$$p(\boldsymbol{\theta}\,|\,\mathbf{y})=\begin{cases}\mathbf{Q} & \textit{uantitative}\\ \mathbf{R} & \textit{esource}\\ \mathbf{A} & \textit{ssessment}\end{cases}$$
LLC

Quantitative Resource Assessment LLC
San Diego, CA
USA.

Evaluation of snow crab catchability and selectivity estimated by trawl survey experiments.

Nontechnical summary

The BSFRF survey data from both the side by side and the pilot study experiments was examined to determine how the implied biases in survey catchability and selectivity (catchability by size) assumed in the stock assessment model would influence the stock assessment results. First the data was analyzed to determine the survey catchability and selectivity. Then the selectivity was included in the stock assessment model and results compared to the results using the current assessment assumptions.

The BSFRF survey data from both the side by side and the pilot study experiments shows that the catchability of the NMFS survey is lower than assumed in the stock assessment and that the selectivity increases with crab size. There appears to be spatial differences in both the absolute level of catchability and how it changes with size. This spatial variation complicates the calculation of catchability from the BSFRF survey data and may explain why there are differences in catchability between males and females.

The implications of the new selectivity curve and catchability estimated by the experiments is not straightforward and the implications are dependent on the other assumptions used in the stock assessment model. The model fit to the data is substantially degraded when the new selectivity curve is used in the assessment model. Therefore, the model assumptions need to be modified to improve the fit to the data. Despite the experiments indicating that the abundance of crabs is larger than previously thought, model adjustments that allow the model to fit the data reduce the productivity of the stock (e.g. reduced male growth rates or modified natural mortality) and produce harvest levels that are similar to those based on the original catchability and selectivity. However, the implications are still uncertain due to uncertainty in the model assumptions.

The BSFRF survey is much better at catching small crab and is therefore a much better indicator of cohorts that will enter the fishery in the future. If the growth assumptions are accurate, there have been several years of poor recruitment recently, but a moderate or good recruitment class can be seen for crab about 40mm.

In conclusion, the new catchability and the selectivity curve estimated from the BSFRF survey are substantially different from that assumed in the current assessment model and they are not consistent with some of the current model assumptions. Therefore, considerably more research and modeling work is needed to ensure that appropriate choices are being made about important model assumptions such as growth, natural mortality, and recruitment.

Data

Data was received from Jack Taggart in the file “BSFRF 09 Densities - to Taggart.xls”. The file included data from both the side by side trawls and the pilot study. The average across all (or tows within a strata) tows (or station averages in the case of the BSFRF tows for the pilot study) of the density in each 5mm carapace width bin were used.

In general, the two survey trawls show a similar length frequency distribution for large crab, but the BSFRF survey trawl catches more individuals (Figures 1 and 2). The NMFS survey trawl catches few small crabs. A large single mode of small crab is seen in the BSFRF data.

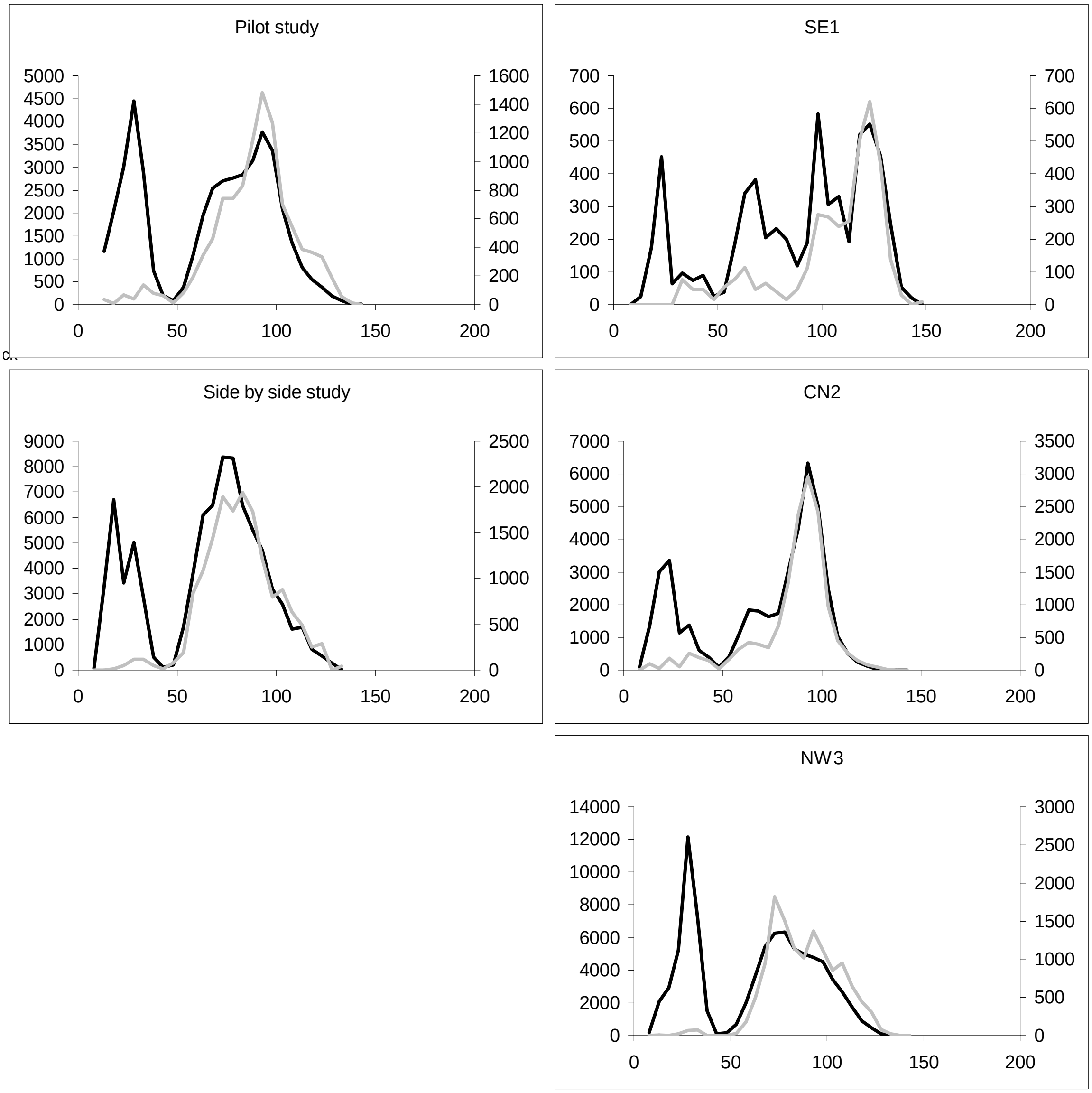

Figure 1. Comparison of average densities between the NMFS (grey – right hand axis) and BSFRF (black – left hand axis) surveys for males.

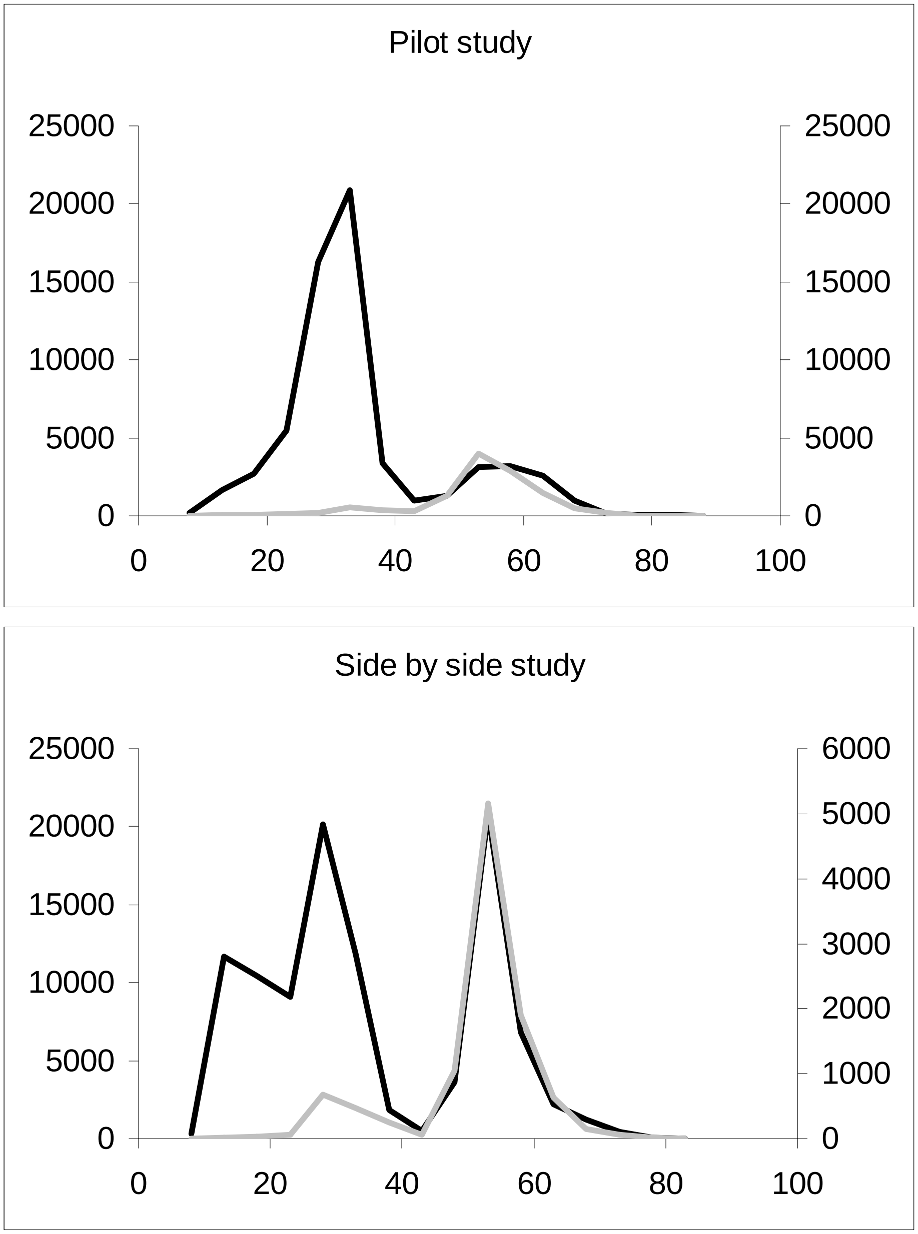

Figure 2. Comparison of average densities between the NMFS (grey – right hand axis) and BSFRF (black – left hand axis) surveys for females.

Selectivity Model

A logistic curve scaled by a catchability parameter was used to model the selectivity.

$$s_{CW} = \frac{q}{1 + \exp\left(-slope\left(CW - CW_{50\%}\right)\right)}$$

The selectivity was used to predict the catch-at-carapace width from the NMFS trawl given the BSFRF catch. This assumes that the BSFRF survey catches all the snow crab within its path. A negative log-likelihood based on the normal approximation to the binomial distribution was used to fit the predicted catch-at-carapace to the observed data. A scaling parameter was added for the standard deviation to account for additional variance. The scaling parameter is particularly important to appropriately weight the data sets when the two surveys are combined.

$$-\ln[L] = \sum_i \ln[\sigma] + \frac{(\mathrm{NMFS_i} - s_i \mathrm{BSFRF}_i)^2}{2\sigma^2}$$

$$\sigma = \delta\sqrt{np(1-p)}$$

Due to the large difference in the catchability of crabs less than 50 mm carapace width, the selectivity model is only fit to data from crabs above 50 mm carapace width. A few carapace width bins have no individuals in the BSFRF survey and these data are not included in the analysis.

Results

Visual examination of the number of crab caught in the NMFS and BSFRF surveys suggest that the catchability of the NMFS survey for the most abundant (in the NMFS survey) sized males is approximately 0.25 (2000/8000) from the side by side and 0.4 (1500/4000) for the pilot study (Figure 1). The catchability differs between the three regions in the pilot study SE1 = 1.0 (600/600); CN2 = 0.5 (3000/6000); and NW3 = 0.3 (1800/6000). The catchability may differ between males and females. The catchability of the NMFS survey for the most abundant sized females (in the NMFS survey) is approximately 0.25 (5000/20000) from the side by side and (above one) 1.3 (4000/3000) for the pilot study (Figure 2). It should be noted that the most abundant size occurs at a different size in each area. For example, the maximum abundance occurs at about 130mm for SE1, but at about 75mm for NE3. Catchability also appears to change with size, for example, although catchability is about one at 140mm for SE1, it is approximately 0.5 and 0.25 at 100mm and 60mm, respectively.

The NMFS survey was much less efficient at catching small crab with carapace widths less that about 50mm (Figures 1 and 2). Cab less than this size form a single mode which may represent a single cohort recruiting to the survey. Future BSFRF surveys would be useful to see how this cohort changes over time and how the NMFS selectivity for small crab changes over time.

The selectivity increases approximately linearly with carapace width for carapace widths above about 50mm and this relationship is generally consistent across the two surveys (Figure 3). However, female selectivity appears to be higher in the pilot study. This may be due to differences in selectivity among areas and different spatial distribution of females compared to males.

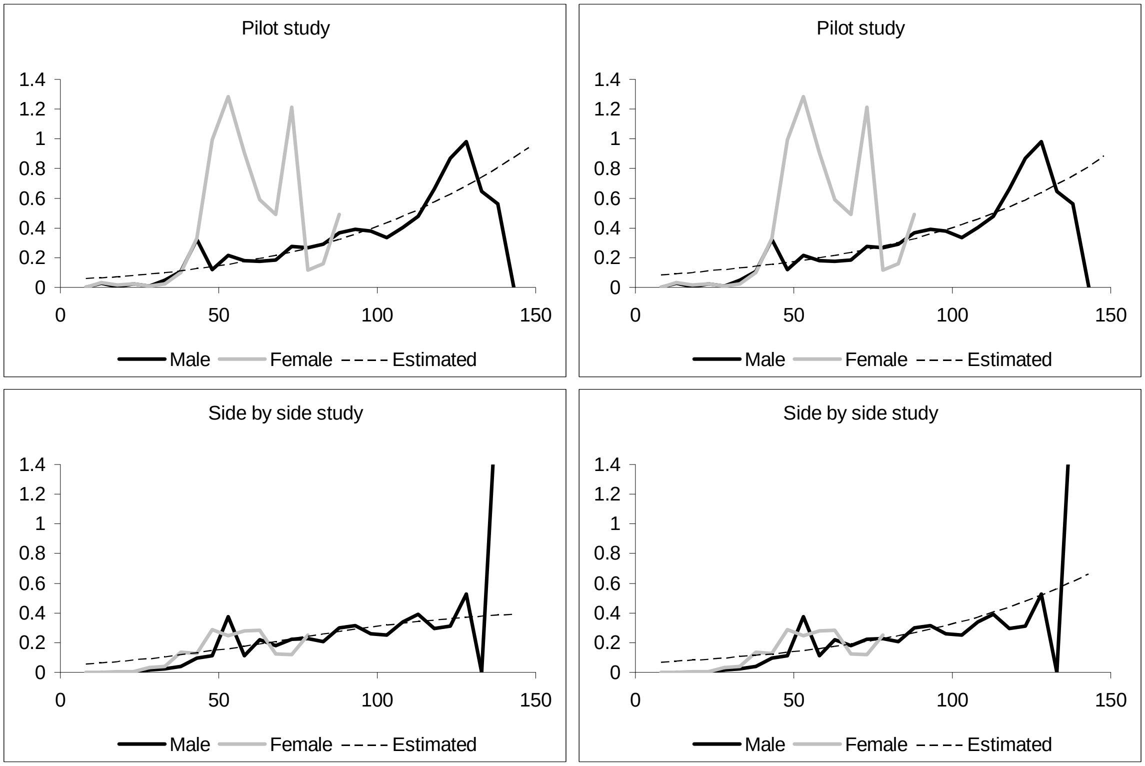

Figure 3. Comparison of empirical (solid lines) and estimated (dashed line) selectivity for the two studies. (note that these estimates are done outside the assessment model) The estimates on the left hand side are estimated independently for each study. The estimates on the right hand side share the slope and CW50% parameters between the two studies.

Implications of the selectivity and catchability on the stock assessment model
The stock assessment model code and data files were received from Jack Turnock (via Jack Tagart). The files included both the model code (AD Model Builder tpl file) and the executable. However, recompiling the code produced different answers than the supplied executable. The "original" results presented below were based on recompiling the model code and not on the supplied executable so as to standardize the comparisons with the results from models for which I modified the code.

The stock assessment model was run with the selectivity and catchability fixed at the values estimated from the combined 2009 experimental survey data. The input data file utilized the "recalculated" annual trawl survey abundance time series. The selectivity model was refit for the combined data using the selectivity formulation used in the stock assessment model to enable the transfer of parameters to the stock assessment model.

$$s_{CW} = \frac{q}{1 + \exp\left(-\ln[19]\left(CW - CW_{50\%}\right)/\left(CW_{95\%} - CW_{50\%}\right)\right)}$$

The estimated selectivity is substantially different than that assumed in the current assessment model in both shape and the catchability (Figure 4). The selectivity curve used in the current assessment model assumes that crab are fully selected at about a carapace width of 40 mm. The model was also run with the new selectivity and estimating mean growth (priors removed), estimating both mean growth and the standard deviation of the growth, estimating natural mortality, and estimating both growth and natural mortality. I had insufficient time to conduct forward projections to determine the sensitivity of annual catch calculations to the survey catchability and other assumptions. However, the Guideline Harvest Level calculations are provided as part of the stock assessment author's generated model outcomes (see: "Harvest Strategy and Projected Catch" [p 55] in Turnock and Rugolo 2009) and these should provide a general indication of the sensitivity of annual catch calculations.

Definitions

Original: Model run from tpl file

New select: Model run with selectivity and catchability fixed at the values estimated from experiment

Growth: "New select" with the parameters of the mean growth increment estimated.

Growth sd: "Growth" with the parameter representing the variation in growth estimated.

EstM: "New select" with the immature and mature female natural mortality estimated (mature males equals immature)

EstM2: "New select" with the immature, mature female and mature male natural mortality estimated.

M2G: "EstM2" with the parameters of the mean growth increment estimated.

Results

The estimated biomass is much higher using the new selectivity curve (Figure 5; Table 1). This is still true when the growth and natural mortality are estimated (Figure 5).

The fit to the survey biomass data is substantially degraded when the new selectivity curve is used (Figure 6; Table 2). The fit is improved if growth or natural mortality is estimated (Figure 6; table 2).

The GHL (Guideline Harvest Level) is larger when the new selectivity is used, but reduces when growth and/or natural mortality are estimated (Table 1).

Growth is estimated to be higher for females and lower for males compared to that assumed in the original analysis. Although, when both growth and natural mortality are estimated, the female growth rate is similar to that assumed in the original model.

The estimates of natural mortality vary depending on what components of natural mortality are estimated and whether growth is also estimated (Table 3). In general, mature male natural mortality is estimated to be higher than female and higher than immature individuals. Mature female natural mortality is estimated to be the same or lower than for immature individuals. These results are opposite to that assumed in the original model. However, some of the estimates of natural mortality are unrealistic indicating that the model is mispecified.

Estimating growth improves the overall fit to the data compared to either estimating the survey selectivity or natural mortality (Total in Table 2). However, estimating the survey selectivity provides the best fit to the survey length frequency data (Table 2). In general, the improvement in fit to the data is substantial if measured using typical statistical standards. However, the statistical properties of the model may be poor and statistical hypothesis tests unreliable.

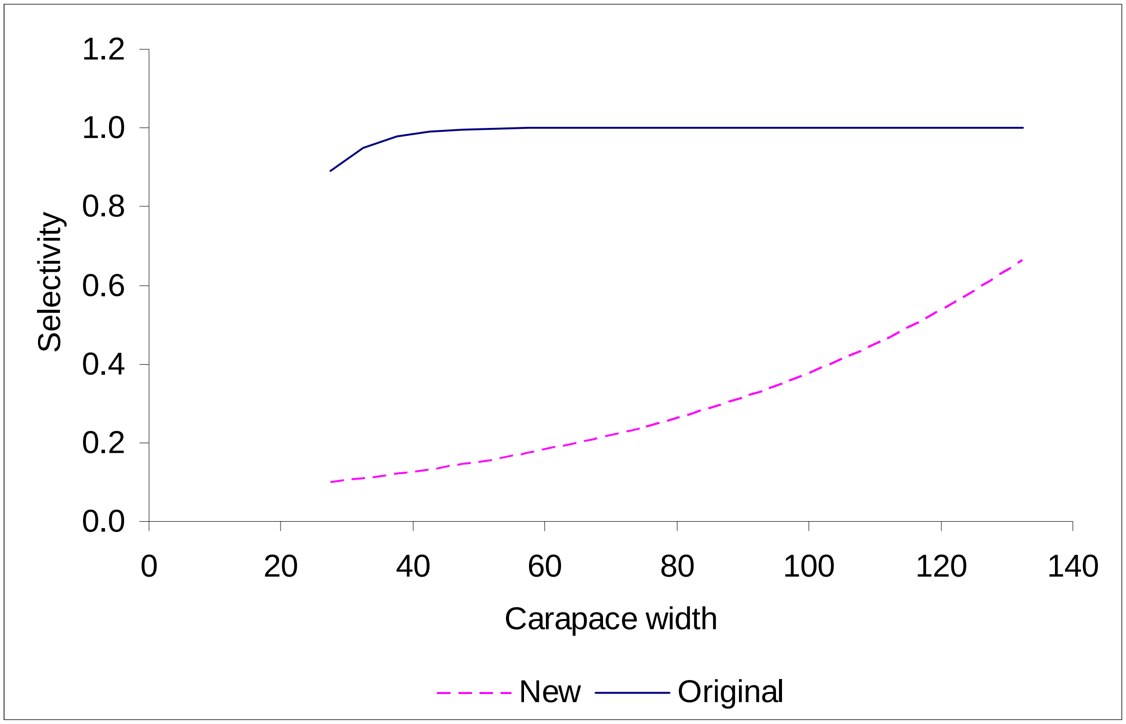

Figure 4. Comparison of the selectivity curve used in the current assessment (Original) to that estimated here (New).

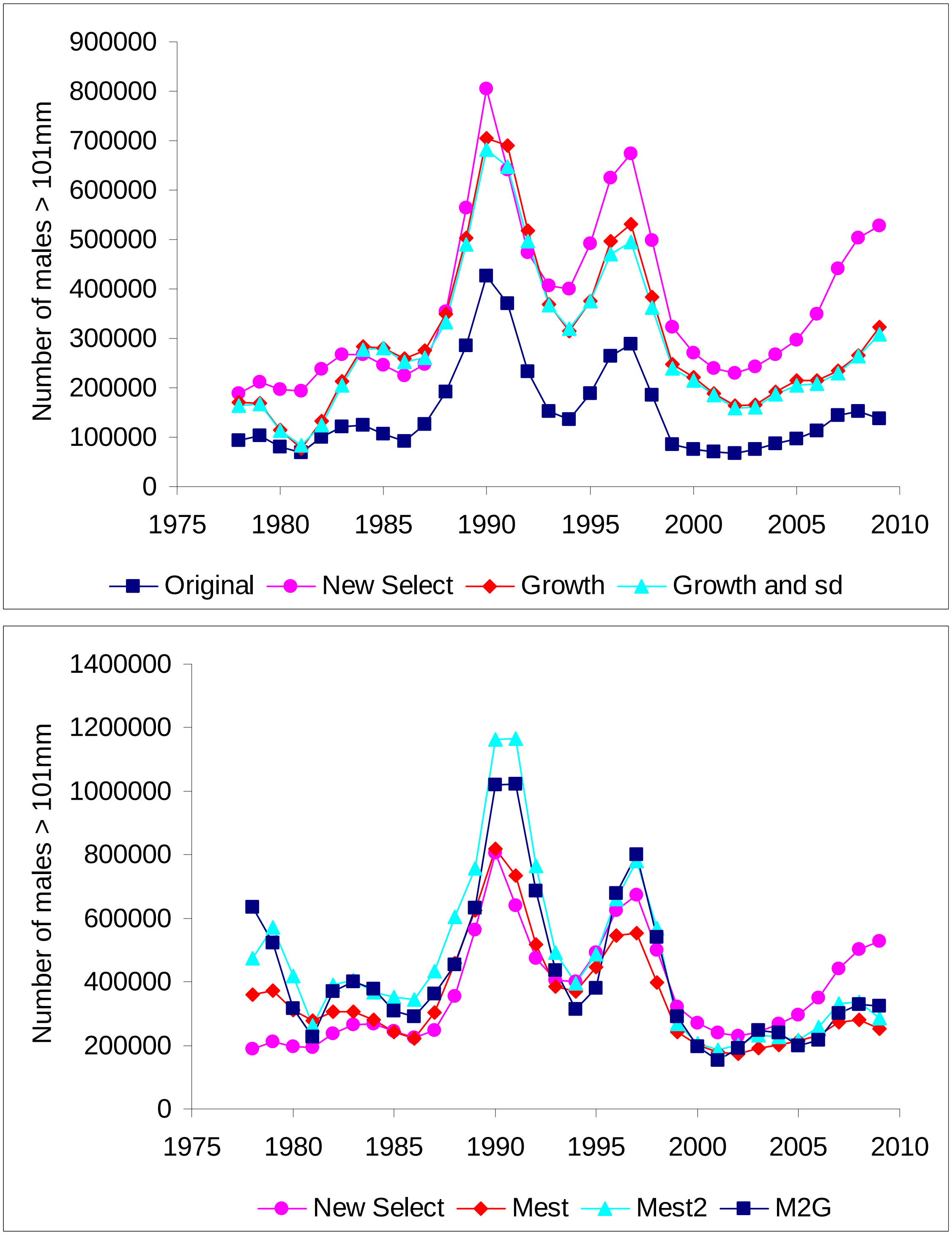

Figure 5. Comparison of the estimates of the number of males greater than 101 mm carapace width.

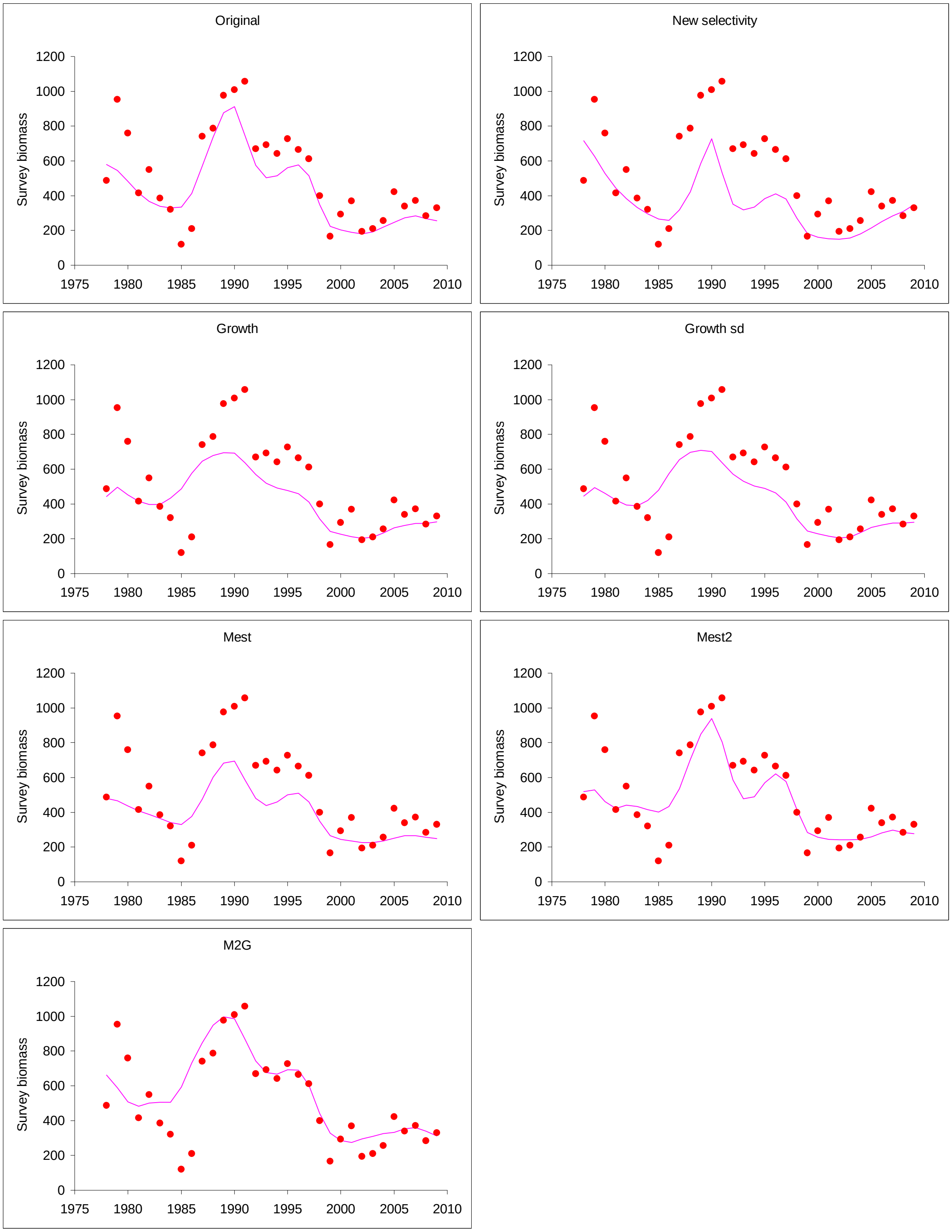

Figure 6. Comparison of the fits to the survey estimates of biomass.

Table 1. Results from the stock assessment model.

	2009 harvest rate	GHL ton	GHL num	2009 Males>101	
				Number	Biomass
Original	0.14	43	34	138	97
new select	0.17	97	76	528	388
Growth	0.15	49	39	322	180
growth sd	0.15	49	38	309	173
EstM	0.14	38	30	252	183
EstM2	0.14	38	30	285	200
M2G	0.14	40	31	324	184

Table 2. Negative log likelihood values (lower is better) for the different data components.

	rec	length total	length survey	fpen	Catch	survey	Init	Total	Dif
Original	24.9	5806.5	4125.0	1172.1	671.7	2381.0	87.8	9710.4	0.0
New select	33.4	7742.3	5434.0	1887.9	2109.8	12271.2	114.5	23155.0	13444.6
Growth	24.8	4782.7	5143.0	1096.8	662.8	2320.5	93.8	8510.5	-1199.9
Growth sd	27.0	4696.6	4975.2	1095.1	653.8	2309.8	90.7	8408.0	-1302.4
EstM	22.0	7353.4	5045.2	1855.1	574.4	2273.9	88.7	11748.4	2038.0
EstM2	15.3	6302.5	5342.6	1016.4	596.1	2141.2	45.8	9750.3	39.9
M2G	22.9	5947.9	6730.8	1046.4	545.7	2006.0	65.4	7011.9	-2698.5

Table 3. Estimates of natural mortality.

	Immature		Mature		Old shell	
	Female	Male	Female	Male	Female	Male
Original	0.23	0.23	0.29	0.23	0.29	0.23
EstM	0.41	0.41	0.10	0.41	0.10	0.41
EstM2	0.13	0.13	0.14	2.58	0.14	2.58
M2G	0.35	0.35	0.24	1.02	0.24	1.02

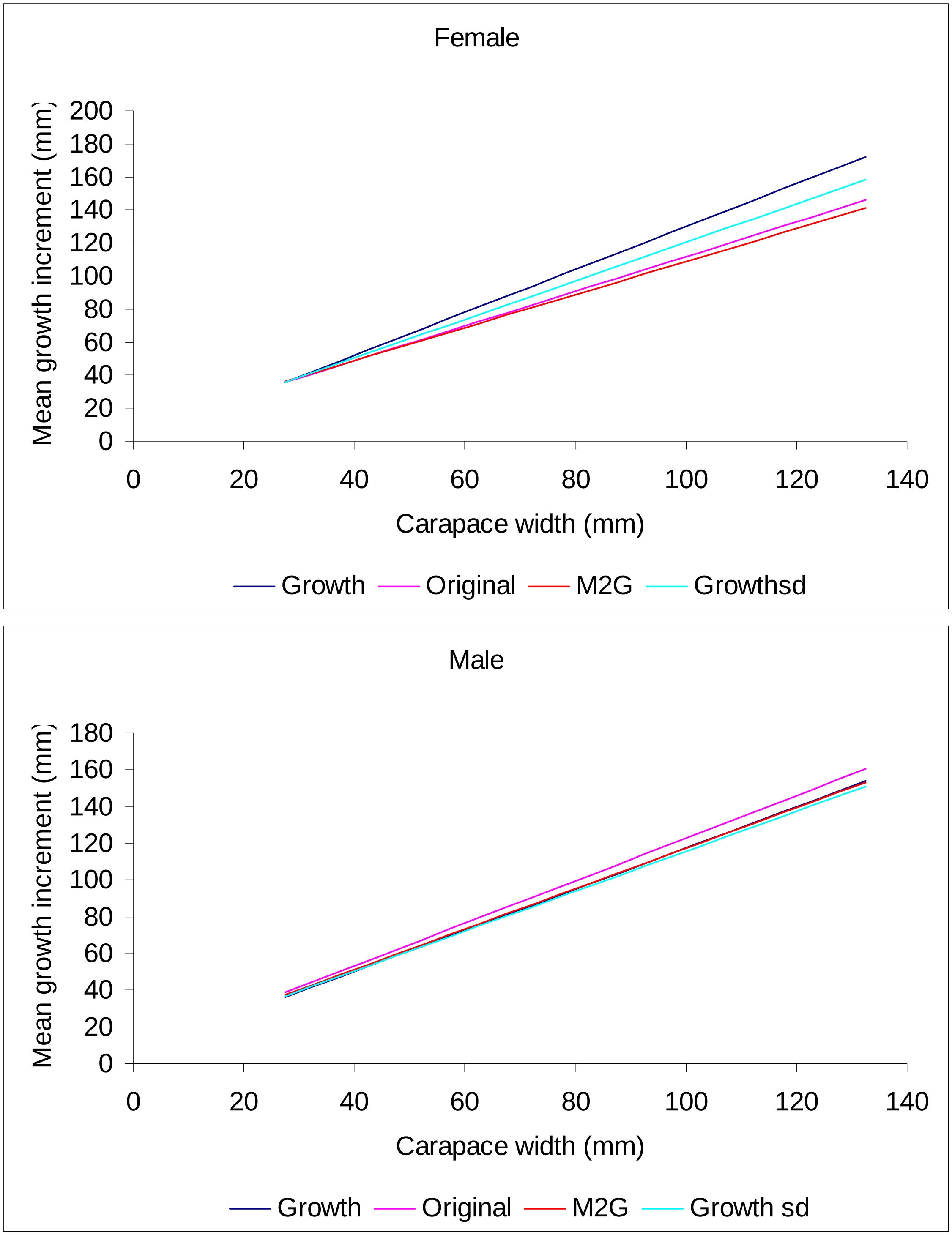

Figure 7. Estimates of mean growth increment from the models that estimate growth with that assumed in the original model.

Spatial variation in selectivity

The pilot study indicates that there is spatial variability in the selectivity (Figure 7). There is also spatial variability in the densities of crab (Figure 8). Females tend to be found mainly in the northwest and they have a higher selectivity than males in that region. Therefore, females are estimated to have a higher selectivity than males.

Conclusions

The selectivity estimated from the two studies is generally similar in shape and catchability, but there appears to be spatial differences in both the shape and catchability. The spatial variation in selectivity and the spatial difference in the male and female distribution may produce different selectivities for males and females. The new selectivity estimates are very different to those used in the current assessment. Using the new selectivity curve in the stock assessment produces larger estimates of abundance, but harvest levels are also dependent on the other parameters used in the model (e.g. growth and probably natural mortality).

The BSFRF survey catches substantially more small crab. Due to the low catchability of the NMFS survey it is not a good indicator of recruitment and the catchability/selectivity of these individuals may be highly variable from year to year. Therefore, it may be prudent to only include individual of 50 mm and greater carapace width in the assessment model. The BSFRF survey should be a better indicator of the incoming recruitment. If the growth assumptions are accurate, there have been several years of poor recruitment recently, but a moderate or good recruitment class can be seen with a model of about 40mm.

Literature Cited:

Turnock, B.J. and L.J. Rugulo. 2009. Stock Assessment of eastern Bering Sea snow crab. P 29-130, *in* Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands Regions 2009 Crab SAFE. North Pacific Fishery Management Council, 605 W. 4th Avenue, #306 Anchorage, AK 99501.

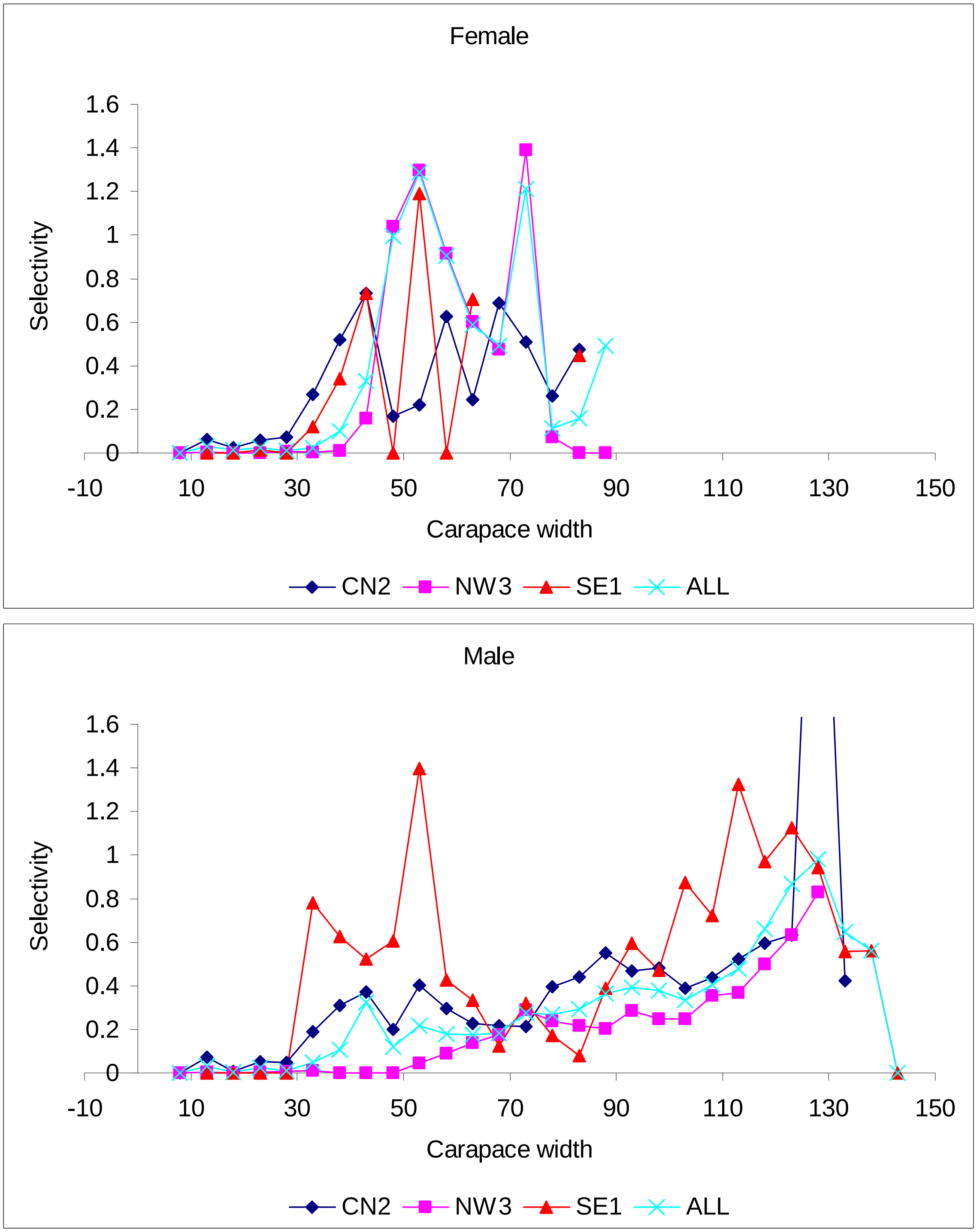

Figure 7. Selectivity by area from the pilot study.

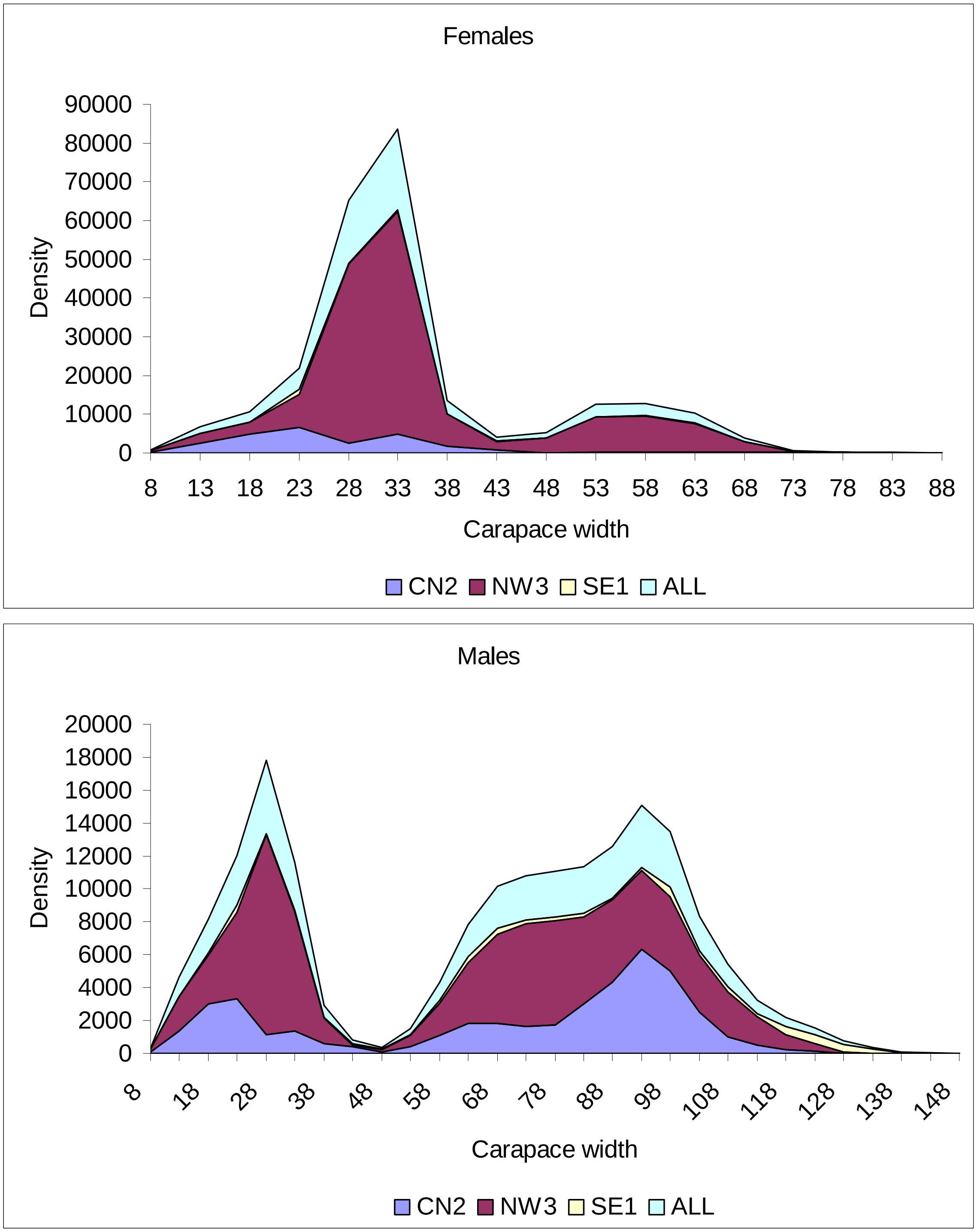

Figure 8. Average density by area from the BSFRF survey pilot study.

Appendix A: Modifications made to the assessment model to allow the fixing of survey selectivity and estimation of growth and natural mortality.

```
DATA_SECTION
  init_int Mbase_phase
  init_int matnM_phase
  init_int matnF_phase
  init_int matoM_phase
  init_int matoF_phase

  //init_vector M(1,2)     //natural mortality females then males
  //init_vector M_matn(1,2)  //natural mortality mature new shell female/male
  //init_vector M_mato(1,2)  //natural mortality mature old shell female/male


INITIALIZATION_SECTION
  srv1_q 7.235827369
  srv2_q 7.235827369
  srv3_q 7.235827369
  srv1_sel95 411.1253983
  srv1_sel50 254.3996434
  srv2_sel95 411.1253983
  srv2_sel50  254.3996434
  srv3_sel95 411.1253983
  srv3_sel50  254.3996434

  lnMbase -1.46967597
  lnmatnM 0
  lnmatnF 0.231801614
  lnmatoM 0
  lnmatoF 0

PARAMETER_SECTION
  init_number lnMbase(Mbase_phase)
  init_number lnmatnM(matnM_phase)
  init_number lnmatnF(matnF_phase)
  init_number lnmatoM(matoM_phase)
  init_number lnmatoF(matoF_phase)

  vector M(1,2)     //natural mortality females then males
  vector M_matn(1,2)  //natural mortality mature new shell female/male
  vector M_mato(1,2)  //natural mortality mature old shell female/male

  init_bounded_number af(0,20,4)
  init_bounded_number am(0,20,4)
```

```
  init_bounded_number bf(1,2,4)
  init_bounded_number bm(1,2,4)

  init_bounded_vector growth_beta(1,2,0.2,2,4)

  init_bounded_number srv1_q(0.2,1000,survsel1_phase)
  init_bounded_number srv1_sel95(30.0,15000,survsel1_phase)
  init_bounded_number srv1_sel50(0.0,15000,survsel1_phase)
  init_bounded_number srv2_q(0.7,1000,survsel1_phase+1)
  init_bounded_number srv2_sel95(30.0,16000,survsel1_phase)
  init_bounded_number srv2_sel50(0.0,9000,survsel1_phase)
  init_bounded_number srv3_q(0.7,1000,survsel1_phase+1)
  init_bounded_number srv3_sel95(40.0,15000,survsel_phase)
  init_bounded_number srv3_sel50(0.0,9000,survsel_phase)


PROCEDURE_SECTION
  M(1)=mfexp(lnMbase);
  M(2)=mfexp(lnMbase);

  M_matn(1)=M(1)*mfexp(lnmatnF);
  M_matn(2)=M(2)*mfexp(lnmatnM);

  M_mato(1)=M_matn(1)*mfexp(lnmatoF);
  M_mato(2)=M_matn(2)*mfexp(lnmatoM);


FUNCTION get_selectivity
       //if(survsel_phase<0)
           {
              //sel_srv3(1,j)=sel_som(1)/(1.+sel_som(2)*mfexp(-
1.*sel_som(3)*length_bins(j)));

           }
            //else
             {
               sel_srv3(1,j)=srv3_q*1./(1.+mfexp(-1.*log(19.)*(length_bins(j)-
srv3_sel50)/(srv3_sel95-srv3_sel50)));
            }
// this sets time periods 1 and 2 survey selectivities to somerton otto as well
             //if(survsel1_phase<0){
              //sel_srv1(1,j)=sel_srv3(1,j);
              //sel_srv2(1,j)=sel_srv3(1,j);
             //}
            //else
              {
```

```
//logistic curve if estimating selectivity parameters
               sel_srv1(1,j)=srv1_q*1./(1.+mfexp(-1.*log(19.)*(length_bins(j)-srv1_sel50)/(srv1_sel95-srv1_sel50)));
               sel_srv2(1,j)=srv2_q*1./(1.+mfexp(-1.*log(19.)*(length_bins(j)-srv2_sel50)/(srv2_sel95-srv2_sel50)));
             }


FUNCTION evaluate_the_objective_function

//bayesian part - likelihood on growth parameters af,am,bf,bm
 if(active(af))
 {
  //like_af   = .5 * square((af    - af_obs)    / sd_af);
  //like_bf = .5 * square((bf - bf_obs) / sd_bf);
  //f += like_bf;
  //cout<<"f8 = "<<f<<endl;
  //f += like_af;
  //cout<<"f9 = "<<f<<endl;
//  cout<<" af = " <<af<<endl;
//  cout<<" bf = " <<bf<<endl;

 }
 if(active(am))
  {
    //like_am   = .5 * square((am-am_obs)/sd_am);
    //f += like_am;
  //cout<<"f10 = "<<f<<endl;
//  cout<<" am = " <<am<<endl;
  }
 if(active(bm))
  {
    //like_bm = .5 * square((bm-bm_obs) /sd_bm);
    //f += like_bm;
  //cout<<"f11 = "<<f<<endl;
//  cout<<" bm = " <<bm<<endl;
  }
```

Appendix B: Data use in the analysis

Table B1. Average densities in the Pilot study.

	Male		Female	
Mid	NMFS	BSFRF	NMFS	BSFRF
8	0	85.39246	0	213.1679
13	34.46916	1161.109	53.25318	1670.626
18	8.107168	2040.538	39.6497	2672.668
23	67.46291	3005.442	133.7272	5452.824
28	40.49666	4447.991	154.2895	16304.81
33	136.4814	2904.128	522.3855	20882.96
38	77.9971	733.8245	337.8954	3385.399
43	64.54525	200.4797	333.5783	1013.202
48	10.60329	88.9746	1281.975	1289.896
53	81.93582	378.9262	4012.022	3121.494
58	191.5722	1079.102	2902.408	3211.96
63	345.3966	1957.249	1502.351	2550.799
68	461.0787	2537.441	477.0992	972.4466
73	744.6441	2702.339	166.1203	137.0303
78	742.4754	2762.742	4.740669	41.19289
83	829.0446	2833.772	4.920931	30.84465
88	1149.478	3146.768	2.494087	5.081887
93	1480.748	3769.883		
98	1269.807	3367.003		
103	698.1526	2085.83		
108	545.7079	1349.701		
113	385.7673	809.2092		
118	364.3706	551.3759		
123	335.7719	386.7841		
128	185.4787	189.2667		
133	56.82636	87.9036		
138	9.900891	17.63309		
143	0	7.16527		
148	2.865184	0		

Table B2. Average densities in the side by side study.

	Male		Female	
Mid	NMFS	BSFRF	NMFS	BSFRF
8	0	0	0	288.3127
13	0	61.71356	12.40568	11687.95
18	0	3289.271	27.97698	10460.36
23	12.71591	6693.813	51.78511	9092.591
28	51.41471	3418.099	679.7046	20135.77
33	119.2187	5011.237	471.3678	11876.16
38	119.3241	2862.175	254.7341	1851.787
43	48.0061	497.6494	62.62637	487.0589
48	13.44713	120.5089	1048.814	3640.33
53	77.7459	206.4607	5154.052	20890.6
58	191.5574	1712.457	1899.992	6841.381
63	840.2757	3807.414	634.519	2238.404
68	1086.423	6102.907	146.9129	1199.055
73	1438.764	6476.023	53.19557	439.2814
78	1893.742	8381.856	12.40568	49.00244
83	1736.907	8328.462	0	0
88	1941.378	6474.802		
93	1730.577	5505.125		
98	1215.324	4714.182		
103	796.0568	3177.64		
108	878.8614	2591.658		
113	631.5737	1617.381		
118	491.0256	1671.607		
123	251.8889	814.0721		
128	288.6207	550.2574		
133	0	258.331		
138	43.32561	21.6357		
143	0	0		
148	0	0		

Table B3. Average male densities in the Pilot study by area.

	SE1		CN2		NW3	
Mid	NMFS	BSFRF	NMFS	BSFRF	NMFS	BSFRF
8	0	0	0	80.35558	0	175.8218
13	0	24.07302	97.28601	1366.629	6.121482	2092.624
18	0	173.2468	24.3215	3013.974	0	2934.393
23	0	453.1488	177.9968	3346.098	24.3919	5217.078
28	0	63.22172	54.31991	1130.828	67.17007	12149.92
33	75.65173	96.74267	259.3848	1371.912	74.40773	7243.728
38	46.55353	74.4607	187.4378	604.5526	0	1522.46
43	46.91175	89.86471	146.724	395.8192	0	115.7552
48	15.92385	26.30757	15.88603	80.08917	0	160.5271
53	52.7332	37.75953	162.5207	405.2378	30.55359	693.7812
58	78.20128	183.5185	319.5704	1073.894	176.945	1979.895
63	114.1663	340.8948	417.9189	1837.018	504.1048	3693.835
68	46.7824	382.5411	393.7257	1805.12	942.728	5424.662
73	65.35746	205.1363	346.457	1629.99	1822.118	6271.89
78	40.15454	231.5307	683.3843	1731.83	1503.887	6324.864
83	15.57209	198.7375	1330.99	3015.078	1140.572	5287.501
88	45.84016	118.404	2385.69	4341.265	1016.903	4980.634
93	112.1623	188.9373	2961.326	6327.597	1368.757	4793.114
98	275.2351	583.8318	2418.283	5018.278	1115.904	4498.899
103	268.2294	306.7921	970.3887	2501.799	855.8397	3448.9
108	238.7118	330.8717	448.0089	1024.861	950.4031	2693.371
113	254.9011	192.3027	261.0147	498.2694	641.386	1737.056
118	504.694	519.8754	143.335	241.0256	445.0827	893.2266
123	621.7368	551.978	74.94104	118.4054	310.6377	489.9689
128	429.3881	454.7582	44.21667	13.27882	82.83134	99.76305
133	137.4546	246.1729	7.400519	17.53789	25.62393	0
138	29.70267	52.89926	0	0	0	0
143	0	21.49581	0	0	0	0
148	8.595551	0	0	0	0	0