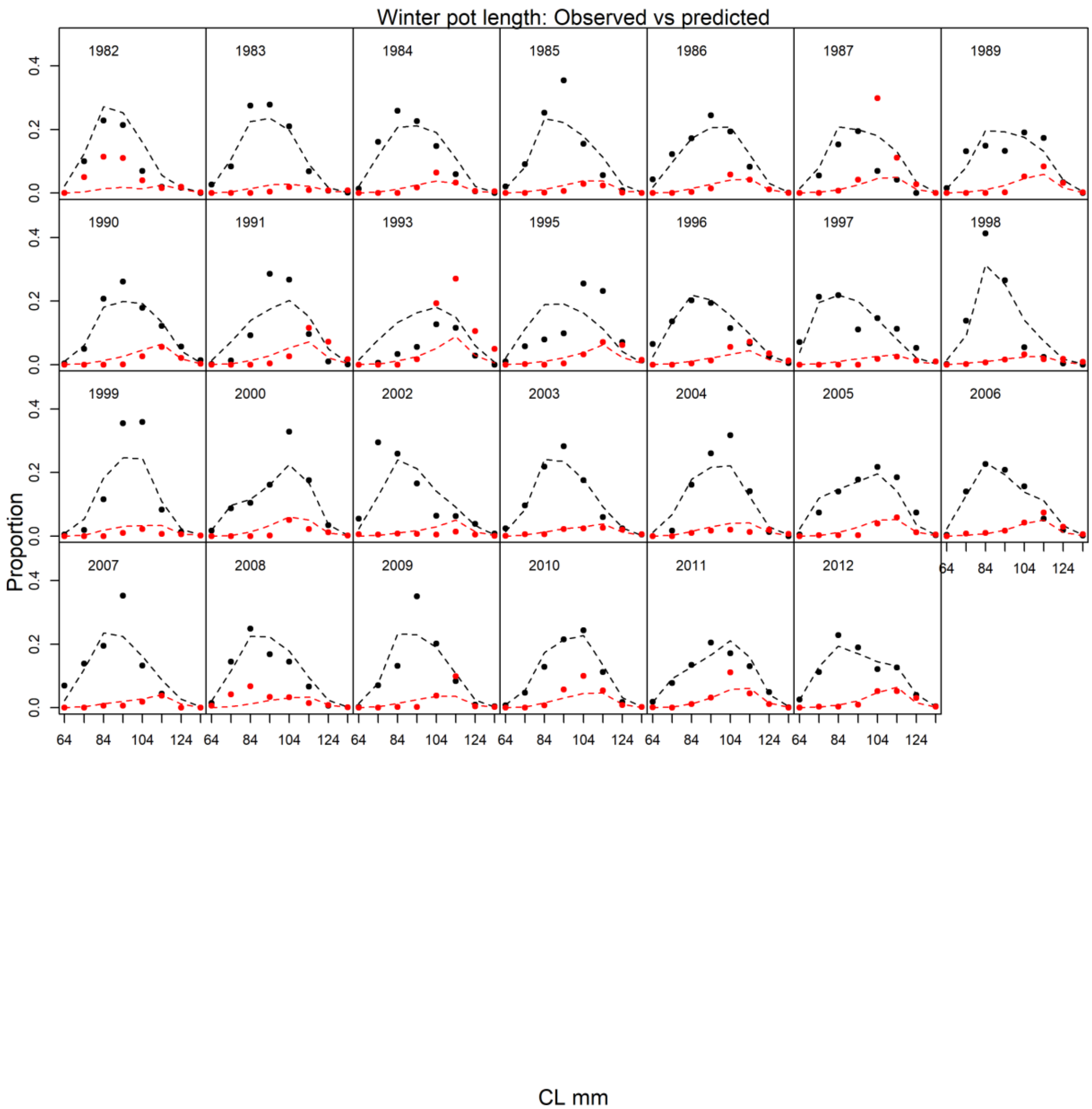
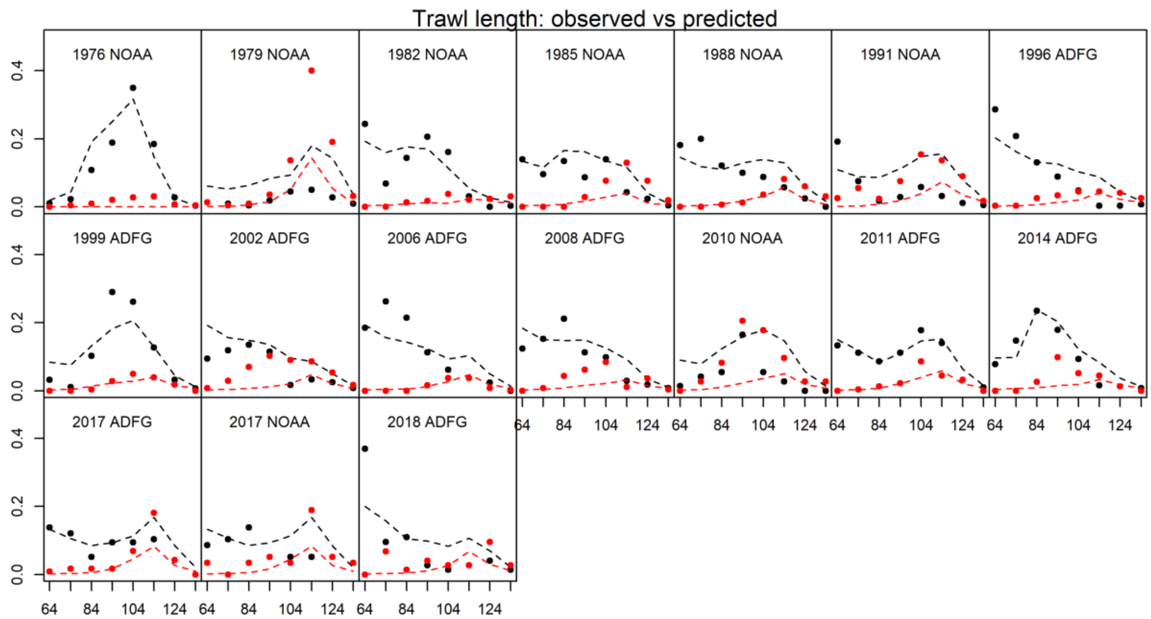



Figure C2-10. Predicted (dashed line) vs. observed (black dots) length class proportions for the winter and spring pot survey.


Trawl length: observed vs predicted
1976 NOAA
1979 NOAA
1982 NOAA
1985 NOAA
1988 NOAA
1991 NOAA
1996 ADFG
1999 ADFG
2002 ADFG
2006 ADFG
2008 ADFG
2010 NOAA
2011 ADFG
2014 ADFG
2017 ADFG
2017 NOAA
2018 ADFG
0.0
0.2
0.4
64
84
104
124

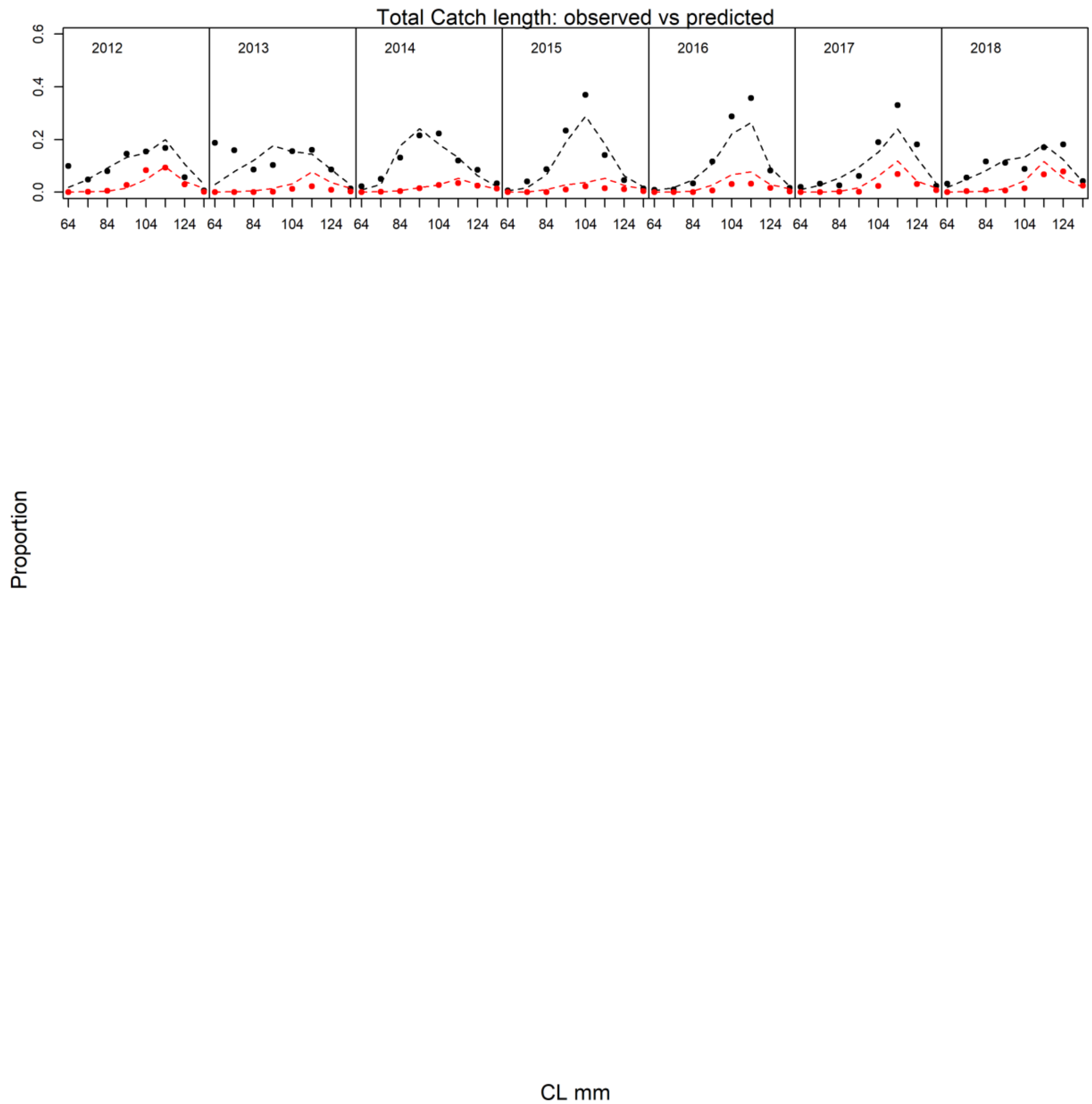



Figure C2-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey.

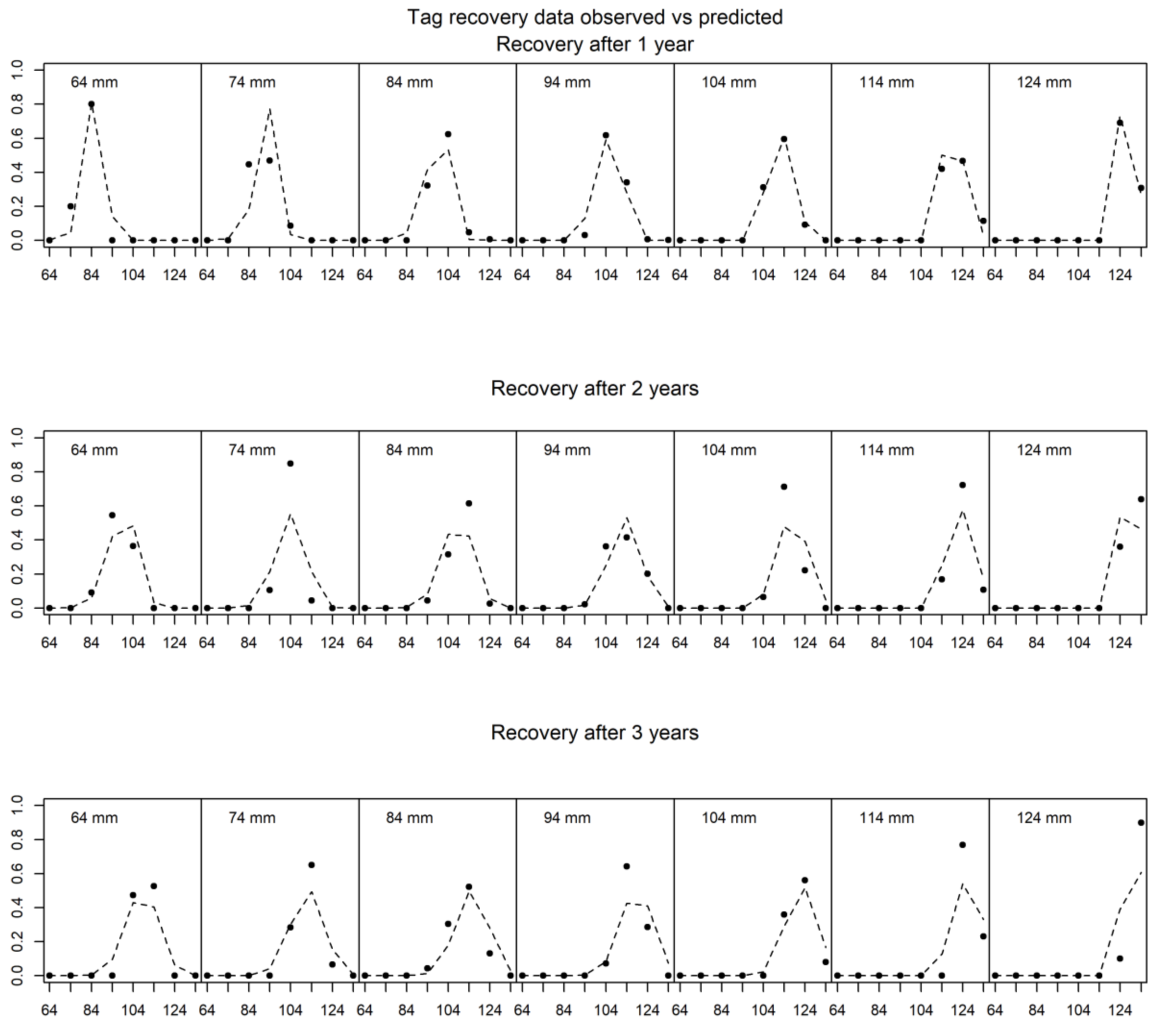



Figure C2-13. Predicted vs. observed length class proportions for tag recovery data.

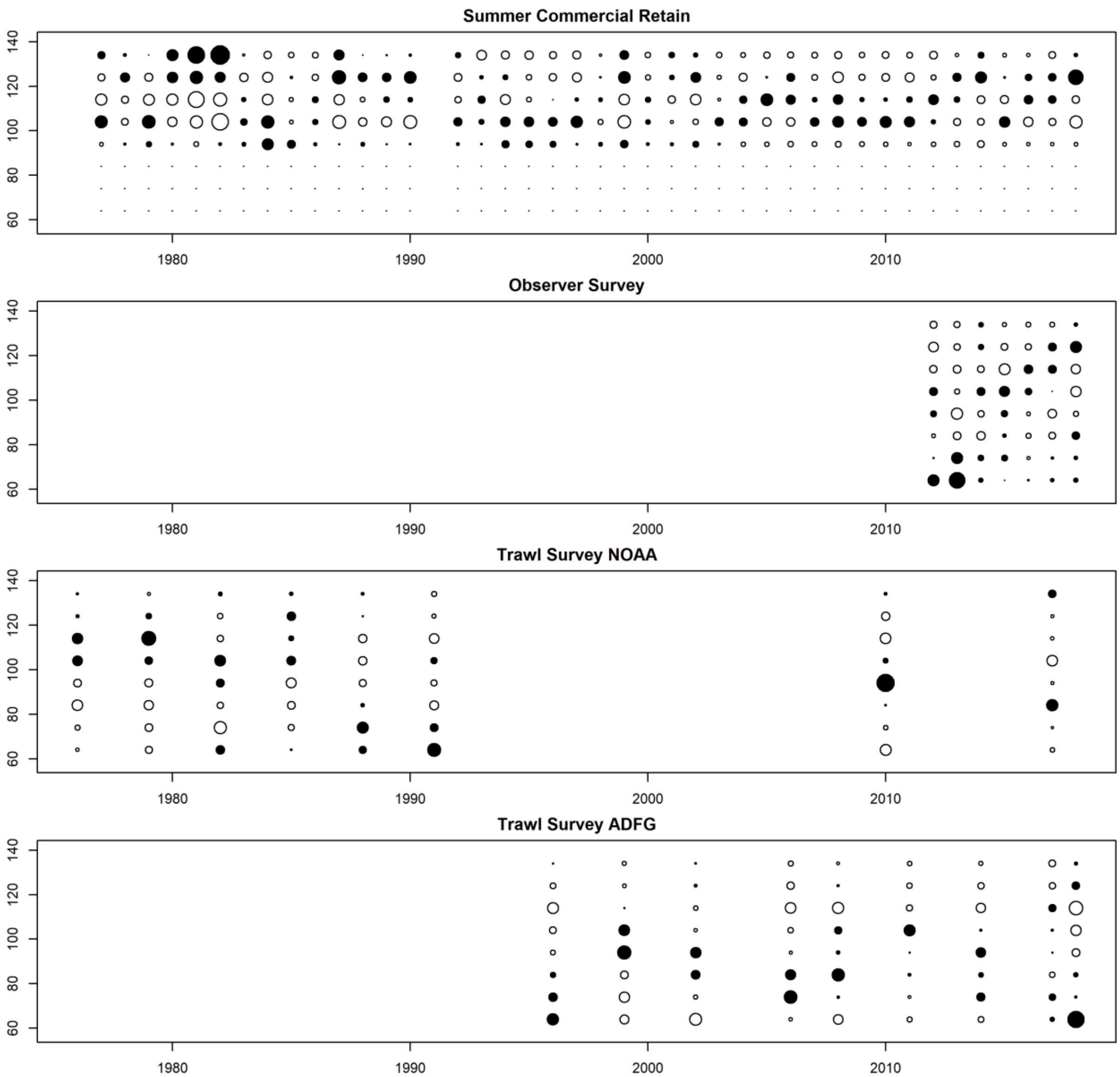



Figure C2-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

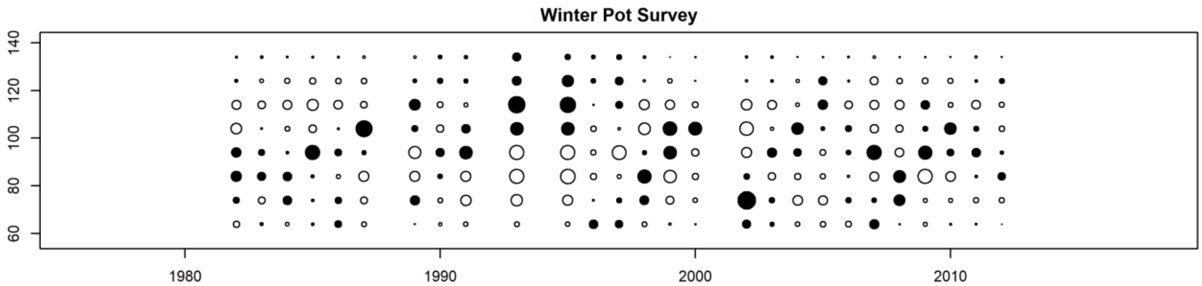



Figure C2-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table C2 . Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

| name | Estimate | std.dev |
|---|---|---|
| $log\_q_1$ | -6.979 | 0.177 |
| $log\_q_2$ | -6.795 | 0.124 |
| $log\_N_{76}$ | 9.046 | 0.130 |
| $R_0$ | 6.433 | 0.082 |
| $log\_R_{76}$ | 0.003 | 0.420 |
| $log\_R_{77}$ | -0.542 | 0.370 |
| $log\_R_{78}$ | -0.714 | 0.355 |
| $log\_R_{79}$ | 0.401 | 0.319 |
| $log\_R_{80}$ | 0.510 | 0.290 |
| $log\_R_{81}$ | 0.422 | 0.267 |
| $log\_R_{82}$ | 0.397 | 0.320 |
| $log\_R_{83}$ | 0.570 | 0.282 |
| $log\_R_{84}$ | 0.180 | 0.301 |
| $log\_R_{85}$ | 0.364 | 0.325 |
| $log\_R_{86}$ | 0.088 | 0.341 |
| $log\_R_{87}$ | 0.214 | 0.269 |
| $log\_R_{88}$ | 0.022 | 0.305 |
| $log\_R_{89}$ | -0.415 | 0.321 |
| $log\_R_{90}$ | -0.322 | 0.272 |
| $log\_R_{91}$ | -0.739 | 0.337 |
| $log\_R_{92}$ | -0.511 | 0.309 |
| $log\_R_{93}$ | -0.524 | 0.306 |
| $log\_R_{94}$ | -0.310 | 0.262 |
| $log\_R_{95}$ | -0.062 | 0.227 |
| $log\_R_{96}$ | 0.587 | 0.217 |
| $log\_R_{97}$ | -0.051 | 0.302 |
| $log\_R_{98}$ | -0.625 | 0.321 |
| $log\_R_{99}$ | 0.004 | 0.311 |
| $log\_R_{00}$ | 0.311 | 0.266 |
| $log\_R_{01}$ | 0.385 | 0.243 |
| $log\_R_{02}$ | -0.020 | 0.317 |
| $log\_R_{03}$ | -0.282 | 0.332 |
| $log\_R_{04}$ | 0.295 | 0.242 |
| $log\_R_{05}$ | 0.404 | 0.224 |
| $log\_R_{06}$ | 0.454 | 0.244 |

| name | Estimate | std.dev |
|---|---|---|
| $log\_R_{07}$ | 0.503 | 0.232 |
| $log\_R_{08}$ | 0.056 | 0.291 |
| $log\_R_{09}$ | -0.409 | 0.293 |
| $log\_R_{10}$ | 0.040 | 0.248 |
| $log\_R_{11}$ | 0.370 | 0.279 |
| $log\_R_{12}$ | 0.894 | 0.193 |
| $log\_R_{13}$ | -0.205 | 0.301 |
| $log\_R_{14}$ | -0.649 | 0.315 |
| $log\_R_{15}$ | -0.701 | 0.282 |
| $log\_R_{16}$ | -0.425 | 0.243 |
| $log\_R_{17}$ | 0.033 | 0.285 |
| $a_1$ | 1.577 | 4.605 |
| $a_2$ | 2.386 | 4.297 |
| $a_3$ | 3.842 | 4.108 |
| $a_4$ | 4.116 | 4.094 |
| $a_5$ | 4.349 | 4.085 |
| $a_6$ | 3.579 | 4.114 |
| $a_7$ | 2.137 | 4.367 |
| r1 | 10.000 | 0.870 |
| r2 | 9.678 | 0.894 |
| log_a | -2.625 | 0.092 |
| log_b | 4.825 | 0.014 |
| $log\_\phi_{st1}$ | -5.000 | 0.102 |
| $log\_\phi_{wa}$ | -2.117 | 0.322 |
| $log\_\phi_{wb}$ | 4.800 | 0.029 |
| Sw1 | 0.074 | 0.036 |
| Sw2 | 0.500 | 353.550 |
| $log\_\phi_1$ | 3.766 | 6510.100 |
| log_ar | -0.836 | 0.204 |
| log_br | 4.647 | 0.012 |
| $w^2_t$ | 0.051 | 0.016 |
| q | 0.749 | 0.129 |
| $\sigma$ | 3.926 | 0.219 |
| $\beta_1$ | 11.921 | 0.784 |
| $\beta_2$ | 7.763 | 0.187 |
| *ms78* | 3.236 | 0.270 |

# Appendix C3: Model 2 Results

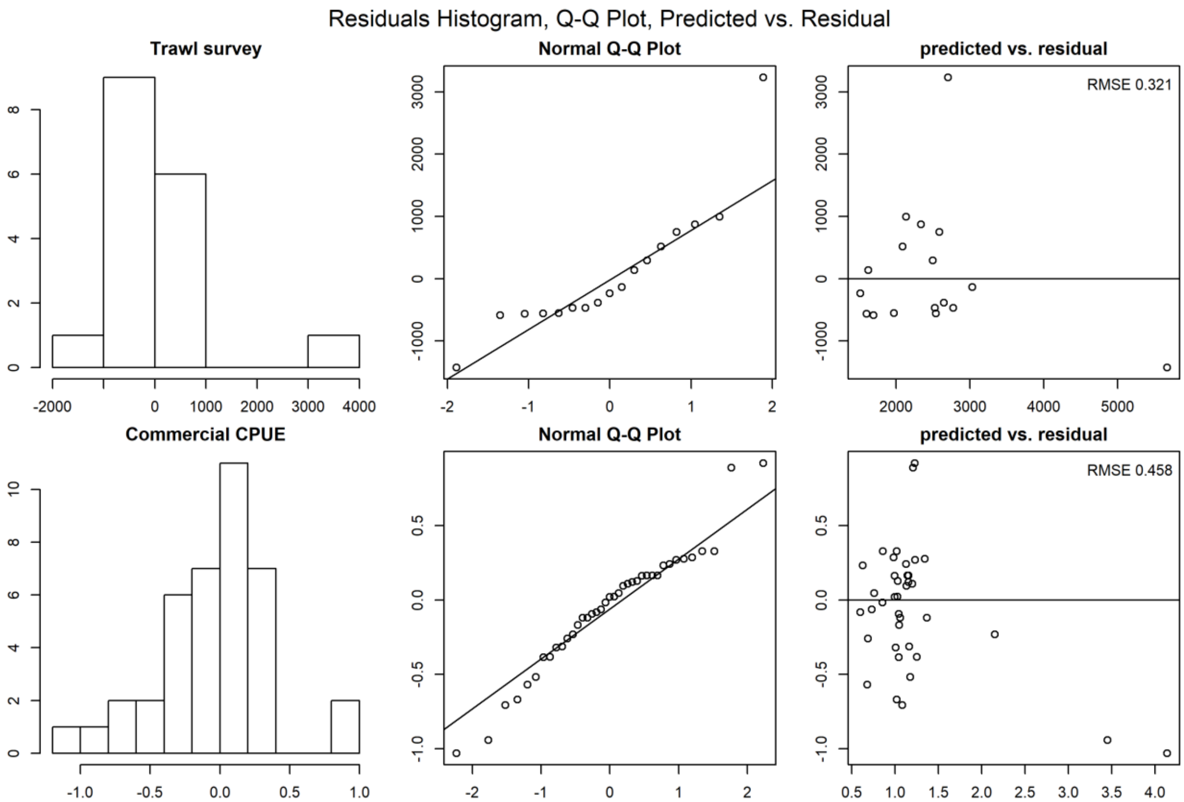



Figure C3-1. QQ Plot of Trawl survey and Commercial CPUE.

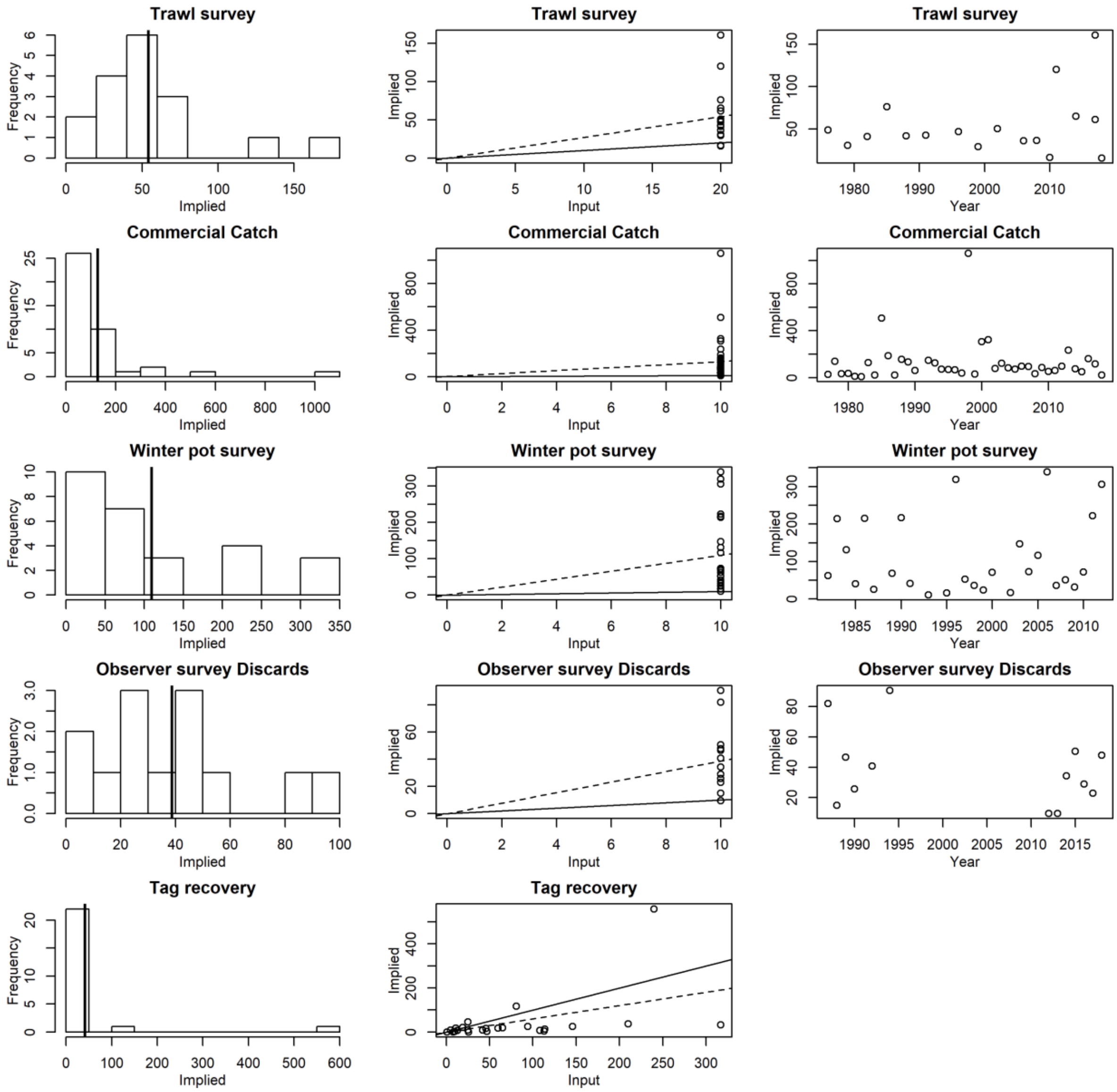



Figure C3-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column show input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

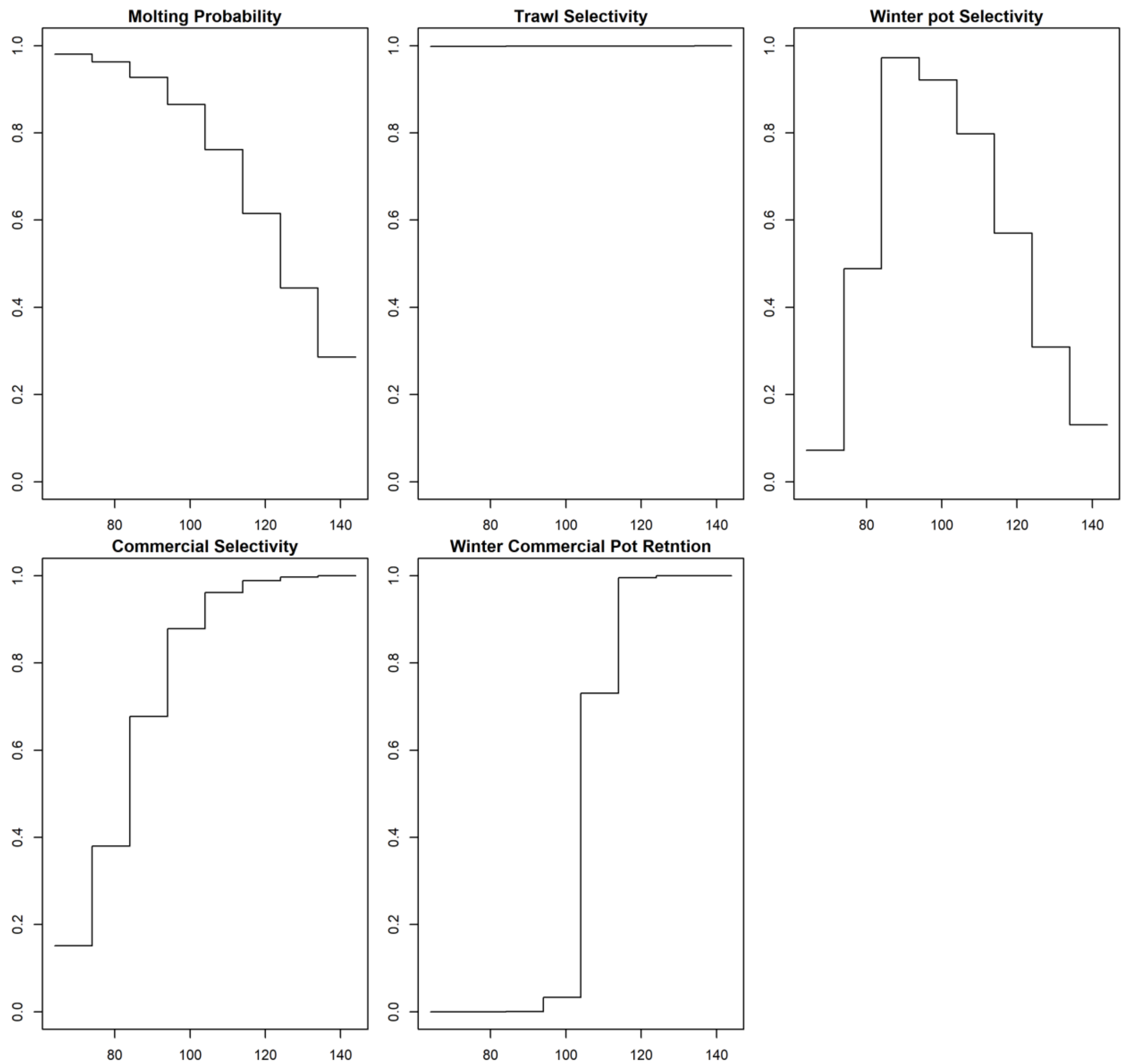



Figure C3-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

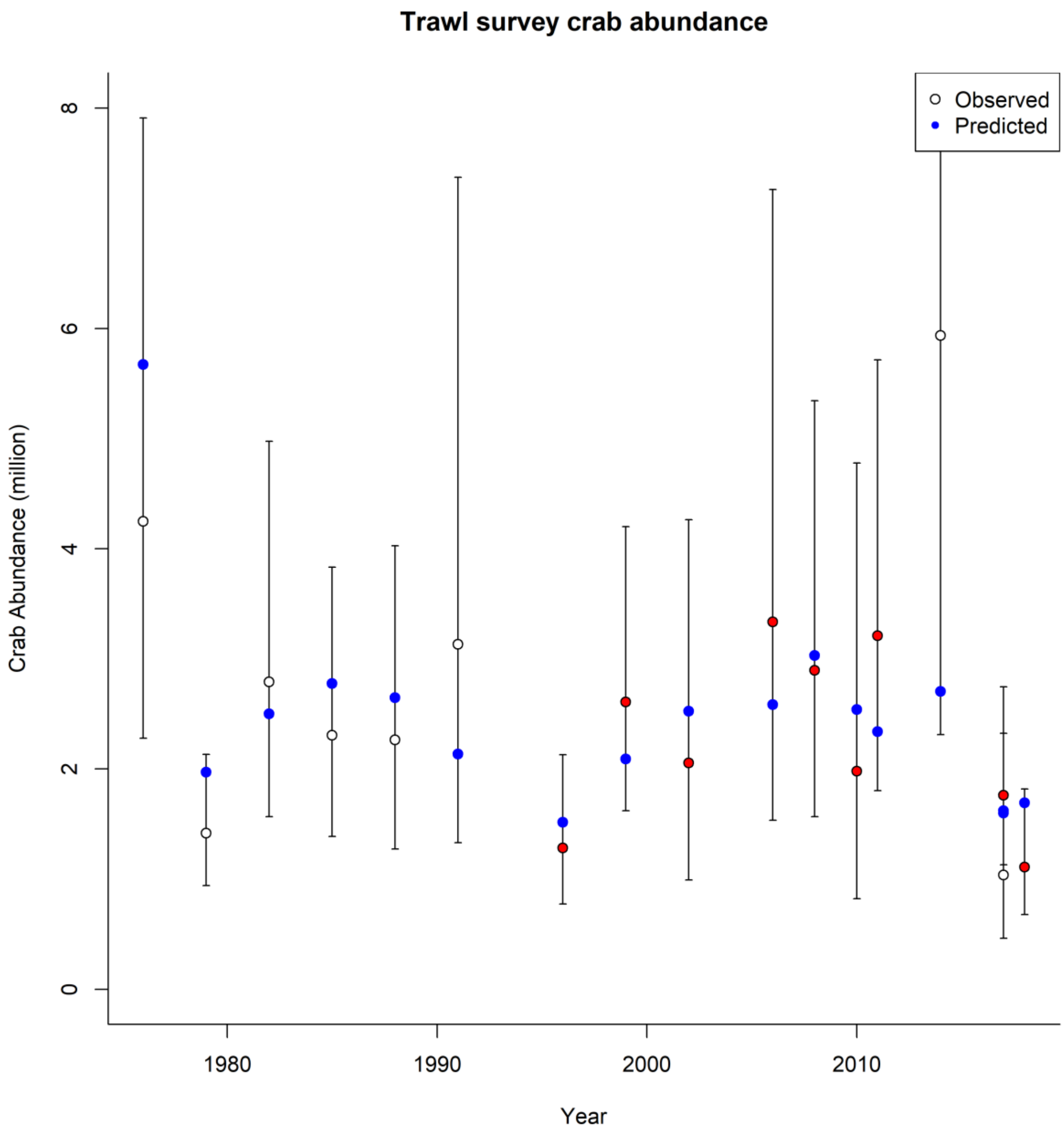



Figure C3-4. Estimated trawl survey male abundance (crab >= 64 mm CL). Observed: White: NOAA Trawl Survey, Red: ADG&G Trawl Survey

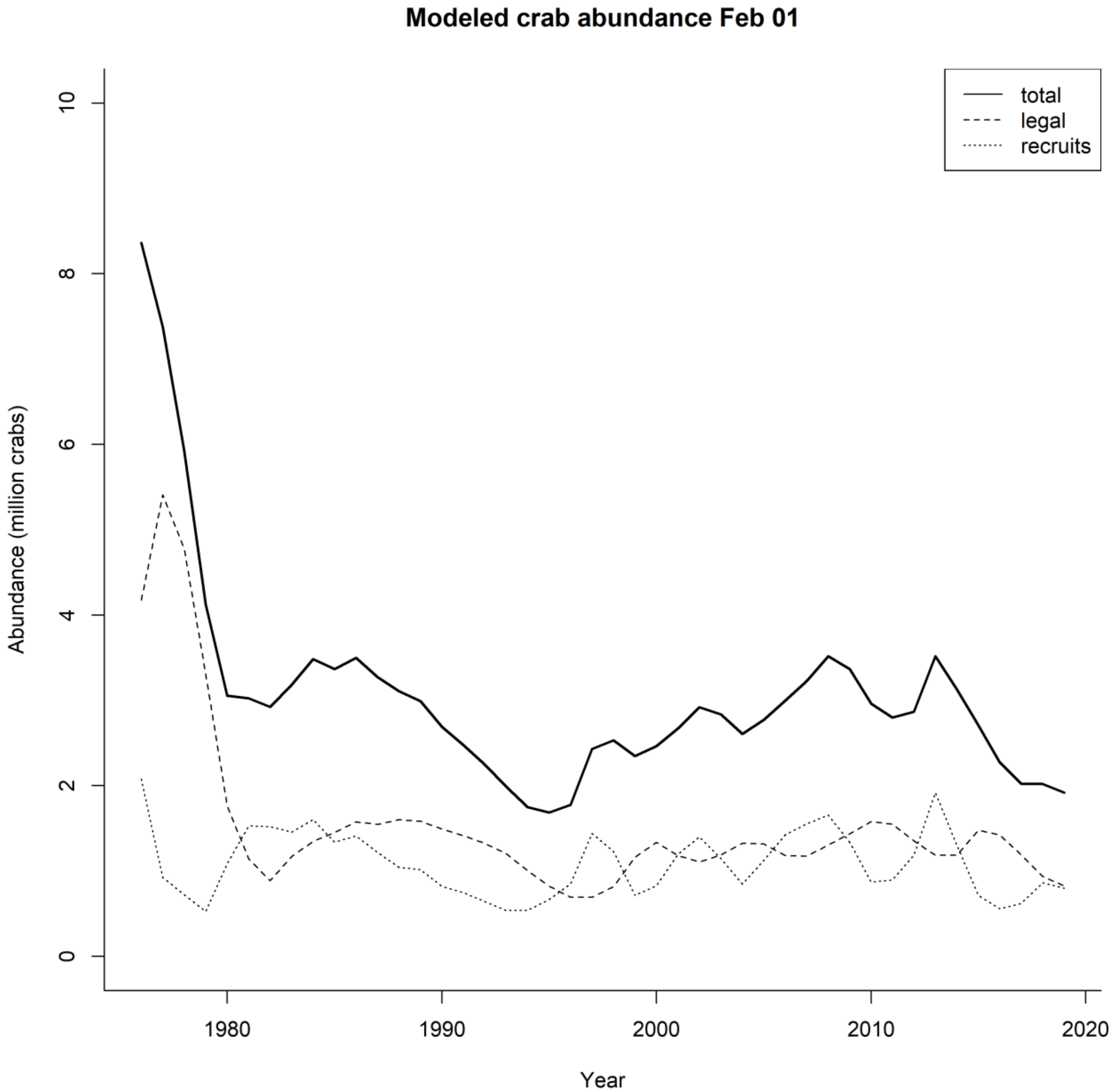



Figure C3-5. Estimated abundance of legal males from 1976-2015.

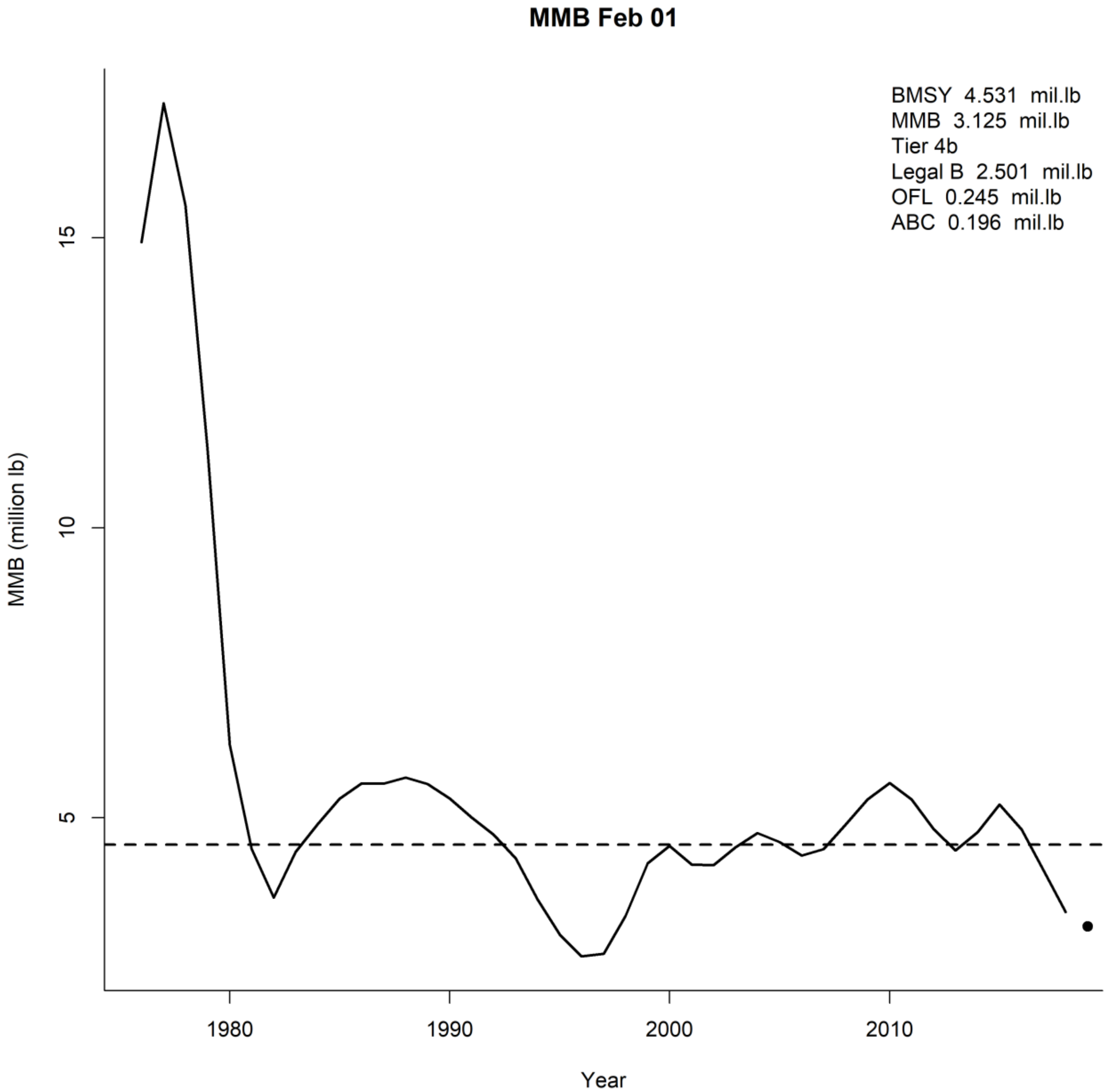



Figure C3-6. Estimated abundance of Mature Male Biomass from 1976-2019. Dash line shows Bmsy (Average MMB of 1980-2019).

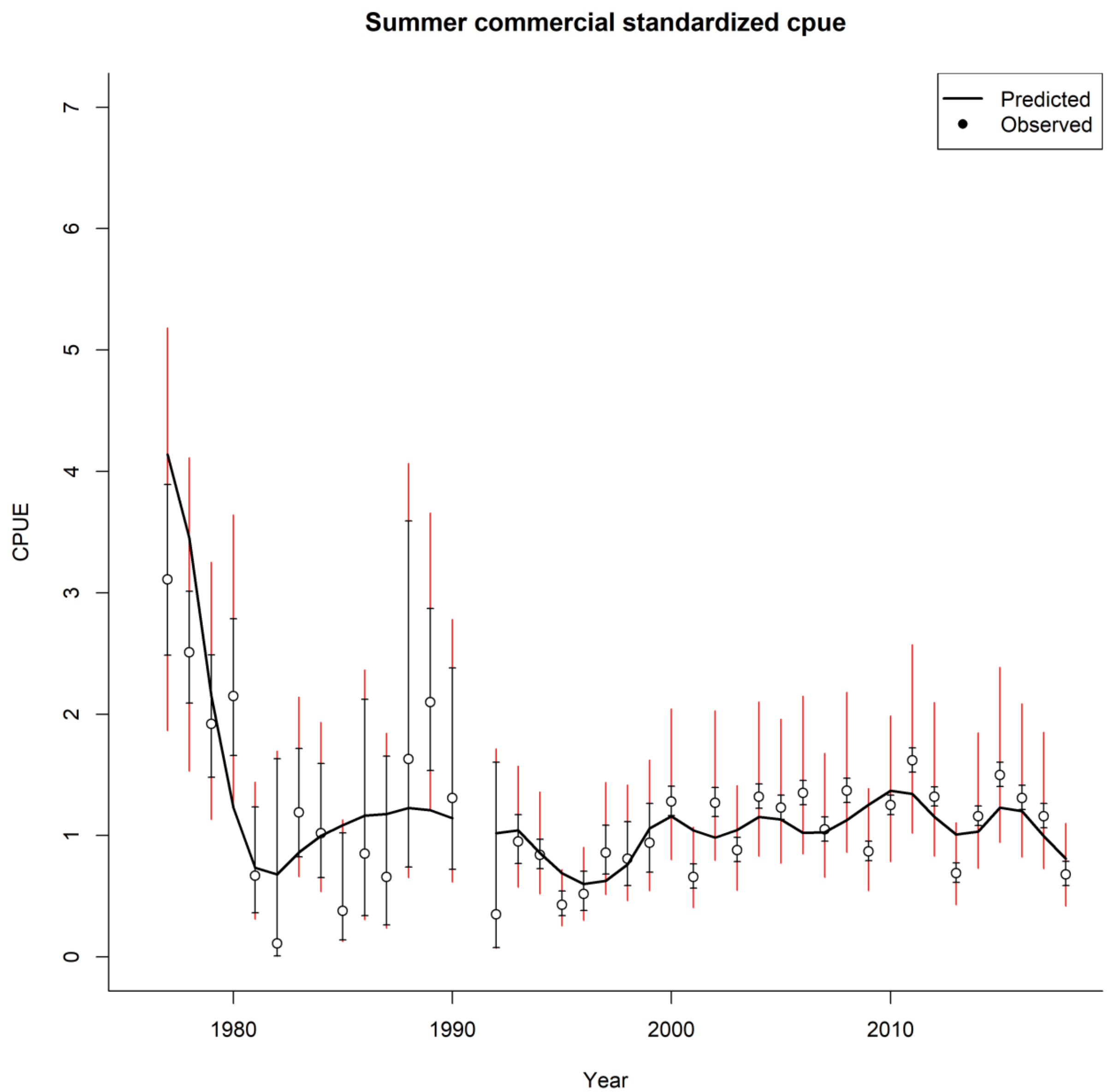



Figure C3-7. Summer commercial standardized cpue 1977-2018.

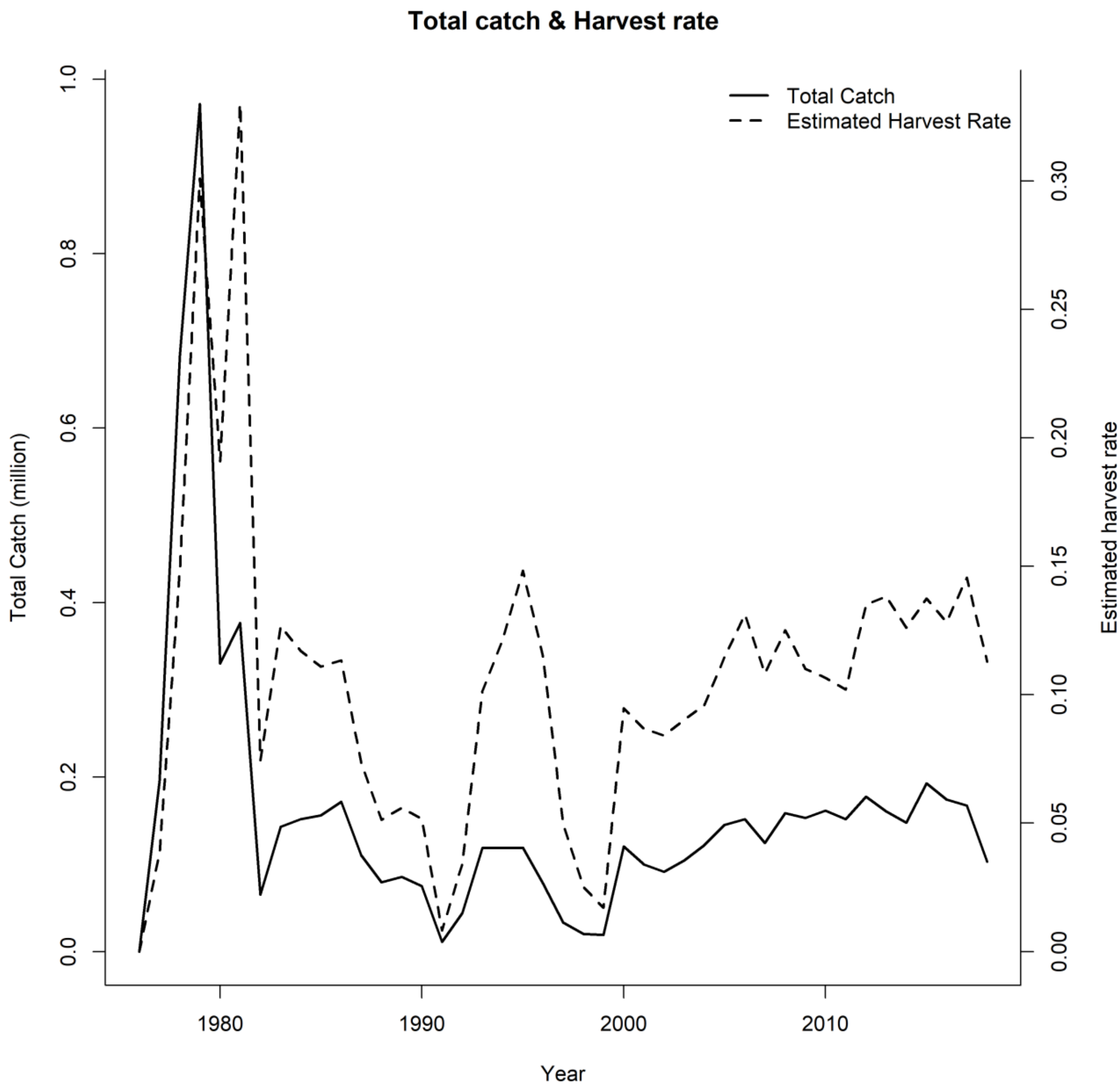



Figure C3-8. Total catch and estimated harvest rate 1976-2018.

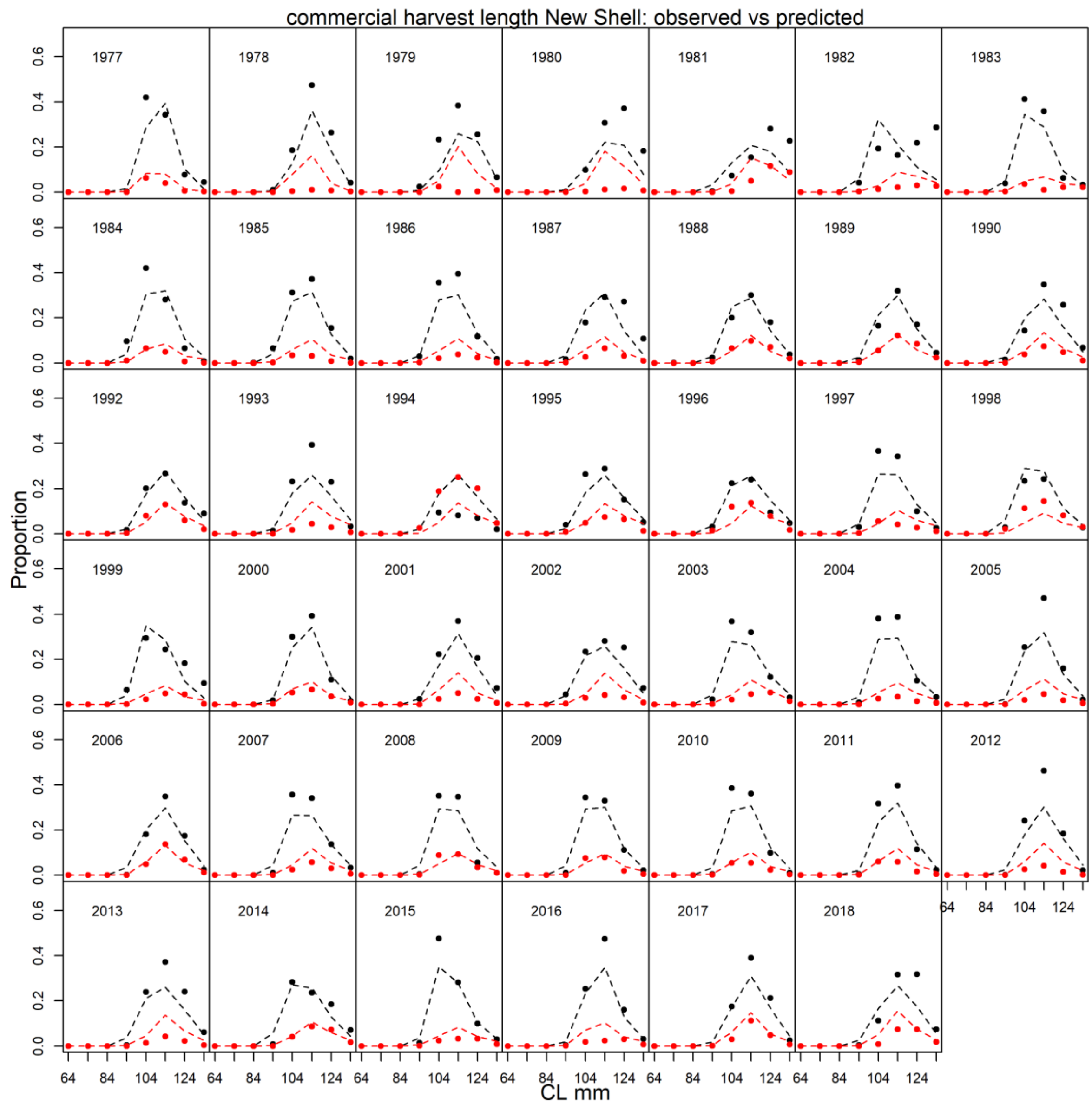



Figure C3-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Bladk: New Shell, Red: Old Shell

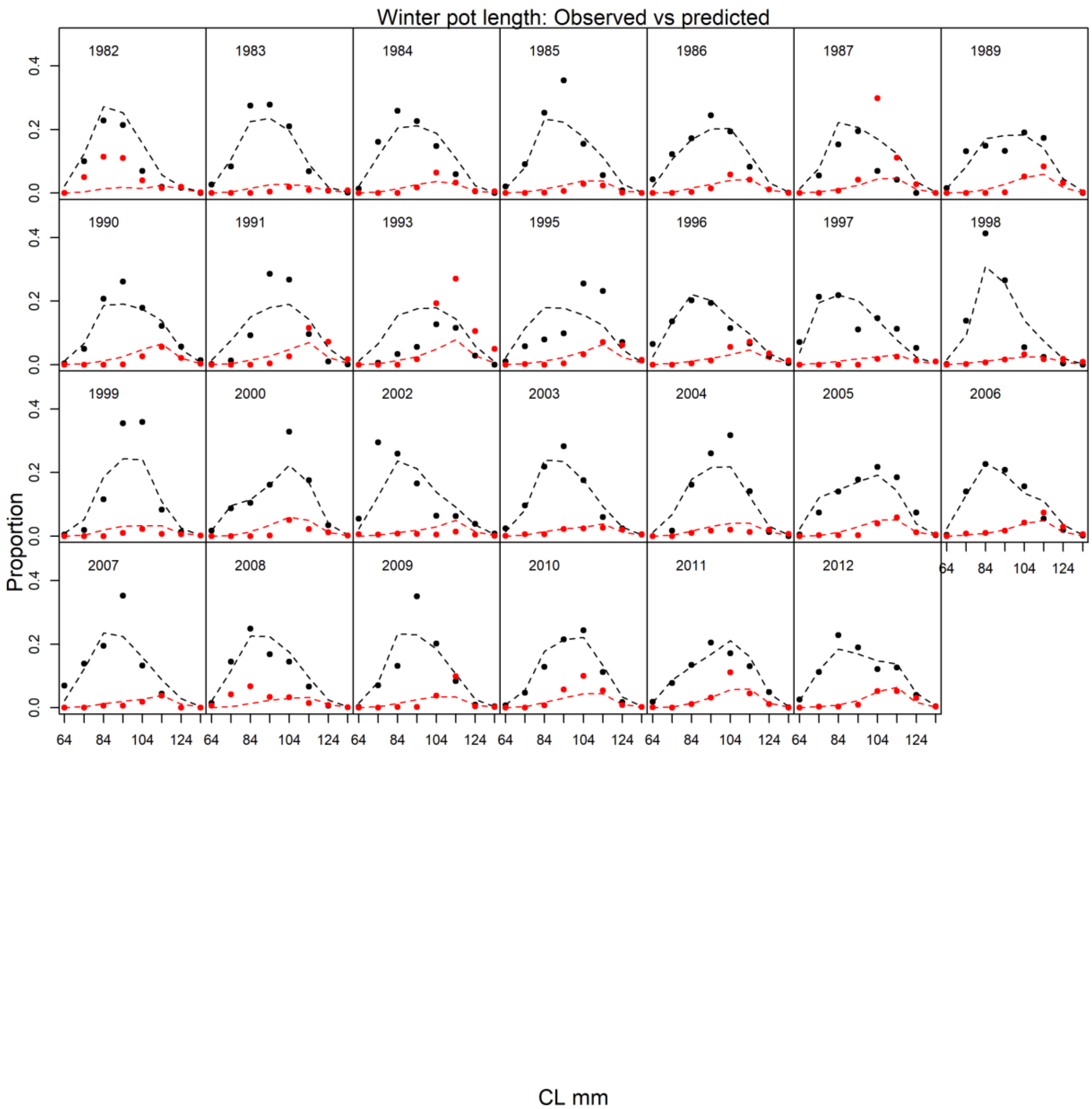
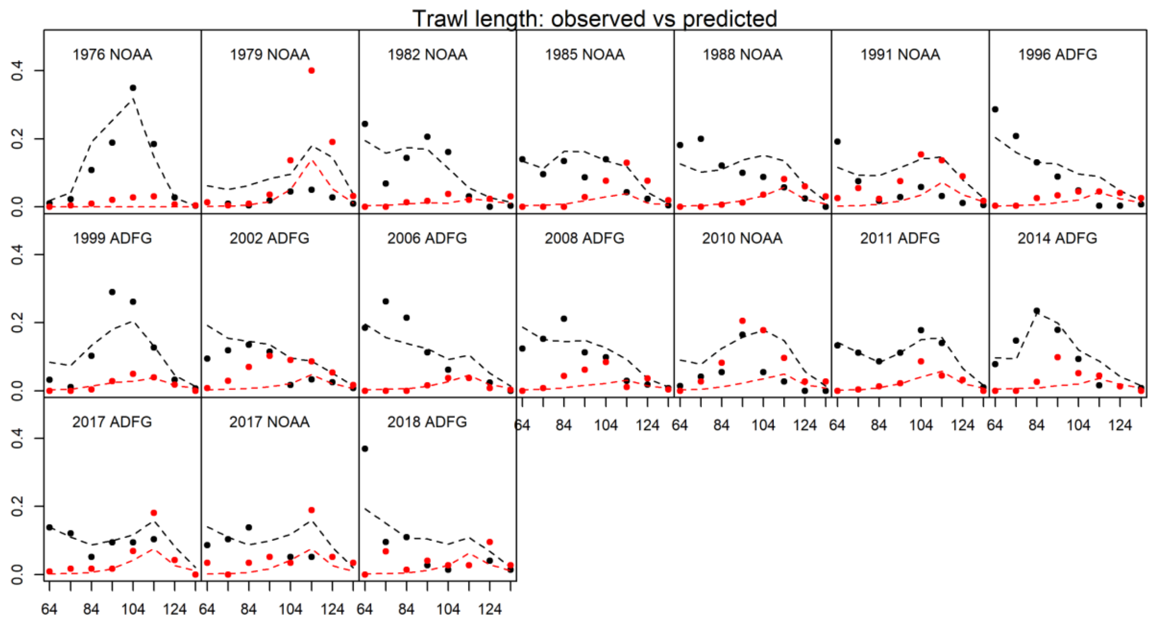
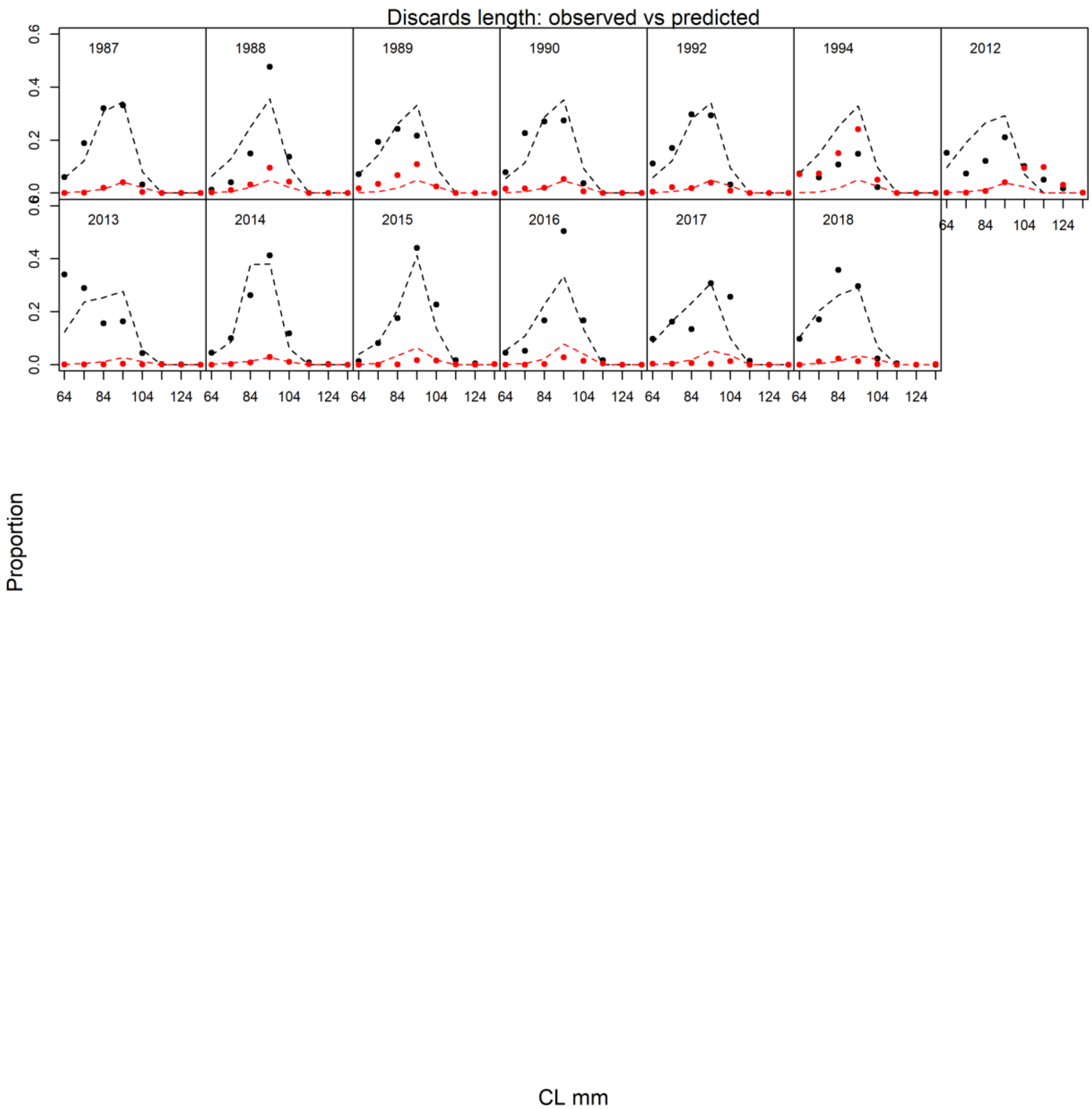



Figure C3-10. Predicted (dashed line) vs. observed (black dots) length class proportions for the winter and spring pot survey.


Trawl length: observed vs predicted
1976 NOAA
1979 NOAA
1982 NOAA
1985 NOAA
1988 NOAA
1991 NOAA
1996 ADFG
1999 ADFG
2002 ADFG
2006 ADFG
2008 ADFG
2010 NOAA
2011 ADFG
2014 ADFG
2017 ADFG
2017 NOAA
2018 ADFG
0.0
0.2
0.4
64
84
104
124



Discards length: observed vs predicted
1987
1988
1989
1990
1992
1994
2012
2013
2014
2015
2016
2017
2018
Proportion
CL mm

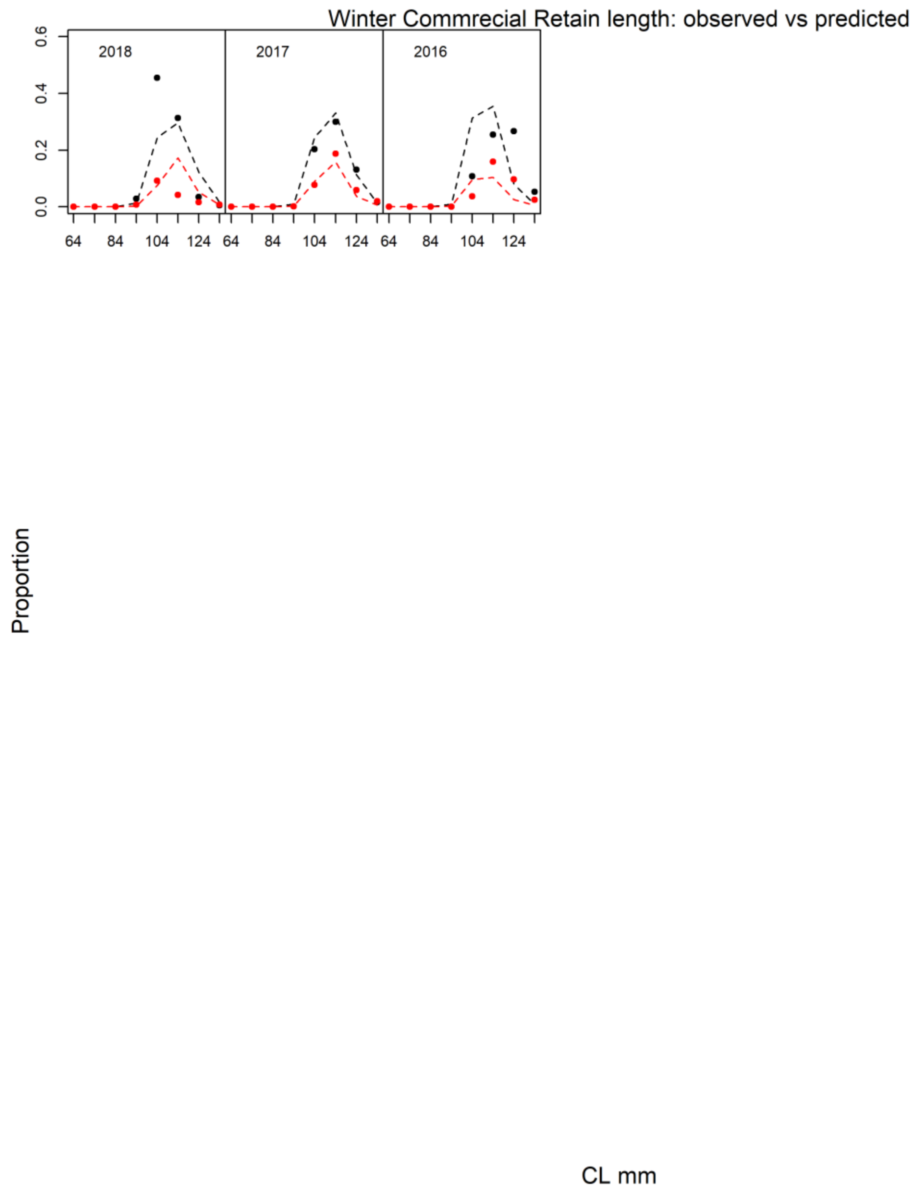



Figure C3-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey.

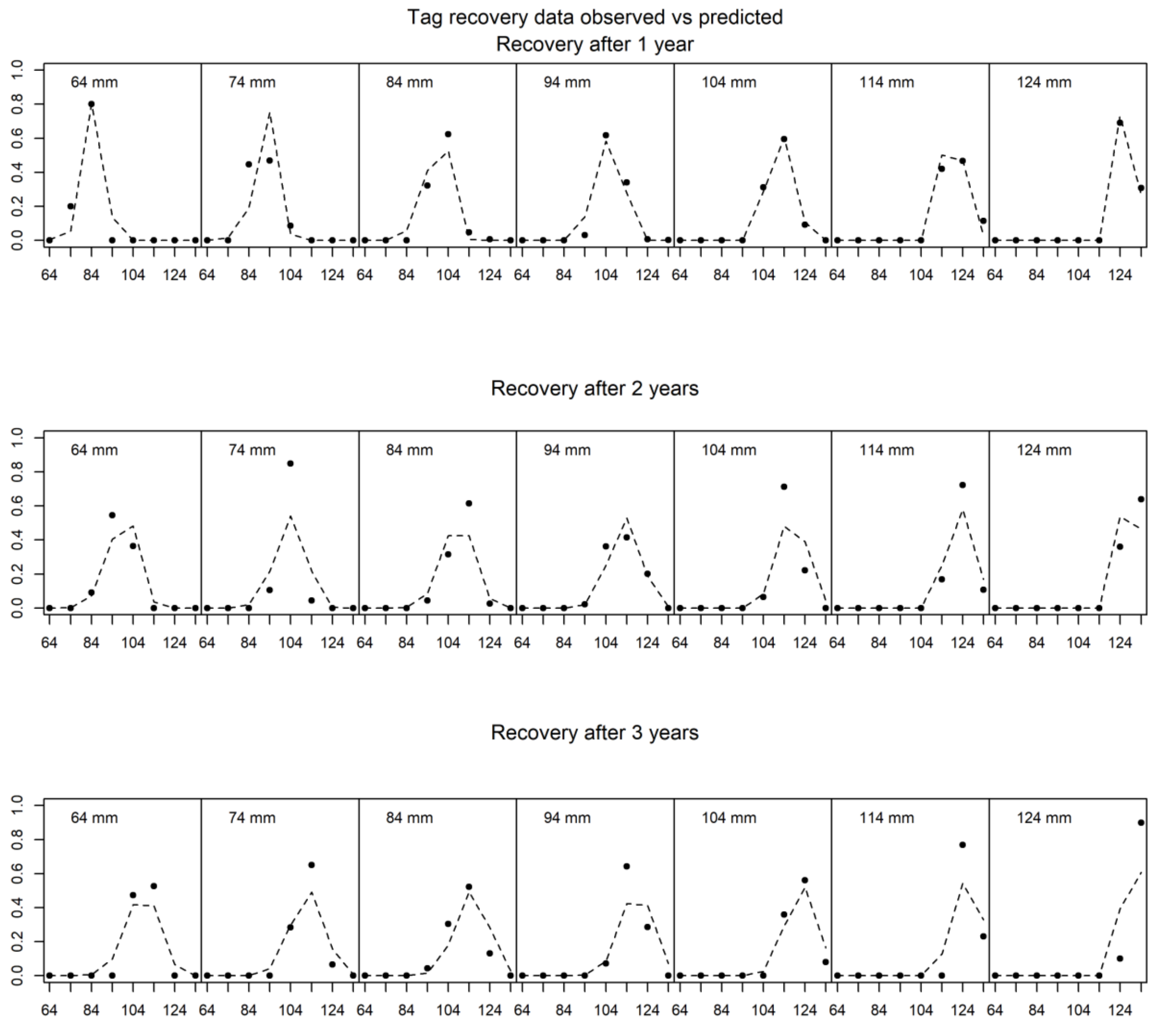



Figure C3-13. Predicted vs. observed length class proportions for tag recovery data.

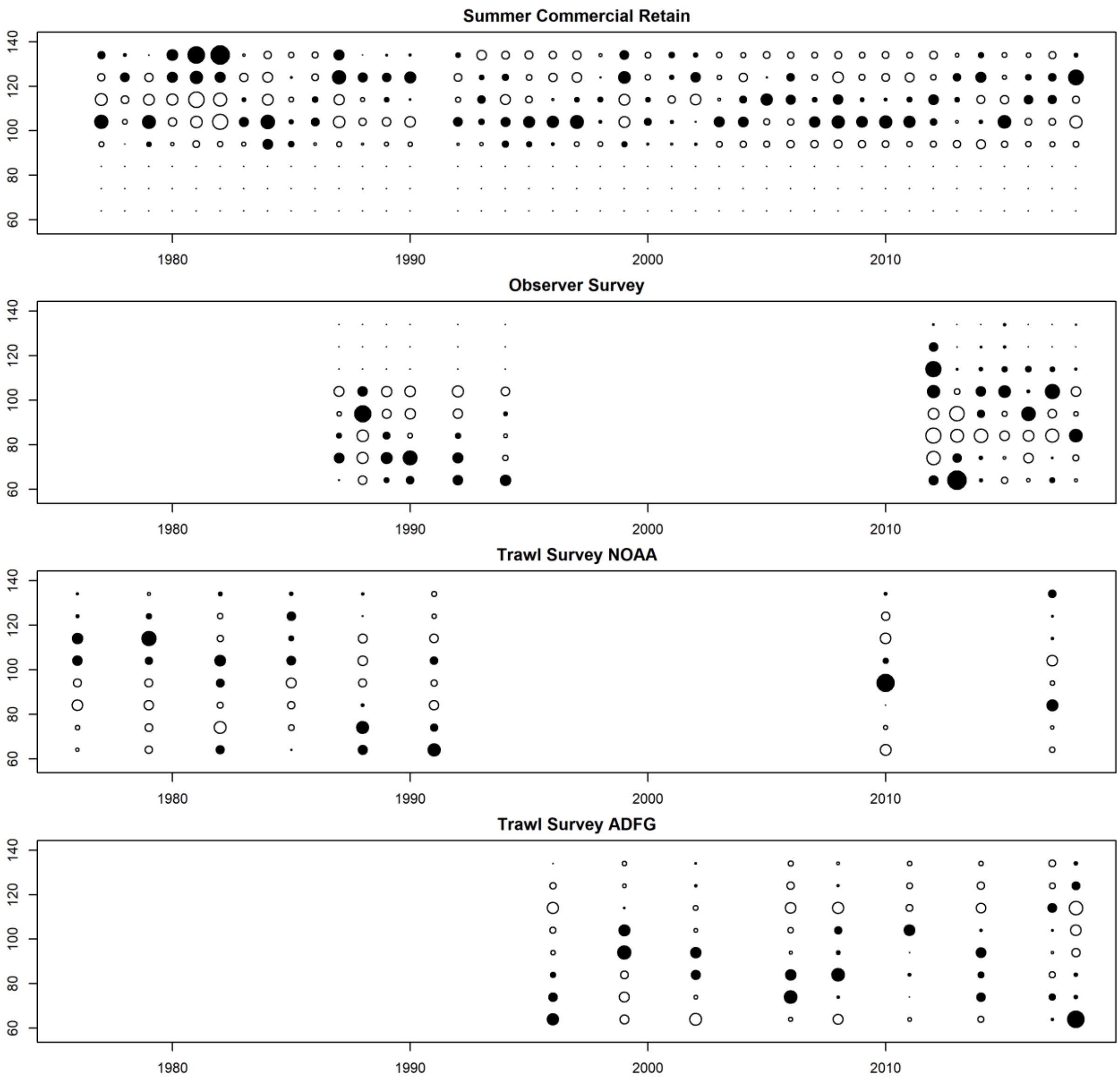



Figure C3-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

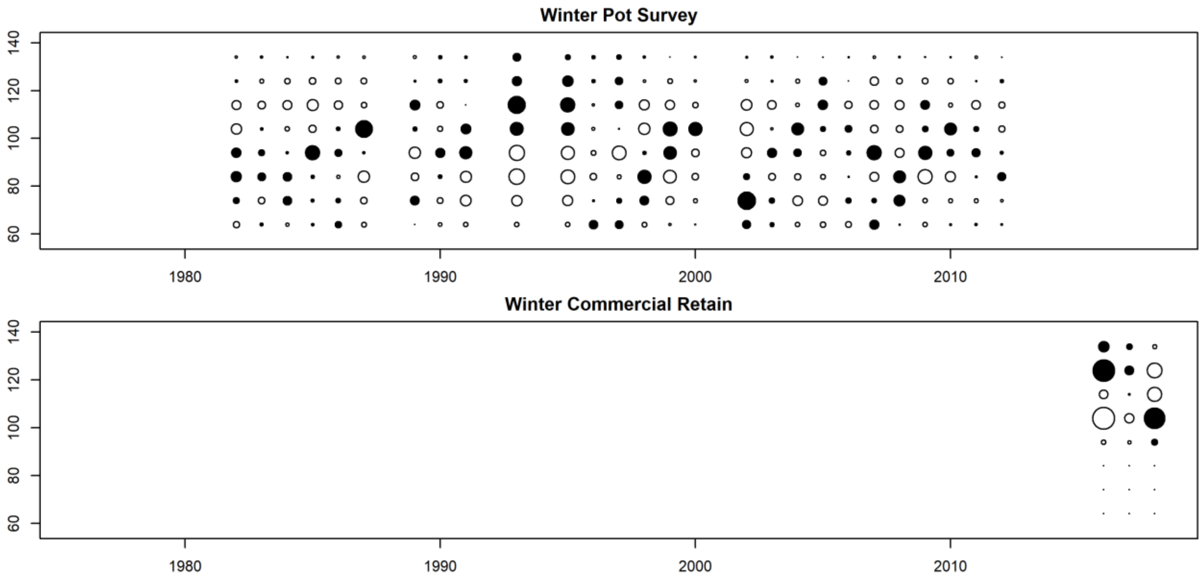



Figure C3-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table C3 . Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

| name | Estimate | std.dev |
|---|---|---|
| log_$q_1$ | -6.967 | 0.168 |
| log_$q_2$ | -6.810 | 0.109 |
| log_$N_{76}$ | 9.031 | 0.130 |
| $R_0$ | 6.441 | 0.081 |
| log_$R_{76}$ | 0.005 | 0.415 |
| log_$R_{77}$ | -0.542 | 0.369 |
| log_$R_{78}$ | -0.726 | 0.353 |
| log_$R_{79}$ | 0.371 | 0.316 |
| log_$R_{80}$ | 0.501 | 0.283 |
| log_$R_{81}$ | 0.403 | 0.263 |
| log_$R_{82}$ | 0.369 | 0.314 |
| log_$R_{83}$ | 0.540 | 0.275 |
| log_$R_{84}$ | 0.146 | 0.291 |
| log_$R_{85}$ | 0.442 | 0.277 |
| log_$R_{86}$ | 0.061 | 0.285 |
| log_$R_{87}$ | 0.019 | 0.246 |
| log_$R_{88}$ | 0.022 | 0.258 |
| log_$R_{89}$ | -0.332 | 0.279 |
| log_$R_{90}$ | -0.278 | 0.253 |
| log_$R_{91}$ | -0.530 | 0.286 |
| log_$R_{92}$ | -0.676 | 0.302 |
| log_$R_{93}$ | -0.583 | 0.289 |
| log_$R_{94}$ | -0.297 | 0.257 |
| log_$R_{95}$ | -0.066 | 0.225 |
| log_$R_{96}$ | 0.569 | 0.218 |
| log_$R_{97}$ | -0.018 | 0.293 |
| log_$R_{98}$ | -0.629 | 0.320 |
| log_$R_{99}$ | -0.015 | 0.310 |
| log_$R_{00}$ | 0.306 | 0.263 |
| log_$R_{01}$ | 0.383 | 0.241 |
| log_$R_{02}$ | -0.011 | 0.314 |
| log_$R_{03}$ | -0.285 | 0.330 |
| log_$R_{04}$ | 0.296 | 0.241 |
| log_$R_{05}$ | 0.424 | 0.222 |
| log_$R_{06}$ | 0.475 | 0.243 |

| name | Estimate | std.dev |
|---|---|---|
| log_$R_{07}$ | 0.539 | 0.232 |
| log_$R_{08}$ | 0.136 | 0.288 |
| log_$R_{09}$ | -0.364 | 0.294 |
| log_$R_{10}$ | 0.003 | 0.253 |
| log_$R_{11}$ | 0.281 | 0.273 |
| log_$R_{12}$ | 0.839 | 0.187 |
| log_$R_{13}$ | -0.232 | 0.282 |
| log_$R_{14}$ | -0.503 | 0.288 |
| log_$R_{15}$ | -0.651 | 0.263 |
| log_$R_{16}$ | -0.378 | 0.226 |
| log_$R_{17}$ | -0.014 | 0.275 |
| $a_1$ | 1.482 | 4.554 |
| $a_2$ | 2.267 | 4.238 |
| $a_3$ | 3.788 | 4.040 |
| $a_4$ | 4.077 | 4.025 |
| $a_5$ | 4.302 | 4.016 |
| $a_6$ | 3.528 | 4.046 |
| $a_7$ | 2.095 | 4.313 |
| r1 | 10.000 | 0.890 |
| r2 | 9.680 | 0.907 |
| log_a | -2.670 | 0.089 |
| log_b | 4.831 | 0.015 |
| log_$\phi_{st1}$ | -5.000 | 0.104 |
| log_$\phi_{wa}$ | -2.219 | 0.311 |
| log_$\phi_{wb}$ | 4.797 | 0.033 |
| Sw1 | 0.072 | 0.035 |
| Sw2 | 0.488 | 0.124 |
| log_$\phi_1$ | 5.462 | 4490.400 |
| log_awr | -0.827 | 0.603 |
| log_bwr | 4.666 | 0.033 |
| $w^2_t$ | 0.053 | 0.017 |
| q | 0.766 | 0.131 |
| $\sigma$ | 3.917 | 0.214 |
| $\beta_1$ | 12.441 | 0.700 |
| $\beta_2$ | 7.656 | 0.173 |
| *ms78* | 3.186 | 0.272 |