Incorporation of BSFRF Side-by-side Survey Data to Bristol Bay Red King Crab Stock Assessments, Spring 2016

Jie Zheng and M.S.M. Siddeek

A. Purpose

The CPT made the following recommendations for incorporating BSFRF side-by-side survey data into Bristol Bay red king crab stock assessments in January 2016:

*"**CPT requests to the Bristol Bay red king crab assessment authors for May 2016 meeting:** The CPT requested two assessments in which data from the 2007 and 2008 BSFRF surveys and the 2013–2015 BSFRF side-by-side are used to estimate trawl survey selectivity using the aforementioned snow crab model "separate survey" approach: one assessment without a prior for survey Q from the Otto-Somerton double-bag study; one assessment with a prior for survey Q from the double-bag study. The CPT also recommended that an approach be developed where the paired design of 2013-2015 BSFRF surveys is used to directly estimate selectivity. This would involve adding size-structured tow-by-tow data in new likelihood component in the assessment model, and was considered as a project for model development. There was no expectation by the CPT that such a model would be a candidate base model for review at the May CPT meeting."*

This draft report addresses these recommendations.

B. New Data

Besides the data used for the Bristol Bay red king crab stock assessment in 2015, new data include BSFRF side-by-side trawl survey data during 2013-2015. The survey includes 60 stations in Bristol Bay that approximately cover current Bristol Bay red king crab distributions. The 59 station data are used to estimate capture probabilities for NMFS surveys. These data were provided by Scott Goodman.

C. Scenarios

Seven scenarios are compared in this report:

1. The base scenario in September 2015. Using BSFRF survey data in 2007 and 2008. The BSFRF survey is treated as an independent survey, and no assumption is made about the capture probabilities of the BSFRF survey. In another word, survey selectivities for both surveys are estimated separately and directly in the model.

1n. Same as scenario 1 plus additional BSFRF survey data in 2013-2015.

1p. Same as scenario 1n except that no prior is used to estimate NMFS survey Q.

For scenarios 1, 1n, and 1p, survey abundances $N^b_{s,y,l}$ (BSFRF survey) and $N^n_{s,y,l}$ (NMFS survey) by sex *s* and in year *y* and length group *l* are computed as follows:

$$N^b_{s,y,l} = N_{s,y,l} s^b_{s,l},$$
$$N^n_{s,y,l} = N_{s,y,l} s^n_{s,l}, \qquad (1)$$

where $s^b_{s,l}$ and $s^n_{s,l}$ are survey selectivities for BSFRF and NMFS surveys by sex *s* and in length group *l*, respectively, and $N_{s,y,l}$ is the population abundance by sex *s* and in year y and length group *l*. The NMFS (1982-2015) and BSFRF survey selectivities are computed as

$$s^n_{s,l} = \frac{Q}{1 + e^{-\beta^n_s (l - L^n_{50,s})}},$$
$$s^b_{s,l} = \frac{1}{1 + e^{-\beta^b_s (l - L^b_{50,s})}}, \qquad (2)$$

where β and L_{50} are parameters and Q is the NMFS survey catchability. Survey selectivity for the first length group (67.5 mm) was assumed to be the same for both males and females, so only three parameters (β, $L50$ for females and $L50$ for males) were estimated in the model for each survey. Q is estimated in the model with or without a prior from the double-bag experiment, depending on scenarios. The BSFRF survey catchability is assumed to be 1.0.

2. Same as scenario 1n except for making an assumption that the BSFRF survey capture probabilities are 1.0 for all length groups. Under this assumption, NMFS survey selectivities are the products of crab availabilities (equal to BSFRF survey selectivities) and NMFS survey capture probabilities (p):

$$s^n_{s,l} = p_{s,l} s^b_{s,l}. \qquad (3)$$

Therefore, the model estimates NMFS survey capture probabilities and BSFRF survey selectivities and computes NMFS survey selectivities from these estimates. NMFS survey capture probabilities are computed as

$$p_{s,l} = \frac{Q}{1+e^{-\beta_s \ (l-L_{50,s})}}, \tag{4}$$

where *β* and *L50* are parameters and similar to the survey selectivities, only three parameters (*β*, *L50* for females and *L50* for males) were estimated in the model for each sex.

2p. Same as scenario 2 except that no prior is used to estimate NMFS survey Q.

3. Same as scenario 2 except that estimated NMFS survey capture probabilities and variances from 2013-2015 side-by-side survey data are used to estimate its capture probabilities within the model. When estimated CVs for capture probabilities are not available, a default CV of 110% maximum estimated CV values for each sex is used to fill-in the missing CV values.

Due to low catch number of each tow, the sum of all tows each year is used, rather than tow specific data. NMFS survey capture probability for a given length group and sex ($\tilde{p}_{s,y,l}$) is equal to the sum of estimated crab abundance per square nm (59 stations) within the length group and sex (*u*) from the NMFS survey each year divided by the corresponding abundance from the side-by-side BSFRF survey:

$$\tilde{p}_{s,y,l} = \sum_{st=1}^{59} u^n_{s,y,l} \Big/ \sum_{st=1}^{59} u^b_{s,y,l} \ . \tag{5}$$

Capture probabilities for each year, sex and length group are estimated from the 2013-2015 paired survey data. Corresponding variances are estimated by a bootstrapping approach. Each replicate consists of 59 paired survey data randomly sampled with replacement from the 59 survey stations, and total 1000 replicates are used.

3p. Same as scenario 3 except that no prior is used to estimate NMFS survey Q.

In addition to these seven scenarios, two more scenarios are added to examine the sensitivity of use of a default CV for the length groups that capture probability CVs cannot be estimated due to few stations with red king crab catch:

3a. Same as scenario 3 except that 150% maximum CV is used as a default.

3b. Same as scenario 3 except that 300% maximum CV is used as a default.

Additional negative loglikelihood for scenarios 3, 3p, 3a, and 3b is computed from the NMFS survey capture probabilities:

$$\sum_{s=1}^{s=2}\sum_{y=13}^{y=15}\sum_{l=1}^{n_s}(\tilde{p}_{s,y,l}-\hat{p}_{s,l})^2/(2\sigma_{s,y,l}^2)\,, \qquad (6)$$

where n_s is total length groups by sex s, $\hat{p}_{s,l}$ is the model estimated NMFS survey capture probability by sex s and in length group l, and $\sigma_{s,y,l}^2$ is the estimated variance of NMFS survey capture probability by sex s and in year y and length group l from the side-by-side data.

D. Results

Estimated capture probabilities of NMFS surveys directly from the side-by-side trawl surveys during 2013-2015 vary greatly between sex and among years (Table 1, Figure 1). Capture probabilities are not able to be estimated for a few length groups due to zero catches from the BSFRF survey. Overall, direct estimated capture probabilities are higher in 2014 than 2013 and 2015 and are higher for females than for males.

The CVs for direct estimated capture probabilities were not able to be estimated by bootstrapping for many length groups (Table 2), especially juvenile crab length groups, because crab were caught only in a small number of stations (Appendix A). The length groups for which CVs are estimable, the estimates varied greatly among length groups, sex, and years (Table 2).

Model estimated capture probabilities of the NMFS survey differ between scenarios with or without using the direct estimated capture probabilities from the paired survey data (Figures 2- 4). Without using paired data (scenarios 2 and 2p), model estimated capture probabilities are generally higher and fit the data points worse than those using paired data (Scenarios 3 and 3p). Scenarios 3 and 3p fit the direct estimated capture probabilities very well.

Model estimated survey selectivities/catchabilities for the NMFS survey vary among scenarios (Figure 5). Scenarios 3 and 3p using paired survey data have lowest selectivities, while scenario 2p without paired survey data and catchability prior results in highest selectivities. Estimated model survey selectivities for both scenarios 3 and 3p are about the same. The difference between estimated model survey selectivities for scenarios 1 and 1n are also very small.

Differences of model estimated selectivities for the BSFRF survey among different scenarios occur mainly for small size crab because the catchability is assumed to be 1.0 (Figure 6). Model selectivities for scenarios 3 and 3p are almost identical and equal to or higher than other scenarios for both males and females. Male model selecitvities for scenarios 1 and 1n are smallest for small size crab, especially for scenario 1. Model selectivity curves are very different between males and females.

The trends over time of total model estimated NMFS survey biomasses for all scenarios are the same (Figure 7). The estimated survey biomass for scenarios 3 and 3p are about the same and slightly lower than other scenarios. Overall, total survey biomasses are fit reasonably well for all scenarios. Similar results for the trends over time and differences among scenarios are also observed for model estimated survey mature male and female abundances (Figure 8).

Total model estimated BSFRF survey biomasses are generally lower than the survey estimates for all scenarios, especially scenarios 1, 1n, 2 and 2p (Figure 9). Given the extremely high survey biomass with both NMFS and BSFRF surveys in 2014, scenarios 3 and 3p seem to fit the BSFRF survey biomasses reasonably well and result in almost identical model BSFRF survey biomass estimates. BSFRF survey biomass estimates by scenarios 1 and 1n are very close.

Mature male biomass (MMB) estimates on February 15 before 1990 are generally very close among all scenarios except for scenario 2p (Figure 10). Due to high NMFS survey selectivities of scenario 2p, MMB estimates are always lower than those under other scenarios. Excluding scenarios 3a and 3b, estimated MMBs with scenarios 3 and 3p are similar and higher than estimates with other scenarios (Figure 10). MMB estimates with scenarios 1n and 2 are very close and higher than estimates with scenario 1 during recent years. Scenario 1p also results in lower MMB estimates, especially during recent years.

Fits of length composition data differ slightly for the BSFRF survey and are very similar for the NMFS survey among scenarios (Figures 11-13). Among the BSFRF survey length composition data, intra-length group variations are much higher during 2013-2015 than those during 2007-2008, which may be resulted from the much smaller sample sizes during the recent period. The length composition data from BSFRF surveys during 2013-2015 also do not track well over time.

Negative loglikelihood values for scenarios 1 and 1n and differences of negative loglikelihood values among scenarios are summarized in Table 3. Generally, negative loglikelihood values are very close between scenarios 1 and 1n except for components involving with the new BSFRF survey data during 2013-2015. Updating with three more years of BSFRF survey data decreases the negative loglikelihood values of BSFRF survey length composition data and total survey biomass for scenario 1n. The differences of negative loglikelihood values are smallest between scenarios 1n and 2 and largest between scenarios 1n and 3. Besides the additional negative loglikelihood values from including the component of NMFS survey capture probabilities, there are notable increases of negative loglikelihood values for NMFS survey biomass, BSFRF survey length composition, retained catch length composition, and decreases of negative loglikelihood values for NMFS survey and trawl bycatch discard length compositions, retained catch biomass and NMFS survey catchability from scenario 1n and scenario 3. Negative loglikelihood values are almost identical between scenarios 3 and 3p.

Parameter estimates for scenarios 2 and 3 are summarized in Tables 4 and 5.

The missing CV values for NMFS survey capture probabilities estimated from the side-by-side paired surveys during 2013-2015 were assumed to be 110% of the maximum estimated CV for a given sex. This assumption was based on the idea that the missing values should be greater than the maximum estimated values. Sensitivities of this assumption were examined through increasing the missing CV values to 150% and 300% of the maximum estimated values. Estimated capture probabilities for the NMFS survey are similar among scenarios 3, 3a and 3b for females but differ between scenario 3 and scenarios 3a and 3b for males (Figure 14). Similar to the results of estimated capture probabilities, estimated survey selectivities for the NMFS survey are close among these three scenarios for females and differ somewhat for males (Figure 15). Mature male biomass estimates are slightly lower for scenario 3 than scenarios 3a and 3b during recent years (Figure 10). Increasing the missing CV values to beyond 150% of the maximum estimated values results in little changes in model results.

E. Discussion

Seven scenarios were used to compare different assumptions on BSFRF survey capture probabilities and uses of BSFRF survey data to estimate NMFS survey selectivities/catchabilities for Bristol Bay red king crab stock assessment in this report. Assuming BSFRF capture probabilities to be 1 and use of BSFRF side-by-side paired survey data to estimate NMFS capture probabilities result in major differences in model results. Including the prior for NMFS survey catchability from the double-bag experiment also produces large differences in NMFS selectivity estimates.

Scenario 1n is a simple update of scenario 1, the base scenario for the fall 2015 assessment, through including the 2013-2015 BSFRF survey data. Scenario 1 assumes that BSFRF surveys are an independent survey and that its capture probabilities may be different from 1.0. Addition of the 2013-2015 BSFRF survey data does not change the NMFS selectivity estimates much, but results in higher abundance estimates during recent years, as expected, because higher abundance estimates from the BSFRF survey than from the NMFS survey after adjusting for survey selectivities during 2013-2015. Although CVs of total survey biomasses are comparable between BSFRF and NMFS surveys in 59 stations during 2013-2015, length composition data from the BSFRF survey do not track very well over time due to relatively small sample sizes, which may explain the limited impact on NMFS survey selectivity estimates from scenario 1 to scenario 1n. Removing the prior for NMFS survey catchability from the double-bag experiment in scenario 1n leads to scenario 1p, resulting in higher NMFS survey catchability estimates, thus higher NMFS survey selectivities. The prior plays a very important role in estimating NMFS survey catchability.

Based on scenario 1n, scenario 2 further assumes capture probabilities for the BSFRF survey to be 1.0 for all length groups. This assumption results in BSFRF survey selectivities equal to crab availabilities to trawl surveys, and crab availabilities are part of NMFS survey selectivities. Therefore, NMFS survey selectivities are directly related to BSFRF survey selectivities with scenario 2. The curve shapes of estimated NMFS survey selectivities with scenario 2 are different from those with scenario 1n. Although the estimated NMFS survey catchability is slightly higher, the overall estimated NMFS survey selectivities with scenario 2 are smaller than the selectivities with scenario 1n, resulting in higher absolute abundance and biomass estimates for scenario 2. Like scenario 1p, scenario 2p produces the highest NMFS survey selectivity estimates and lowest population abundance and biomass estimates without the prior for NMFS survey catchability from the double-bag experiment.

Scenario 2 is about the same approach as the snow crab model to deal with side-by-side paired data. The difference between scenario 2 and the snow crab model is that crab availabilities are estimated in the model only as BSFRF survey selectivities in scenario 2 (three parameters for three years of data) and a combined inside model estimates and outside of the model as a smoothing function of the survey data for the snow crab model (total 30 parameters for two years of data). Therefore, scenario 2 is much more parsimonious than the snow crab model for incorporating the side-by-side paired data into the stock assessments.

Scenario 3 further relies on BSFRF survey data to estimate NMFS survey selectivities/ catchability through utilizing the side-by-side paired survey data during 2013-2015 to estimate NMFS survey capture probabilities and their variances, which were incorporated into the integrated model to estimate NMFS survey selectivities. The main difference between scenarios 2 and 3 is the additional negative loglikelihood (equation 6) added to scenario 3. Although the shapes of NMFS survey selectivity curves are similar between scenarios 2 and 3, estimated NMFS survey catchabilities are more than 6% lower for scenario 3, resulting in lower estimated survey selectivities. Interesting results are that without the prior for NMFS survey catchability from the double-bag experiment (scenario 3p), estimated NMFS survey selectivities are about the same. Incorporating the side-by-side paired survey data produces a NMFS survey catchability estimate almost to be the same as estimated from the double-bag experiment data alone (0.895 vs 0.896). The results will likely change with more future NMFS survey data since NMFS survey data tend to result in higher survey catchability estimates.

BSFRF stated that the goal of the side-by-side survey as *“to cover all of the BBRKC survey distribution (over 2013 through 2015 survey seasons) with the two survey trawls (Nephrops trawl and NMFS trawl) operating side-by-side and to compare BBRKC CPUE results to directly inform the NMFS 83-112 trawl selectivity in the length-based stock assessment model currently used by ADF&G/NMFS for management of the BBRKC stock.”* By covering almost all of distribution areas of red king crab in Bristol Bay, this goal has been completed. The project design is also very efficient logistically and economically, and the survey can also be used to estimate total survey abundances. However, there are some drawbacks on using the side-by-side paired data obtained through this project to estimate NMFS trawl survey efficiency. First, the NMFS tow time is 30 minutes while BSFRF tow time is about 6-8 minutes. Previous researches (1995 for BBRKC and Somerton et al. (2002) for snow crab) indicated that crab CPUE increased when tow time was reduced. Second, the sizes of the BSFRF nephrops trawl net are smaller than those of the NMFS trawl net and towing speed is slower, which could lead to a greater contribution to CPUE from the herding of crab into the trawl path (Craig Rose, AFSC, per. comm.). Third, the BSFRF survey did not catch any female red king crab in a large percentage of 60 stations. Percentages of stations with male red king crab fare better, but still only slightly above 50%. Among stations caught with red king crab, many of them have 1 male or 1 female. There are a few length groups without any crab caught. In some years, only one BSFRF tow had red king crab for several length groups. The length composition data do not track very well over time due to small sample sizes. Fourth, for each paired data, the area-swept of the NMFS survey is about 6-7 times as much as that of the BSFRF survey. With a very short trawling duration for the BSFRF gear, errors on computing area-swept may be larger than those of the NMFS gear. Finally, due to aggregation of crab distributions, both gears may not sweep the same density of crab to produce a given paired data. The first two concerns may underestimate the NMFS survey selectivities and thus inflate the population abundance estimates. Increasing sample sizes would help minimizing some of the above problems. In the future, if more side-by-side surveys are to be conducted, ideally the surveys are undertaken in a few high density stations, if possible. This can be done with much less survey time due to less travel and will increase the chance of catching red king crab in each tow.

F. Recommendations

Recommendation for selecting a base scenario for the assessment in fall 2016 depends on perceptions of the reliability of the side-by-side paired data and the assumption of 100% capture probability of the BSFRF survey:

1. If we believe that both NMFS and BSFRF surveys are truly independent, then scenario 1n should be used.
2. If we believe the 100% capture probability of the BSFRF survey for all length groups used in the model and do not want to use side-by-side paired data, then scenario 2 may be the base scenario.
3. If we trust the side-by-side paired data, then either alternative scenario 3 or 3p may be chosen as the base scenario. Scenario 3 uses all available information on gear efficiency studies and may be preferred over scenario 3p.
4. Due to concerns for side-by-side paired data that may result in underestimating NMFS survey selectivities and overestimating population abundance, we recommend either status quo (scenario 1n) or the approach similar to the snow crab model (scenario 2). Because the paired data concerns have least impacts on Scenario 1n among all scenarios examined, we prefer the status quo scenario 1n as the base scenario for the assessment in fall 2016.

G. References

Somerton, D.A., Otto, R.S., Syrjala, S.E. 2002. Can changes in tow duration on bottom trawl surveys lead to changes in CPUE and mean size? Fisheries Research. 55: 63-70.

Table 1. NMFS survey capture probabilities estimated from side-by-side trawl surveys during 2013-2015. Missing values are due to zero catch of the BSFRF survey.

	Males			Females		
Mid Length of Size Bin (mm CL)	2013	2014	2015	2013	2014	2015
67.5			0.294	0.149		0.371
72.5	0.223		0.261			0.231
77.5	0.541	0.828	0.162	0.311	0.165	0.276
82.5	0.318	0.286	0.336	0.276	1.031	0.461
87.5	0.632	1.303	0.390	0.242	0.628	0.456
92.5	0.815	0.674	0.396	0.703	0.802	0.592
97.5	0.417	0.771	0.692	1.373	0.869	1.476
102.5	0.440	0.793	0.498	0.576	0.732	0.570
107.5	0.499	0.632	0.376	1.141	1.044	0.606
112.5	0.363	1.103	0.443	0.985	1.049	0.751
117.5	0.459	1.005	0.557	0.612	1.140	0.820
122.5	0.579	0.950	0.331	0.888	1.575	1.071
127.5	0.460	1.410	0.581	1.228	0.749	0.587
132.5	0.570	0.795	0.672	0.777	0.857	0.801
137.5	1.066	1.589	0.970	0.658	1.533	0.993
142.5	1.349	0.834	0.430	1.038	1.171	0.814
147.5	0.626	0.841	0.706			
152.5	0.632	0.685	0.396			
157.5	0.688	1.311	0.355			
162.5	0.479	0.923	0.629			

Table 2. CVs of NMFS survey capture probabilities estimated from side-by-side trawl surveys during 2013-2015 using 1000 bootstrap replicates. Missing values are due to zero catches of one or more bootstrap replicates from the BSFRF survey. The 110% of the maximum value (0.807) is used to fill-in the missing values for males and (0.827) for females.

Original estimates:

	Males			Females		
Mid Length of Size Bin (mm CL)	2013	2014	2015	2013	2014	2015
67.5						
72.5						
77.5						
82.5				0.413		
87.5						
92.5						
97.5		0.347				
102.5	0.578	0.431		0.439		
107.5	0.495	0.317			0.289	0.383
112.5	0.428			0.512	0.239	**0.752**
117.5	0.266	0.498	0.605		0.183	0.269
122.5	0.477	0.326	0.586		0.399	0.313
127.5	0.372	0.497			0.552	0.372
132.5	0.503	0.234	**0.734**		0.559	0.236
137.5					0.609	
142.5		0.469	0.343	0.261	0.275	0.300
147.5	0.464	0.720	0.730			
152.5	0.446	0.491	0.447			
157.5	0.422		0.360			
162.5	0.205	0.369	0.427			

Table 3. Negative loglikelihood components for scenarios 1 and 1n and differences in negative loglikelihood components among model scenarios.

	Scenarios and differences of scenarios							
	1	1n	1-1n	1n-1p	1n-2	1n-2p	1n-3	1n-3p
Rec	80.61	80.31	0.30	-0.37	1.20	0.88	-0.75	-0.76
Ret.len	-979.49	-979.55	0.06	1.10	-0.96	1.76	-3.31	-3.33
Pot Dis.M.Len	-998.27	-997.61	-0.66	-0.83	-0.22	-1.44	0.11	0.12
Pot Dis. F.Len	-2334.30	-2333.81	-0.49	0.78	0.84	5.23	0.23	0.21
Sur. Len	-46200.1	-46199.5	-0.60	1.80	8.50	15.90	4.80	4.80
Tr. Dis. Len	-2027.93	-2026.98	-0.95	-1.78	0.74	-4.57	3.66	3.70
Tan. Dis. Len.	-398.41	-399.35	0.94	0.53	1.07	1.90	0.65	0.64
BSFRF Len	-237.78	-567.38	329.60	0.27	-5.44	-3.62	-6.76	-6.79
Ret.Catch Bio	47.31	47.11	0.20	-0.63	0.49	-0.84	1.12	1.12
Pot Dis. M.Bio	219.50	219.88	-0.38	0.32	0.28	1.55	-0.37	-0.38
Pot Dis. F. Bio	0.13	0.13	0.00	0.00	0.00	0.00	0.00	0.00
Tr. Dis. Bio	0.90	0.91	-0.01	-0.01	-0.02	-0.03	-0.02	-0.02
Tan. Dis. Bio.	0.13	0.13	0.00	-0.02	0.01	-0.02	0.01	0.01
Sur. Bio.	95.08	94.89	0.19	1.17	-3.18	-2.64	-8.29	-8.32
BSFRF Bio	-4.95	-7.74	2.79	-0.70	0.04	-1.23	0.48	0.48
Q	0.64	0.74	-0.09	0.74	-2.01	0.74	0.74	0.74
Capt. prob.							-51.35	-51.22
Others	20.82	20.82	0.00	0.02	-0.13	-0.06	-0.14	-0.20
Total	-52716.1	-53047.0	330.90	2.40	1.20	13.50	-59.20	-59.20
Free parameters	272	272	0	0	0	0	0	0

	Scen. 1	Scen. 1n	Scen. 1p	Scen. 2	Scen.2p	Scen. 3	Scen.3p
Q value	0.924	0.926	0.997	0.955	1.139	0.895	0.894
Bmsy	26.064	26.369	25.644	27.298	25.739	28.027	28.035
MMB2015	24.691	25.903	24.738	26.640	23.876	27.622	27.632
OFL2015	6.732	7.386	6.876	7.434	6.174	7.797	7.801

Note that biomass and catch are in 1000 t.

Comparision of some estimated values of scenarios 3, 3a and 3b:

Scenario	3	3a	3b
Q value	0.895	0.903	0.905
Bmsy	28.027	27.745	27.703
MMB2015	27.622	28.346	28.051
OFL2015	7.797	8.388	8.312

Table 4. Summary of model parameter estimates (scenario 2) for Bristol Bay red king crab. Estimated values and standard deviations. All values are on a log scale. Male recruit is exp(mean+males), and female recruit is exp(mean+males+females).

Year	Recruits				F for Directed Pot Fishery				F for Trawl	
	Females	SD	Males	SD	Males	SD	Females	SD	Estimate	SD
Mean	15.932	0.025	15.932	0.025	-1.984	0.042	0.011	0.001	-5.264	0.063
Limits↑	13,18		13,18		-4.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.43		-6.0,3.5		-10,10	
1975					1.122	0.101				
1976	0.034	0.267	0.736	0.136	1.121	0.070			0.185	0.107
1977	0.542	0.160	0.616	0.103	1.116	0.060			0.709	0.105
1978	0.483	0.136	0.825	0.085	1.324	0.055			0.702	0.104
1979	0.749	0.102	1.104	0.076	1.595	0.052			0.737	0.104
1980	0.263	0.116	1.303	0.076	2.390	0.049			0.778	0.105
1981	0.108	0.148	0.496	0.101	2.425	0.007			0.354	0.104
1982	0.071	0.059	2.073	0.052	0.576	0.047			2.082	0.106
1983	0.014	0.074	1.393	0.051	-10.17	0.697			1.962	0.105
1984	0.467	0.060	1.391	0.050	0.948	0.056			2.926	0.103
1985	0.141	0.195	-0.704	0.122	1.060	0.064			1.879	0.105
1986	0.582	0.064	0.637	0.047	1.615	0.063			0.810	0.105
1987	-0.049	0.144	-0.246	0.075	1.228	0.059			0.496	0.104
1988	0.323	0.174	-0.941	0.108	0.263	0.050			1.468	0.102
1989	0.110	0.157	-0.787	0.090	0.350	0.047			0.053	0.102
1990	-0.029	0.073	0.359	0.046	0.948	0.043	2.025	0.101	0.340	0.102
1991	-0.064	0.099	-0.104	0.056	0.925	0.045	-0.106	0.101	0.675	0.103
1992	-0.473	0.401	-1.849	0.171	0.404	0.046	2.195	0.101	0.848	0.103
1993	-0.254	0.104	-0.333	0.057	1.051	0.048	2.078	0.102	1.104	0.103
1994	-0.312	0.447	-2.178	0.196	-4.095	0.048	1.455	0.129	-0.362	0.104
1995	0.034	0.047	1.237	0.036	-4.438	0.045	1.577	0.134	0.266	0.103
1996	-0.776	0.280	-0.618	0.118	0.106	0.042	-3.628	0.152	-0.446	0.103
1997	-0.802	0.401	-1.451	0.167	0.214	0.043	-0.969	0.103	-0.830	0.103
1998	-0.298	0.128	-0.202	0.068	0.909	0.043	2.107	0.100	-0.107	0.102
1999	0.090	0.065	0.628	0.043	0.464	0.043	-2.026	0.105	0.114	0.102
2000	-0.078	0.147	-0.316	0.081	0.089	0.042	-0.225	0.100	-0.642	0.102
2001	0.709	0.186	-0.971	0.140	0.107	0.042	1.142	0.100	-0.196	0.102
2002	0.238	0.061	1.072	0.041	0.209	0.042	-2.187	0.106	-0.294	0.101
2003	0.013	0.245	-0.673	0.144	0.735	0.041	1.213	0.100	-0.231	0.101
2004	-0.170	0.157	0.055	0.084	0.594	0.042	0.417	0.099	-0.578	0.102
2005	0.358	0.066	0.990	0.047	1.015	0.043	0.943	0.100	-0.348	0.101
2006	-0.710	0.173	0.376	0.066	0.733	0.042	-1.474	0.101	-0.636	0.102
2007	-0.257	0.159	-0.187	0.084	1.057	0.043	-0.250	0.100	-0.520	0.102
2008	0.139	0.162	-0.652	0.103	1.146	0.046	-0.562	0.101	-0.387	0.102
2009	0.252	0.144	-0.626	0.097	0.846	0.048	-0.787	0.101	-0.833	0.103
2010	-0.039	0.104	0.003	0.065	0.701	0.050	-0.244	0.101	-1.062	0.104
2011	0.006	0.110	-0.027	0.069	0.019	0.052	-1.168	0.103	-1.272	0.105
2012	-0.222	0.146	-0.262	0.080	-0.091	0.054	-1.702	0.105	-1.402	0.106
2013	-0.747	0.191	-0.379	0.084	0.082	0.057	0.247	0.102	-0.600	0.106
2014	-0.300	0.421	-1.895	0.209	0.310	0.061	-0.068	0.104	-0.270	0.107
2015	-0.146	0.144	0.106	0.097						

Table 4 (continued). Summary of model parameter estimates for Bristol Bay red king crab (scenario 2). Estimated values and standard deviations. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

				Initial Length Composition 1975			
Parameter	Value	SD	Limits	Length	Value	SD	Limits
Mm80-84	0.464	0.017	0.184, 1.0	68	1.154	0.103	-5, 5
Mf80-84	0.807	0.022	0.276, 1.5	73	1.177	0.089	-5, 5
Mf76-79,85-93	0.088	0.007	0.0, 0.108	78	0.514	0.108	-5, 5
log_betal, females	0.299	0.059	-0.67, 1.32	83	0.591	0.089	-5, 5
log_betal, males	0.618	0.082	-0.67, 1.32	88	0.403	0.089	-5, 5
log_betar, females	-0.640	0.060	-1.14, 0.5	93	0.212	0.094	-5, 5
log_betar, males	-0.614	0.052	-1.14, 0.5	98	0.220	0.093	-5, 5
Bsfrf_CV	0.000	0.000	0.00, 0.40	103	0.009	0.105	-5, 5
moltp_slope, 75-78	0.134	0.022	0.01, 0.207	108	0.085	0.103	-5, 5
moltp_slope, 79-14	0.096	0.004	0.01, 0.207	113	0.216	0.101	-5, 5
log_moltp_L50, 75-78	4.970	0.014	4.47, 5.62	118	0.016	0.119	-5, 5
log_moltp_L50, 79-14	4.946	0.004	4.47, 5.62	123	0.058	0.124	-5, 5
log_N75	19.999	0.035	15.0, 21.0	128	-0.026	0.140	-5, 5
log_avg_L50_ret	4.921	0.002	4.78, 5.05	133	-0.039	0.149	-5, 5
ret_fish_slope	0.531	0.032	0.05, 0.70	138	-0.135	0.138	-5, 5
pot disc.males, φ	-0.329	0.014	-0.40, 0.00	143	-0.256	0.143	-5, 5
pot disc.males, κ	0.004	0.000	0.0, 0.005	148	-0.445	0.155	-5, 5
pot disc.males, γ	-0.015	0.001	-0.025, 0.0	153	-0.786	0.189	-5, 5
pot disc.fema., slope	0.211	0.064	0.05, 0.69	158	-1.318	0.263	-5, 5
log_pot disc.fema., L50	4.431	0.021	4.24, 4.61	163	-1.332	0.276	-5, 5
trawl disc slope	0.063	0.003	0.01, 0.20	68	1.633	0.105	-5, 5
log_trawl disc L50	4.952	0.029	4.40, 5.20	73	1.537	0.101	-5, 5
log_srv_L50, m, bsfrf	4.333	0.028	3.59, 5.49	78	1.501	0.094	-5, 5
srv_slope, f, bsfrf	0.030	0.007	0.01, 0.435	83	1.334	0.093	-5, 5
log_srv_L50, f, bsfrf	4.537	0.072	4.09, 5.54	88	1.282	0.086	-5, 5
log_srv_L50, m, 75-81	4.349	0.010	4.09, 5.54	93	0.821	0.103	-5, 5
srv_slope, f, 75-81	0.069	0.004	0.01, 0.33	98	0.448	0.125	-5, 5
log_srv_L50, f, 75-81	4.487	0.017	4.09, 4.70	103	0.155	0.149	-5, 5
log_srv_L50, m, 82-15	4.367	0.101	4.09, 5.10	108	-0.001	0.155	-5, 5
srv_slope, f, 82-15	0.077	0.007	0.01, 0.30	113	-0.240	0.180	-5, 5
log_srv_L50, f, 82-15	4.263	0.032	4.09, 4.90	118	-0.828	0.281	-5, 5
TC_slope, females	0.365	0.133	0.02, 0.40	123	-0.932	0.317	-5, 5
log_TC_L50, females	4.535	0.014	4.24, 4.90	128	-1.217	0.413	-5, 5
TC_slope, males	0.225	0.089	0.05, 0.90	133	-2.141	0.904	-5, 5
log_TC_L50, males	4.589	0.022	4.25, 5.14	138	-2.167	1.010	-5, 5
Q	0.955	0.022	0.6, 1.2	143	NA	NA	
log_TC_F, males, 91	-4.130	0.086	-10.0, 1.00				
log_TC_F, males, 92	-6.103	0.088	-10.0, 1.00				
log_TC_F, males, 93	-6.835	0.090	-10.0, 1.00				
log_TC_F, males, 13	-8.310	0.097	-10.0, 1.00				
log_TC_F, males, 14	-7.470	0.096	-10.0, 1.00				
log_TC_F, females, 91	-2.944	0.088	-10.0, 1.00				
log_TC_F, females, 92	-4.590	0.088	-10.0, 1.00				
log_TC_F, females, 93	-6.479	0.090	-10.0, 1.00				
log_TC_F, females, 13	-7.744	0.086	-10.0, 1.00				
log_TC_F, females, 14	-7.597	0.086	-10.0, 1.00				

Table 5. Summary of model parameter estimates (scenario 3) for Bristol Bay red king crab. Estimated values and standard deviations. All values are on a log scale. Male recruit is exp(mean+males), and female recruit is exp(mean+males+females).

Year	Recruits				F for Directed Pot Fishery				F for Trawl	
	Females	SD	Males	SD	Males	SD	Females	SD	Estimate	SD
Mean	15.955	0.025	15.955	0.025	-2.019	0.041	0.011	0.001	-5.294	0.062
Limits↑	13,18		13,18		-4.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.43		-6.0,3.5		-10,10	
1975					1.137	0.100				
1976	0.007	0.269	0.747	0.136	1.148	0.071			0.211	0.107
1977	0.530	0.161	0.632	0.103	1.148	0.061			0.735	0.105
1978	0.463	0.136	0.852	0.086	1.357	0.055			0.727	0.104
1979	0.731	0.102	1.141	0.078	1.625	0.052			0.758	0.104
1980	0.239	0.115	1.353	0.078	2.415	0.049			0.793	0.104
1981	0.079	0.147	0.555	0.102	2.425	0.007			0.356	0.104
1982	0.087	0.058	2.071	0.051	0.562	0.046			2.069	0.106
1983	0.009	0.074	1.393	0.052	-10.218	0.731			1.954	0.105
1984	0.431	0.062	1.424	0.048	0.951	0.056			2.929	0.103
1985	0.161	0.200	-0.746	0.127	1.064	0.063			1.892	0.104
1986	0.574	0.064	0.639	0.048	1.637	0.063			0.828	0.104
1987	-0.052	0.144	-0.244	0.076	1.258	0.058			0.514	0.104
1988	0.328	0.175	-0.951	0.110	0.287	0.051			1.482	0.102
1989	0.118	0.158	-0.800	0.091	0.368	0.047			0.065	0.102
1990	-0.039	0.073	0.374	0.046	0.957	0.044	2.010	0.101	0.350	0.102
1991	-0.060	0.098	-0.094	0.057	0.925	0.045	-0.117	0.101	0.677	0.103
1992	-0.506	0.419	-1.865	0.174	0.398	0.047	2.185	0.101	0.842	0.103
1993	-0.238	0.103	-0.326	0.057	1.039	0.048	2.069	0.102	1.094	0.103
1994	-0.371	0.466	-2.185	0.198	-4.108	0.048	1.445	0.129	-0.380	0.104
1995	0.044	0.045	1.250	0.036	-4.444	0.045	1.562	0.134	0.254	0.103
1996	-0.723	0.281	-0.633	0.122	0.100	0.043	-3.641	0.152	-0.455	0.103
1997	-0.829	0.418	-1.475	0.172	0.206	0.043	-0.975	0.102	-0.841	0.103
1998	-0.275	0.126	-0.197	0.069	0.899	0.044	2.105	0.100	-0.117	0.102
1999	0.108	0.064	0.630	0.044	0.455	0.044	-2.028	0.105	0.104	0.102
2000	-0.064	0.146	-0.316	0.082	0.083	0.043	-0.229	0.100	-0.651	0.102
2001	0.727	0.188	-0.980	0.142	0.100	0.042	1.141	0.099	-0.204	0.102
2002	0.256	0.058	1.077	0.041	0.203	0.042	-2.187	0.106	-0.302	0.101
2003	0.023	0.249	-0.682	0.147	0.731	0.042	1.209	0.100	-0.237	0.101
2004	-0.141	0.156	0.054	0.085	0.590	0.042	0.416	0.099	-0.585	0.102
2005	0.365	0.064	0.999	0.048	1.008	0.043	0.946	0.100	-0.355	0.101
2006	-0.669	0.170	0.372	0.067	0.726	0.043	-1.472	0.101	-0.643	0.102
2007	-0.244	0.160	-0.214	0.086	1.050	0.044	-0.246	0.100	-0.525	0.102
2008	0.148	0.162	-0.671	0.105	1.133	0.047	-0.550	0.101	-0.394	0.103
2009	0.267	0.143	-0.620	0.098	0.833	0.049	-0.773	0.101	-0.840	0.104
2010	-0.041	0.105	0.005	0.066	0.691	0.051	-0.232	0.101	-1.069	0.105
2011	0.007	0.110	-0.027	0.071	0.011	0.053	-1.156	0.103	-1.278	0.106
2012	-0.208	0.144	-0.264	0.081	-0.098	0.055	-1.690	0.105	-1.407	0.107
2013	-0.756	0.196	-0.417	0.088	0.074	0.059	0.260	0.102	-0.605	0.107
2014	-0.327	0.432	-1.933	0.208	0.302	0.063	-0.053	0.104	-0.275	0.108
2015	-0.157	0.144	0.074	0.098						

Table 5 (continued). Summary of model parameter estimates for Bristol Bay red king crab (scenario 3). Estimated values and standard deviations. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

				Initial Length Composition 1975			
Parameter	Value	SD	Limits	Length	Value	SD	Limits
Mm80-84	0.471	0.016	0.184, 1.0	68	1.153	0.104	-5, 5
Mf80-84	0.803	0.021	0.276, 1.5	73	1.181	0.090	-5, 5
Mf76-79,85-93	0.083	0.006	0.0, 0.108	78	0.520	0.109	-5, 5
log_betal, females	0.301	0.057	-0.67, 1.32	83	0.597	0.090	-5, 5
log_betal, males	0.623	0.084	-0.67, 1.32	88	0.404	0.090	-5, 5
log_betar, females	-0.625	0.060	-1.14, 0.5	93	0.208	0.094	-5, 5
log_betar, males	-0.596	0.052	-1.14, 0.5	98	0.212	0.093	-5, 5
Bsfrf_CV	0.000	0.000	0.00, 0.40	103	-0.003	0.105	-5, 5
moltp_slope, 75-78	0.134	0.020	0.01, 0.207	108	0.073	0.104	-5, 5
moltp_slope, 79-14	0.093	0.005	0.01, 0.207	113	0.202	0.101	-5, 5
log_moltp_L50, 75-78	4.965	0.012	4.47, 5.62	118	0.003	0.119	-5, 5
log_moltp_L50, 79-14	4.943	0.004	4.47, 5.62	123	0.045	0.124	-5, 5
log_N75	20.015	0.034	15.0, 21.0	128	-0.039	0.140	-5, 5
log_avg_L50_ret	4.921	0.002	4.78, 5.05	133	-0.050	0.149	-5, 5
ret_fish_slope	0.531	0.032	0.05, 0.70	138	-0.139	0.138	-5, 5
pot disc.males, φ	-0.329	0.015	-0.40, 0.00	143	-0.260	0.142	-5, 5
pot disc.males, κ	0.004	0.000	0.0, 0.005	148	-0.449	0.154	-5, 5
pot disc.males, γ	-0.015	0.001	-0.025, 0.0	153	-0.787	0.188	-5, 5
pot disc.fema., slope	0.216	0.066	0.05, 0.69	158	-1.313	0.260	-5, 5
log_pot disc.fema., L50	4.428	0.022	4.24, 4.61	163	-1.323	0.271	-5, 5
trawl disc slope	0.063	0.003	0.01, 0.20	68	1.637	0.105	-5, 5
log_trawl disc L50	4.956	0.029	4.40, 5.20	73	1.539	0.101	-5, 5
log_srv_L50, m, bsfrf	4.209	0.037	3.59, 5.49	78	1.500	0.094	-5, 5
srv_slope, f, bsfrf	0.010	0.002	0.01, 0.435	83	1.333	0.093	-5, 5
log_srv_L50, f, bsfrf	5.150	0.189	4.09, 5.54	88	1.279	0.086	-5, 5
log_srv_L50, m, 75-81	4.354	0.011	4.09, 5.54	93	0.818	0.102	-5, 5
srv_slope, f, 75-81	0.069	0.004	0.01, 0.33	98	0.446	0.125	-5, 5
log_srv_L50, f, 75-81	4.488	0.017	4.09, 4.70	103	0.153	0.148	-5, 5
log_srv_L50, m, 82-15	4.520	0.035	4.09, 5.10	108	-0.003	0.154	-5, 5
srv_slope, f, 82-15	0.071	0.004	0.01, 0.30	113	-0.240	0.179	-5, 5
log_srv_L50, f, 82-15	4.380	0.021	4.09, 4.90	118	-0.827	0.279	-5, 5
TC_slope, females	0.367	0.135	0.02, 0.40	123	-0.929	0.313	-5, 5
log_TC_L50, females	4.533	0.014	4.24, 4.90	128	-1.210	0.406	-5, 5
TC_slope, males	0.229	0.092	0.05, 0.90	133	-2.119	0.876	-5, 5
log_TC_L50, males	4.587	0.022	4.25, 5.14	138	-2.139	0.974	-5, 5
Q	0.895	0.019	0.6, 1.2	143	NA	NA	
log_TC_F, males, 91	-4.171	0.085	-10.0, 1.00				
log_TC_F, males, 92	-6.149	0.087	-10.0, 1.00				
log_TC_F, males, 93	-6.887	0.089	-10.0, 1.00				
log_TC_F, males, 13	-8.354	0.097	-10.0, 1.00				
log_TC_F, males, 14	-7.513	0.097	-10.0, 1.00				
log_TC_F, females, 91	-3.004	0.086	-10.0, 1.00				
log_TC_F, females, 92	-4.655	0.086	-10.0, 1.00				
log_TC_F, females, 93	-6.548	0.088	-10.0, 1.00				
log_TC_F, females, 13	-7.784	0.086	-10.0, 1.00				
log_TC_F, females, 14	-7.635	0.086	-10.0, 1.00				

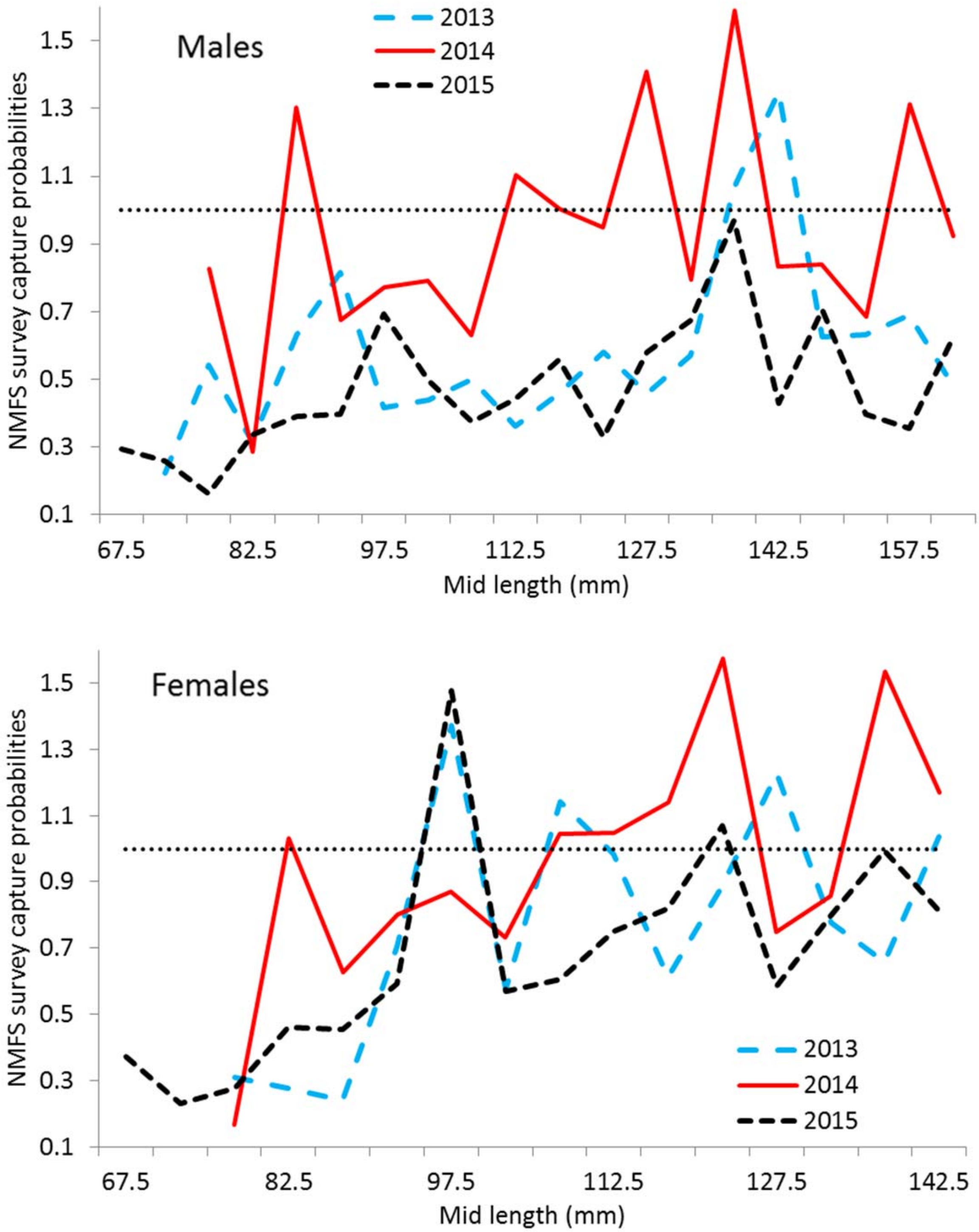
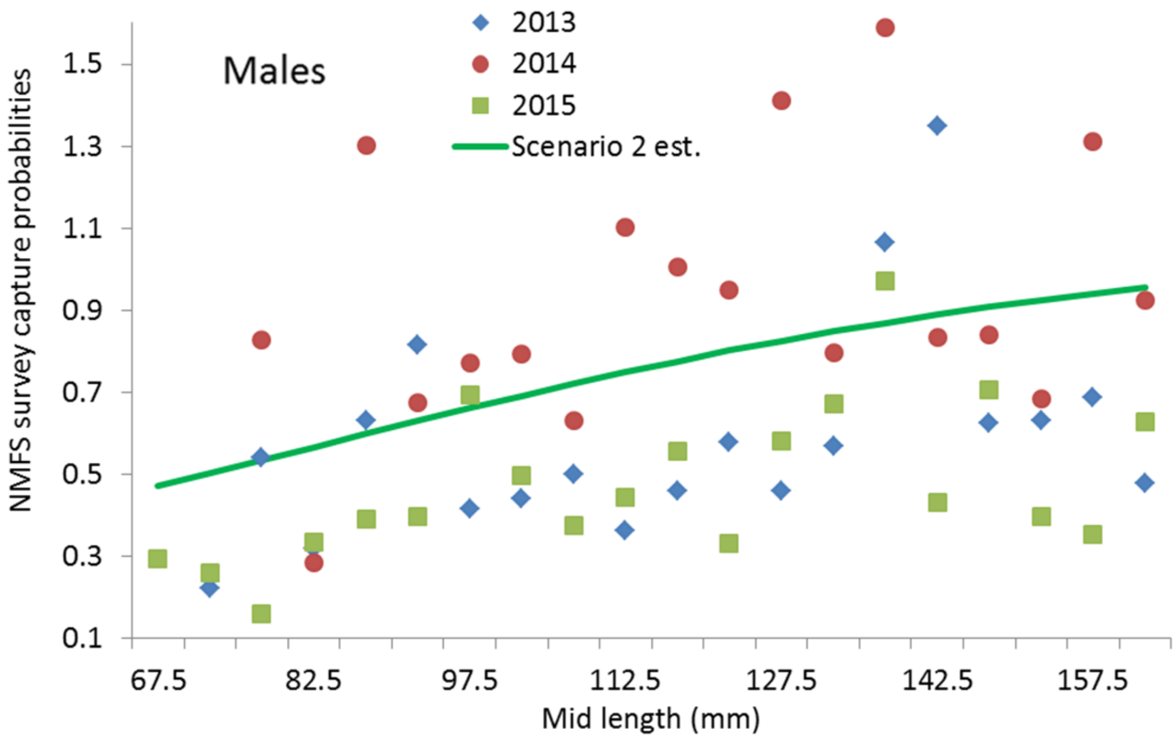


Figure 1. NMFS survey capture probabilities estimated from side-by-side trawl surveys during 2013-2015. Missing values are due to zero catch of the BSFRF survey.



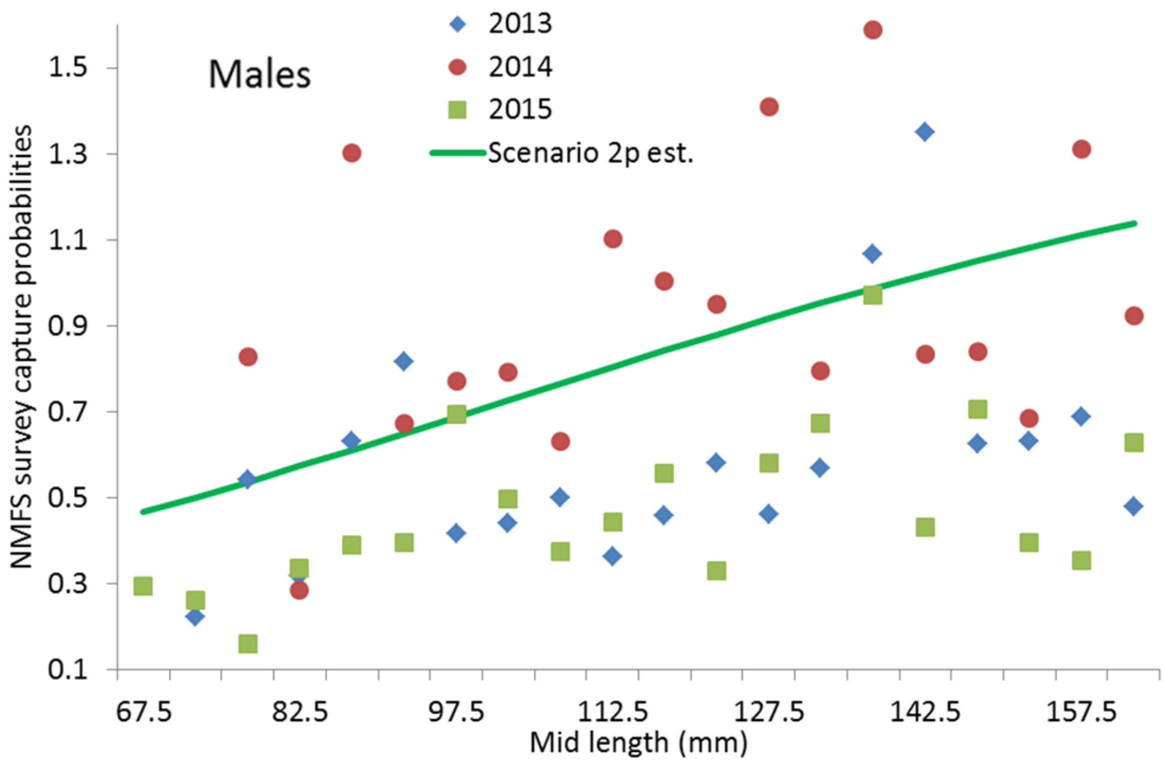
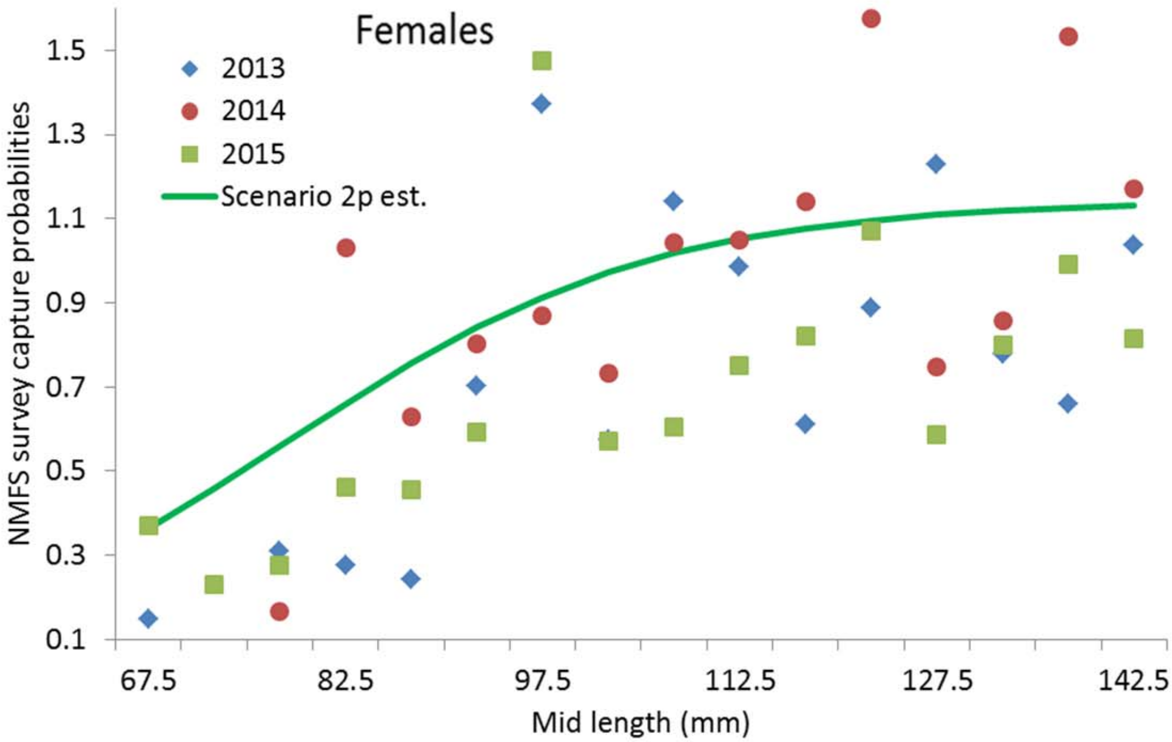


Figure 2. Comparison of side-by-side survey and model (line) estimated capture probabilities of male red king crab during 2013-2015 for scenarios 2 (above) and 2p (below). Missing values are due to zero catch of the BSFRF survey.



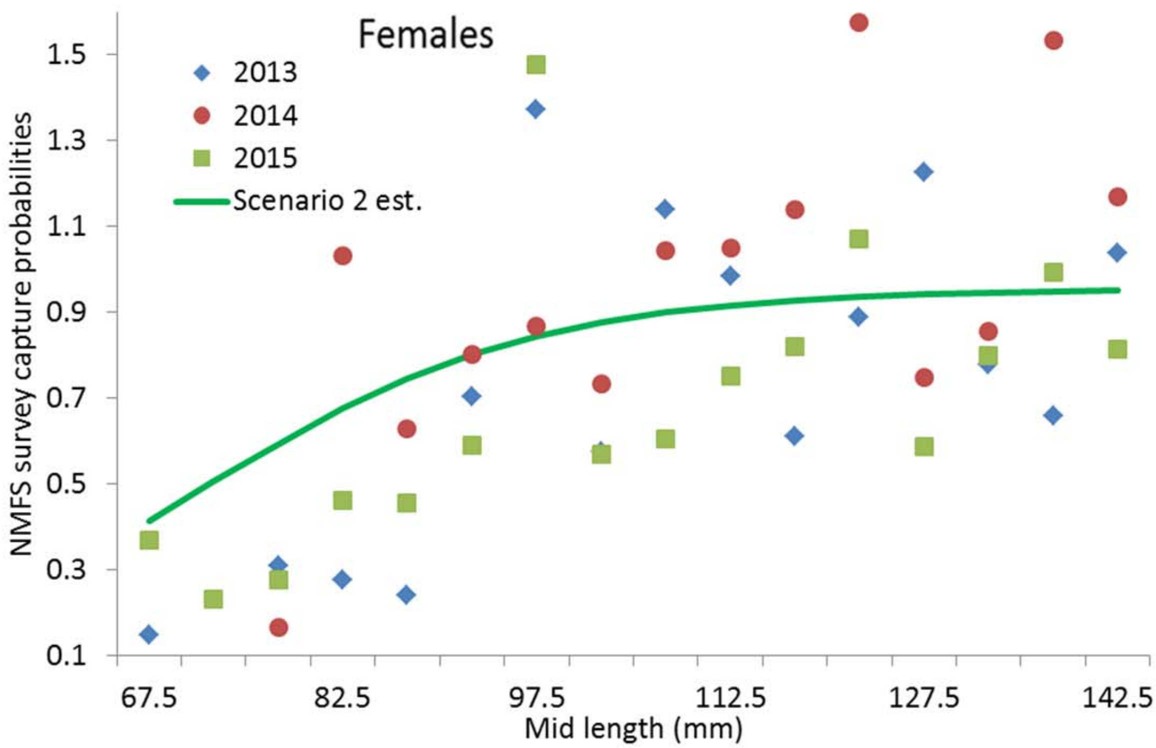


Figure 3. Comparison of side-by-side survey and model (line) estimated capture probabilities of female red king crab during 2013-2015 for scenarios 2 (above) and 2p (below). Missing values are due to zero catch of the BSFRF survey.

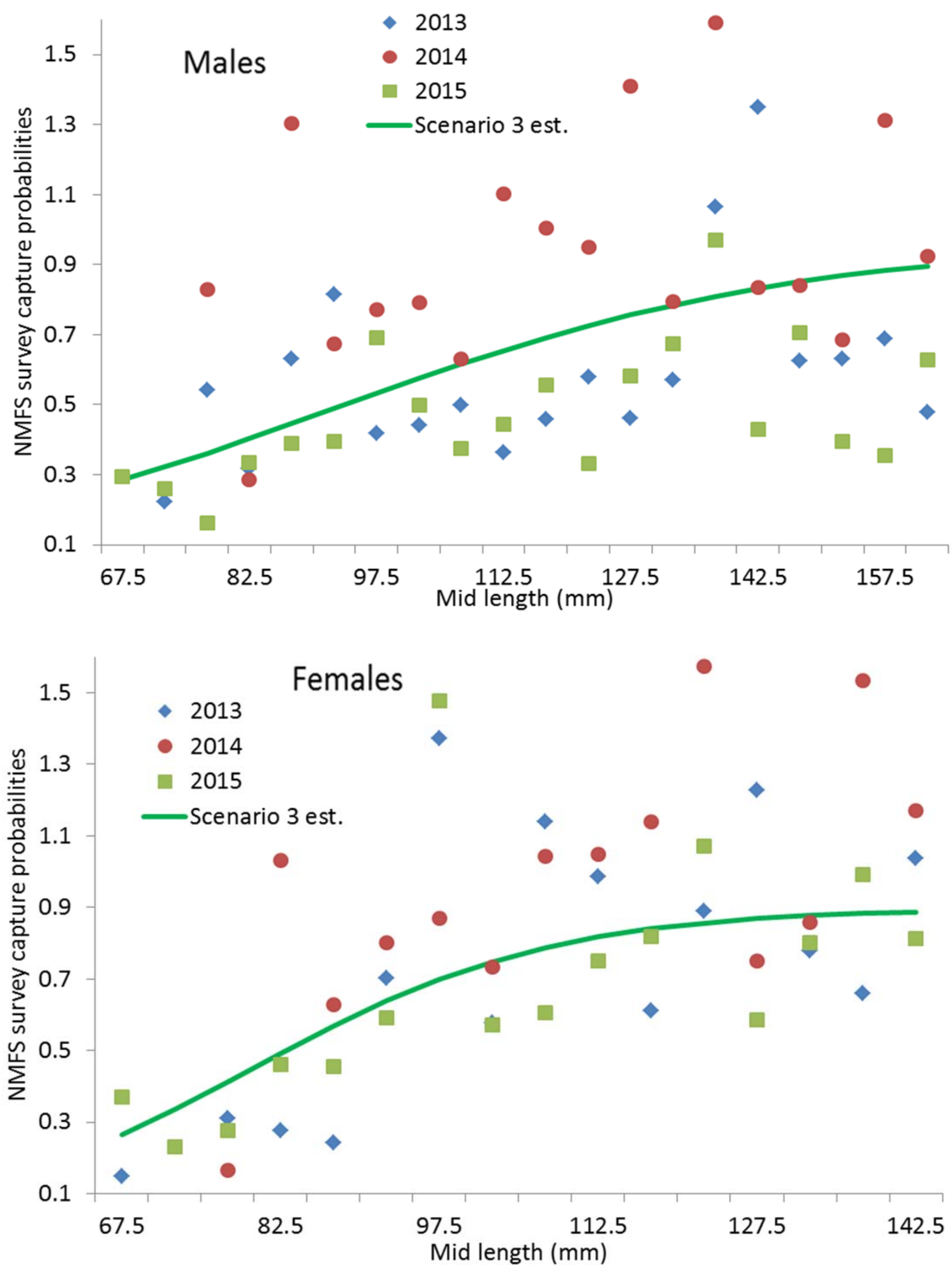


Figure 4. Comparison of side-by-side survey and model (line) estimated capture probabilities of red king crab during 2013-2015 for scenario 3. Missing values are due to zero catch of the BSFRF survey.

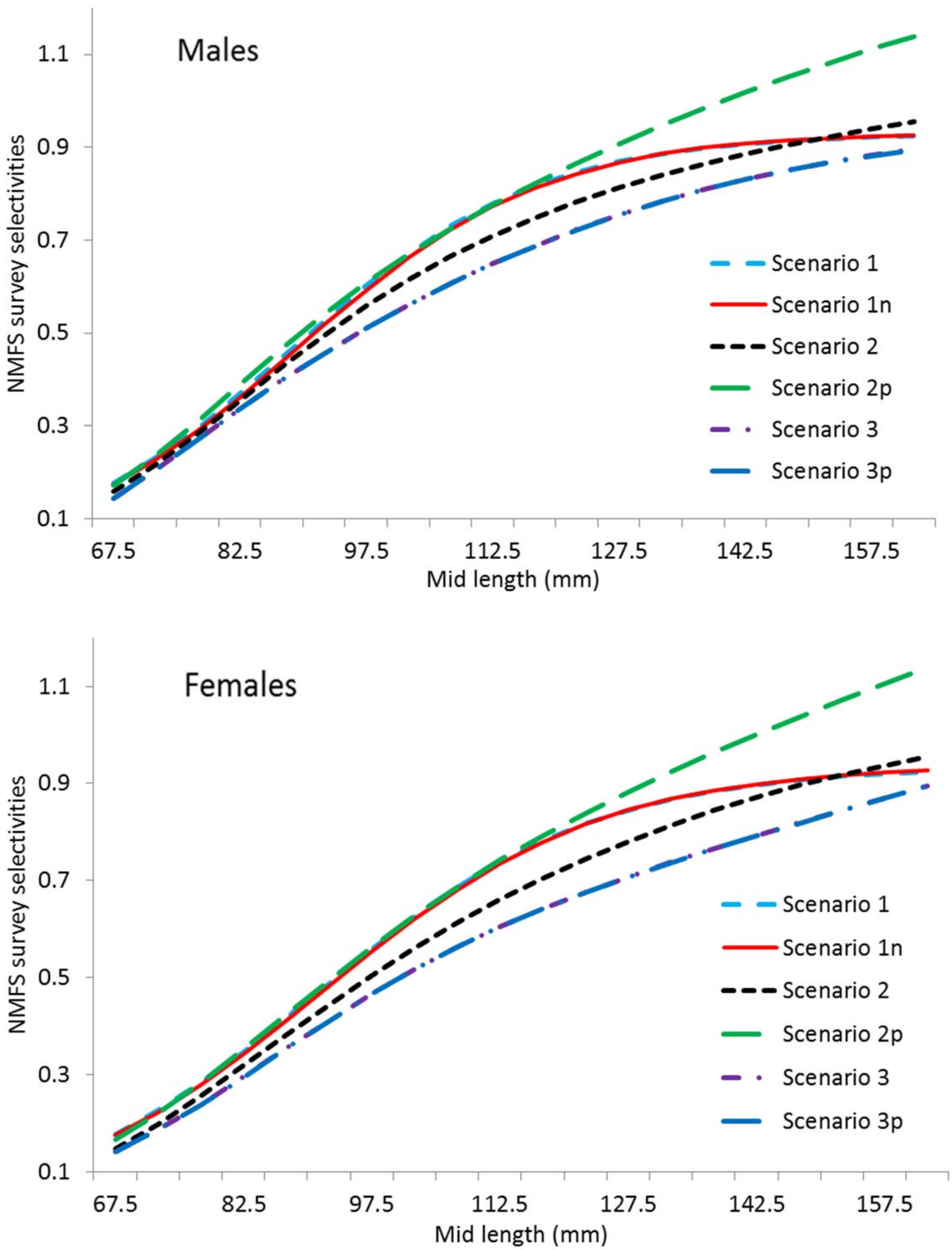


Figure 5. Estimated selectivities of NMFS trawl survey during 1982-2015 with different dataset of BSFRF survey data and six scenarios.

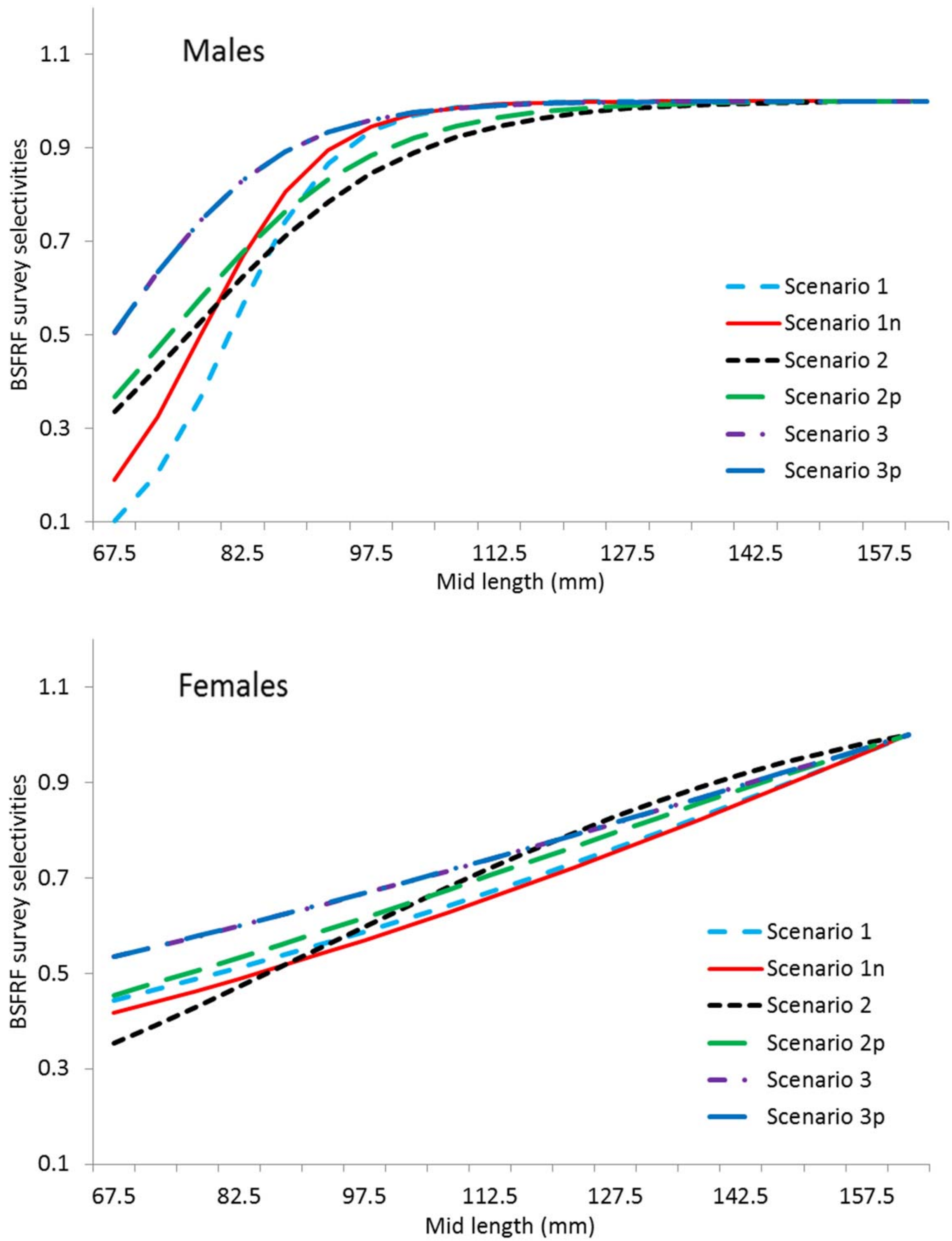


Figure 6. Estimated selectivities of BSFRF trawl survey during 2007-08 and 2013-2015 with different dataset of BSFRF survey data and six scenarios.

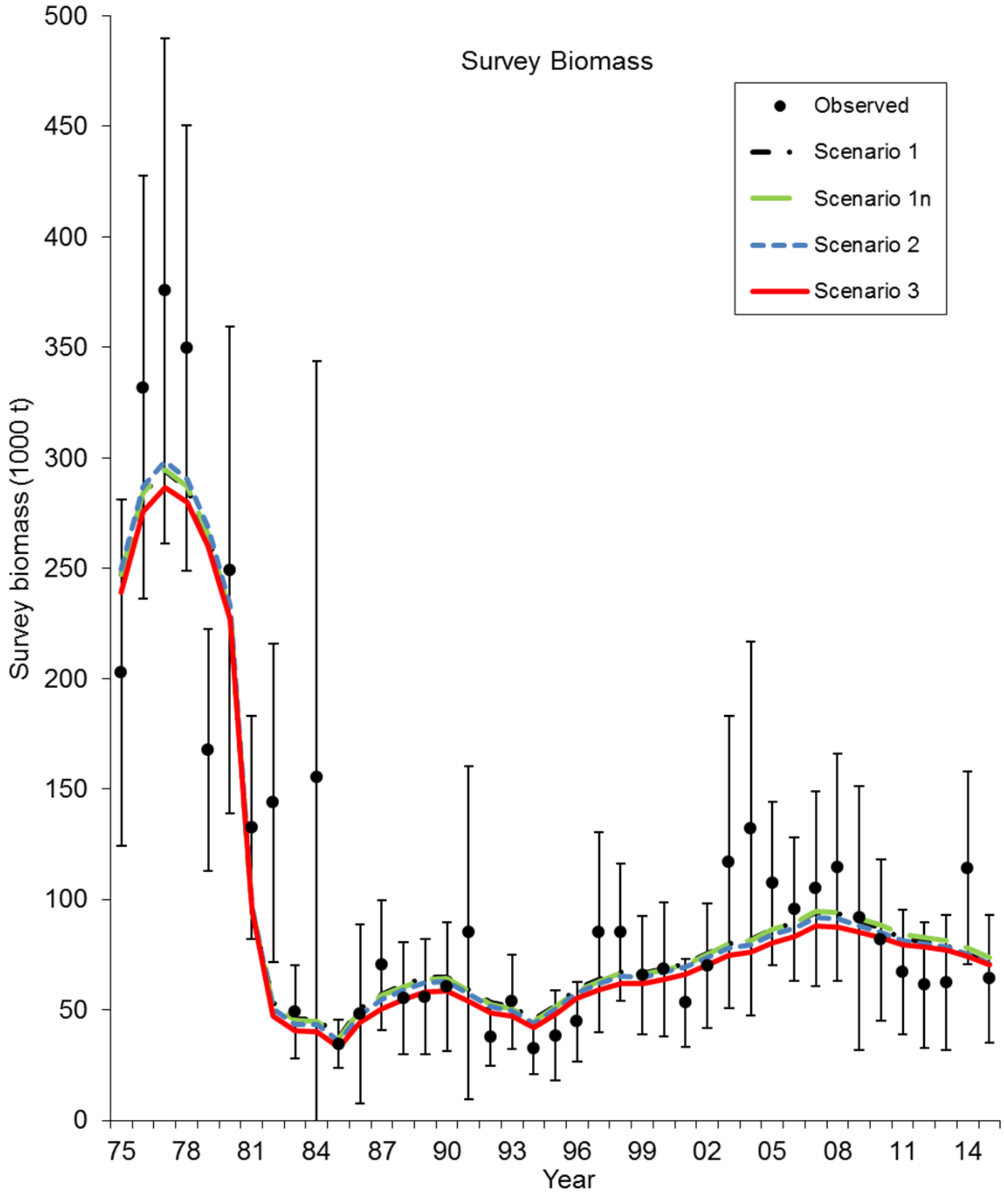


Figure 7. Comparisons of area-swept estimates of total NMFS survey biomass and model prediction for model estimates in 2015 under scenarios 1, 1n, 2 and 3. The error bars are plus and minus 2 standard deviations.

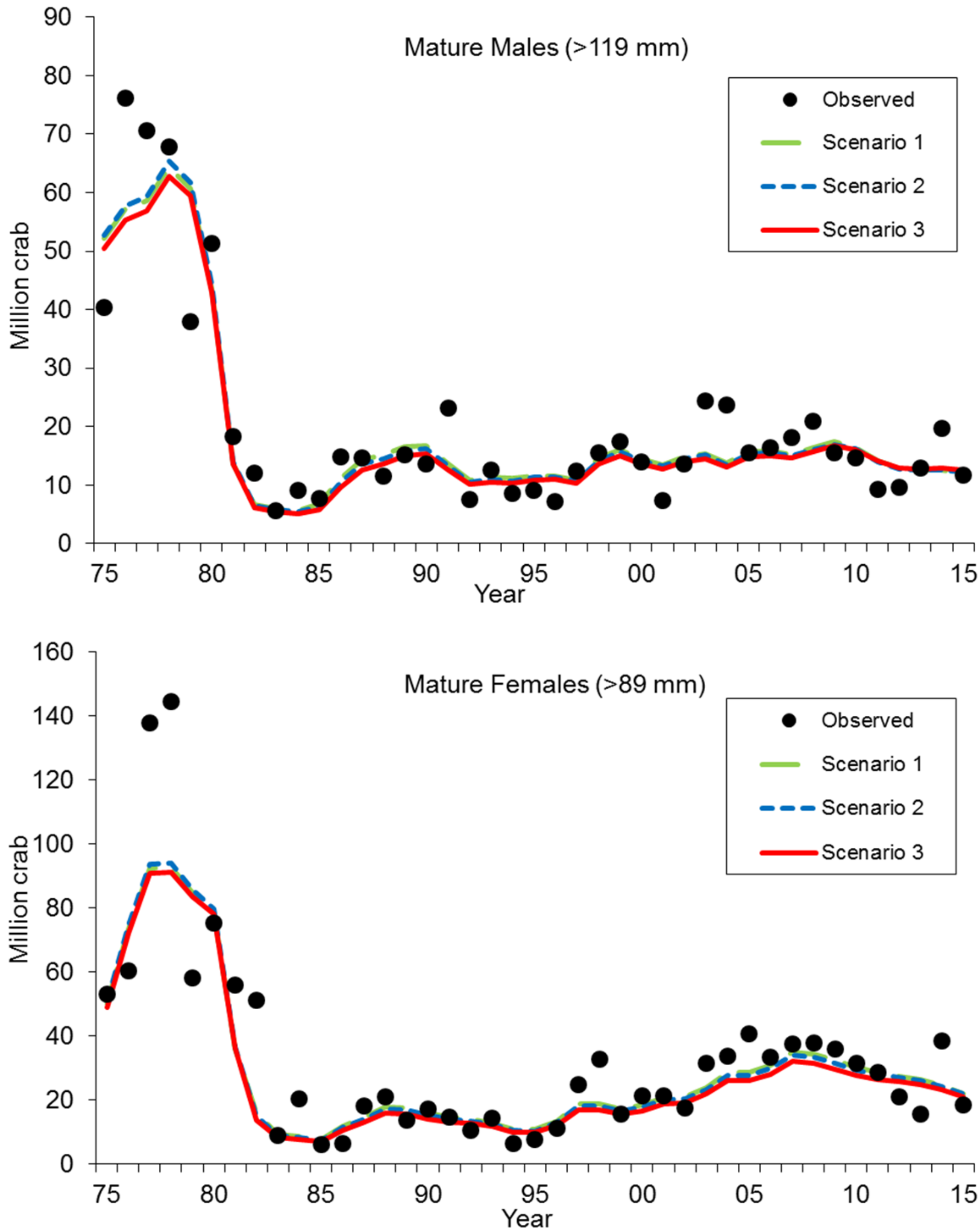


Figure 8. Comparisons of NMFS survey area-swept estimates of male (>119 mm) and female (>89 mm) abundance and model prediction for model estimates in 2015 under scenarios 1, 2 and 3.

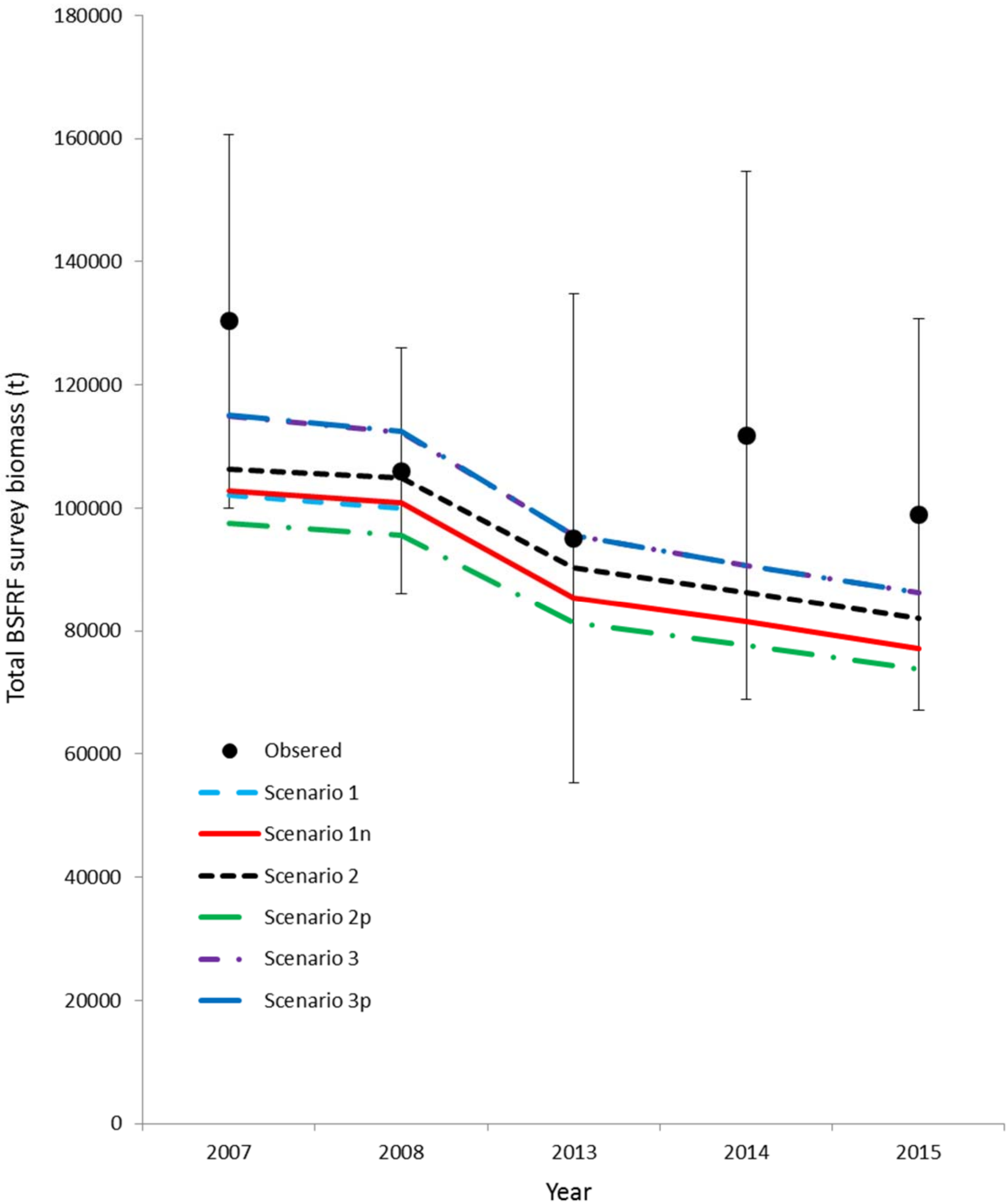


Figure 9. Comparisons of total survey biomass estimates by the BSFRF survey and the model for model estimates in 2015 (scenarios 1, 1n, 2, 2p, 3 & 3p). The error bars are plus and minus 2 standard deviations of scenario 1n.

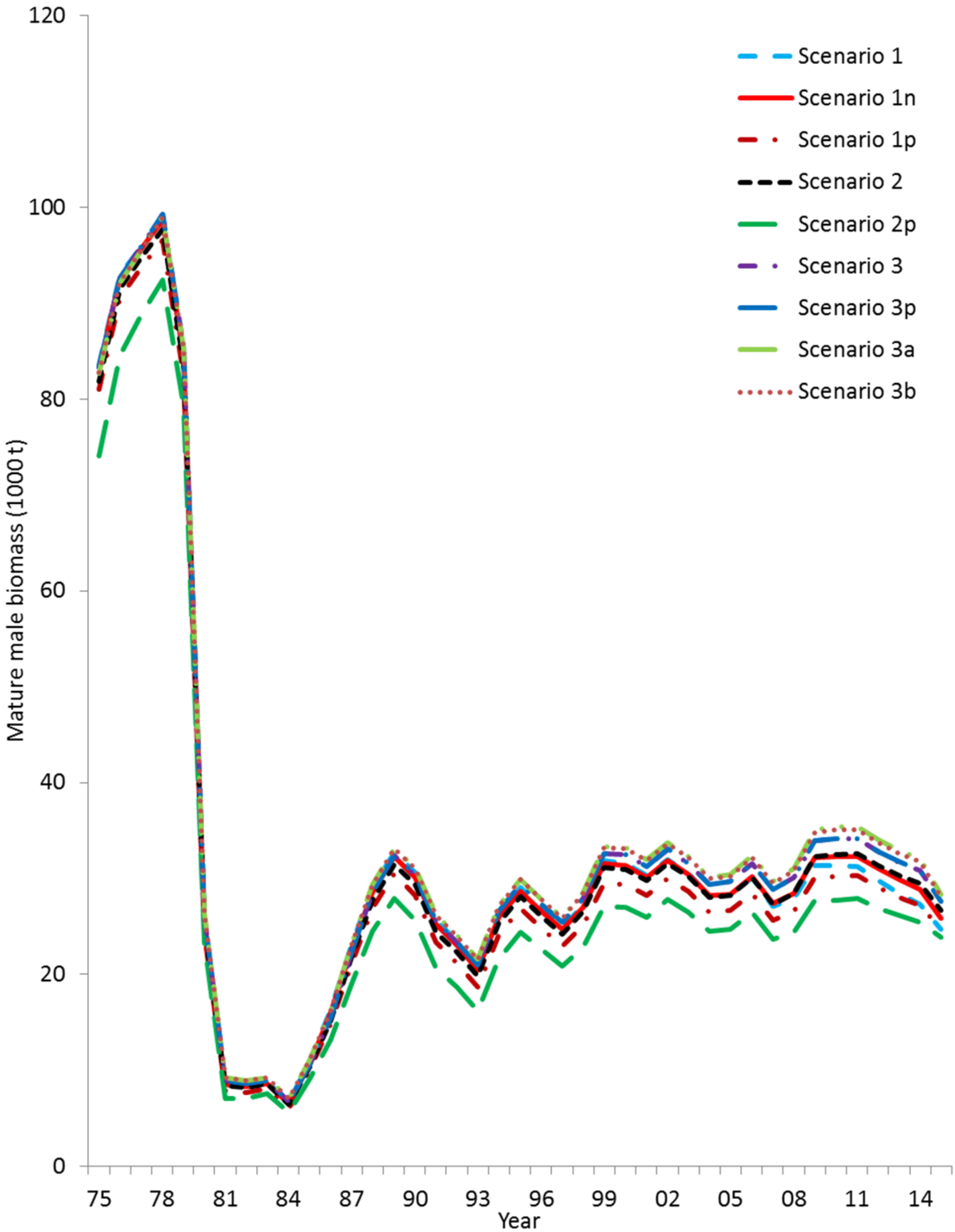


Figure 10. Comparisons of mature male biomass on Feb. 15 under scenarios 1, 1n, 1p, 2, 2p, 3, 3p, 3a and 3b.

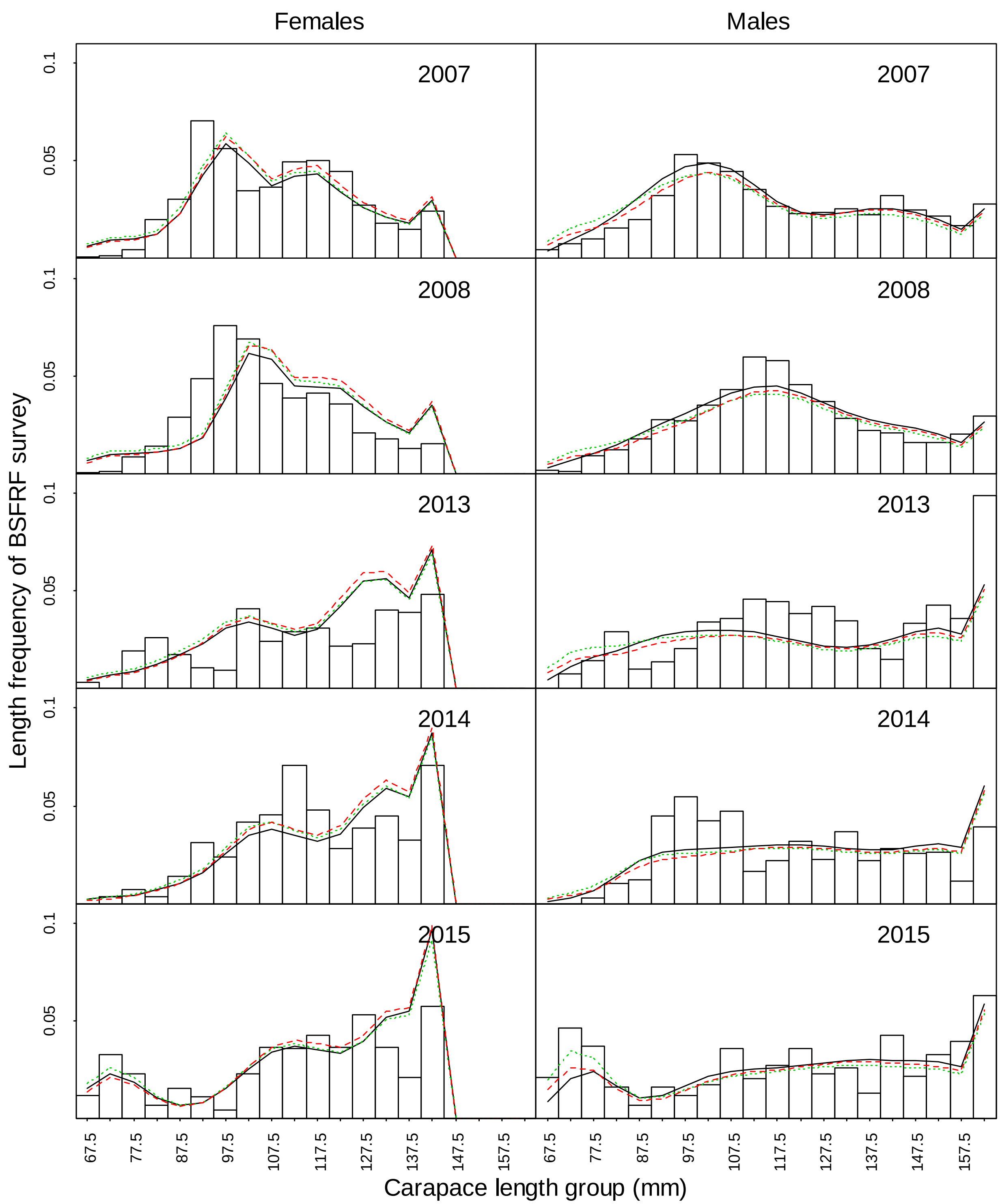


Figure 11. Comparison of area-swept and model fits of BSFRF survey length compositions with scenarios 1n (black lines), 2 (red lines), and 3 (green lines).

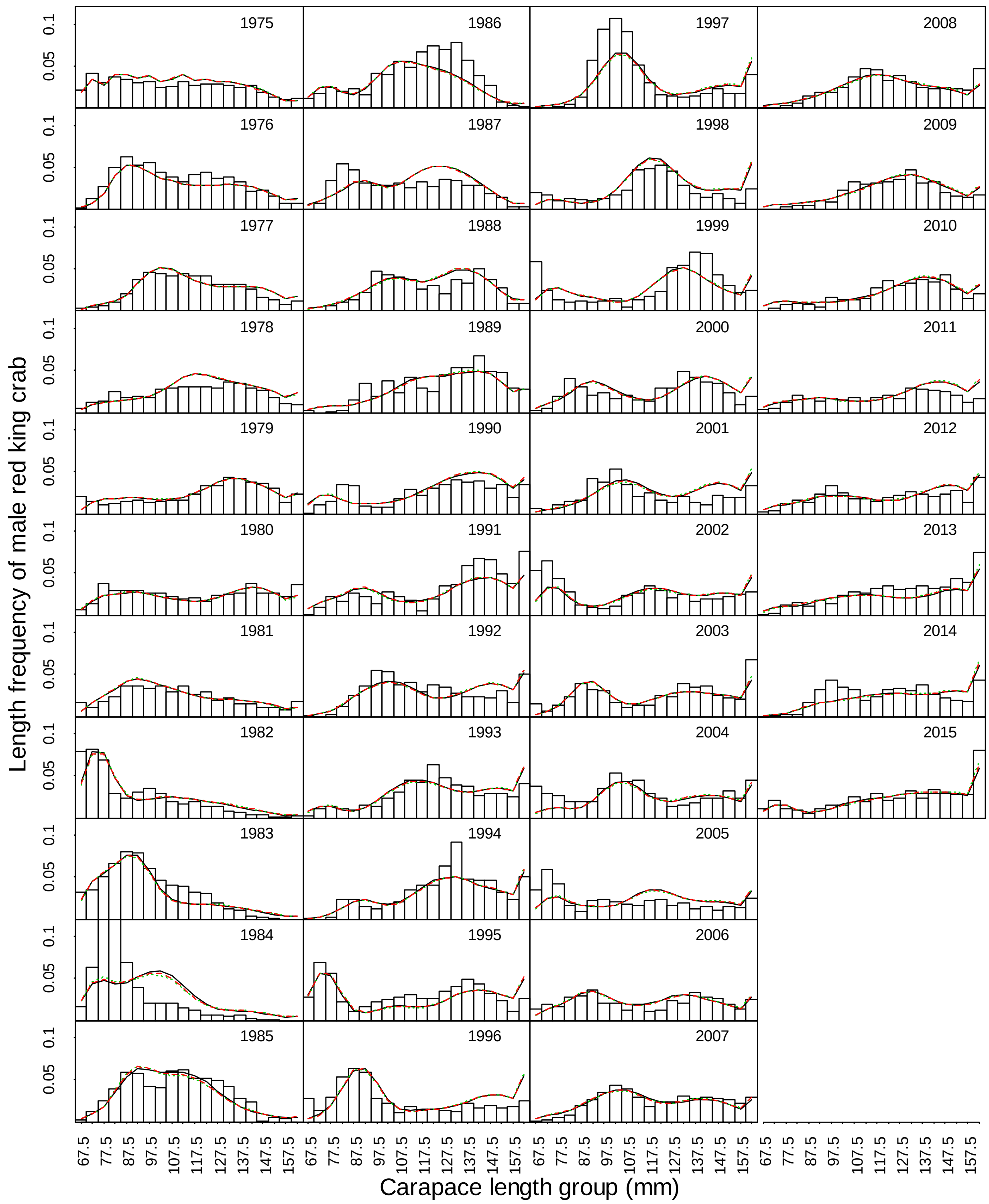


Figure 12. Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay male red king crab by year under scenarios 1n(solid black), 2(dashed red), and 3 (green lines).

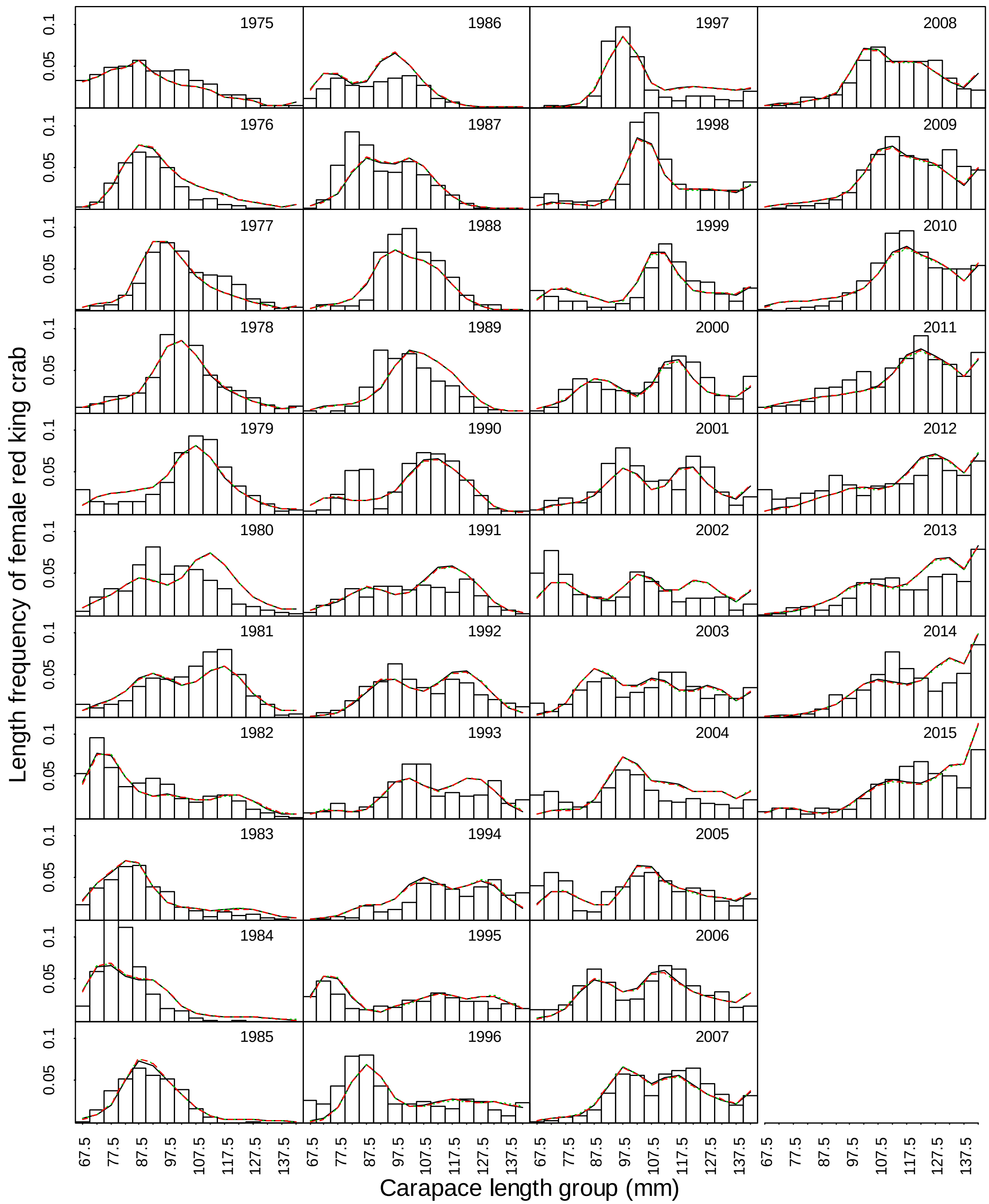


Figure 13. Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay female red king crab by year under scenarios 1n(solid black), 2(dashed red), and 3 (green lines).

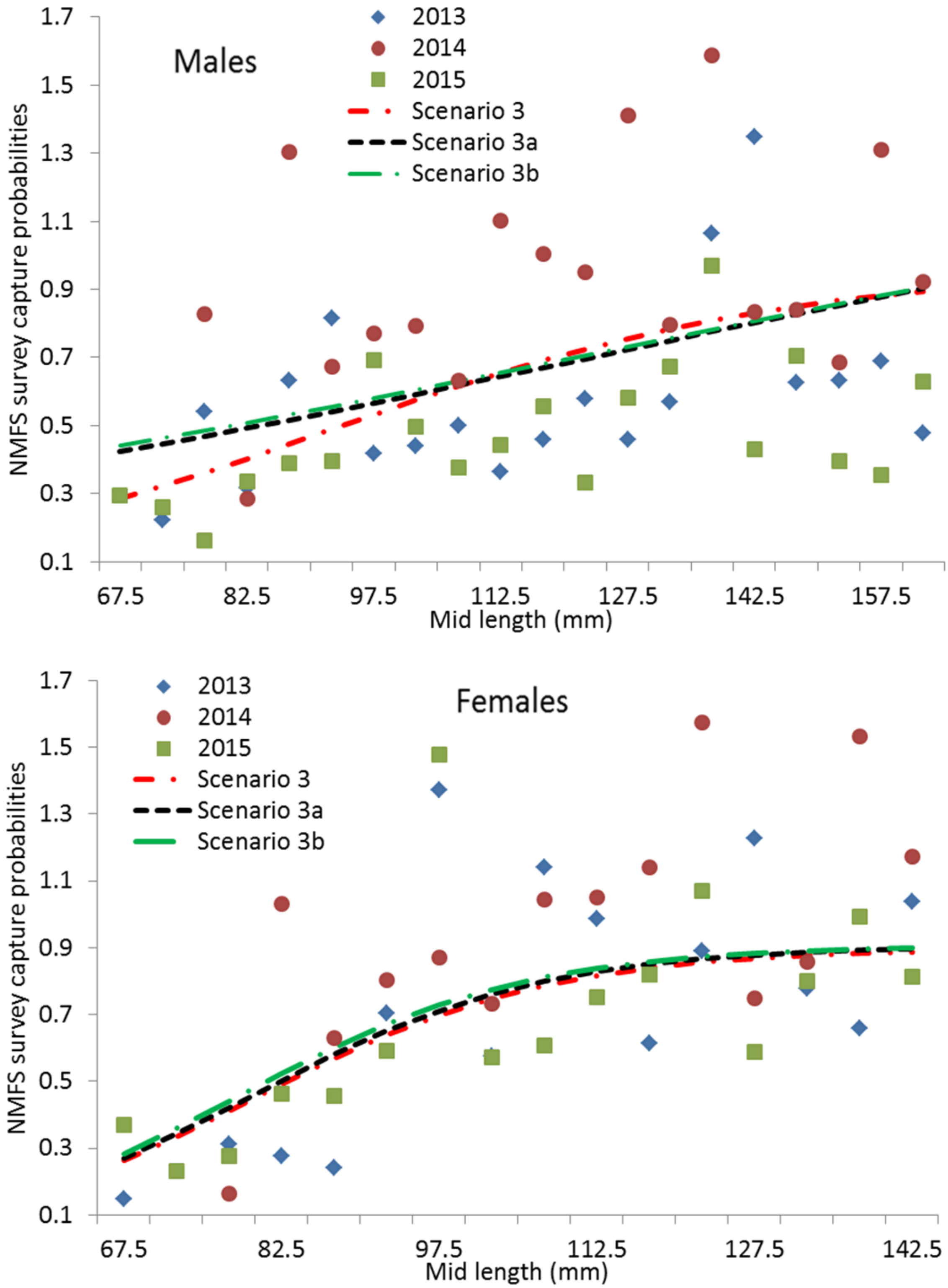


Figure 14. Comparison of side-by-side survey and model (line) estimated capture probabilities of red king crab during 2013-2015 for scenarios 3, 3a and 3b. Missing values are due to zero catch of the BSFRF survey.

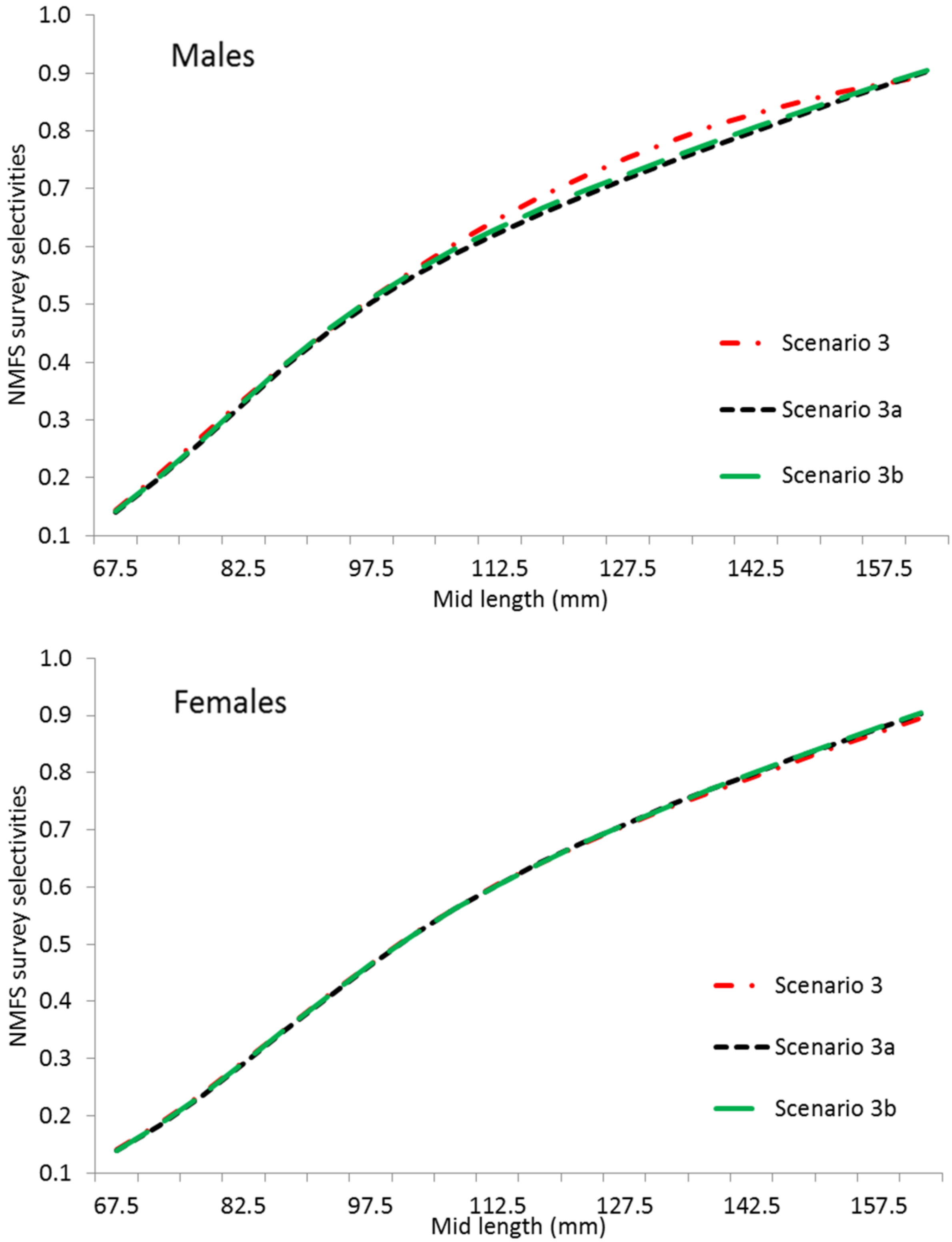
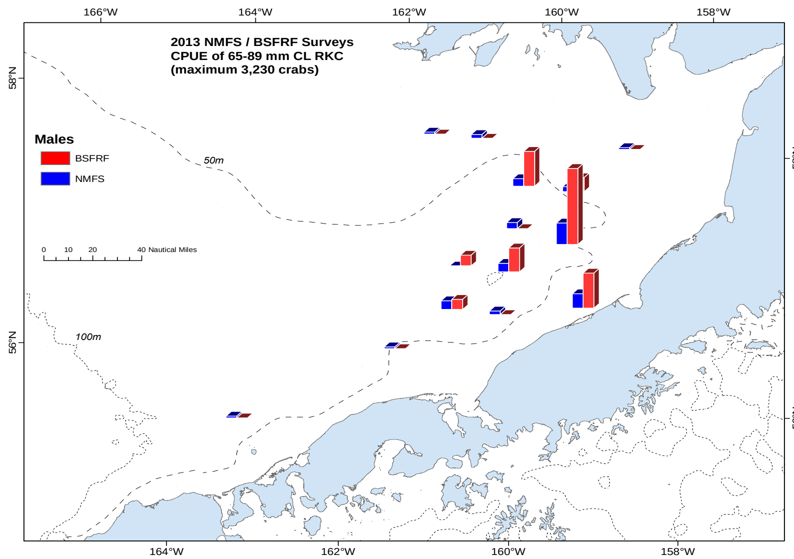
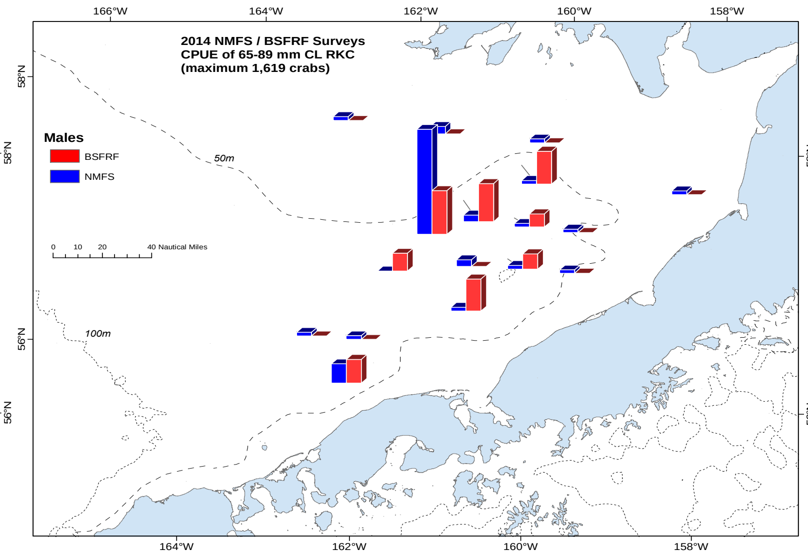
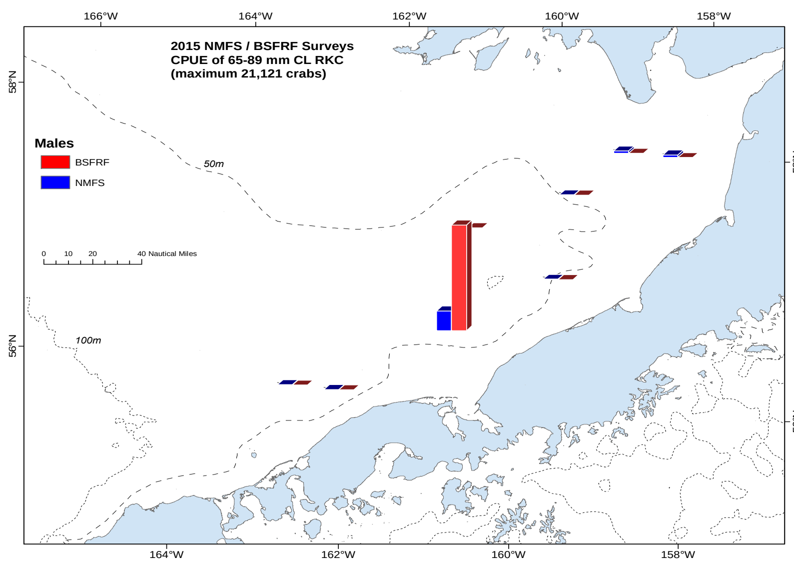


Figure 15. Estimated selectivities of NMFS trawl survey during 1982-2015 with three scenarios (3, 3a and 3b).

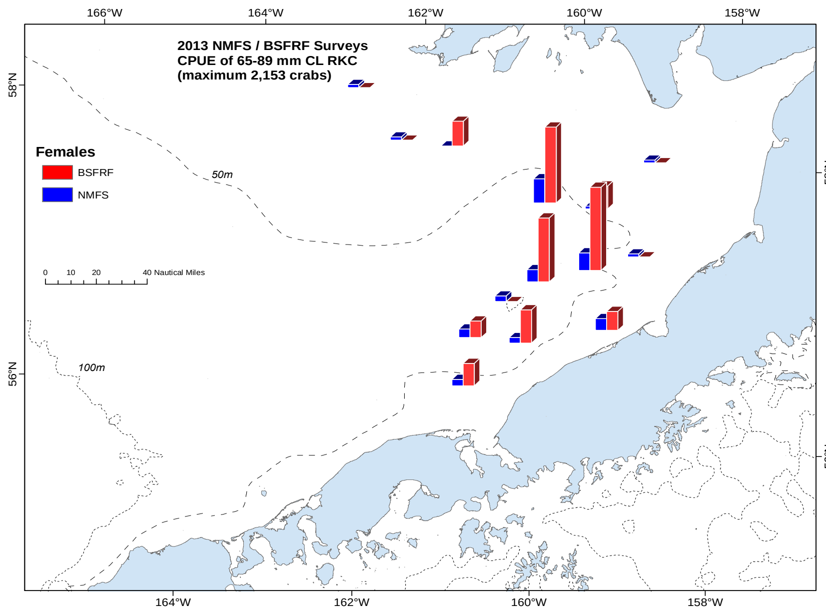
Appendix A. Spatial distributions of juvenile male and female red king crab in Bristol Bay (65-89 mm CL) from 2013-2015 side-by-side summer trawl surveys.

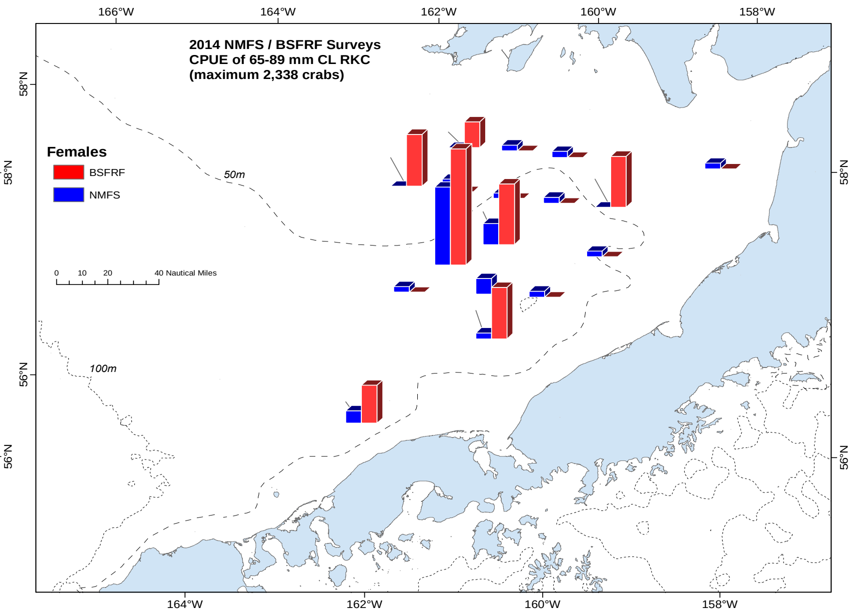


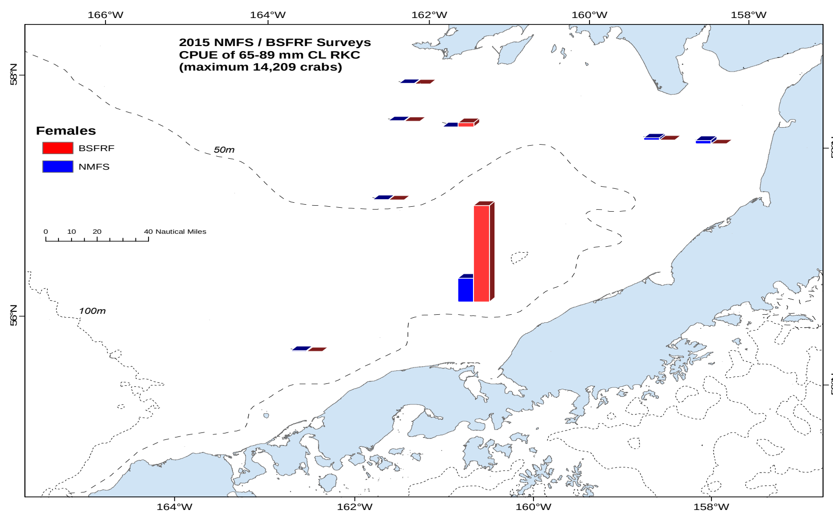




Males. CPUE values in bar plots are estimated number of crab per square nm. The lowest bars have zero catch. Generally, NMFS surveys have much more stations with catch than BSFRF surveys.







Females. CPUE values in bar plots are estimated number of crab per square nm. The lowest bars have zero catch. Generally, NMFS surveys have much more stations with catch than BSFRF surveys.

Appendix B. Alternative approach to scenarios 3 and 3p

An alternative approach to scenario 3 is to use abundance proportions of NMFS survey in the paired data to compute the negative loglikelihood value. NMFS survey abundance proportion for a given length group *l* and sex *s* ($\tilde{r}_{s,y,l}$) is equal to the sum of estimated crab abundance per square nm (59 stations) within the length group and sex (*u*) from the NMFS survey each year divided by the corresponding total abundance from the both surveys:

$$\tilde{r}_{s,y,l} = \sum_{st=1}^{59} u^{n}_{s,y,l} \Big/ \left(\sum_{st=1}^{59} u^{b}_{s,y,l} + \sum_{st=1}^{59} u^{n}_{s,y,l}\right). \qquad \text{(B1)}$$

Abundance proportions for each year, sex and length group are estimated from the 2013-2015 paired survey data. Corresponding variances are estimated by a bootstrapping approach. Each replicate consists of 59 paired survey data randomly sampled with replacement from the 59 survey stations, and total 500 replicates are used. The advantages of this approach to the capture probability are not discarded data points such as estimated infinitive values and much better estimates of CV values from the bootstrapping. If the tow specific paired data are used, a binomial distribution may be assumed for the proportions of catch. However, the tow specific data are too little and the sum of all 59 tows has to be used to estimate the proportions. Therefore, we assume a normal approximation, and the additional negative loglikelihood is

$$\sum_{s=1}^{s=2}\sum_{y=13}^{y=15}\sum_{l=1}^{n_s}(\tilde{r}_{s,y,l} - \hat{r}_{s,l})^2 / (2\sigma^2_{s,y,l}), \qquad \text{(B2)}$$

where model estimated NMFS abundance $\hat{r}_{s,l}$ is derived from NMFS survey capture probability ($p_{s,l}$) as

$$\hat{r}_{s,l} = p_{s,l} / (1 + p_{s,l}). \qquad \text{(B3)}$$

Tables 1-3 and Figures 4-10 are updated. The CVs of NMFS survey abundance proportions are estimated with a bootstrapping approach with 500 replicates. The main differences of results are higher NMFS survey selectivity estimates for both scenarios 3 and 3p and higher NMFS survey selectivity estimates for scenario 3p than for scenario 3. The corresponding abundance and OFL estimates are also lower due to higher estimated survey selectivities.

Table 1. NMFS survey abundance proportions estimated from side-by-side trawl surveys during 2013-2015. Missing values are due to zero catch of both surveys.

	Males			Females		
Mid Length of Size Bin (mm CL)	2013	2014	2015	2013	2014	2015
67.5	1.000		0.227	0.130		0.270
72.5	0.182	1.000	0.207	1.000	0.000	0.188
77.5	0.351	0.453	0.139	0.237	0.142	0.217
82.5	0.241	0.223	0.251	0.217	0.508	0.315
87.5	0.387	0.566	0.281	0.195	0.386	0.313
92.5	0.449	0.403	0.284	0.413	0.445	0.372
97.5	0.294	0.435	0.409	0.579	0.465	0.596
102.5	0.305	0.442	0.332	0.365	0.423	0.363
107.5	0.333	0.387	0.273	0.533	0.511	0.377
112.5	0.266	0.525	0.307	0.496	0.512	0.429
117.5	0.315	0.501	0.358	0.380	0.533	0.450
122.5	0.367	0.487	0.249	0.470	0.612	0.517
127.5	0.315	0.585	0.367	0.551	0.428	0.370
132.5	0.363	0.443	0.402	0.437	0.462	0.445
137.5	0.516	0.614	0.492	0.397	0.605	0.498
142.5	0.574	0.455	0.301	0.509	0.539	0.449
147.5	0.385	0.457	0.414			
152.5	0.387	0.407	0.284			
157.5	0.408	0.567	0.262			
162.5	0.324	0.480	0.386			

Table 2. CVs of NMFS survey abundance proportions estimated from side-by-side trawl surveys during 2013-2015 using 500 bootstrap replicates. Missing values are due to zero catches of one or more bootstrap replicates from both surveys. The 110% of the maximum value (0.689) is used to fill-in the missing values for males and (0.695) for females.

Original estimates:

	Males			Females		
Mid Length of Size Bin (mm CL)	2013	2014	2015	2013	2014	2015
67.5						
72.5						
77.5	0.463	0.484		0.552		
82.5	0.398	**0.627**		0.292	0.461	
87.5		0.294		**0.632**	0.414	0.620
92.5	0.319	0.217	0.439	0.433	0.260	
97.5	0.299	0.214	0.266	0.273	0.237	0.311
102.5	0.292	0.158	0.471	0.241	0.155	0.230
107.5	0.254	0.195	0.429	0.208	0.127	0.215
112.5	0.289	0.189	0.325	0.230	0.109	0.263
117.5	0.178	0.187	0.288	0.289	0.082	0.139
122.5	0.237	0.140	0.293	0.247	0.114	0.130
127.5	0.233	0.134	0.287	0.267	0.248	0.213
132.5	0.261	0.133	0.296	0.253	0.194	0.126
137.5	0.229	0.187	0.168	0.230	0.185	0.162
142.5	0.234	0.219	0.227	0.128	0.123	0.148
147.5	0.209	0.223	0.272			
152.5	0.234	0.213	0.235			
157.5	0.199	0.316	0.246			
162.5	0.120	0.149	0.221			

Table 3. Negative loglikelihood components for scenarios 1 and 1n and differences in negative loglikelihood components among model scenarios.

	Scenarios and differences of scenarios							
	1	1n	1-1n	1n-1p	1n-2	1n-2p	1n-3	1n-3p
Rec	80.61	80.31	0.30	-0.37	1.20	0.88	-0.39	0.21
Ret.len	-979.49	-979.55	0.06	1.10	-0.96	1.76	-2.55	-1.59
Pot Dis.M.Len	-998.27	-997.61	-0.66	-0.83	-0.22	-1.44	-0.03	-0.32
Pot Dis. F.Len	-2334.30	-2333.81	-0.49	0.78	0.84	5.23	0.55	2.31
Sur. Len	-46200.1	-46199.5	-0.60	1.80	8.50	15.90	6.80	7.00
Tr. Dis. Len	-2027.93	-2026.98	-0.95	-1.78	0.74	-4.57	3.17	-0.49
Tan. Dis. Len.	-398.41	-399.35	0.94	0.53	1.07	1.90	0.82	1.44
BSFRF Len	-237.78	-567.38	329.60	0.27	-5.44	-3.62	-5.69	-2.42
Ret.Catch Bio	47.31	47.11	0.20	-0.63	0.49	-0.84	1.02	0.78
Pot Dis. M.Bio	219.50	219.88	-0.38	0.32	0.28	1.55	0.03	0.65
Pot Dis. F. Bio	0.13	0.13	0.00	0.00	0.00	0.00	0.00	0.00
Tr. Dis. Bio	0.90	0.91	-0.01	-0.01	-0.02	-0.03	-0.02	-0.02
Tan. Dis. Bio.	0.13	0.13	0.00	-0.02	0.01	-0.02	0.01	0.01
Sur. Bio.	95.08	94.89	0.19	1.17	-3.18	-2.64	-6.41	-5.42
BSFRF Bio	-4.95	-7.74	2.79	-0.70	0.04	-1.23	0.36	0.32
Q	0.64	0.74	-0.09	0.74	-2.01	0.74	-0.05	0.74
Abun. Prop.							-61.42	-64.76
Others	20.82	20.82	0.00	0.02	-0.13	-0.06	-0.18	-0.13
Total	-52716.1	-53047.0	330.90	2.40	1.20	13.50	-64.00	-61.70
Free parameters	272	272	0	0	0	0	0	0

	Scen. 1	Scen. 1n	Scen. 1p	Scen. 2	Scen.2p	Scen. 3	Scen.3p
Q value	0.924	0.926	0.997	0.955	1.139	0.927	0.974
Bmsy	26.064	26.369	25.644	27.298	25.739	27710.8	26864.4
MMB2015	24.691	25.903	24.738	26.640	23.876	26961.3	26805.6
OFL2015	6.732	7.386	6.876	7.434	6.174	7478.1	7879.1

Note that biomass and catch are in 1000 t.

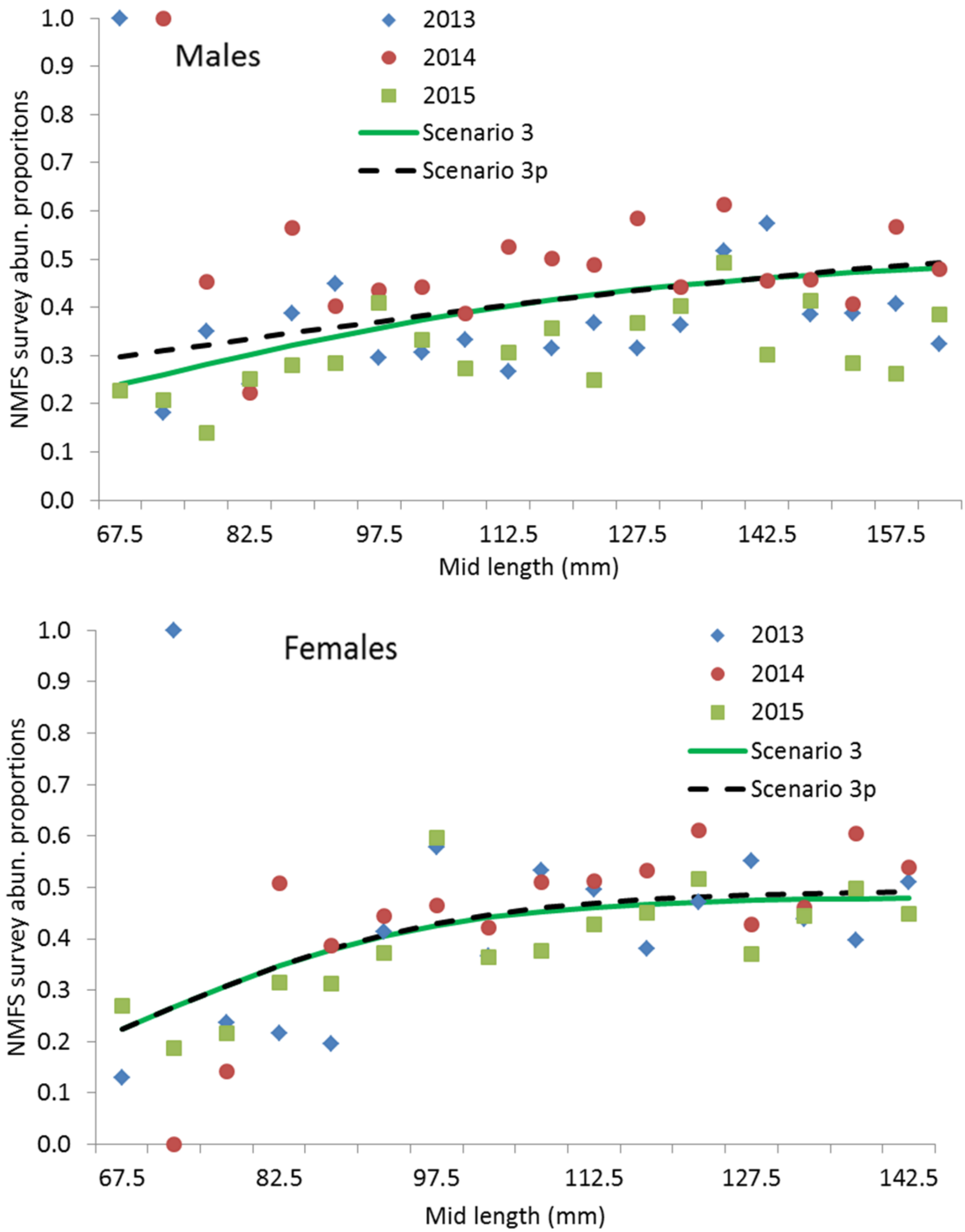


Figure 4. Comparison of side-by-side survey and model (line) estimated abundance proportions of red king crab from NMFS survey during 2013-2015 for scenarios 3 and 3p. Missing values are due to zero catches of both BSFRF surveys.

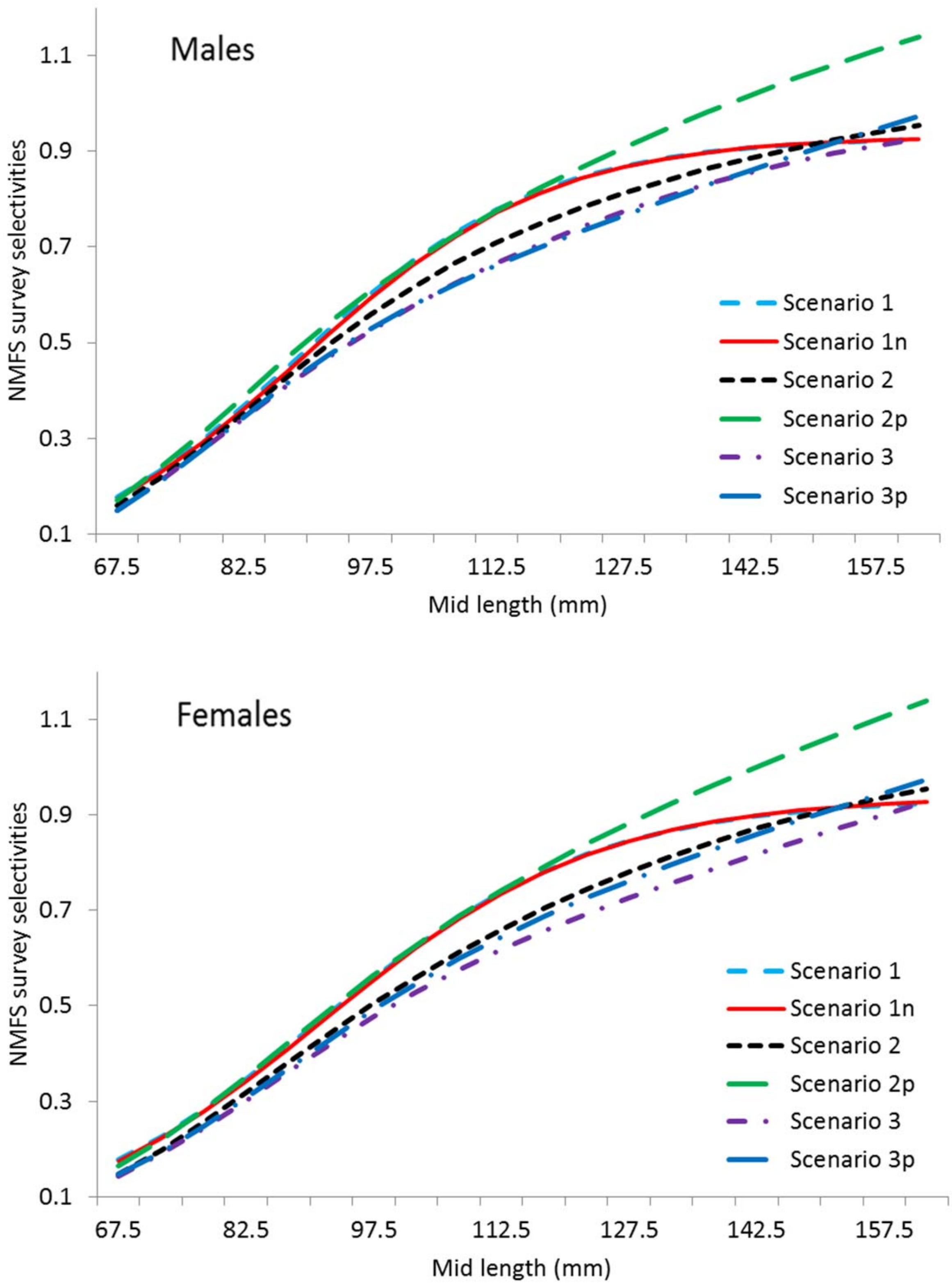


Figure 5. Estimated selectivities of NMFS trawl survey during 1982-2015 with different dataset of BSFRF survey data and six scenarios.

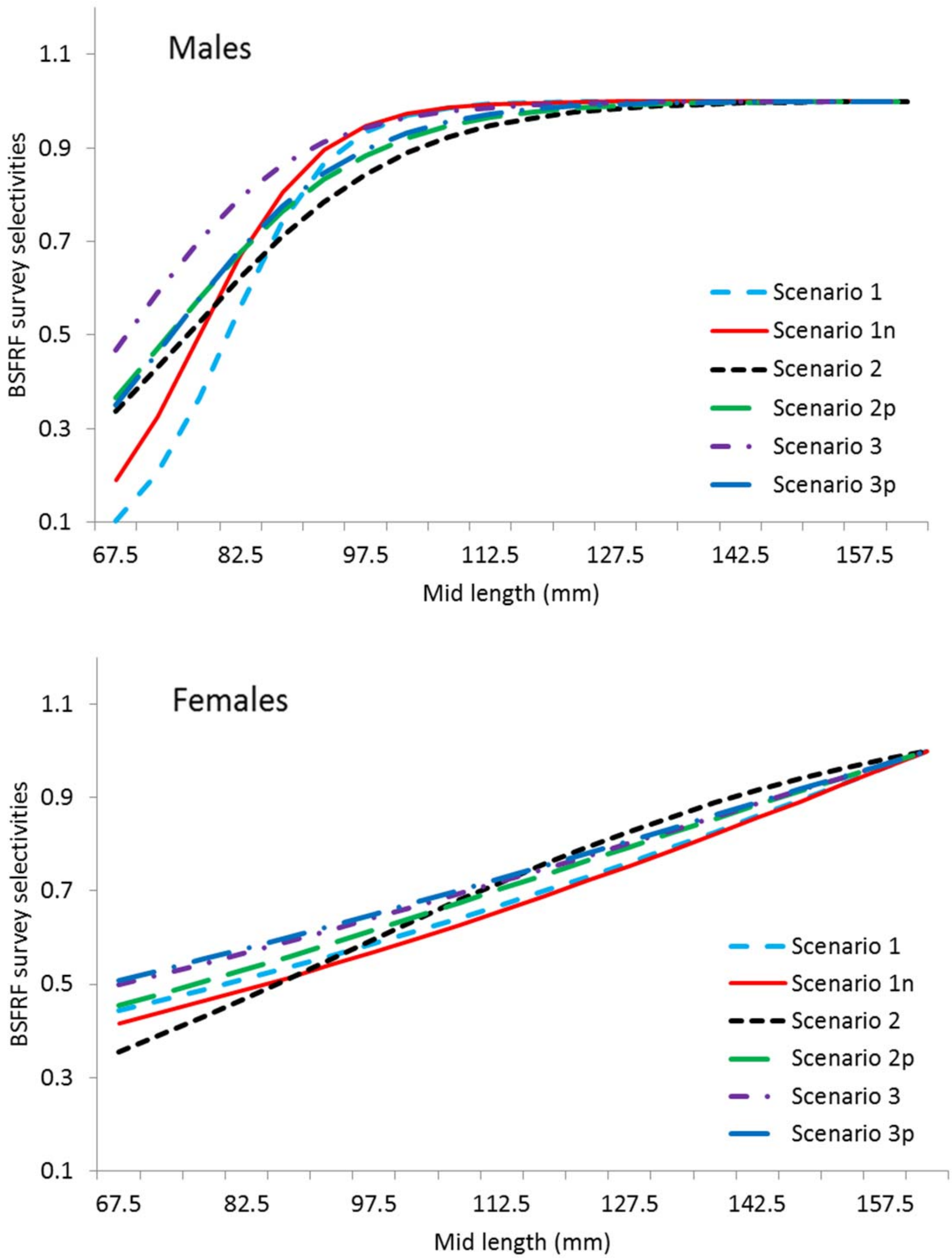


Figure 6. Estimated selectivities of BSFRF trawl survey during 2007-08 and 2013-2015 with different dataset of BSFRF survey data and six scenarios.

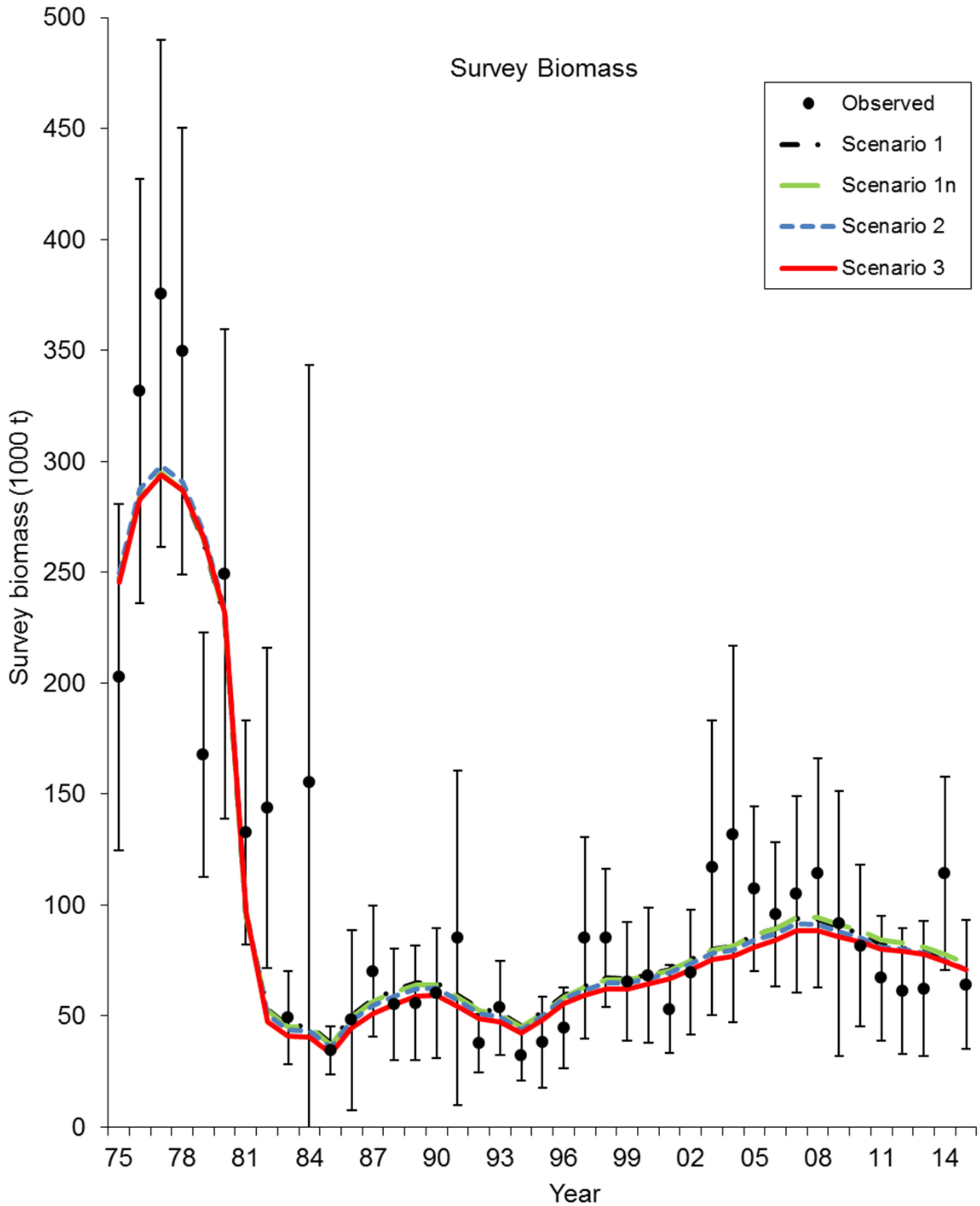


Figure 7. Comparisons of area-swept estimates of total NMFS survey biomass and model prediction for model estimates in 2015 under scenarios 1, 1n, 2 and 3. The error bars are plus and minus 2 standard deviations.

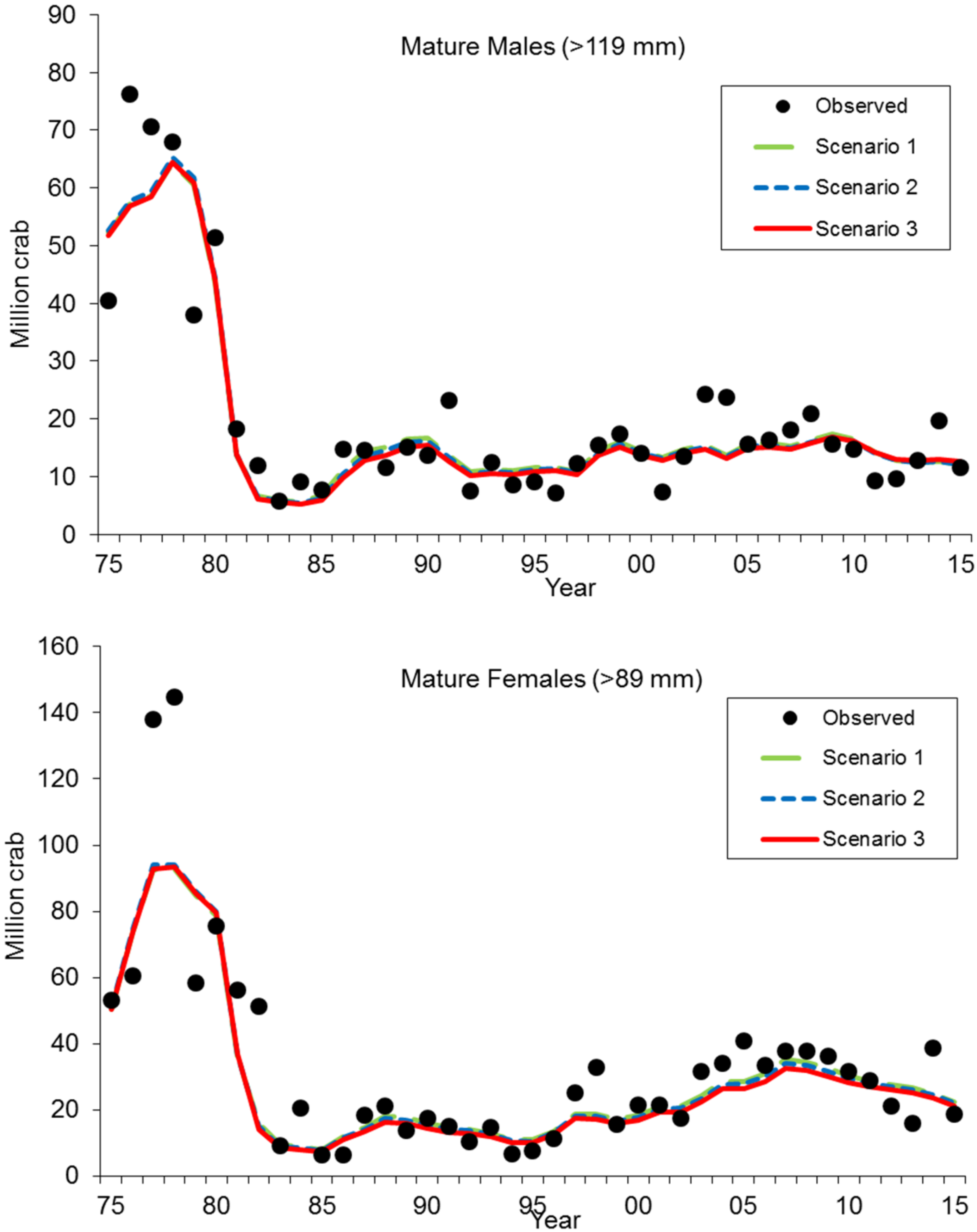


Figure 8. Comparisons of NMFS survey area-swept estimates of male (>119 mm) and female (>89 mm) abundance and model prediction for model estimates in 2015 under scenarios 1, 2 and 3.

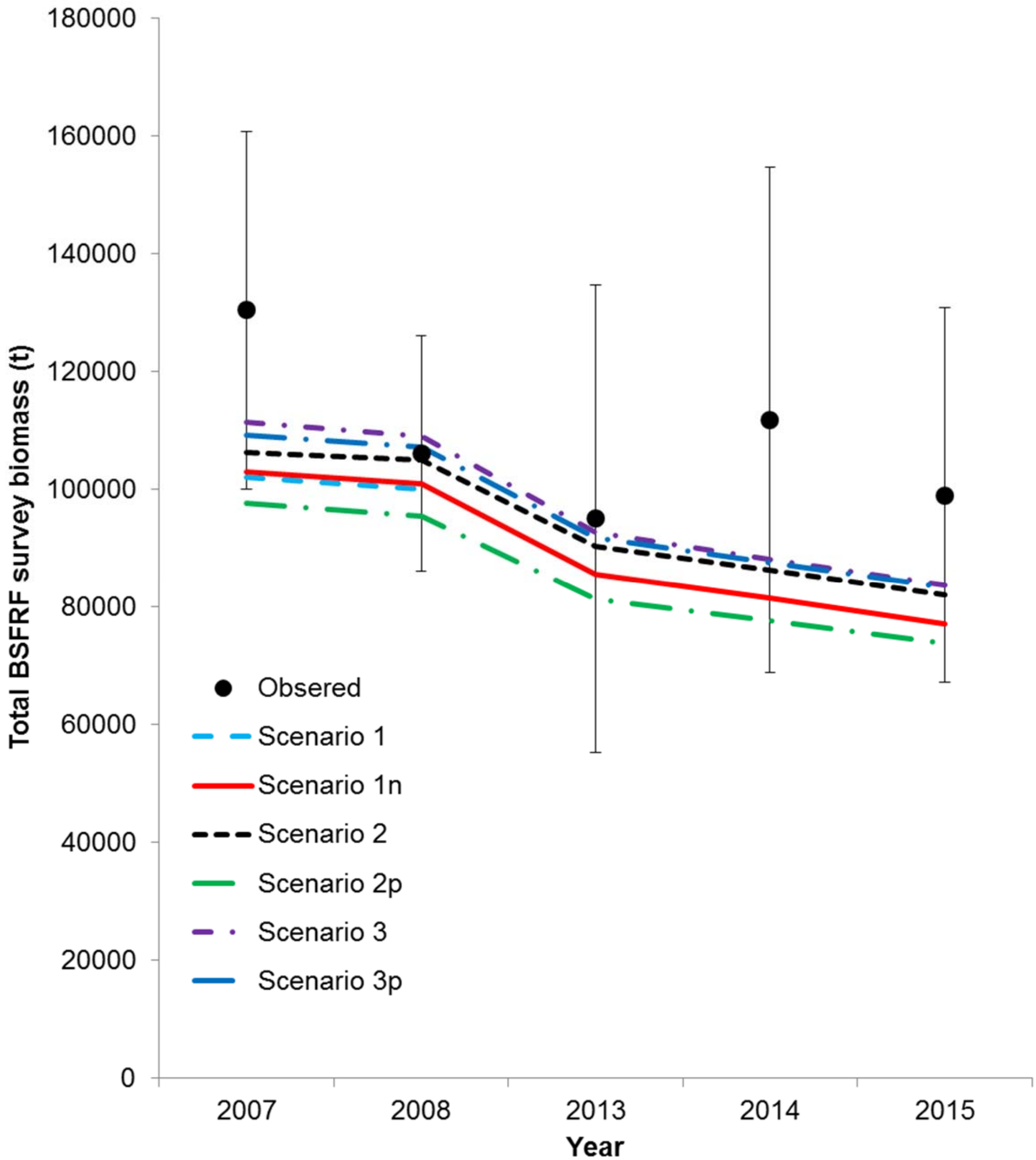


Figure 9. Comparisons of total survey biomass estimates by the BSFRF survey and the model for model estimates in 2015 (scenarios 1, 1n, 2, 2p, 3 & 3p). The error bars are plus and minus 2 standard deviations of scenario 1n.

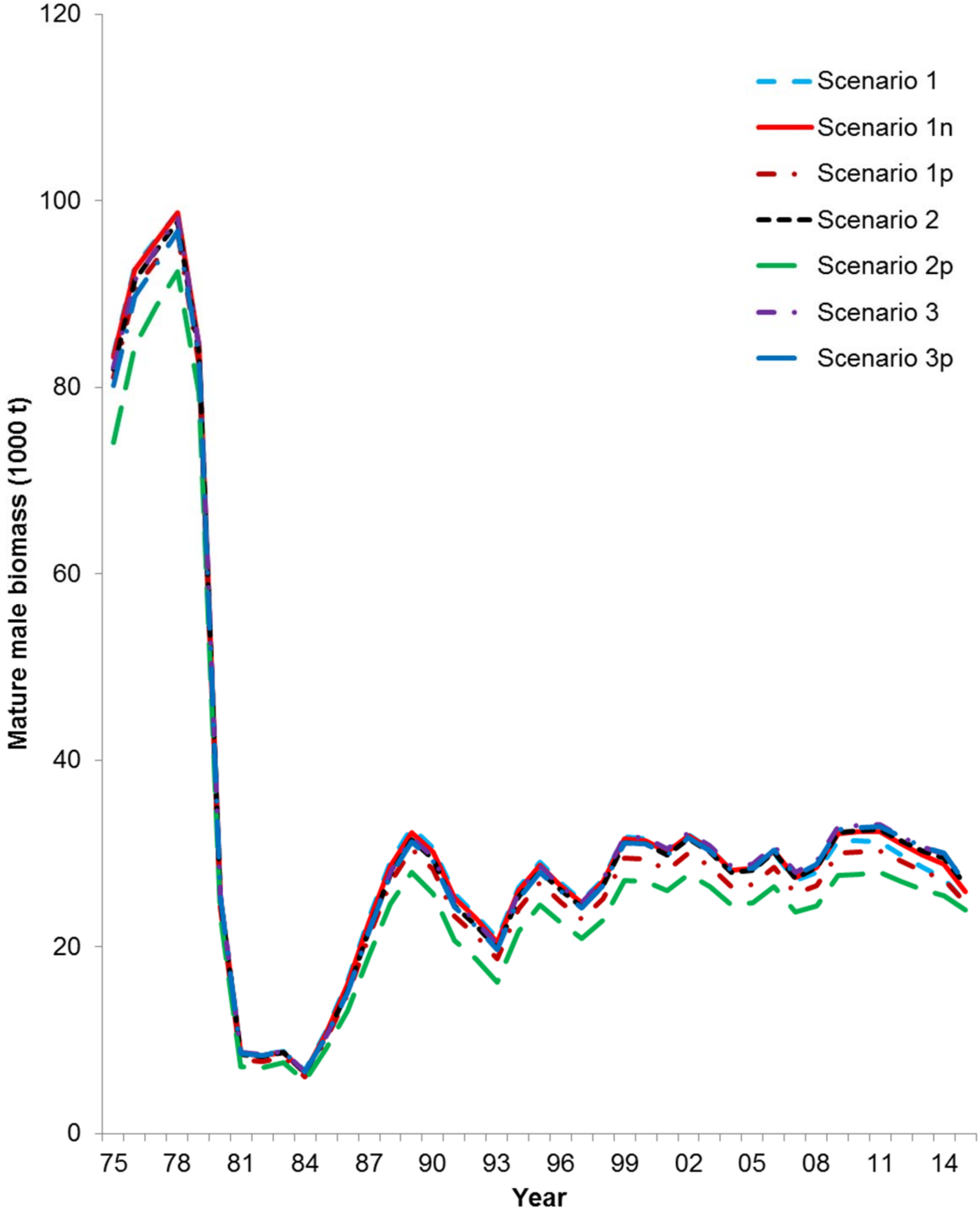


Figure 10. Comparisons of mature male biomass on Feb. 15 under scenarios 1, 1n, 1p, 2, 2p, 3, 3p.