Tables

Table 1. Model likelihoods and results. Colors indicate same data and weighting. Note that the 2015 Model, Model 16.6, and Model 16.6.0 have different adjustments to the size composition data and therefore composition likelihoods should not be compared with other models.

Label	2015 Model	16.6	16.6.0	16.6.1	16.6.2.1 Q	16.6.2.2 M	16.6.2.3 S	16.6.2.4 QM	16.6.2.5 QMS
Parameters	244	79	82	82	83	83	88	84	90
TOTAL_like	2352.55	1604.16	1848.62	672.57	593.29	563.98	545.47	563.59	528.35
Survey_like	25.76	22.72	44.48	20.58	-2.12	-5.37	-5.24	-6.11	-7.01
Length_comp_like	1990.68	1176.06	1390.51	374.44	340.81	321.61	303.82	321.76	290.27
Age_comp_like	347.06	89.67	82.48	26.74	18.67	19.27	21.29	18.86	18.42
Parm_priors_like	0	0	0	0	0	9.11	0	4.89	0.82
Size_at_age_like	0	282.50	289.42	258.65	238.93	238.47	242.96	237.02	238.01
R0_billions	0.31	0.22	0.20	0.22	0.18	5.06	0.35	1.75	0.61
SR_BH_steep	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Natural Mortality	0.38	0.38	0.38	0.38	0.38	0.81	0.38	0.69	0.51
L at Amin	44.59	5.34	5.87	5.53	5.45	5.83	4.39	5.78	4.98
L at Amax	89.84	105.32	106.13	107.91	115.03	119.64	111.48	120.23	117.08
VonBert K	0.23	0.15	0.15	0.15	0.14	0.13	0.15	0.13	0.14
SPB_Virgin_thousand_mt	304.87	174.03	160.53	184.63	156.70	219.00	323.47	154.99	200.53
Bratio_2015	0.87	0.35	0.42	0.35	0.25	0.71	0.41	0.54	0.40
SPRratio_2014	0.99	1.16	1.13	1.14	1.25	0.46	0.93	0.74	0.95
Trawl survey Q 1994-2015	1.00	1.00	1.00	1.00	2.85	1.00	1.00	1.89	1.60
Trawl survey Q 1977-1993	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Label	16.6.3	16.6.4.1	16.6.4.2	16.6.11 S	16.6.15 QM	16.6.20	16.6.22 QMS
Parameters	316	317	317	320	315	82	90
TOTAL_like	614.00	581.32	603.21	511.89	509.18	643.21	512.86
Survey_like	22.40	21.63	24.37	-8.91	-6.33	21.71	-4.90
Length_comp_like	322.30	295.82	313.51	261.21	259.96	348.60	276.25
Age_comp_like	27.35	27.31	26.87	21.14	18.96	26.62	17.64
Parm_priors_like	0	0	0	0	9.22	0	0.77
Size_at_age_like	255.28	248.03	249.87	240.98	236.25	250.29	235.98
R0_billions	0.23	0.22	0.22	0.34	3.17	0.20	0.59
SR_BH_steep	1	1.00	1	1.00	1.00	1.00	1.00
Natural Mortality	0.38	0.38	0.38	0.38	0.75	0.38	0.50
L at Amin	5.70	5.74	5.78	4.56	5.87	5.63	5.06
L at Amax	109.64	111.90	111.84	112.57	119.86	110.61	117.15
VonBert K	0.15	0.14	0.14	0.15	0.13	0.15	0.14
SPB_Virgin_thousand_mt	197.80	193.14	191.37	313.20	193.37	175.48	200.54
Bratio_2015	0.34	0.34	0.34	0.43	0.64	0.36	0.39
SPRratio_2014	1.15	1.16	1.16	0.94	0.58	1.15	0.97
Trawl survey Q 1994-2015	1.00	1.00	1.00	1.00	1.24	1.00	1.73
Trawl survey Q 1977-1993	1.00	1.00	1.75	1.00	1.00	1.00	1.00

Table 1. Cont. Model likelihoods and results. Note that the 16.7 series of models have the <27 cm fish removed from bottom trawl survey index, and length and age composition data. Colors indicate same data and weighting.

Label	16.7	16.7.0	16.7.1	16.7.2	16.7.3
Parameters	79	82	82	316	82
TOTAL_like	1540.51	1784.01	638.93	577.08	627.93
Survey_like	54.30	65.09	16.73	15.40	22.64
Length_comp_like	1118.79	1333.48	358.45	304.60	346.14
Age_comp_like	60.70	55.21	20.03	20.43	19.84
Parm_priors_like	0.00	0.00	0.00	0.00	0.00
Size_at_age_like	279.96	297.66	255.86	252.99	247.97
R0_billions	0.24	0.23	0.25	0.26	0.23
SR_BH_steep	1.00	1.00	1.00	1.00	1.00
Natural Mortality	0.38	0.38	0.38	0.38	0.38
L at Amin	5.55	6.57	6.47	6.82	6.65
L at Amax	104.06	103.60	105.75	107.41	108.44
VonBert K	0.15	0.15	0.15	0.15	0.15
SPB_Virgin_thousand_mt	189.14	174.63	199.61	214.29	190.13
Bratio_2015	0.41	0.47	0.44	0.42	0.45
SPRratio_2014	1.09	1.07	1.05	1.06	1.06
Trawl survey Q 1994-2015	1.00	1.00	1.00	1.00	1.00
Trawl survey Q 1977-1993	1.00	1.00	1.00	1.00	1.00

Table 2. Likelihoods by fleet for models 16.6 and 16.6.0 showing changes with the addition of the GOA AFSC sablefish longline survey.

Likelihoods	ALL	FshTrawl	FshLL	FshPot	Srv	LLSrv
Model 16.6						
Surv_like	22.72				22.72	
Length_like	1176.06	477.57	320.21	194.10	184.18	
Age_like	89.67				89.67	
sizeatage_like	282.50				282.50	
Model 16.6.0						
Surv_like	44.48				32.70	11.78
Length_like	1390.51	465.16	339.93	198.24	182.93	204.26
Age_like	82.48				82.48	
sizeatage_like	289.42				289.42	

Table 3: Female spawning stock biomass retrospective analysis results for models evaluated. Reds are further from 0, blues are closer.

Model	Rho	WH Rho	RMSE
16.6	0.281	0.000	0.086
16.6.0	0.098	0.001	0.054
16.6.1	0.072	0.001	0.041
16.6.3	0.077	-0.003	0.040
16.6.4.1	0.070	-0.012	0.044
16.6.4.2	0.065	-0.017	0.048
16.6.11	0.258	0.110	0.123
16.6.15	0.322	0.153	0.169
16.6.20	0.065	-0.013	0.049
16.6.22	0.554	0.317	0.334
16.7	0.489	0.015	0.110
16.7.0	0.212	0.014	0.065
16.7.1	0.115	-0.007	0.051
16.7.3	0.120	-0.024	0.065

Table 4. Model effective sample size and adjustments comparing un-tuned (Model 16.6.0) and Francis method tuned (Model 16.6.1) models.

FleetName	mean_effN	mean(inputN*Adj)	HarMean(effN)	Var_Adj	HarEffN/ MeanInputN	Index RMSE
Model 16.6.0						
FshTrawl	530.95	152.05	207.39	1.00	1.36	
FshLL	660.34	155.86	357.12	1.00	2.29	
FshPot	886.94	180.27	635.02	1.00	3.52	
Srv	415.15	100.00	274.82	1.00	2.75	0.56
LLSrv	374.28	100.00	311.66	1.00	3.12	0.34
Srv_Age	85.91	100.00	43.03	1.00	0.43	
Model16.6.1.2_Francis						
FshTrawl	452.91	14.69	144.82	0.10	9.86	
FshLL	560.76	11.33	260.50	0.07	22.99	
FshPot	885.98	39.87	582.27	0.22	14.60	
Srv	304.51	44.96	218.29	0.45	4.86	0.48
LLSrv	453.06	73.91	362.46	0.74	4.90	0.31
Srv_Age	39.50	24.36	32.15	0.24	1.32	

Table 5. Fleet negative log likelihoods, red are highest for the category, blue are lowest.

Model	Label	ALL	FshTrawl	FshLL	FshPot	Srv	LLSrv
16.6.1	Age_like	26.74				26.74	
16.6.2.1 Q	Age_like	18.67				18.67	
16.6.2.2 M	Age_like	19.27				19.27	
16.6.2.3 S	Age_like	21.29				21.29	
16.6.2.4 QM	Age_like	18.86				18.86	
16.6.2.5 QMS	Age_like	18.42				18.42	
16.6.1	Length_like	374.44	59.05	38.70	48.37	102.23	126.09
16.6.2.1 Q	Length_like	340.81	59.39	46.65	50.11	83.21	101.47
16.6.2.2 M	Length_like	321.61	57.00	35.33	53.33	80.29	95.67
16.6.2.3 S	Length_like	303.82	56.33	42.25	49.65	81.62	73.96
16.6.2.4 QM	Length_like	321.76	56.45	38.22	52.97	81.58	92.53
16.6.2.5 QMS	Length_like	290.27	54.48	32.87	49.36	78.76	74.81
16.6.1	sizeatage_like	258.65				258.65	
16.6.2.1 Q	sizeatage_like	238.93				238.93	
16.6.2.2 M	sizeatage_like	238.47				238.47	
16.6.2.3 S	sizeatage_like	242.96				242.96	
16.6.2.4 QM	sizeatage_like	237.02				237.02	
16.6.2.5 QMS	sizeatage_like	238.01				238.01	
16.6.1	Surv_like	20.58				18.54	2.03
16.6.2.1 Q	Surv_like	-2.12				-5.26	3.14
16.6.2.2 M	Surv_like	-5.37				-0.67	-4.71
16.6.2.3 S	Surv_like	-5.24				-0.28	-4.97
16.6.2.4 QM	Surv_like	-6.11				-3.35	-2.76
16.6.2.5 QMS	Surv_like	-7.01				-2.87	-4.14

Table 6. Estimates of Pacific cod natural mortality.

Area	Author	Year	Value
Eastern Bering Sea	Low	1974	0.3-0.45
Eastern Bering Sea	Wespestad et al.	1982	0.7
Eastern Bering Sea	Bakkala and Wespestad	1985	0.45
Eastern Bering Sea	Thompson and Shimada	1990	0.29
Eastern Bering Sea	Thompson and Methot	1993	0.37
Eastern Bering Sea	Shimada and Kimura	1994	0.96
Gulf of Alaska	Thompson and Zenger	1993	0.27
Gulf of Alaska	Thompson and Zenger	1995	0.5
British Columbia	Ketchen	1964	0.56-0.63
British Columbia	Fournier	1983	0.65
Korea	Jung et al.	2009	0.82
Japan	Ueda et al.	2004	0.2

Table 7. Fleet and data specific likelihoods for Model 16.6.1, Model 16.6.3, Model 16.6.4.1 and Model 16.6.4.2.

Label	ALL	FshTrawl	FshLL	FshPot	Srv	LLSrv
Model 16.6.1						
Surv_like	20.58				18.54	2.03
Length_like	374.44	59.05	38.70	48.37	102.23	126.09
Age_like	26.74				26.74	
sizeatage_like	258.65				258.65	
Model 16.6.3						
Surv_like	22.40				20.02	2.38
Length_like	322.30	33.13	18.82	48.53	105.81	116.01
Age_like	27.35				27.35	
sizeatage_like	255.28				255.28	
Model 16.6.4.1						
Surv_like	21.63				18.56	3.08
Length_like	295.82	34.27	19.62	47.31	86.00	108.62
Age_like	27.31				27.31	
sizeatage_like	248.03				248.03	
Model 16.6.4.2						
Surv_like	24.37				20.51	3.86
Length_like	313.51	33.43	19.78	47.89	104.10	108.31
Age_like	26.87				26.87	
sizeatage_like	249.87				249.87	
	24.37				20.51	3.86

Figures

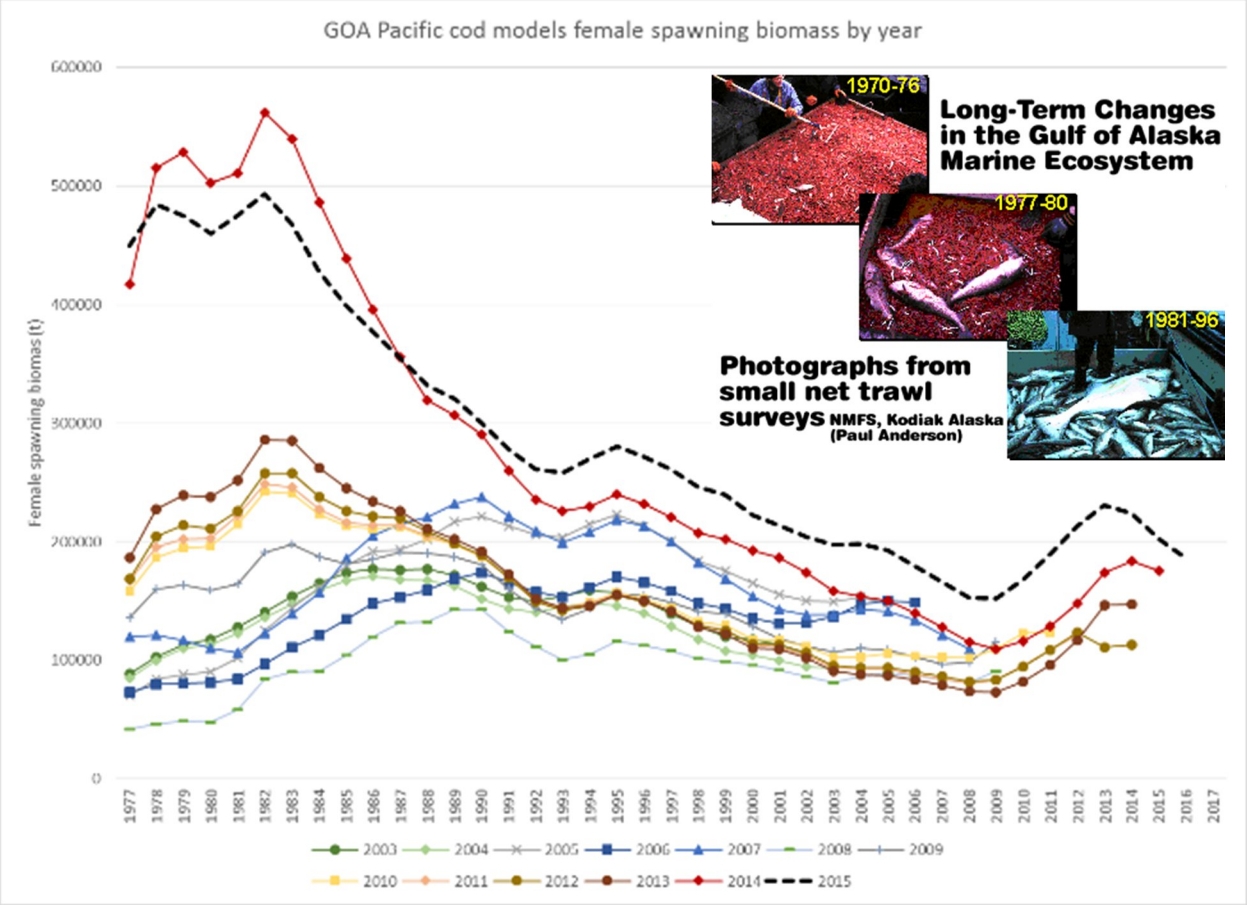

Figure 1. 1977-2015 Gulf of Alaska Pacific cod female spawning biomass from the 2003 through 2015 stock assessments and (inset) images from the NMFS small net surveys off Kodiak Alaska showing change in species composition over time from: http://www.thenakedscientists.com/HTML/articles/article/brucewrightcolumn1.htm/

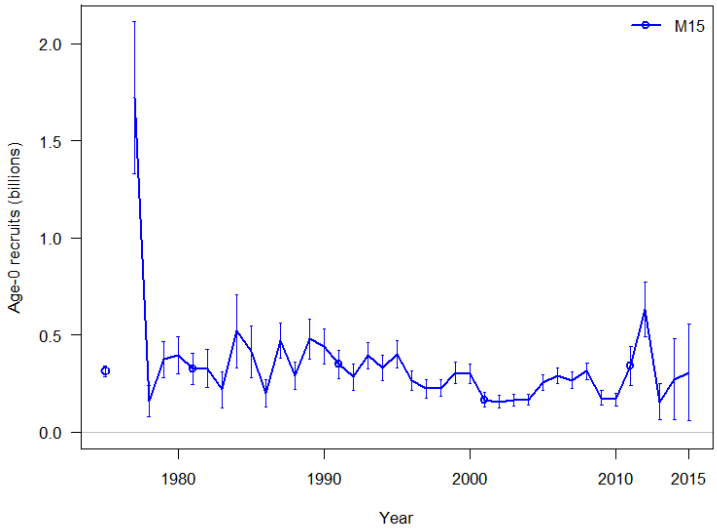

Figure 2. 1977-2015 Gulf of Alaska Pacific cod numbers at age-0 from the 2015 Model.

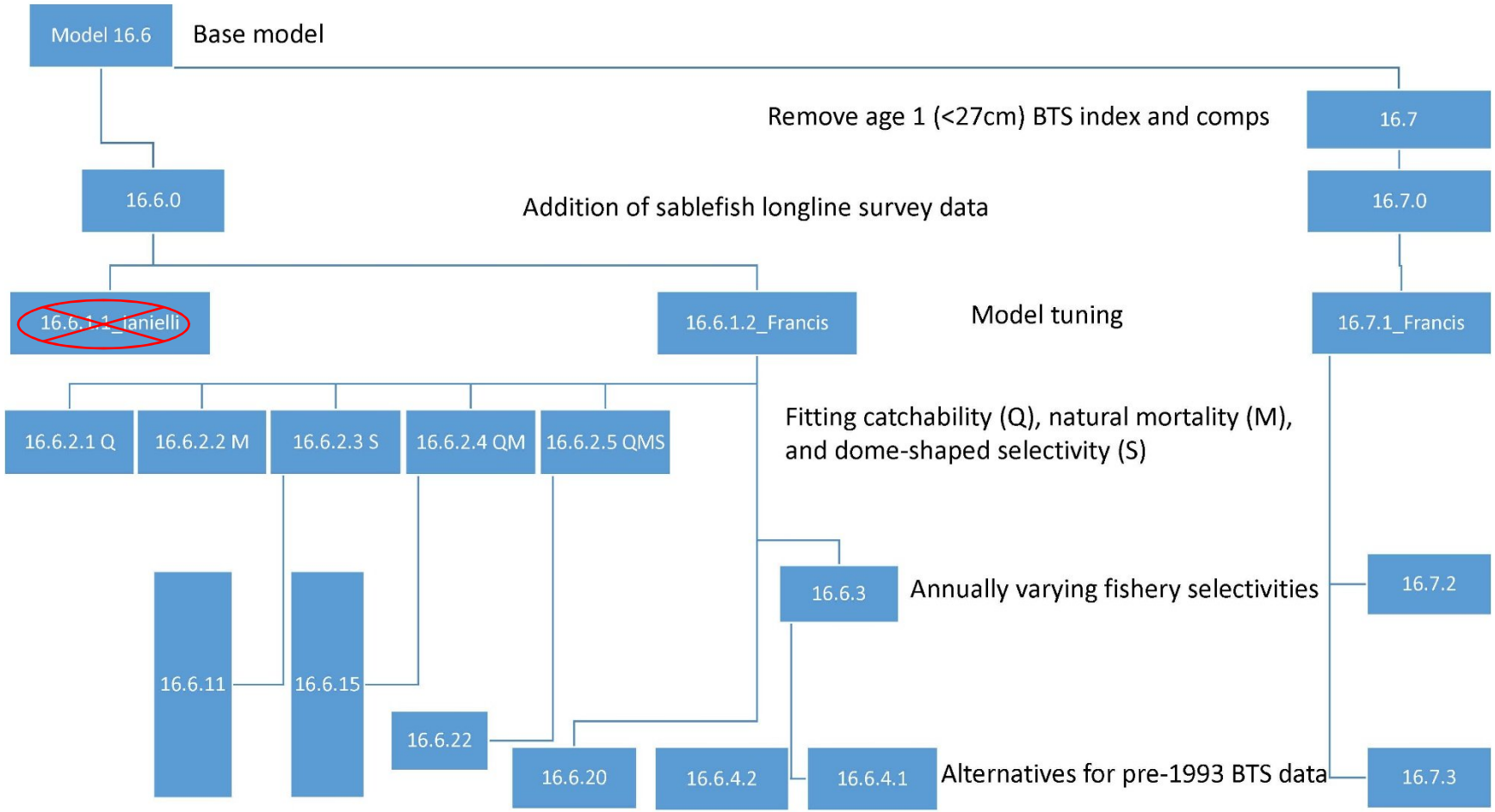

Figure 3. Hierarchy for models evaluated in this document. Models with red x were not presented.

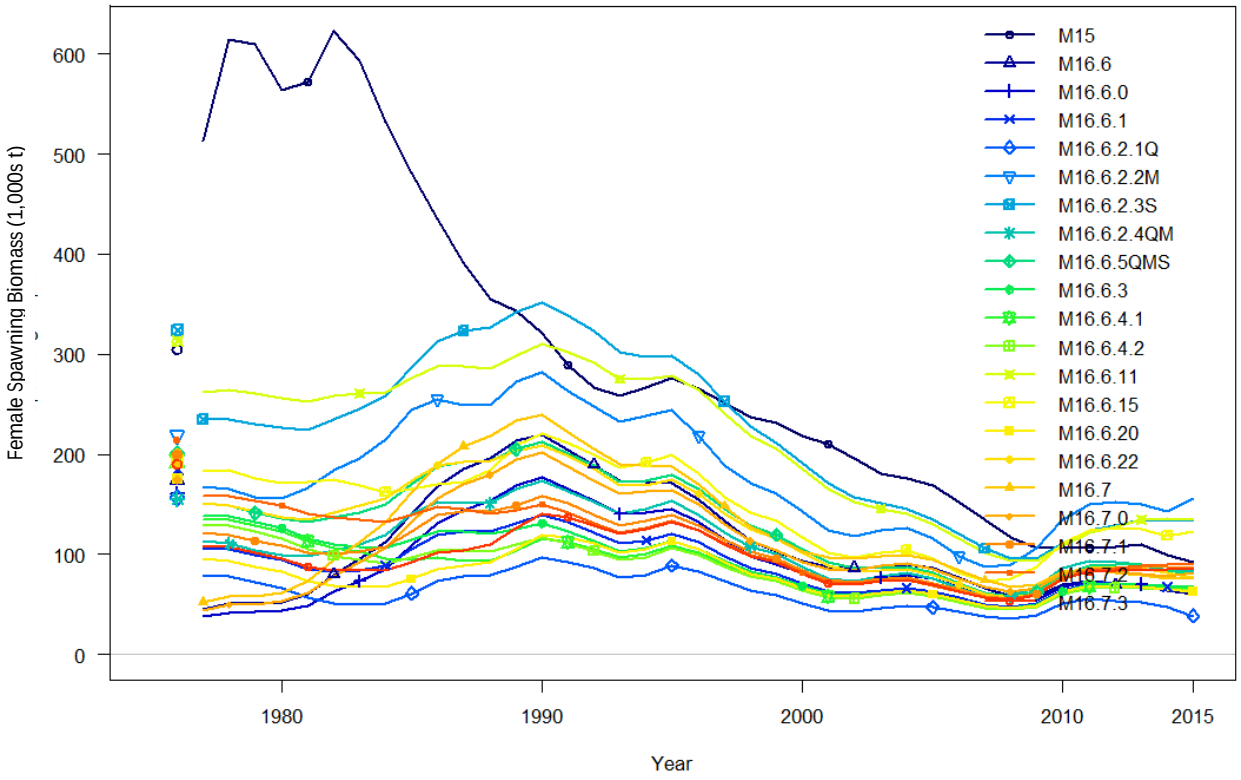

Figure 4. Female spawning stock biomass in 1000's tons for the 2015 Model (M15) and models presented in this document. The points on the far left are estimates of female virgin spawning biomass.

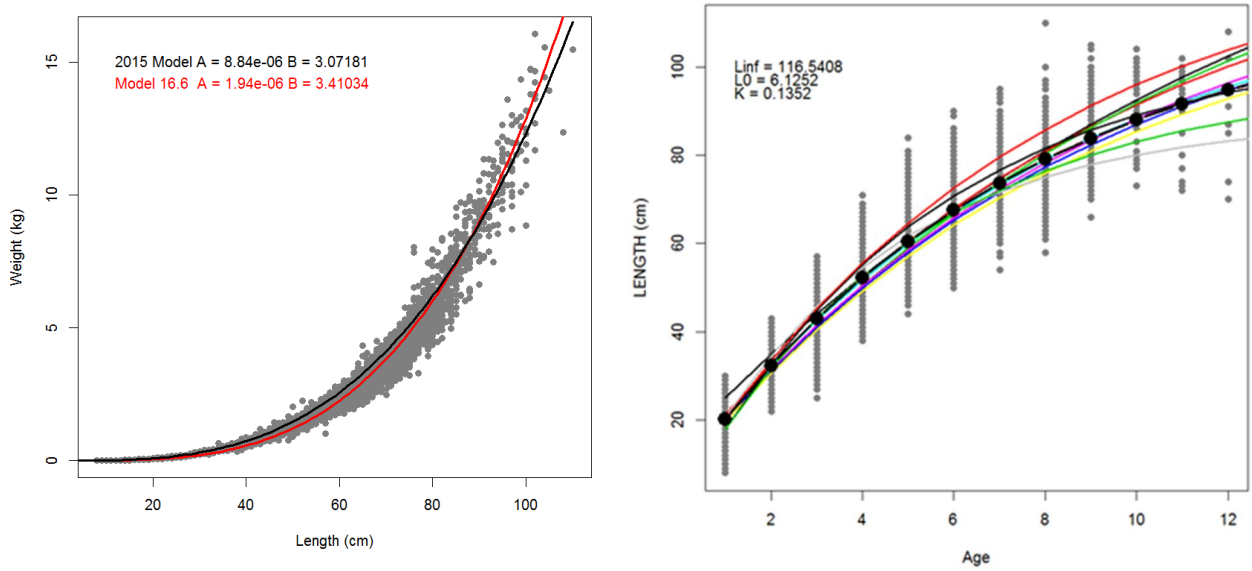

Figure 5. Weight at length for Model 16.6 and 2015 Model (Left), and Von Bertalanffy fits to Pacific cod length at age data (right) from the 1990-2013 bottom trawl survey. In the right-hand figure black dots are the fit for all data combined, colored lines are fits to individual years.

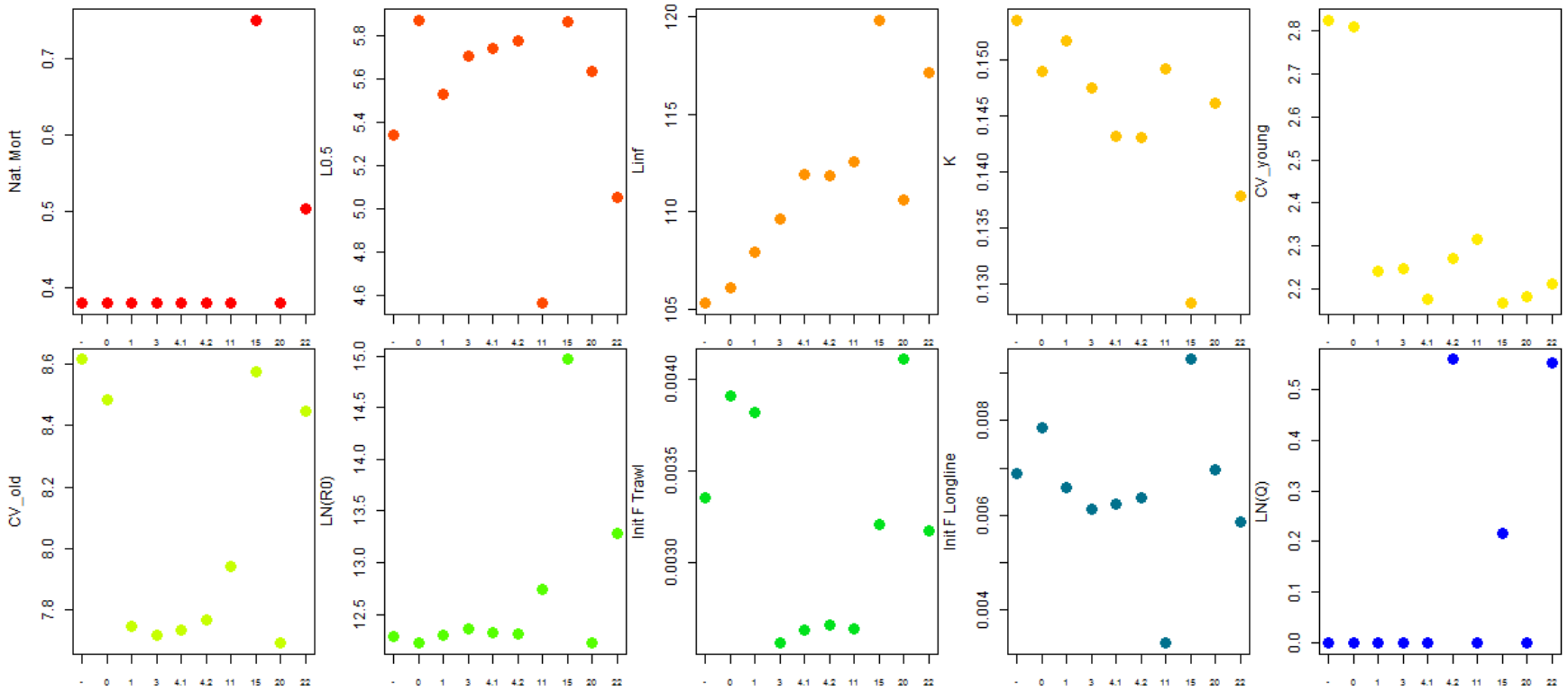

Figure 6. Non-selectivity parameters for Models 16.6.xx.

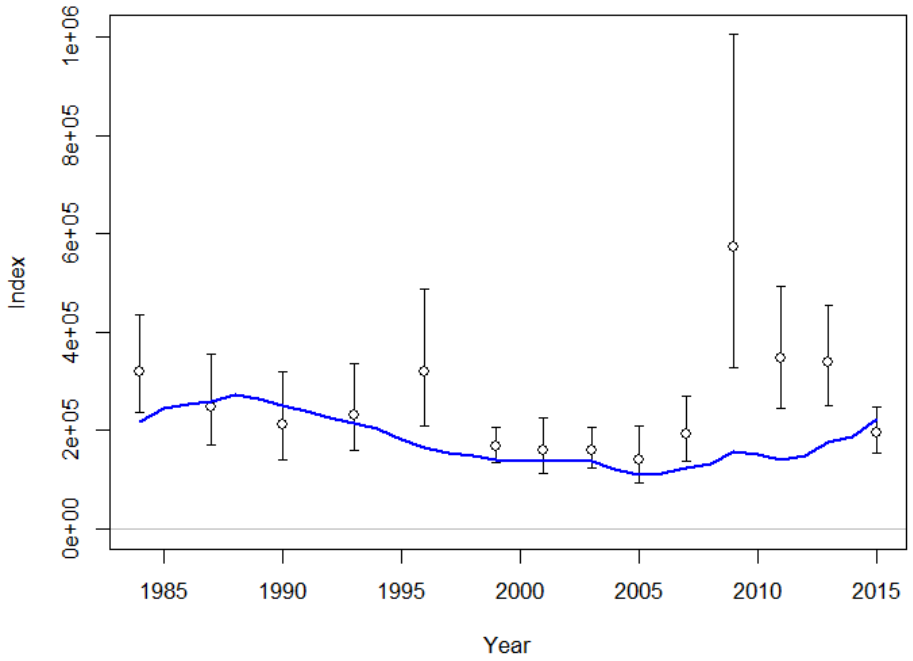

Figure 7. Bottom trawl survey Pacific cod index of abundance for 1984-2015 in numbers of fish. The blue line is the Model 16.6 fit to the index.

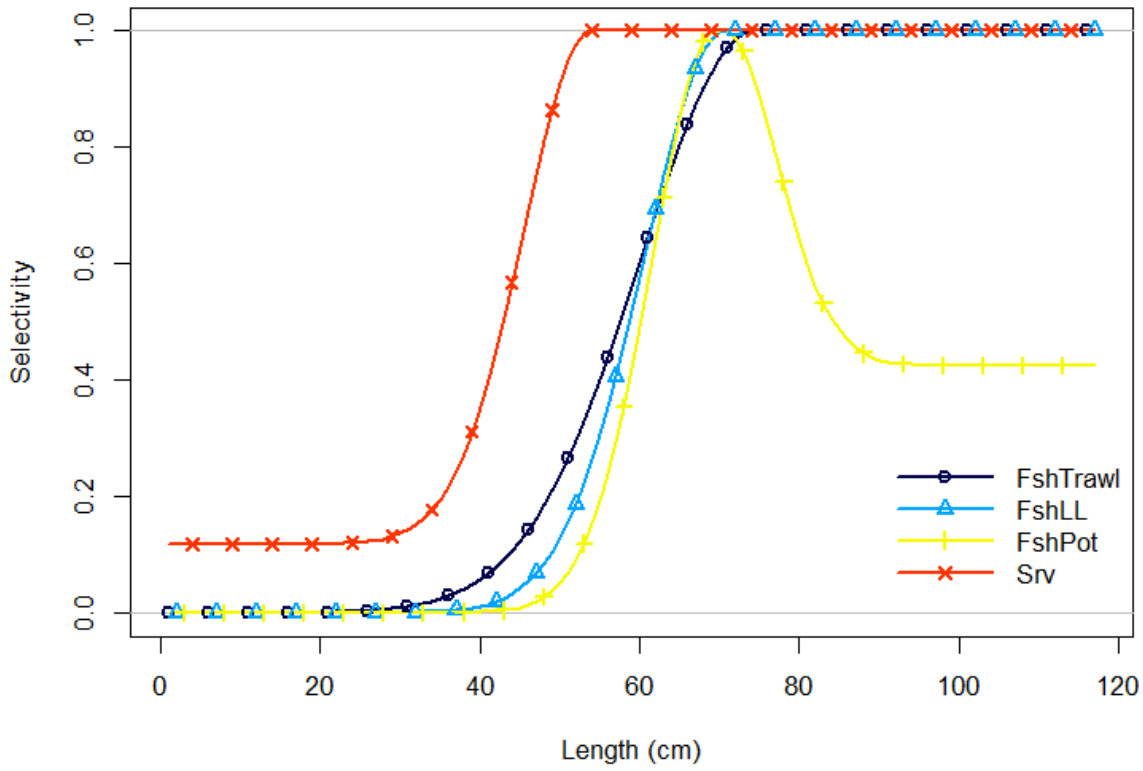

Figure 8. Model 16.6 length based selectivity for all fisheries and the bottom trawl survey.

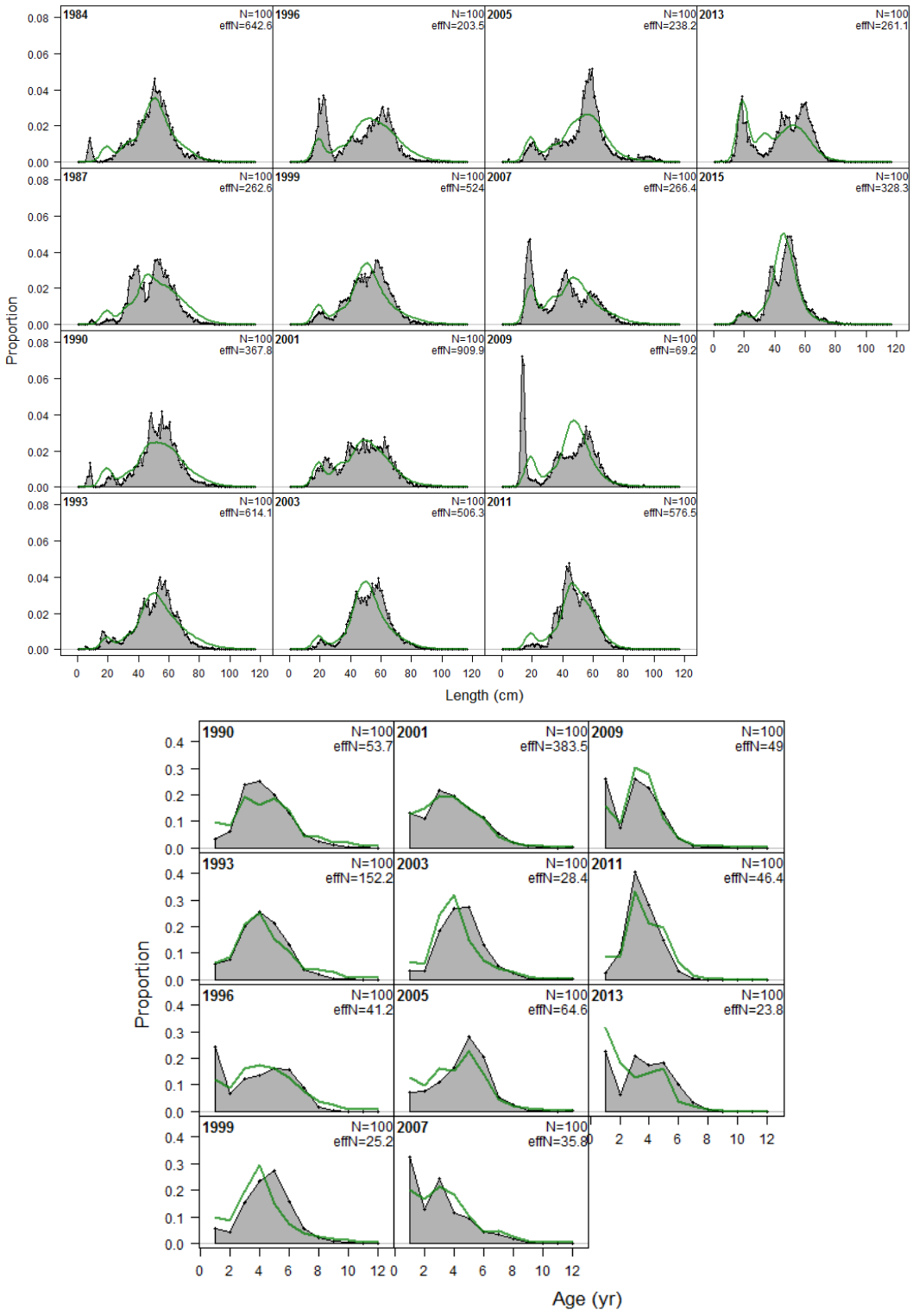

Figure 9. Bottom trawl length composition (top) and age composition (bottom) data with Model16.6 estimates in green.

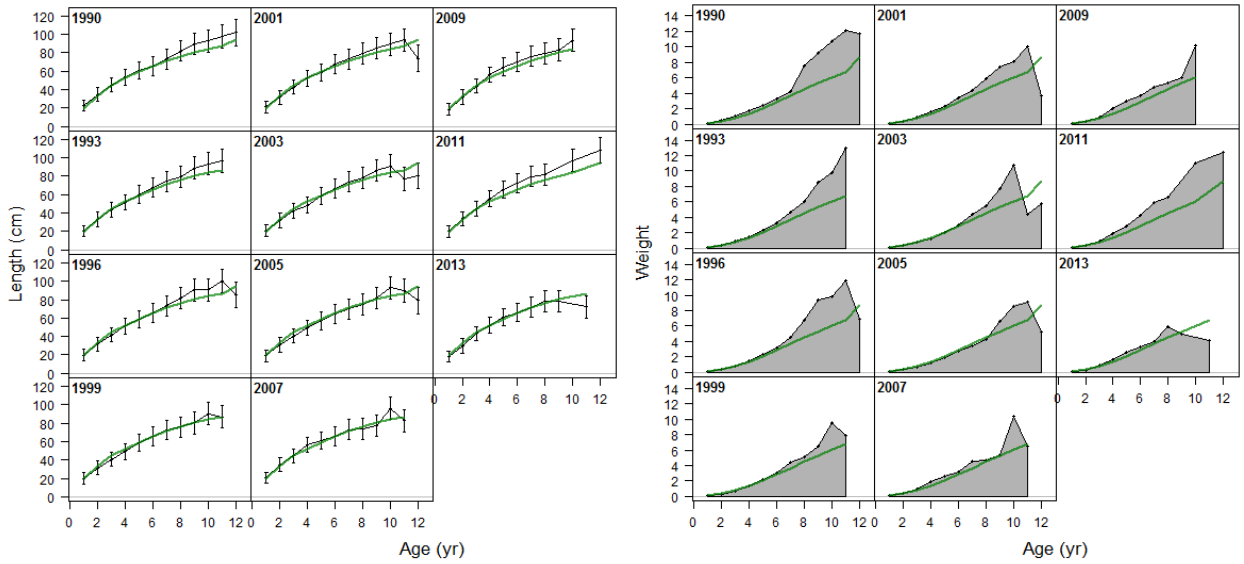

Figure 10. Bottom trawl survey (left) length at age and (right) weight at age with Model 16.6 estimates in green.

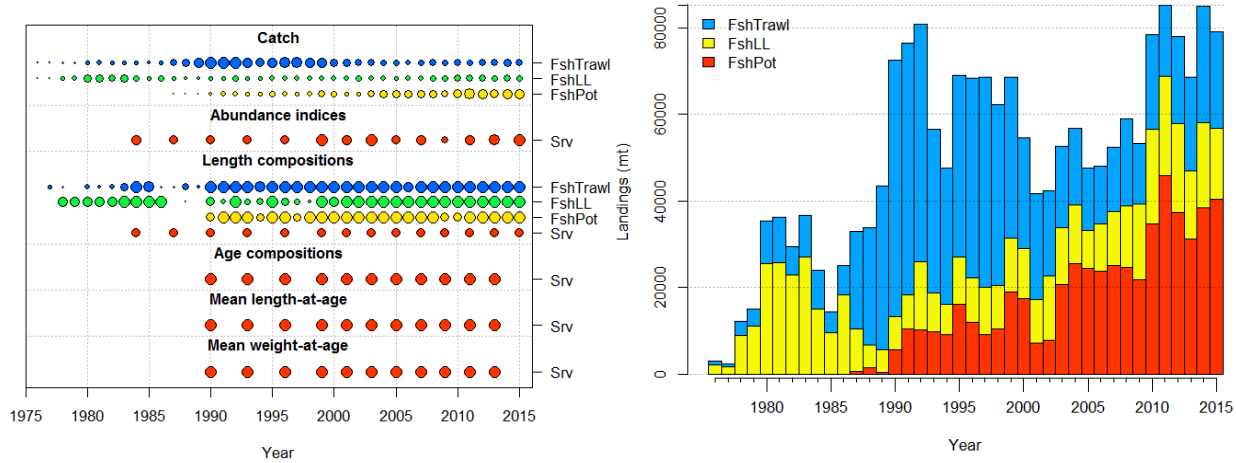

Figure 11. (Left) Data types used in Model 16.6, circle area is relative to data precision for each data type and (right) fishery catch data for 1977-2015 for the three fisheries.

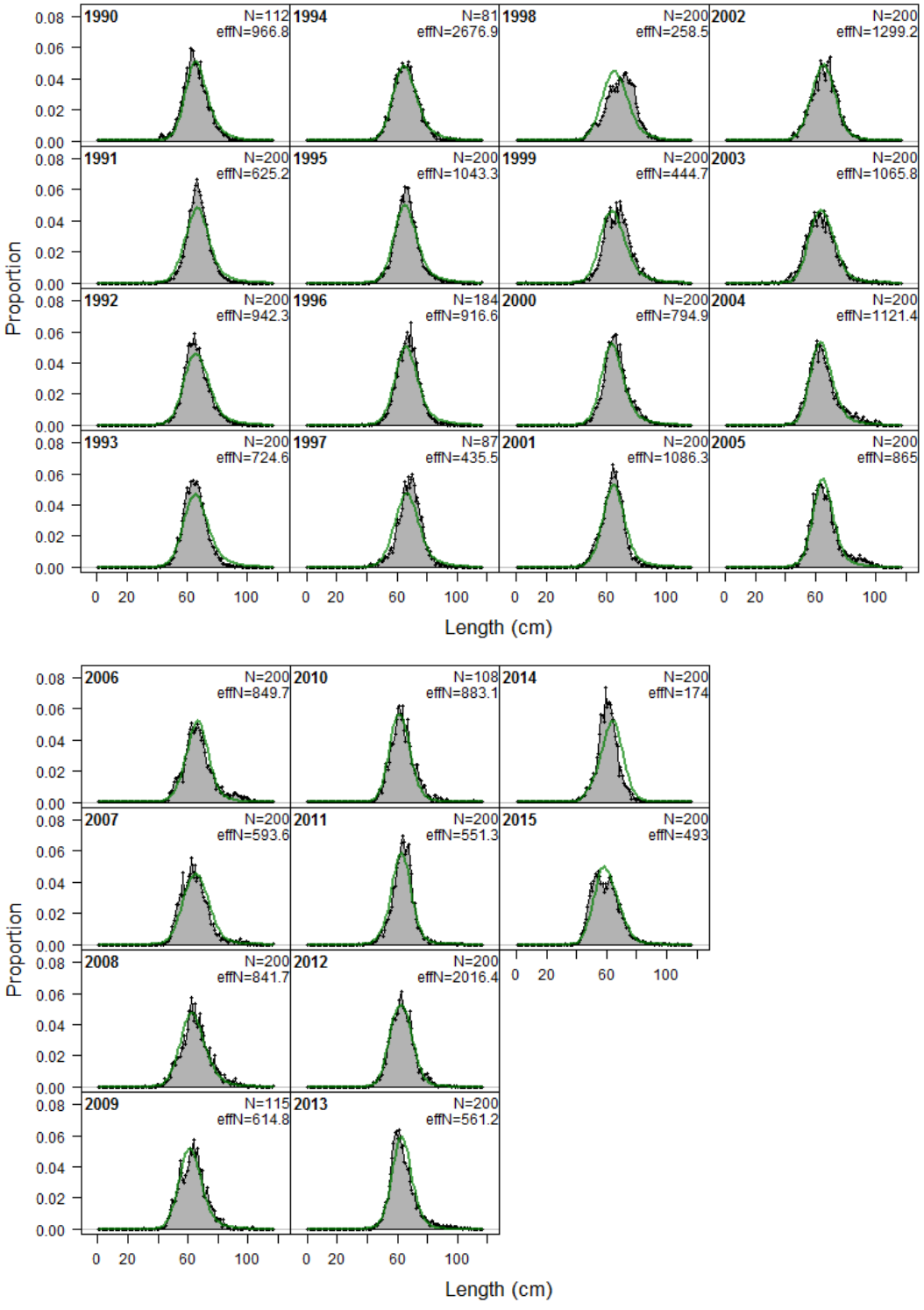

Figure 12. Pot fishery length composition and Model 16.6 estimates (green line)..

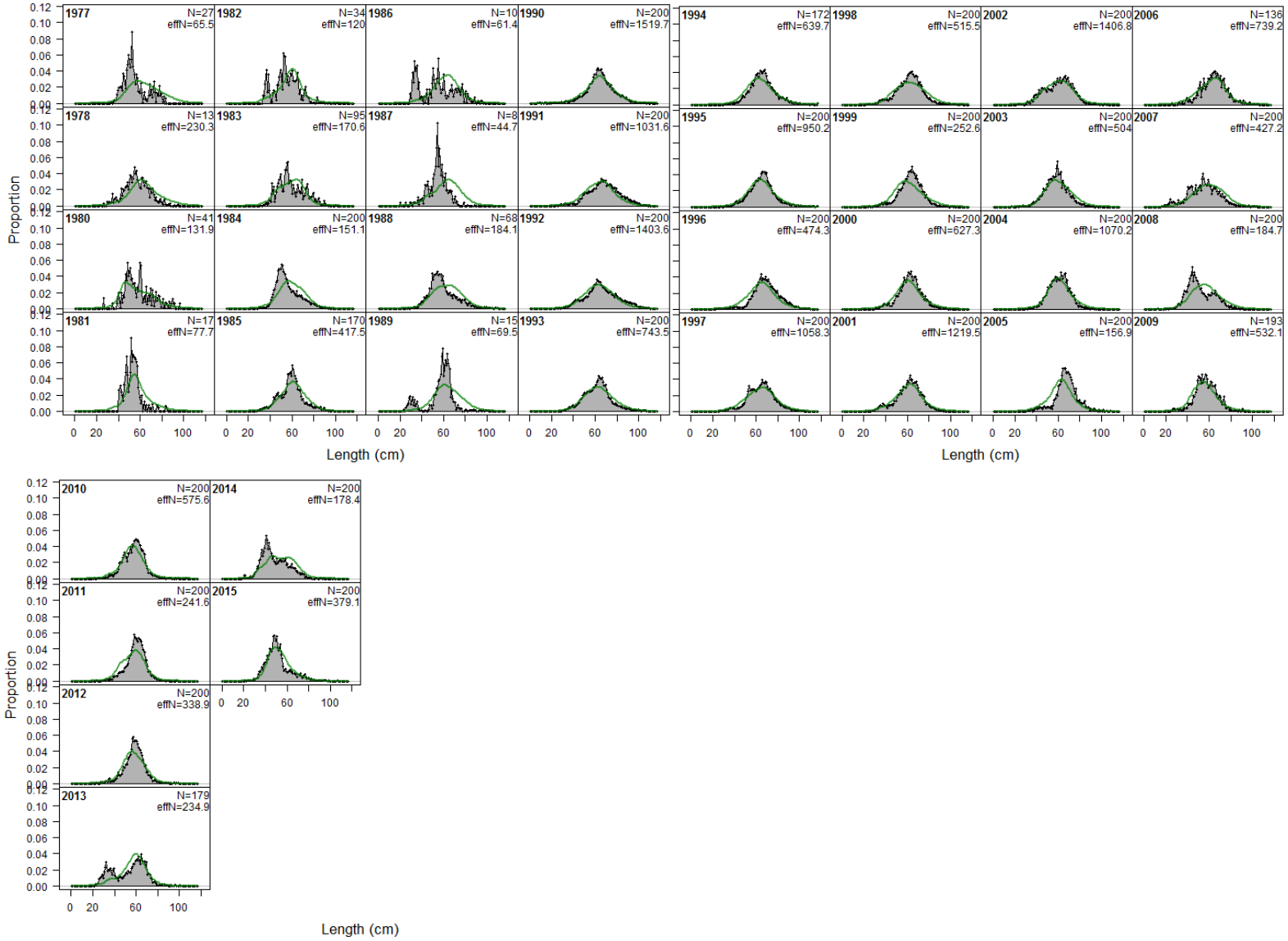

Figure 13. Trawl fishery length composition data and Model 16.6 estimates (green line).

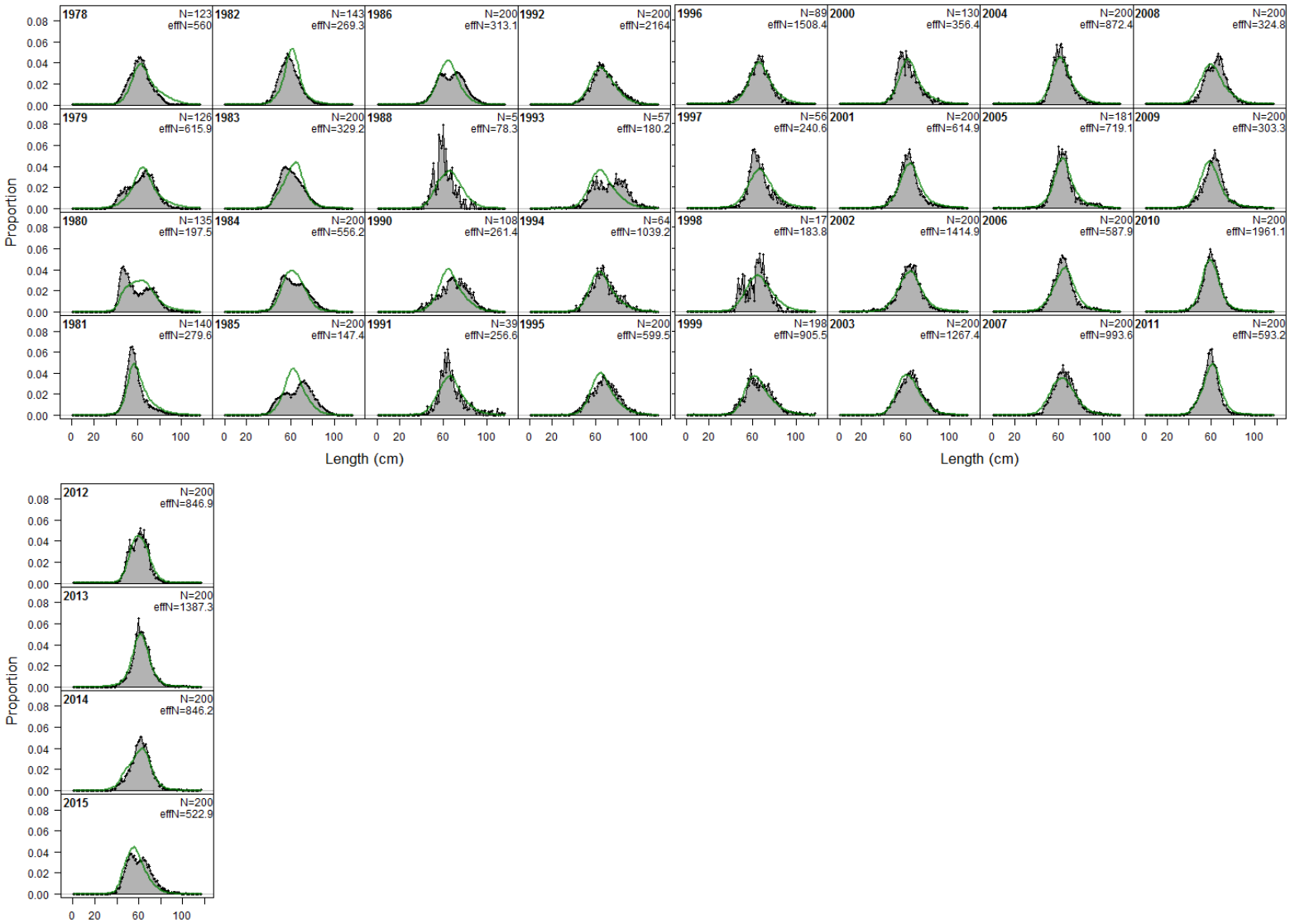

Figure 14. Longline fishery length composition data and Model 16.6 estimates (green line).

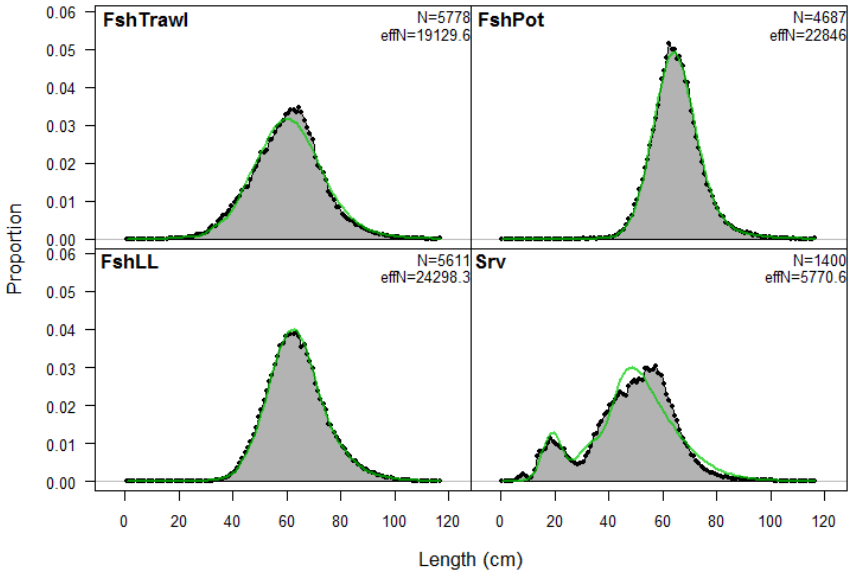

Figure 15. Model 16.6 fit to length composition data for the four data components, green line being the model estimate.

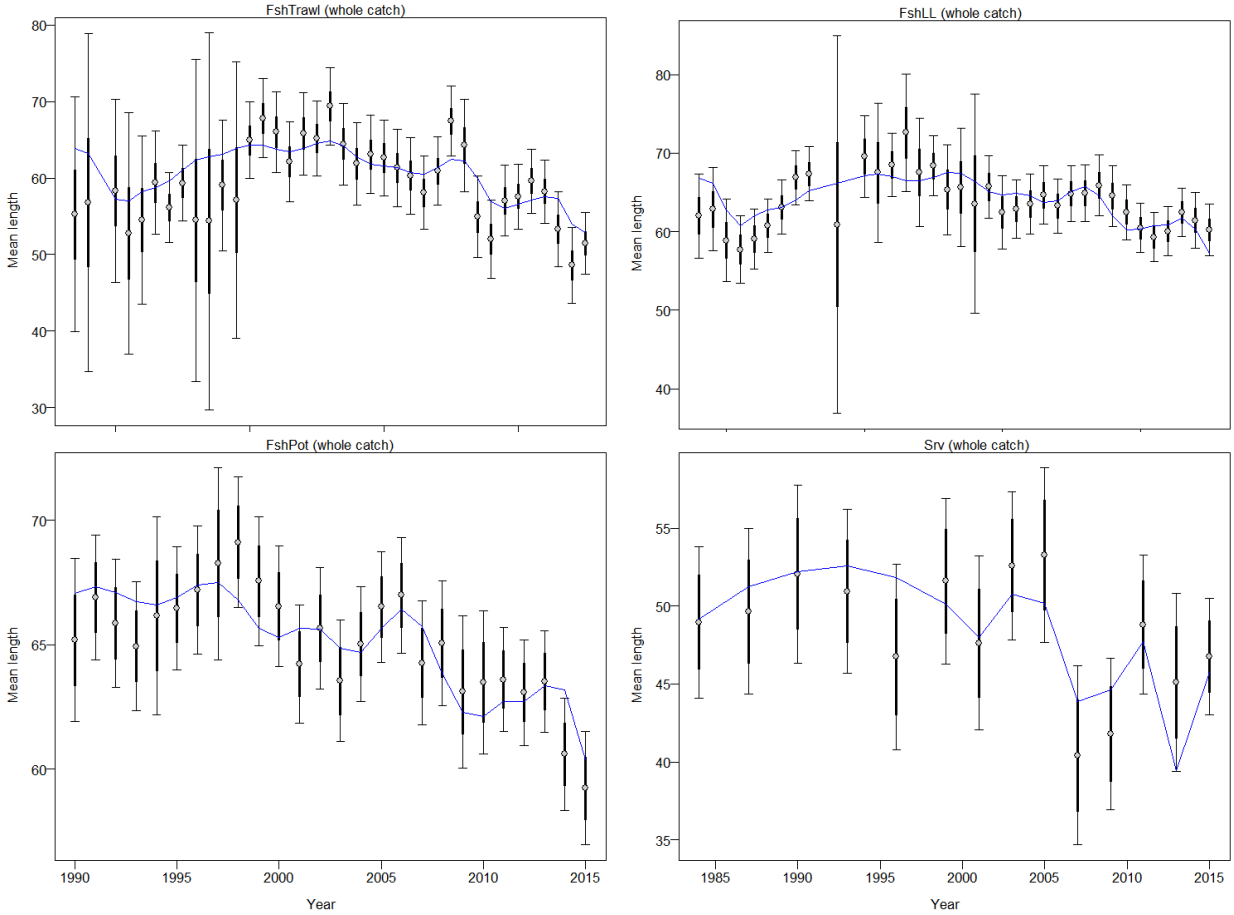

Figure 16. Model 16.6 fit to mean length by year from the length composition data for the four components. Blue lines being model estimates.

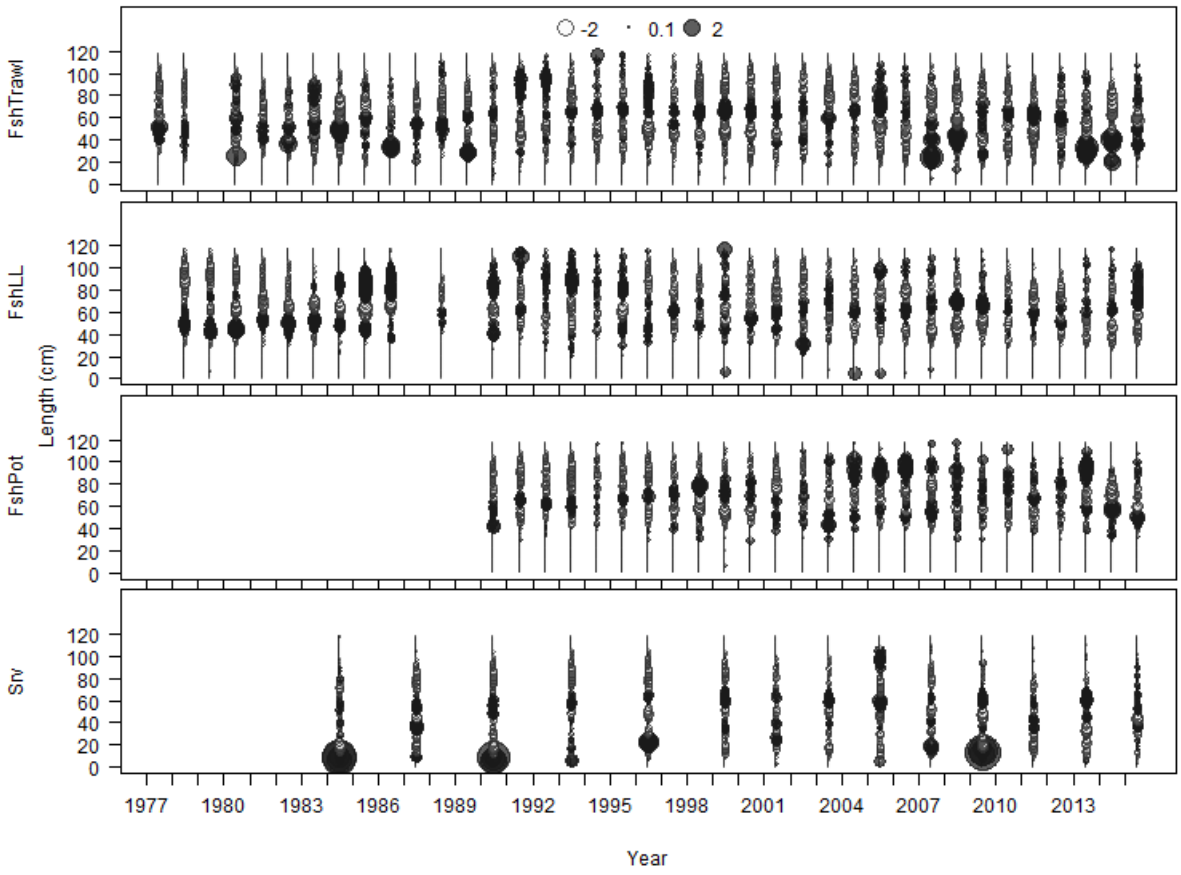

Figure 17. Model 16.6 Pearson residuals for fit to length composition data for the four components.

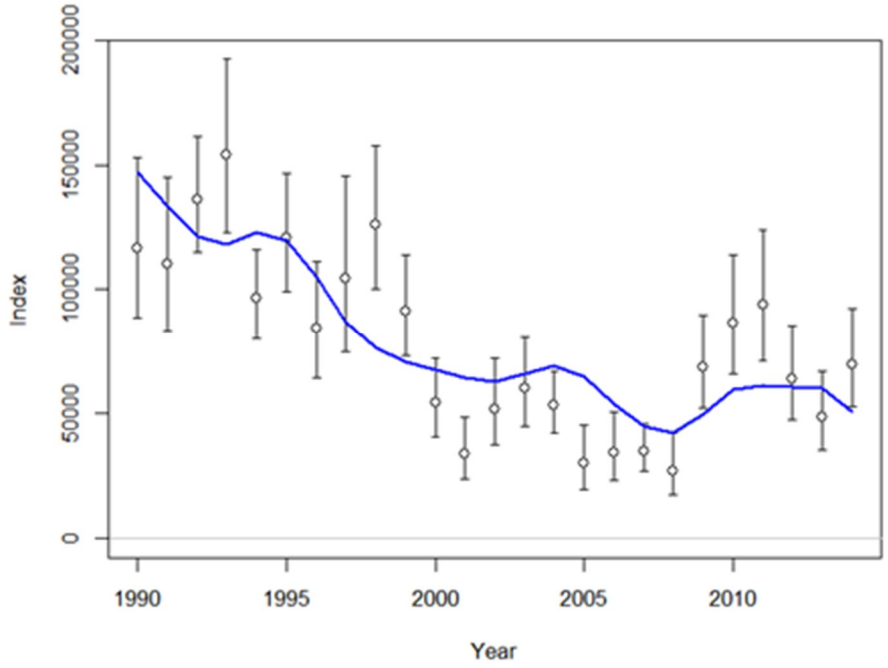

Figure 18. Sablefish longline RPN index in numbers of fish with Model 16.6.0 estimate (blue line) .

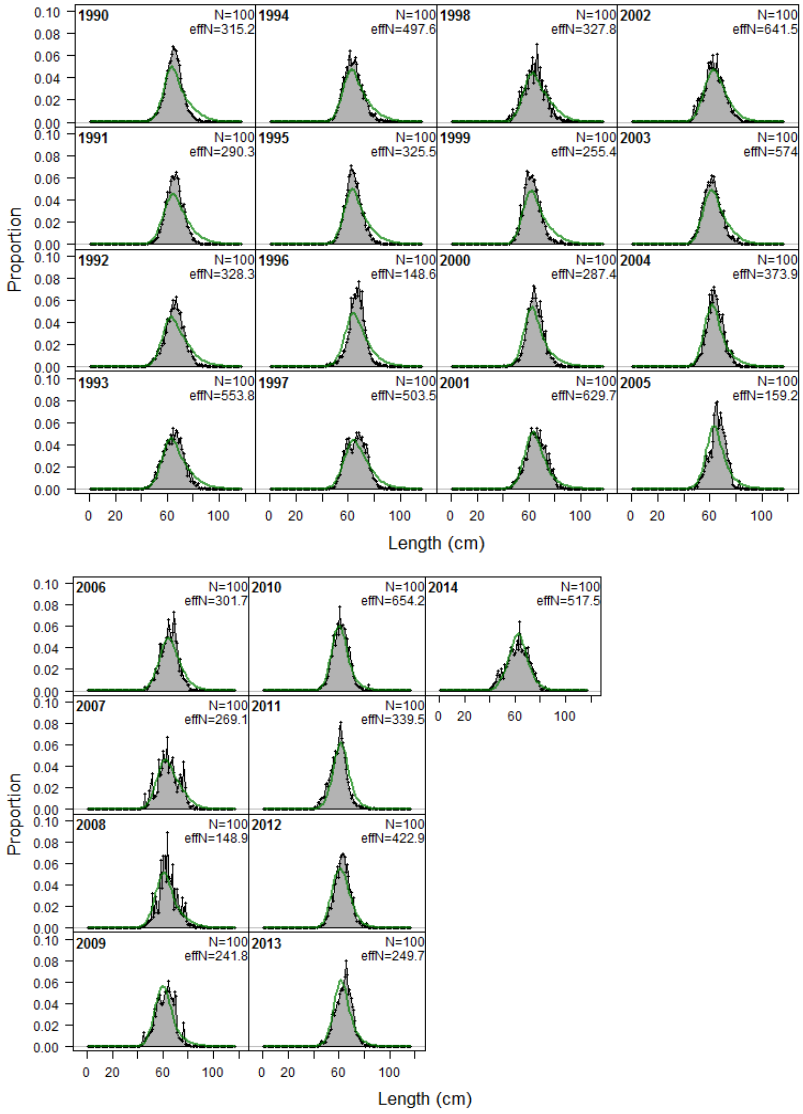

Figure 19. Pacific cod length composition data from the Sablefish longline survey and Model 16.6.0 estimates (green lines).

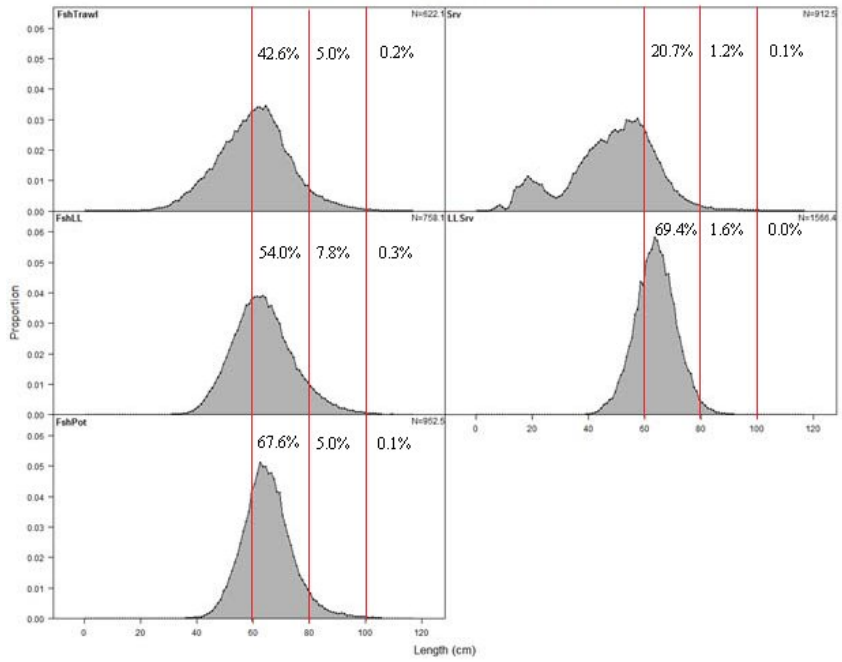

Figure 20. Pacific cod length composition data aggregated for all years. Number within the red boxes are the percentage of the overall length data for each type within the length bounds.

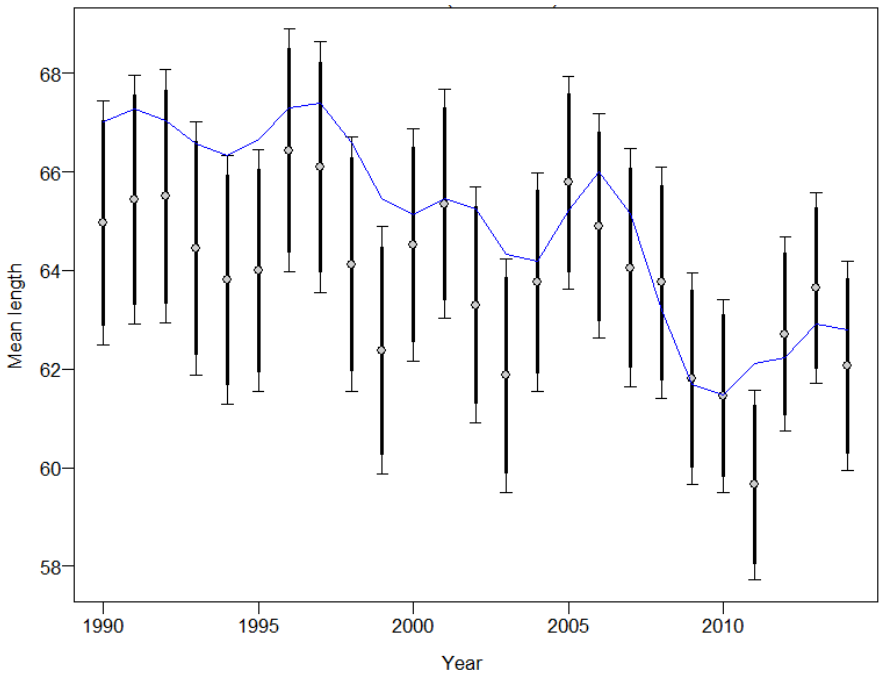

Figure 21. Pacific cod mean length from the sablefish longline survey and Model 16.6.0 estimates (blue line).

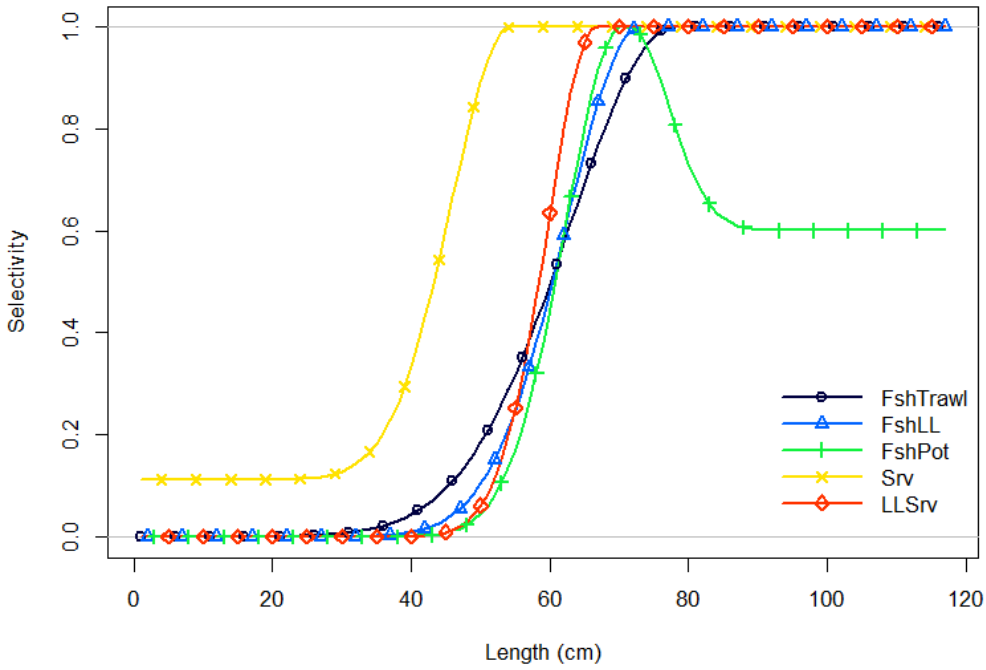

Figure 22. Length-based selectivity for Model 16.6.0 for all length composition components.

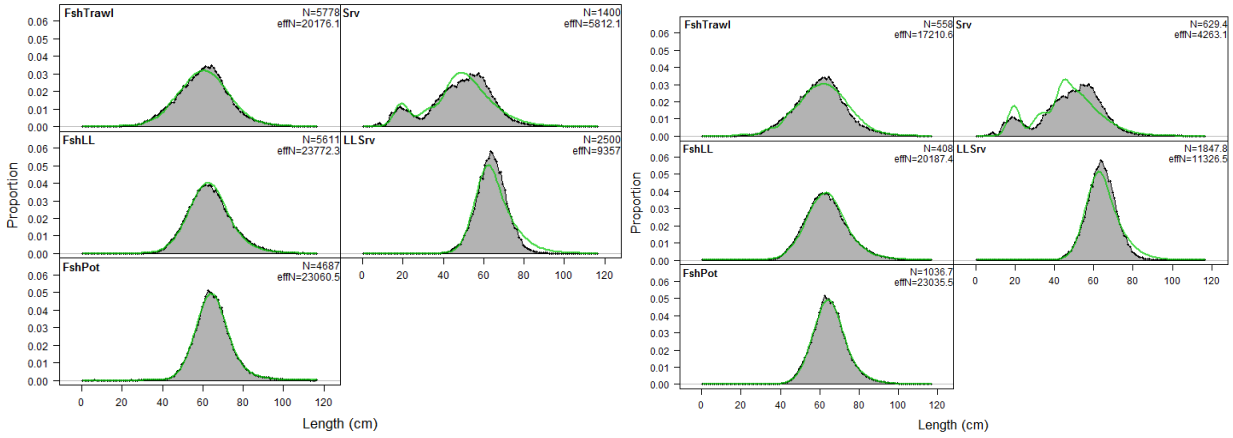

Figure 23. Overall estimate (green line) to all length composition data combined for each gear in Model 16.6.0 (left) and Model 16.6.1 (right).

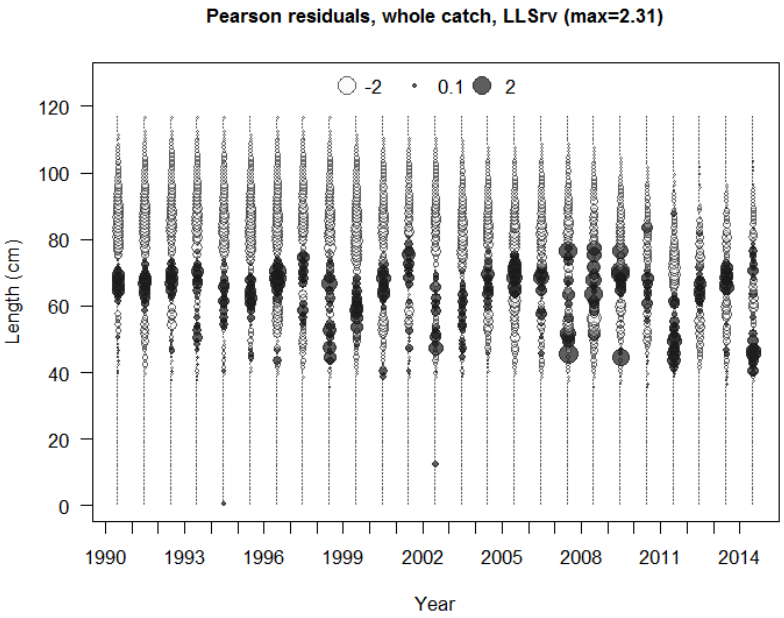

Figure 24. Model 16.6.0 Pearson residuals for fit to longline survey length composition.

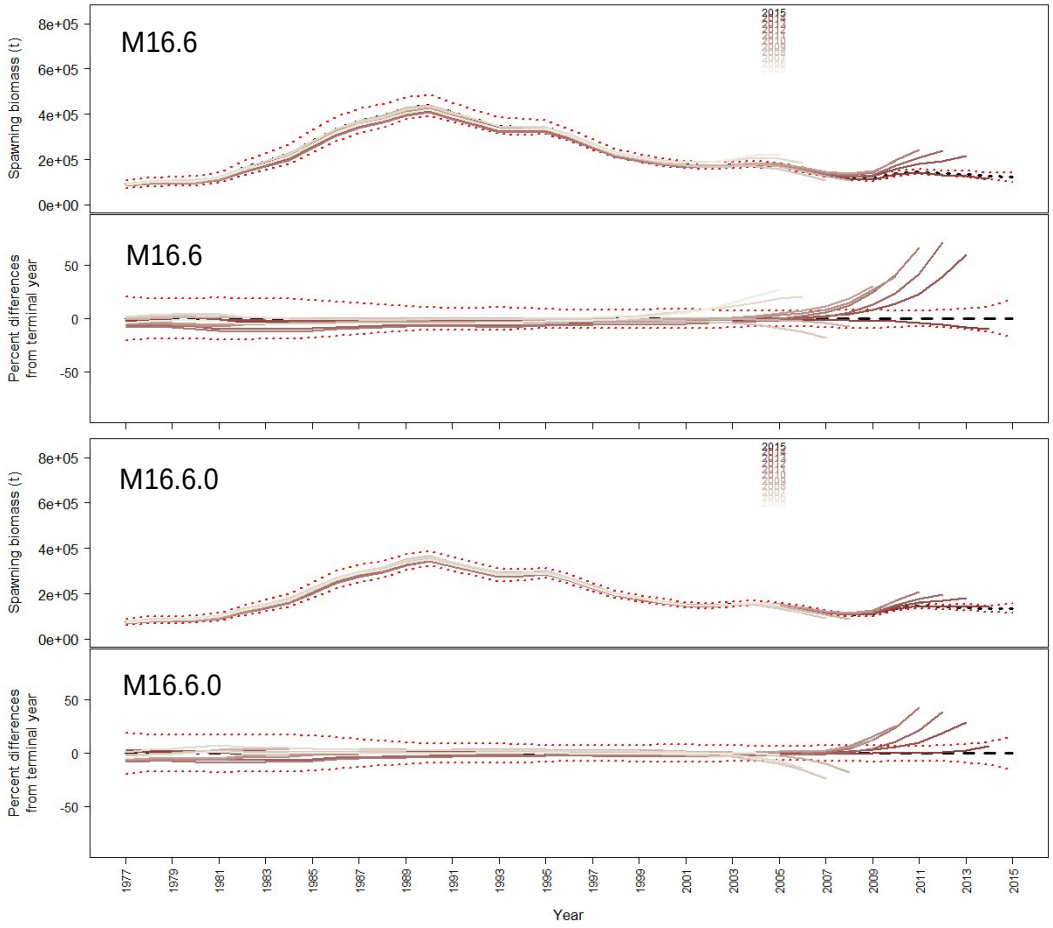

Figure 25. Model 16.6 (top) and Model 16.6.0 (bottom) retrospective of spawning biomass in tons and percentage differences from the full model estimates for each year.

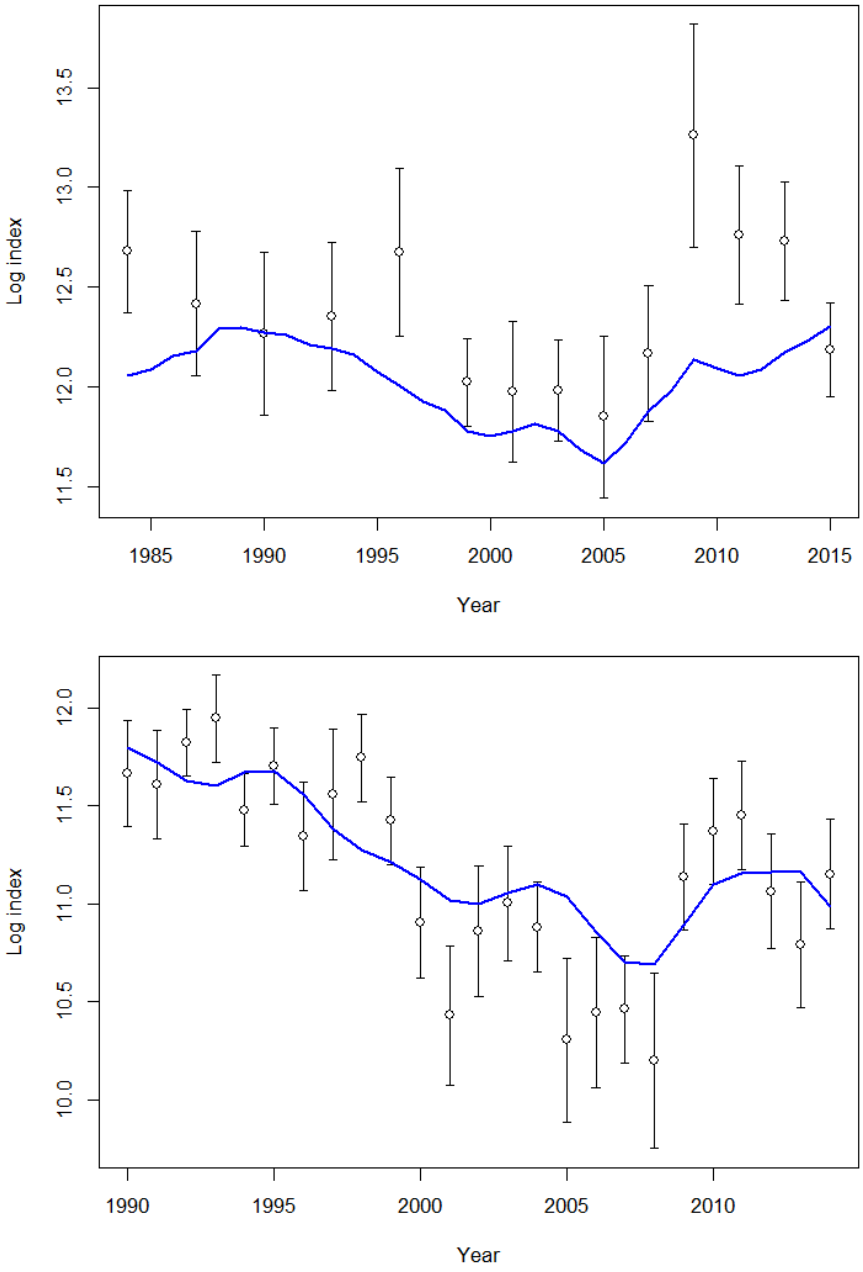

Figure 26. Model 16.6.1 fit to the bottom trawl survey (top) and sablefish longline survey (bottom).

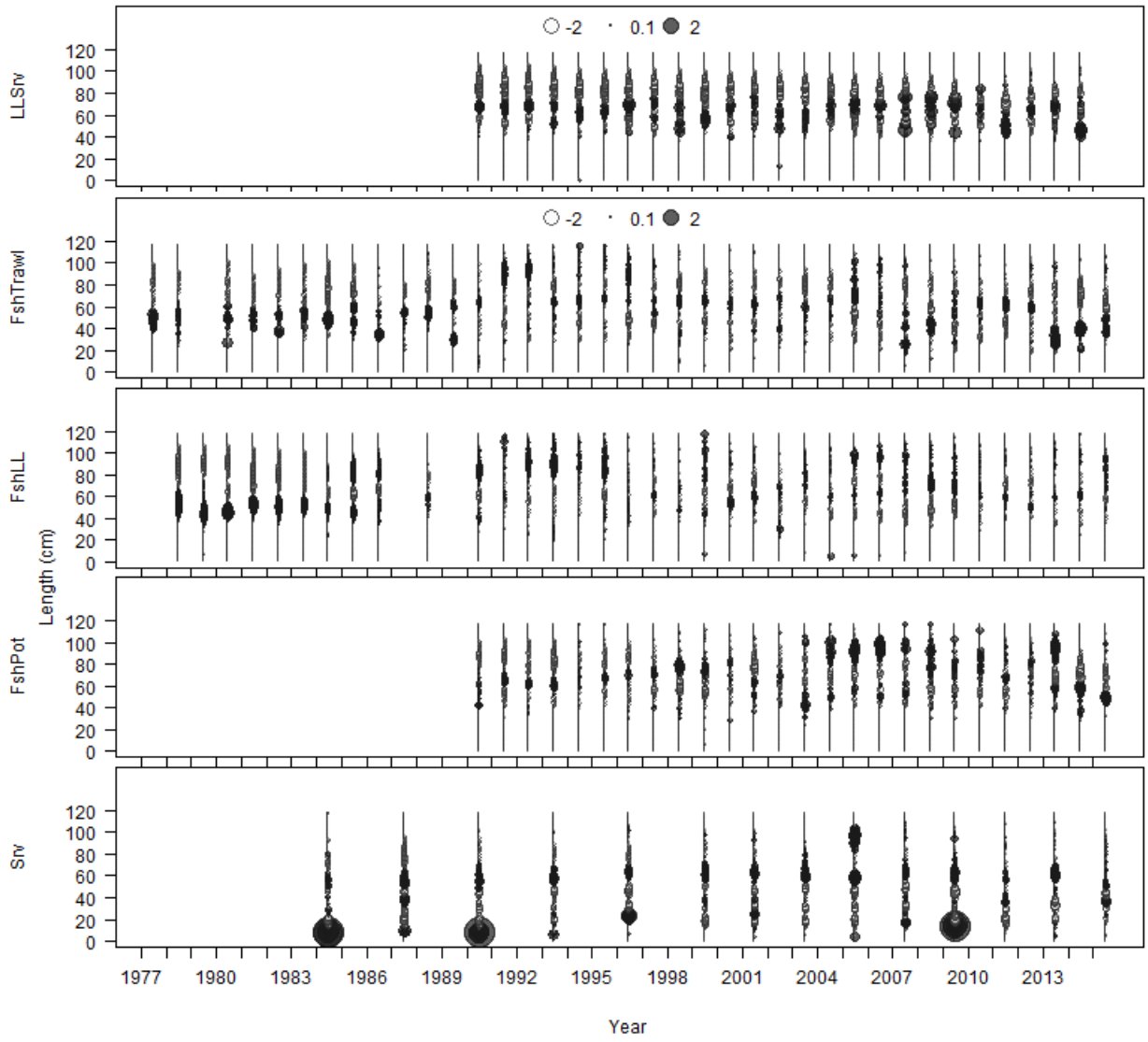

Figure 27. Pearson residuals for Model 16.6.1 length composition data fits.

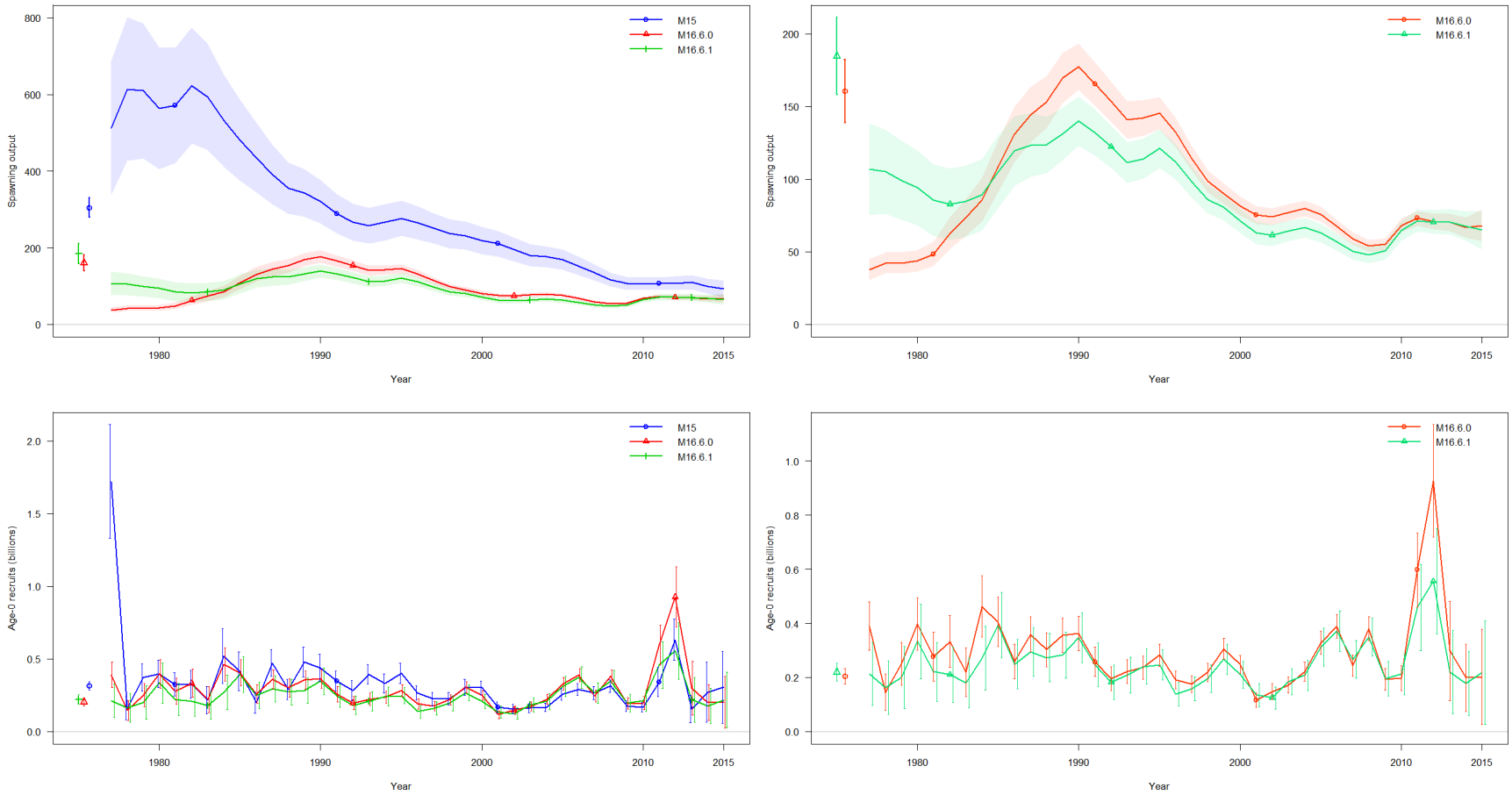

Figure 28. Female spawning biomass (top) and age-0 Recruits (bottom) from 2015 Model (blue), Model 16.6.0 (red) and 16.6.1 (green).

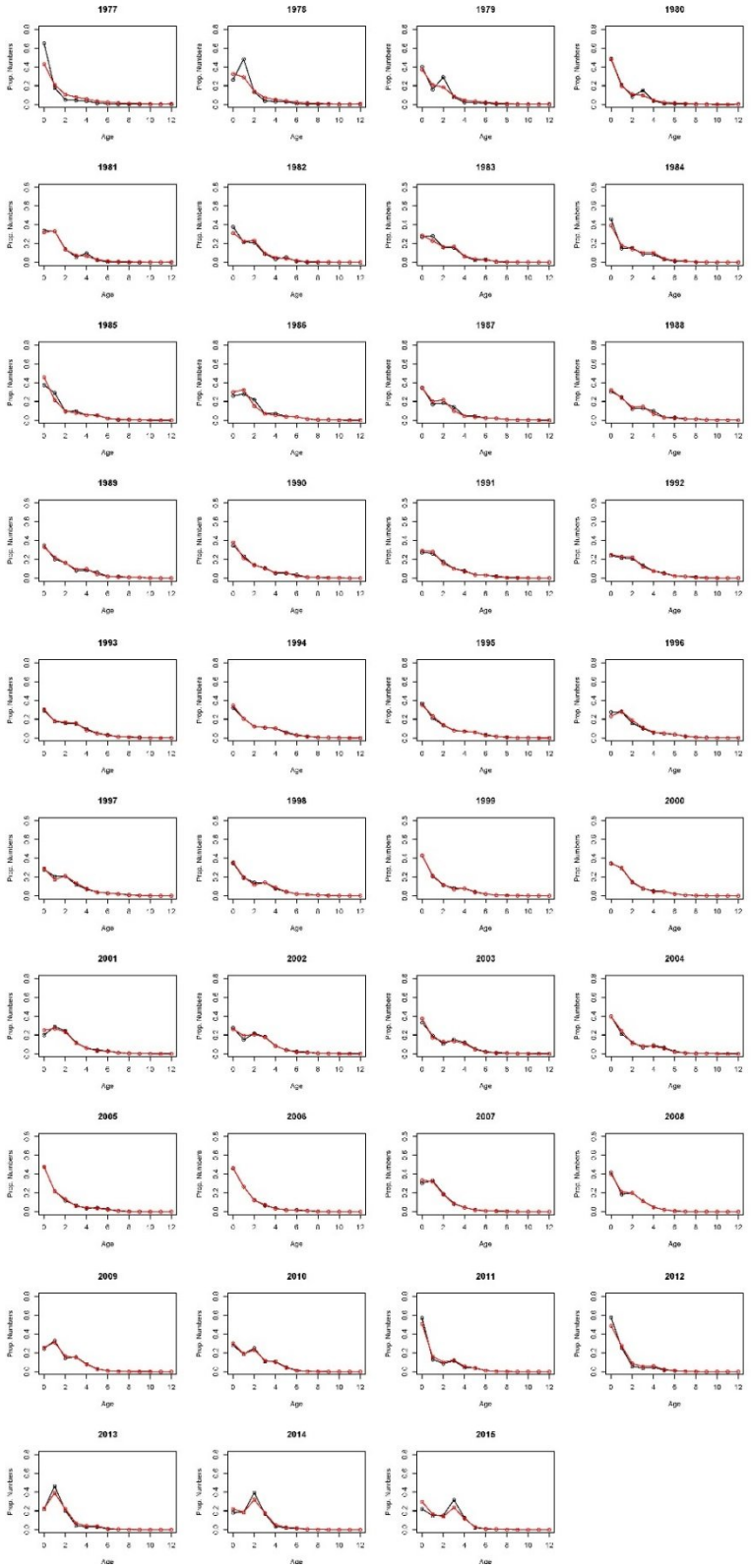

Figure 29. Predicted population proportion of fish by age (numbers) for Model 16.6.0 (black) and Model 16.6.1 with Francis tuned composition sample sizes (red).

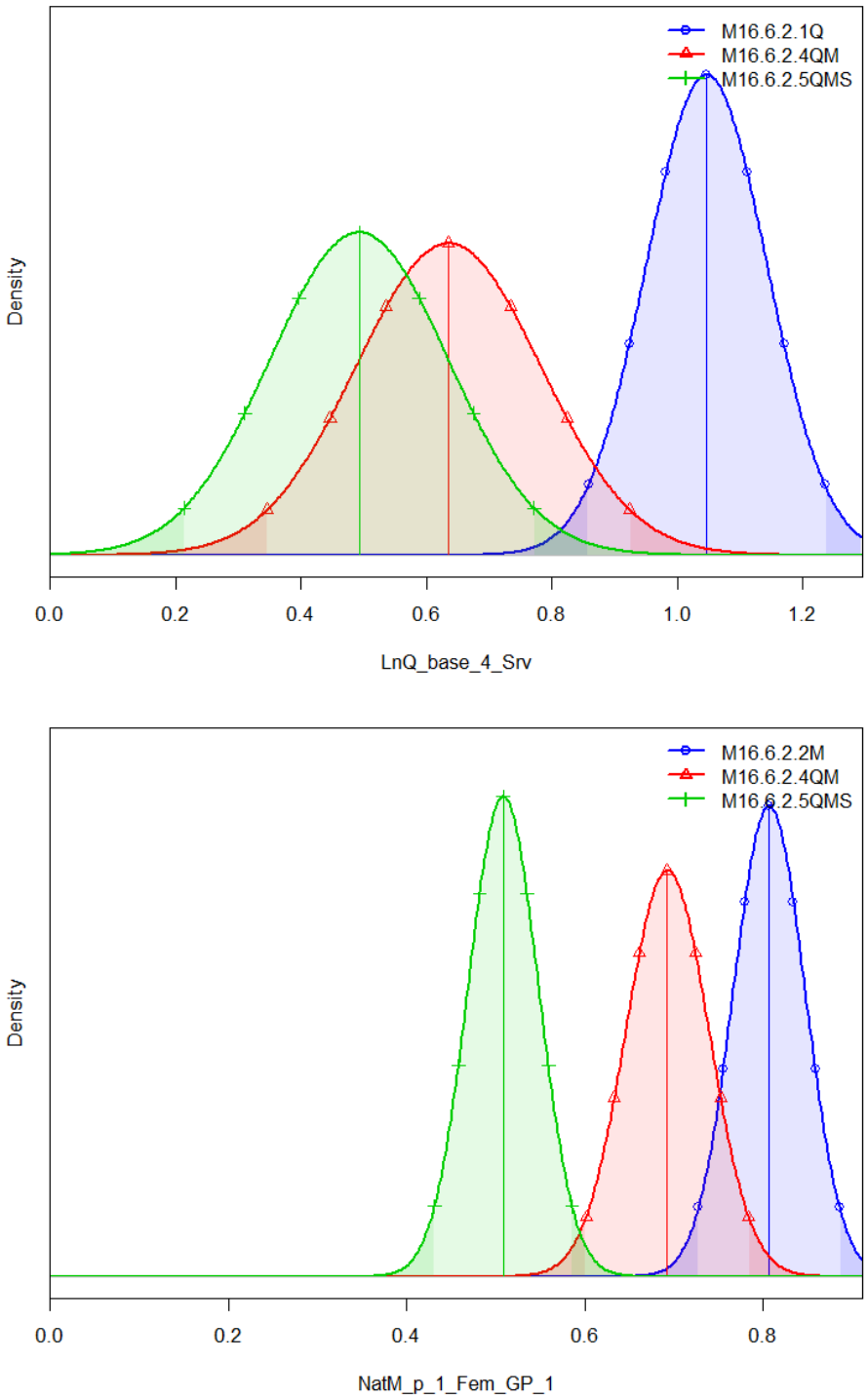

Figure 30. Estimates for survey catchability (Log(Q)) from models M16.2.1Q, M16.2.4QM, M16.2.5QMS (top) and estimates for natural mortality from models M16.2.2M, M16.2.4QM, M16.2.5QMS (bottom). Q was set at 1.0 in Model 16.6.1 and the Jensen (1996) estimate for GOA Pacific cod natural mortality used in Model 16.6.1 was 0.38.

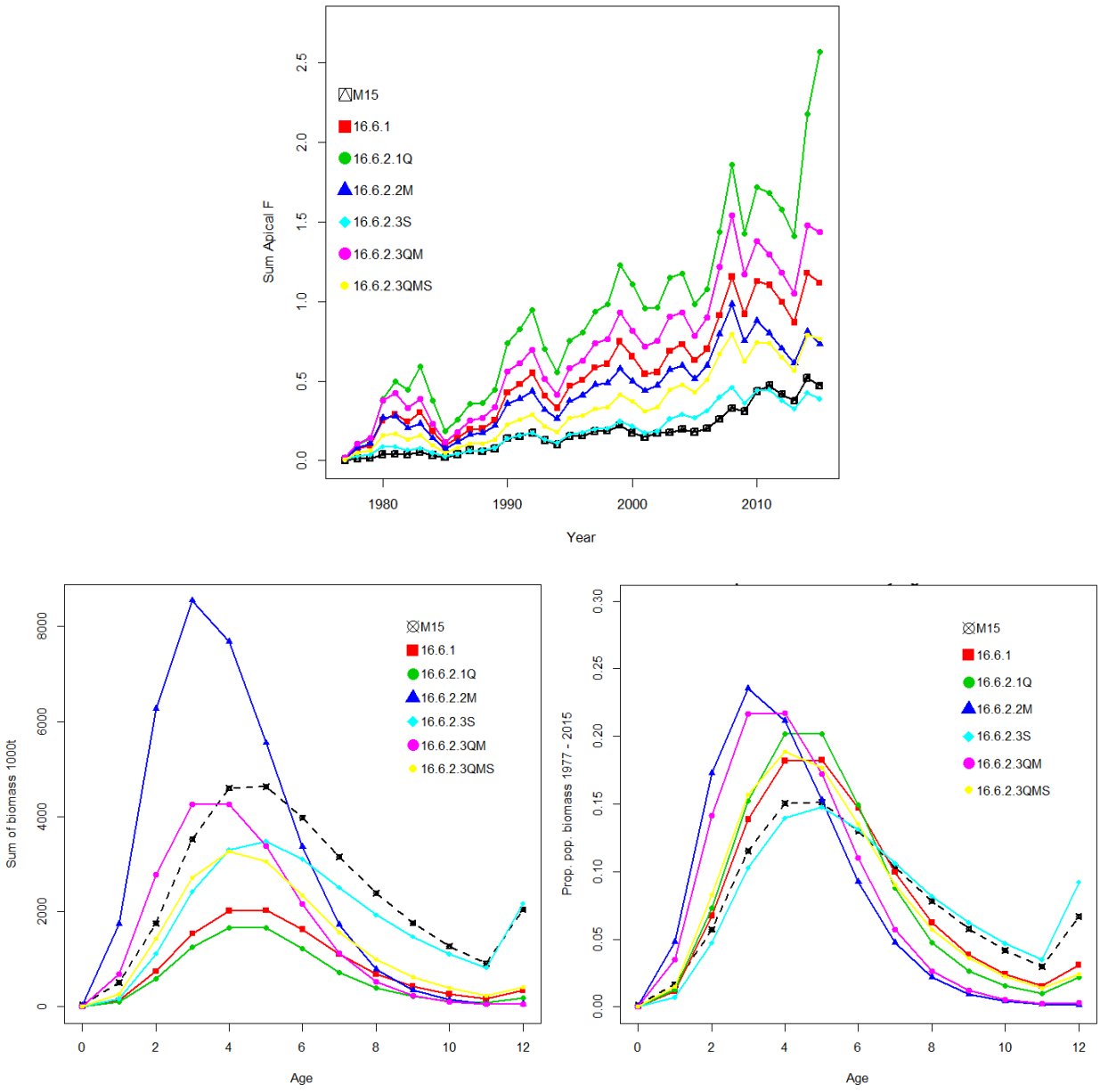

Figure 31. Sum of the apical F for 1977-2015 (top), population biomass (left) and proportion of population biomass (right) at each age summed for all years 1977-2015 for the 2015 Model (M15) and models 16.6.1, 16.6.2.1Q, 16.6.2.2M, 16.6.2.3S, 16.6.2.4QM, and 16.6.2.5_QMS demonstrating model effects on fitting catchability, natural mortality, dome-shaped selectivity, and mixtures of each.

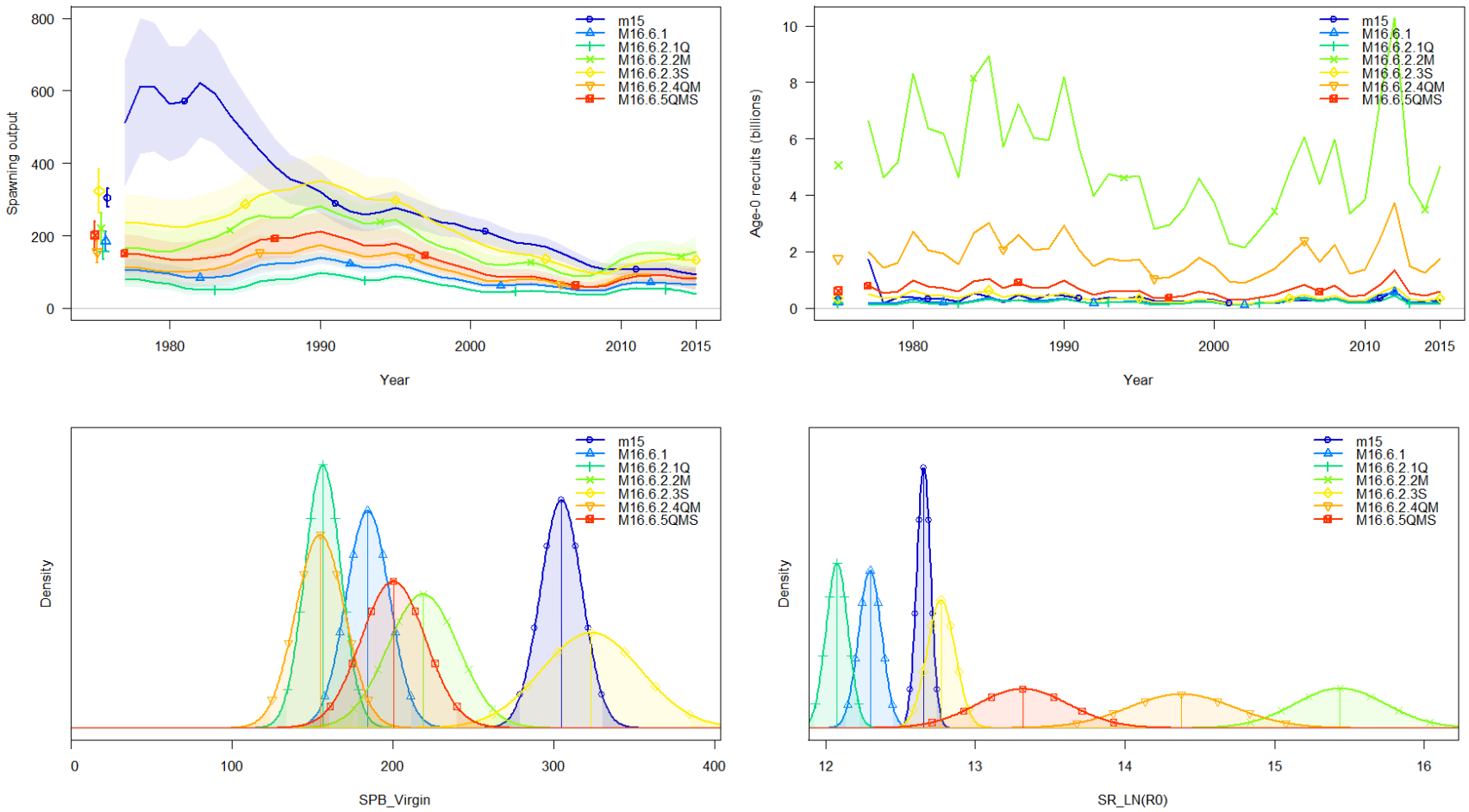

Figure 32. Female spawning biomass (1000 t) (top left), age-0 recruits (billions) (top right), model estimates of female virgin spawning biomass (1000 t; bottom left), and log(R_0) (bottom right) for the 2015 Model and models 16.6.1, 16.6.2.1Q, 16.6.2.2M, 16.6. 2.3S, 16.6.2.4QM, and 16.6.2.5_QMS demonstrating model effects on fitting catchability, natural mortality, dome-shaped selectivity, and mixtures of each.

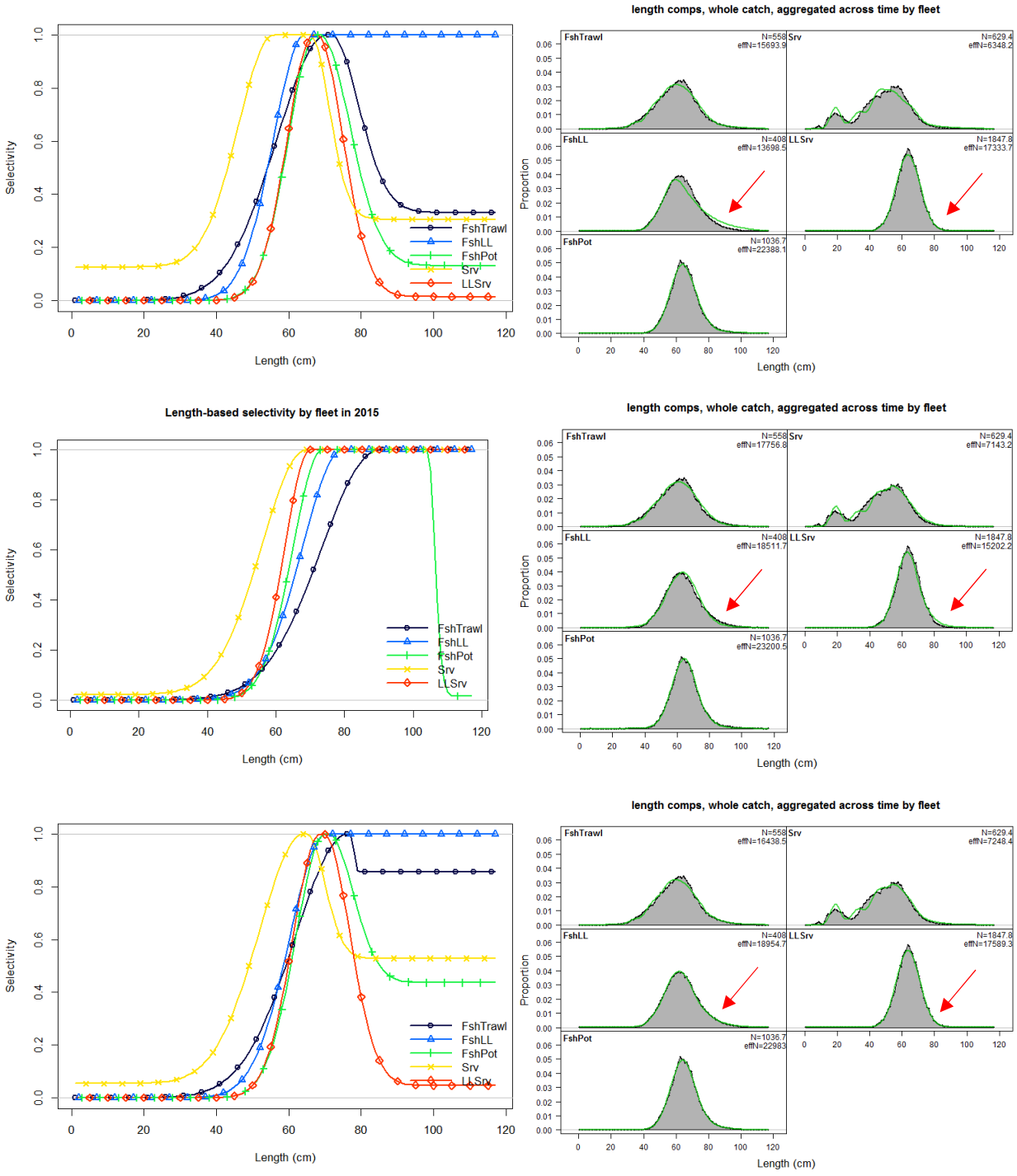

Figure 33. Selectivity (left) for Model 16.6.2.3S (top), Model 16.6.2.4QM (middle), and Model 16.6.2.5QMS (bottom) with overall estimates of length composition data (right). Red arrow highlights estimates of fish >75cm most impacted by dome-shaped selectivity.

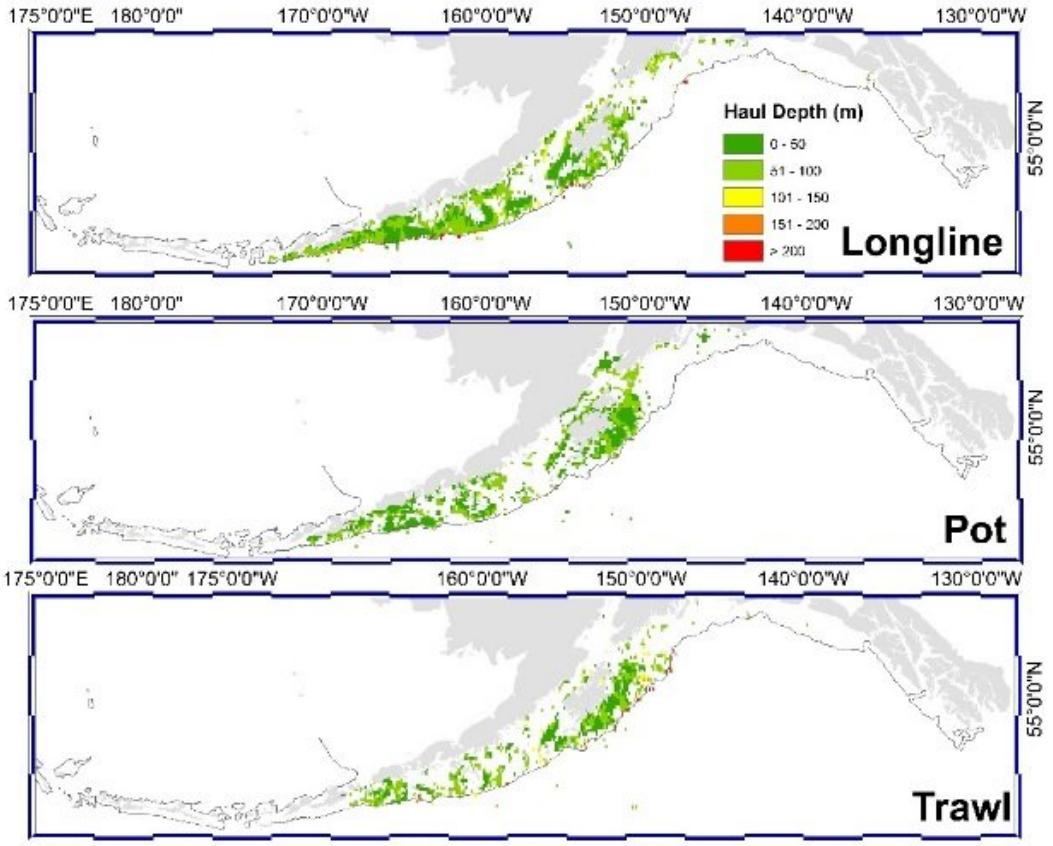

Figure 34. Distribution of all observed Pacific cod fishing activity by gear type for 1998-2016, color denotes depth.

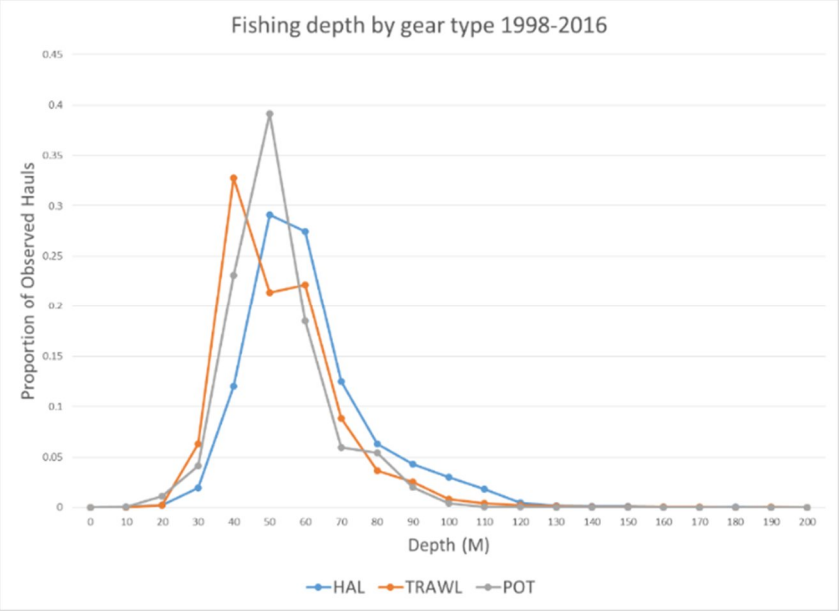

Figure 35. Proportion of observed hauls by depth in the GOA for all observed Pacific cod fishing activity by gear type for 1998-2016.

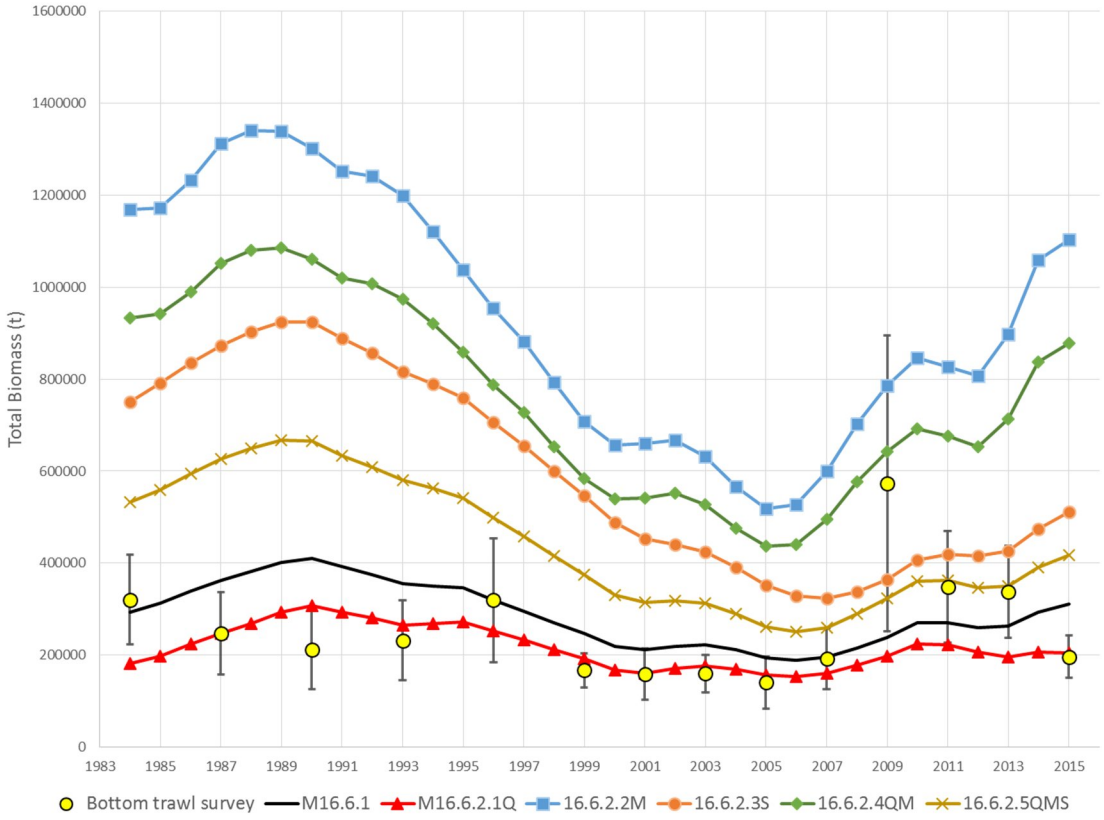

Figure 36.Total biomass estimates Bottom trawl survey, Model 16.6.1 and 16.6.2 series models.

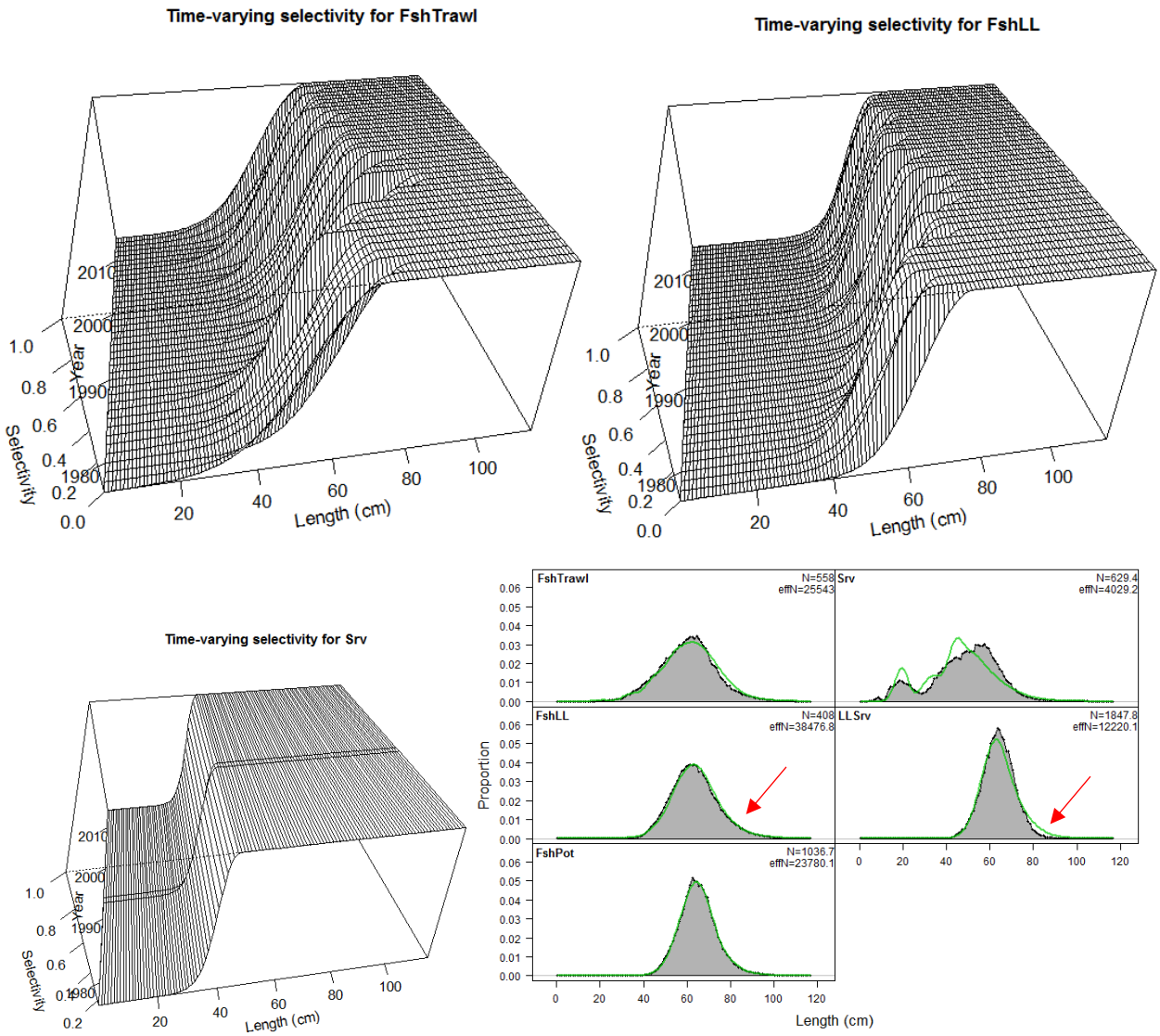

Figure 37.Time varying selectivity curves fit in Model 16.6.3 and aggregated estimates of length composition data. Note that the y-axis for the bottom trawl survey (Srv) graph does not start at 0.

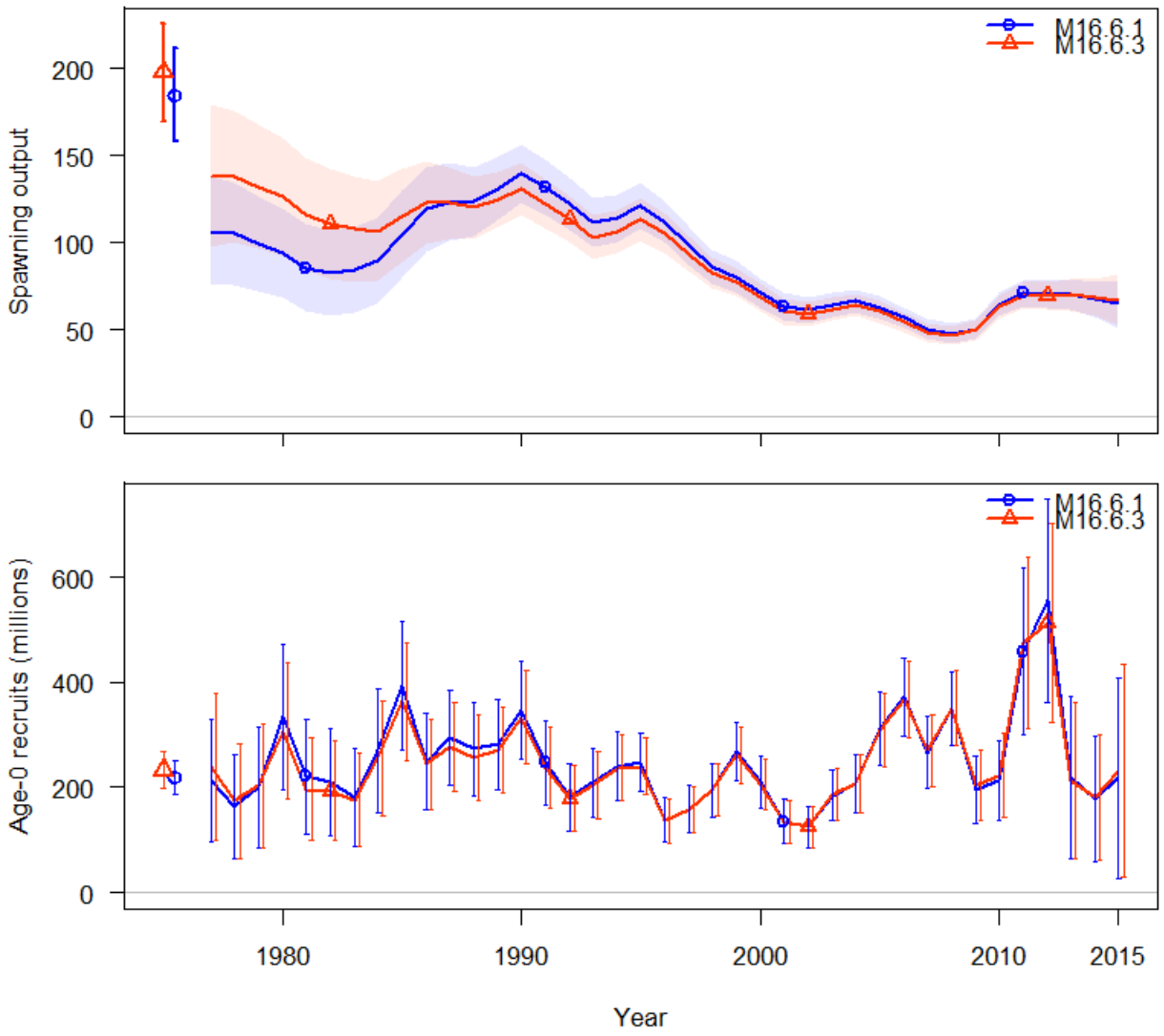

Figure 38. Female spawning biomass (1000 t; top) and age-0 recruits (bottom) for in Model 16.6.1 and Model 16.6.3.

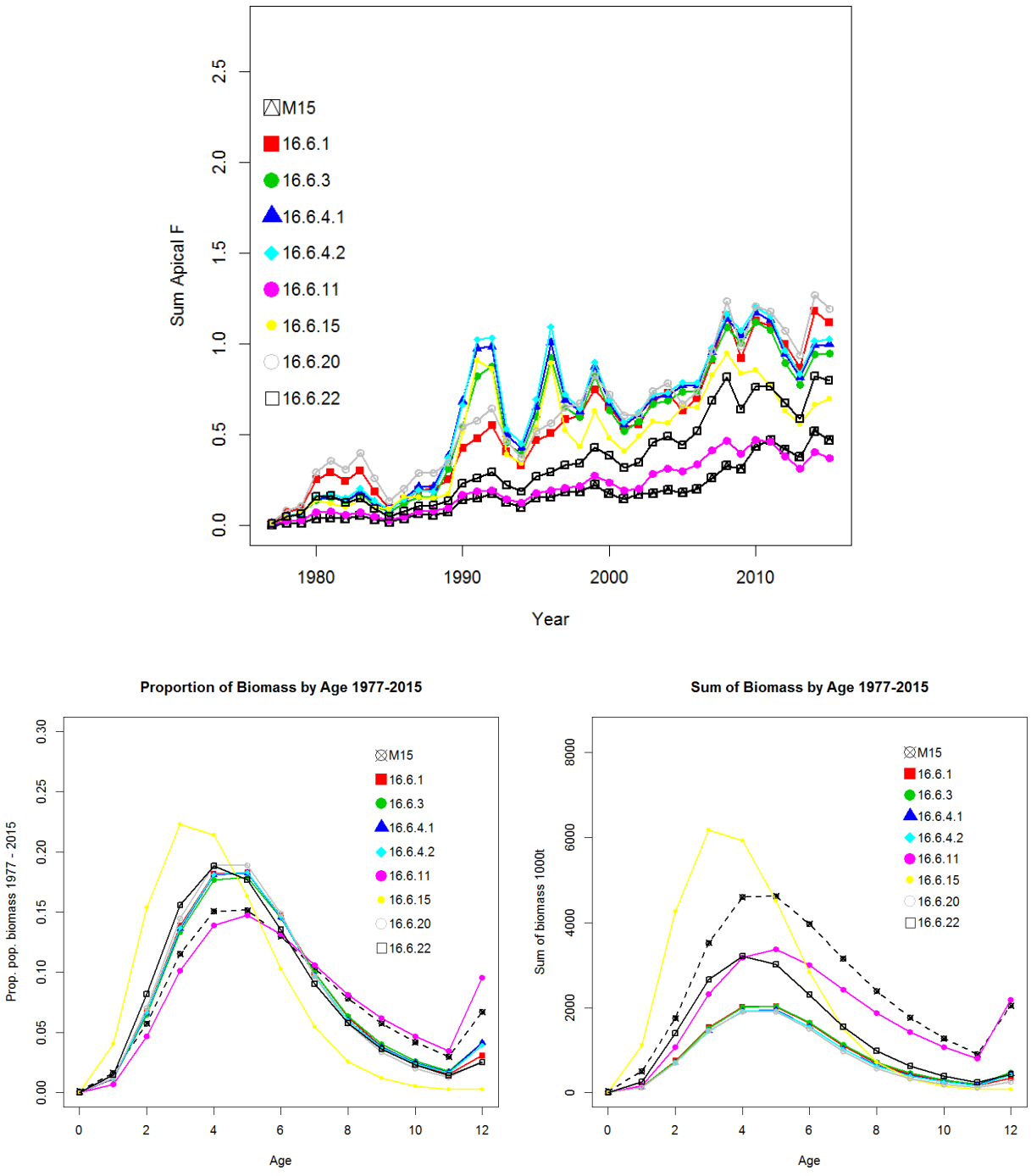

Figure 39. Sum of the apical F for 1977-2015 (top), population biomass (left) and proportion of population biomass (right) at each age summed for all years 1977-2015 for the 2015 Model (M15) and models 16.6.1, 16.6.2.3, 16.6.4.1, 16.6.4.2, 16.6.11, 16.6.15, 16.6.20, and 16.6.22

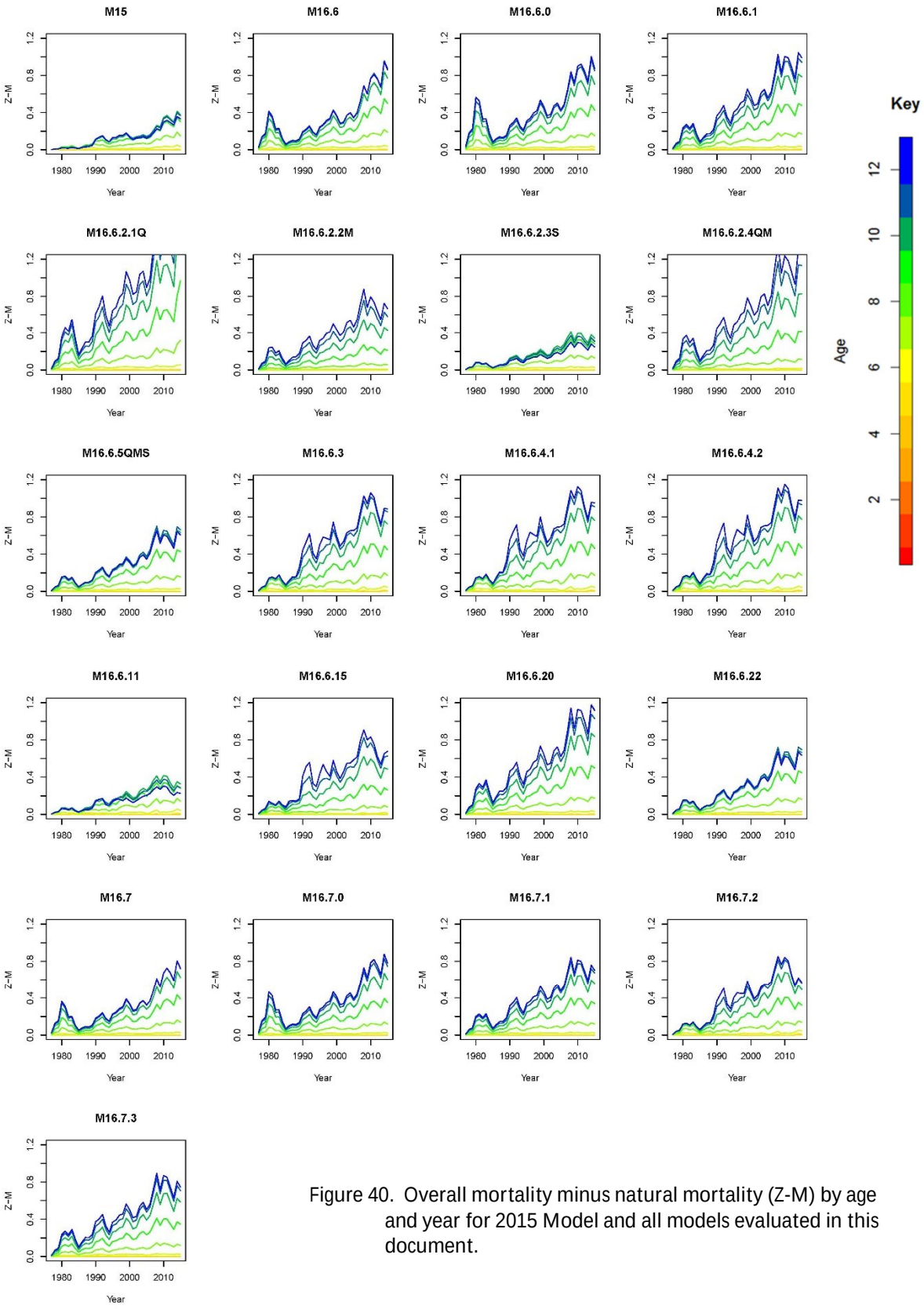

Figure 40. Overall mortality minus natural mortality (Z-M) by age and year for 2015 Model and all models evaluated in this document.

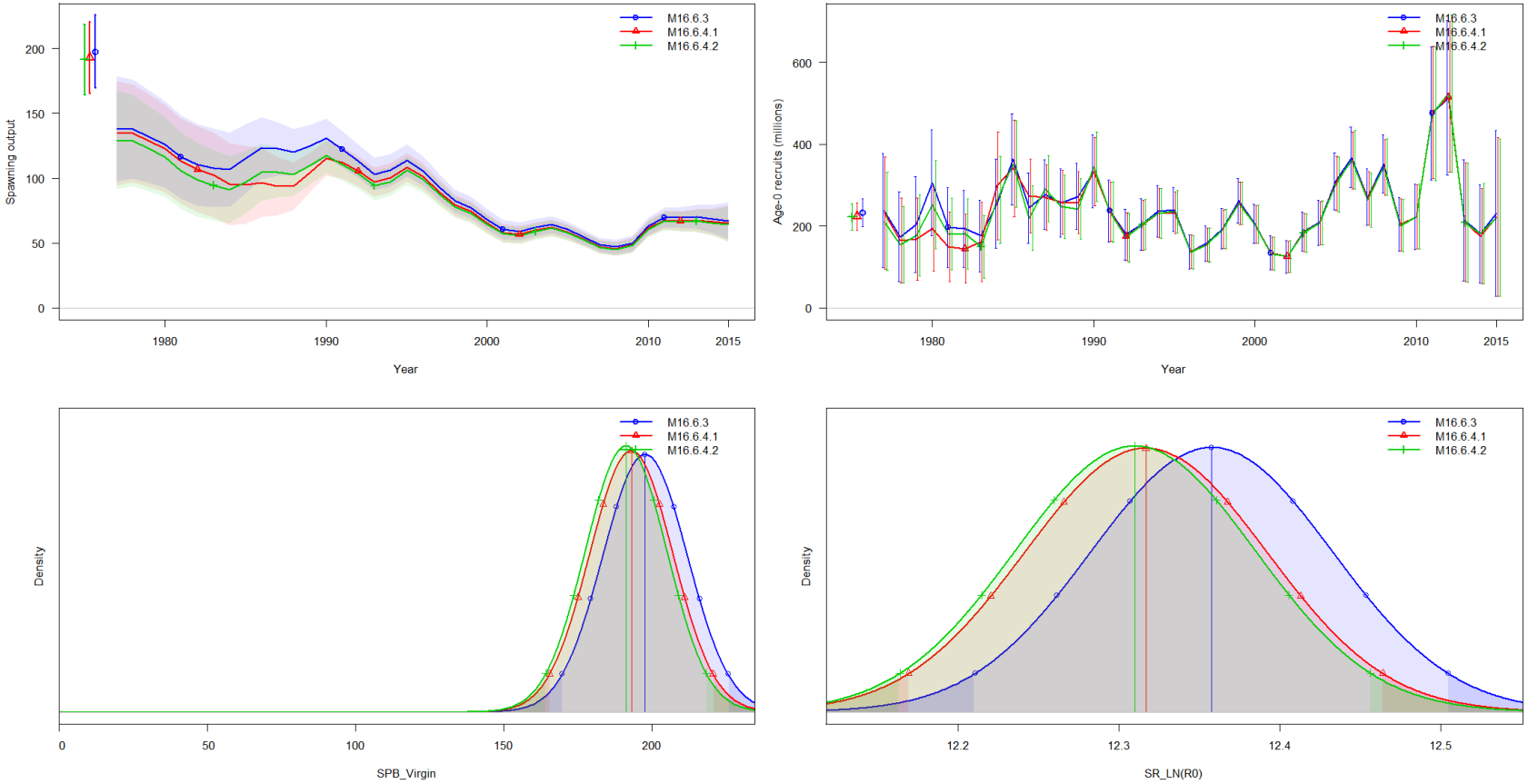

Figure 41. Female spawning biomass (1000 t) (top left), age-0 recruits (billions) (top right), model estimates of female virgin spawning biomass (1000 t; bottom left), and log(R_0) (bottom right) for models 16.6.3, 16.6.4.1, and 16.6. 4.2.

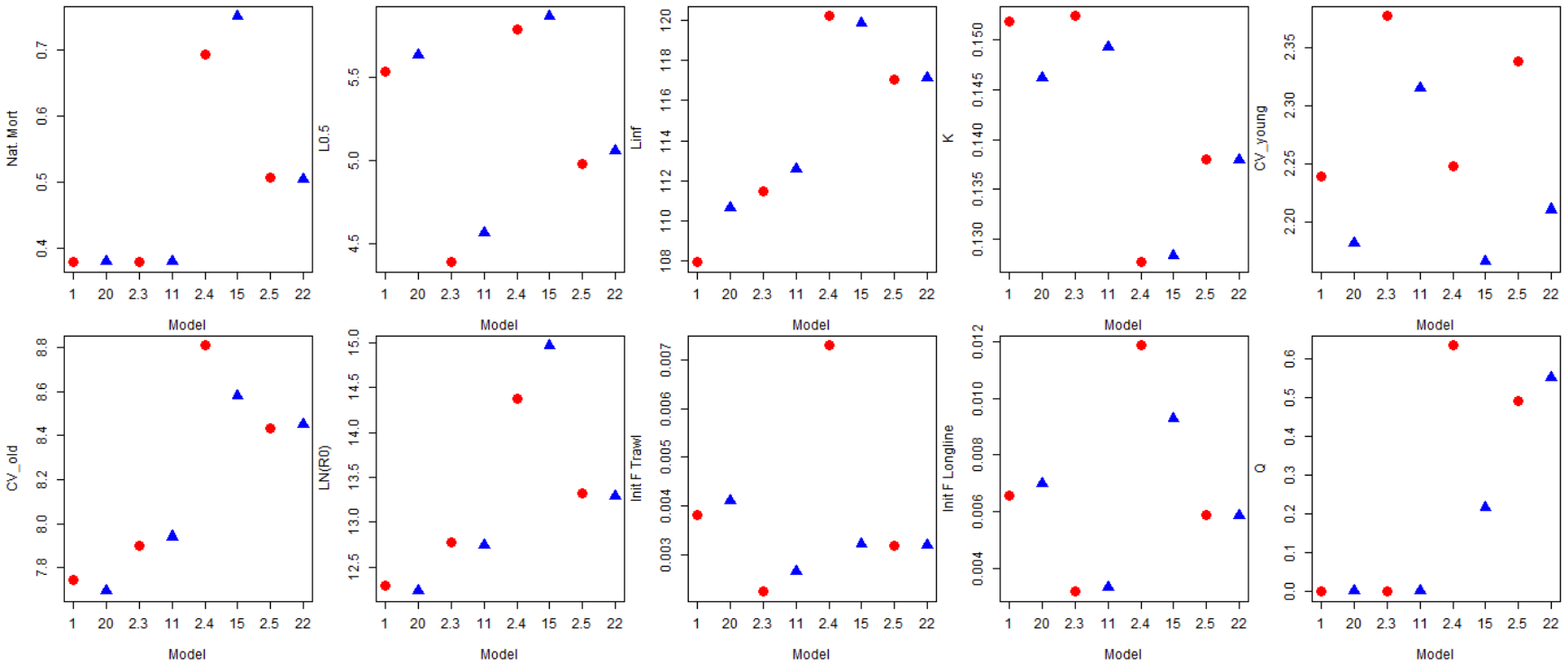

Figure 42. Parameters for paired Models 16.6.xx. Red circles are from the initial models and blue triangles are from models without the 1984 and 1987 bottom trawl survey data. Note that Q in this figure should read LN(Q) .

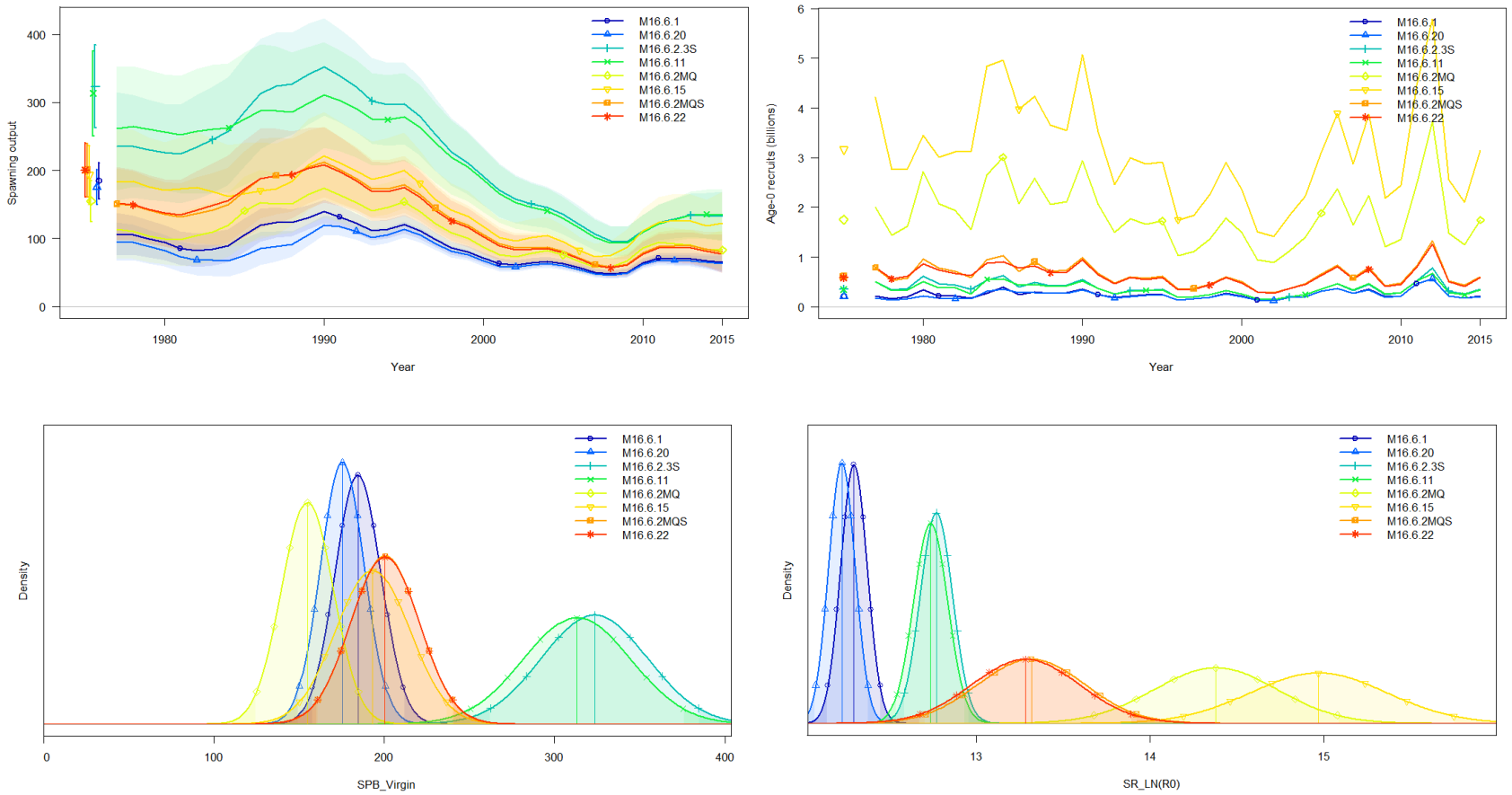

Figure 43. Female spawning biomass (1000 t) (top left), age-0 recruits (billions) (top right), model estimates of the female virgin spawning biomass (1000 t; bottom left), and log(R_0) (bottom right) for paired Models 16.6.1 and 16.6.20,16.6.2.3S and 16.6.11, 16.6.2.4MQ, and 16.6.15, and 16.6.2.5MQS and 16.6.22.

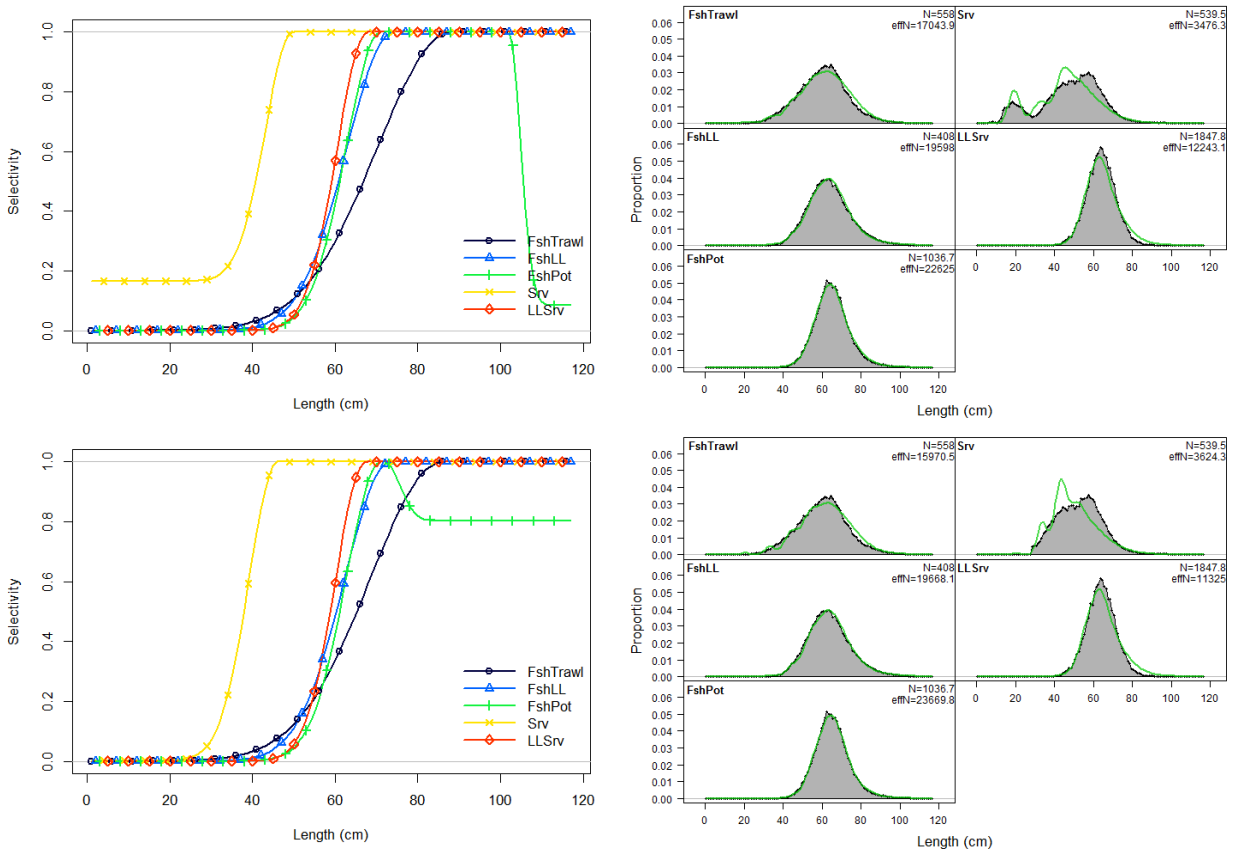

Figure 44. Length-based selectivity (left) for Model 16.6.20 (top), Model 16.73 (bottom) with overall estimates of length composition data (right).

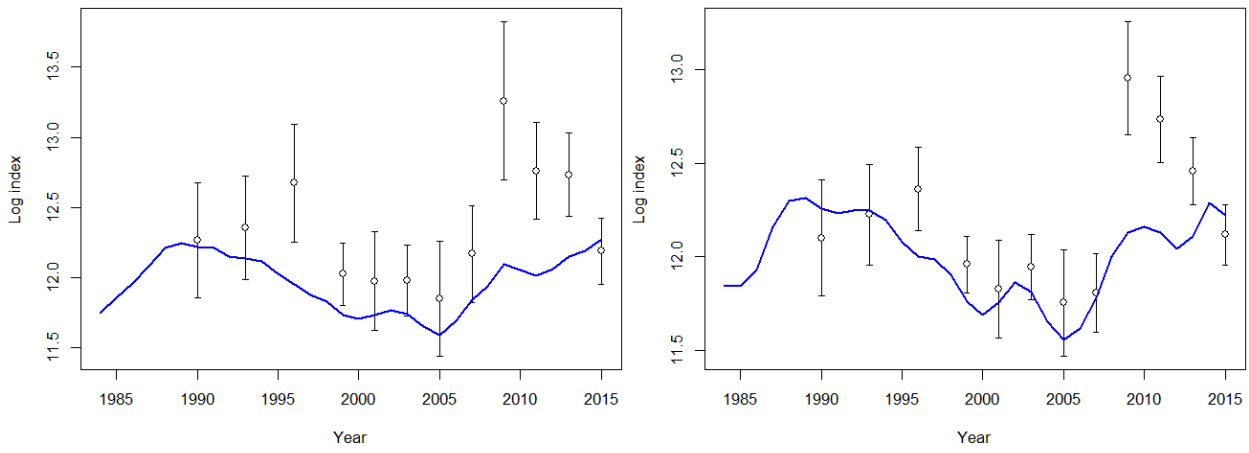

Figure 45. Model 16.6.20 (left) and Model 16.7.3 observed versus predicted (blue line) bottom trawl survey abundance index.

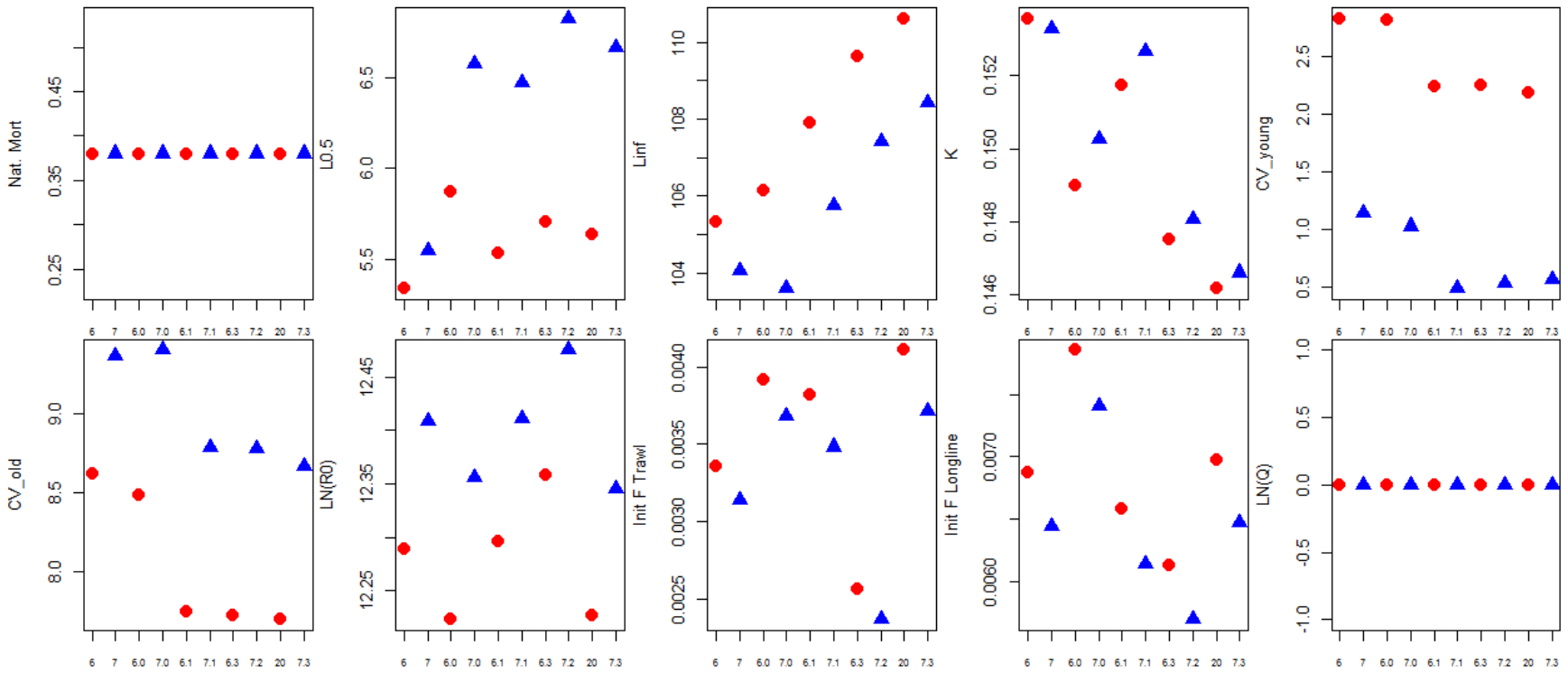

Figure 46. Parameters for paired Models 16.xx. Red circles are from the initial models and blue triangles are from models without the Age 1 (<27cm) data for the bottom trawl survey index, length composition and age composition data.

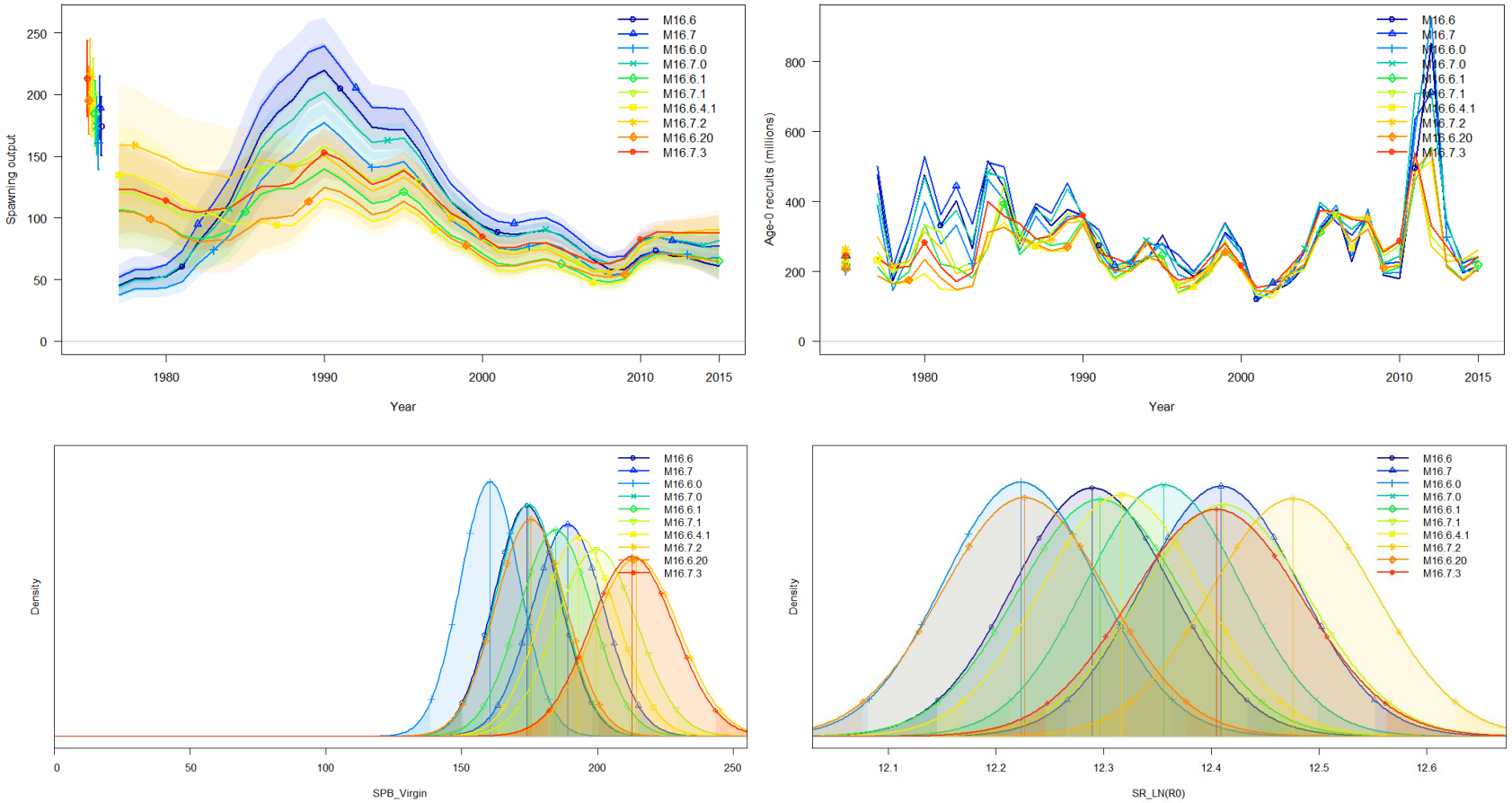

Figure 47. Female spawning biomass (1000 t) (top left), age-0 recruits (billions) (top right), model estimates of the female virgin spawning biomass (1000 t; bottom left), and log(R_0) (bottom right) for models 16.6,16.7, 16.6.0,16.7.0,16.6.1, 16.7.1, 16.6.4.1, 16.7.2, 16.6.20, and 16.7.3.

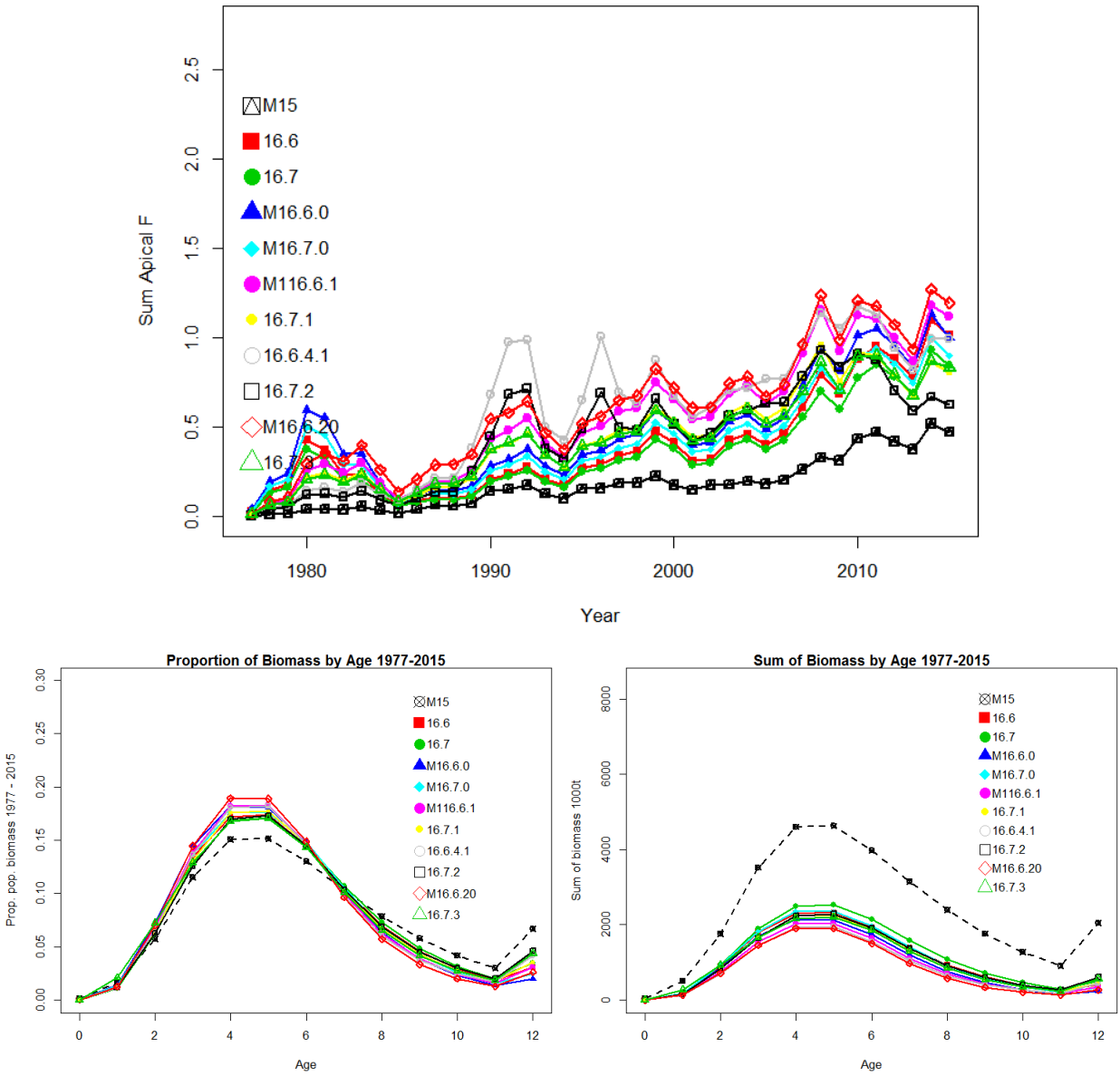

Figure 48. Sum of the apical F for 1977-2015 (top), population biomass (left) and proportion of population biomass (right) at each age summed for all years 1977-2015 for the 2015 Model (M15) and models 16.6, 16.7, 16.6.0, 16.7.0, 16.6.1, 16.7.1, 16.6.4.2, 16.7.2, 16.6.20,and 16.7.3.

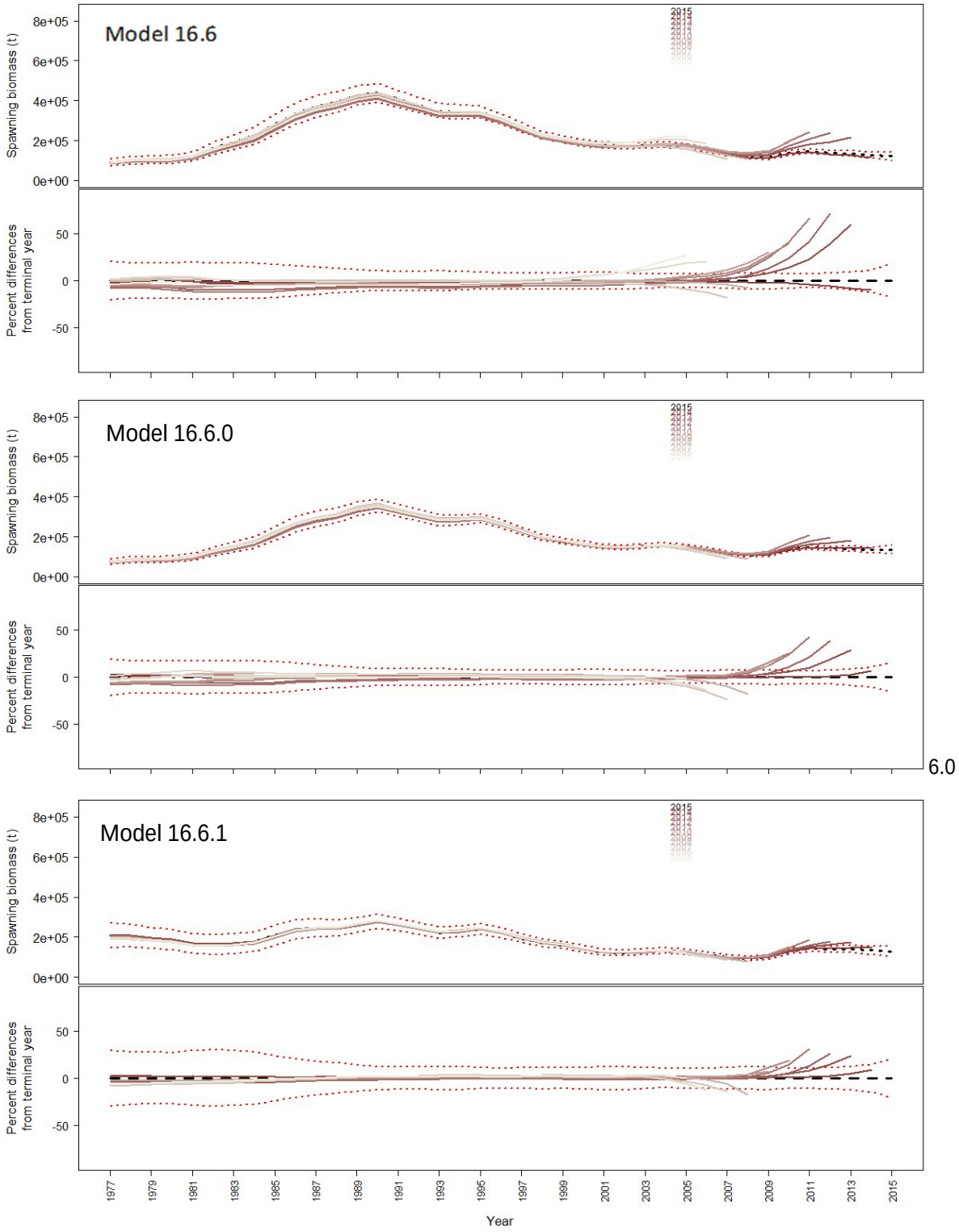

Figure 49. Retrospective analysis of female spawning biomass (top of each pair) and percentage of difference in female spawning biomass (bottom of each pair).

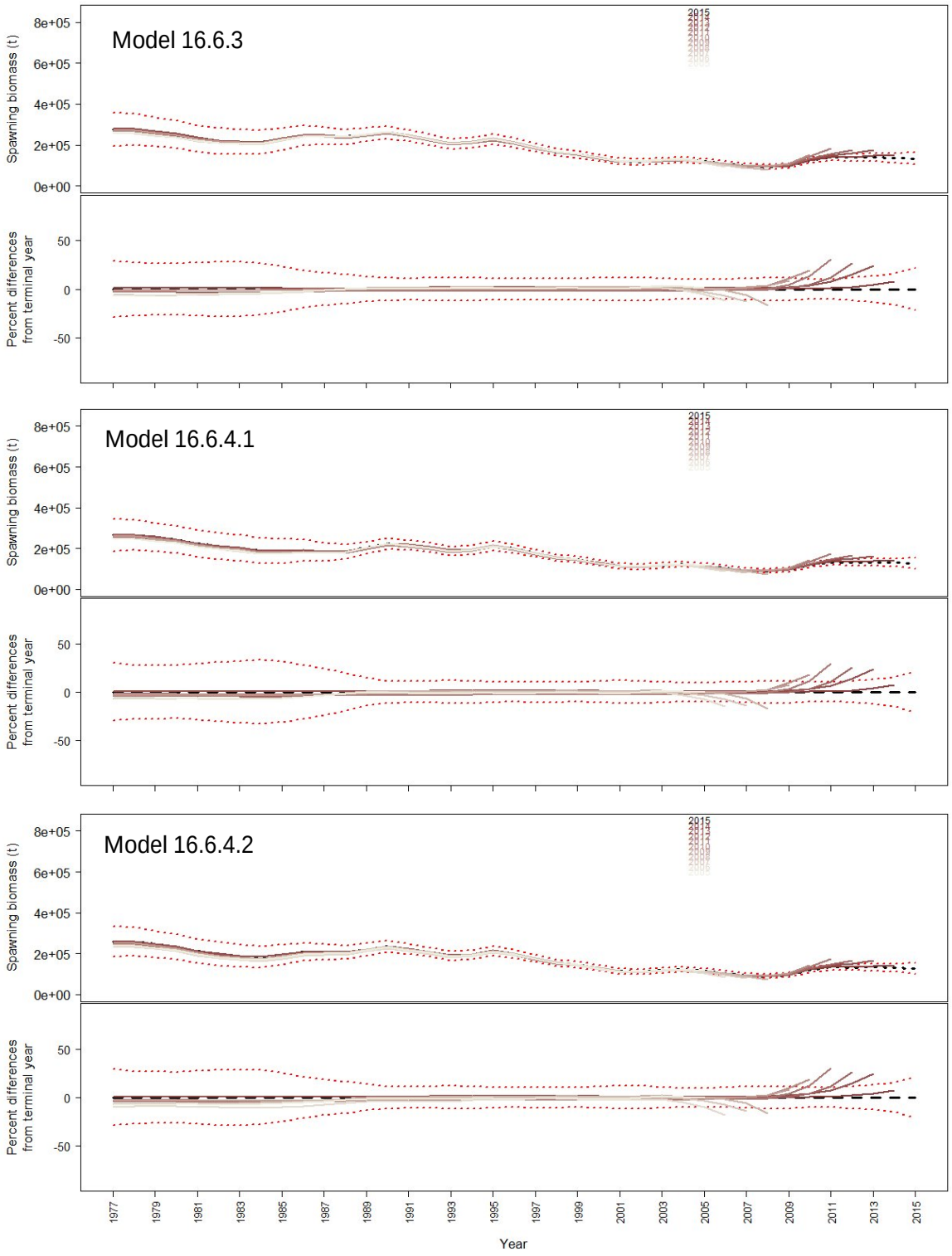

Figure 49 cont. Retrospective analysis of female spawning biomass (top of each pair) and percentage of difference in female spawning biomass (bottom of each pair).

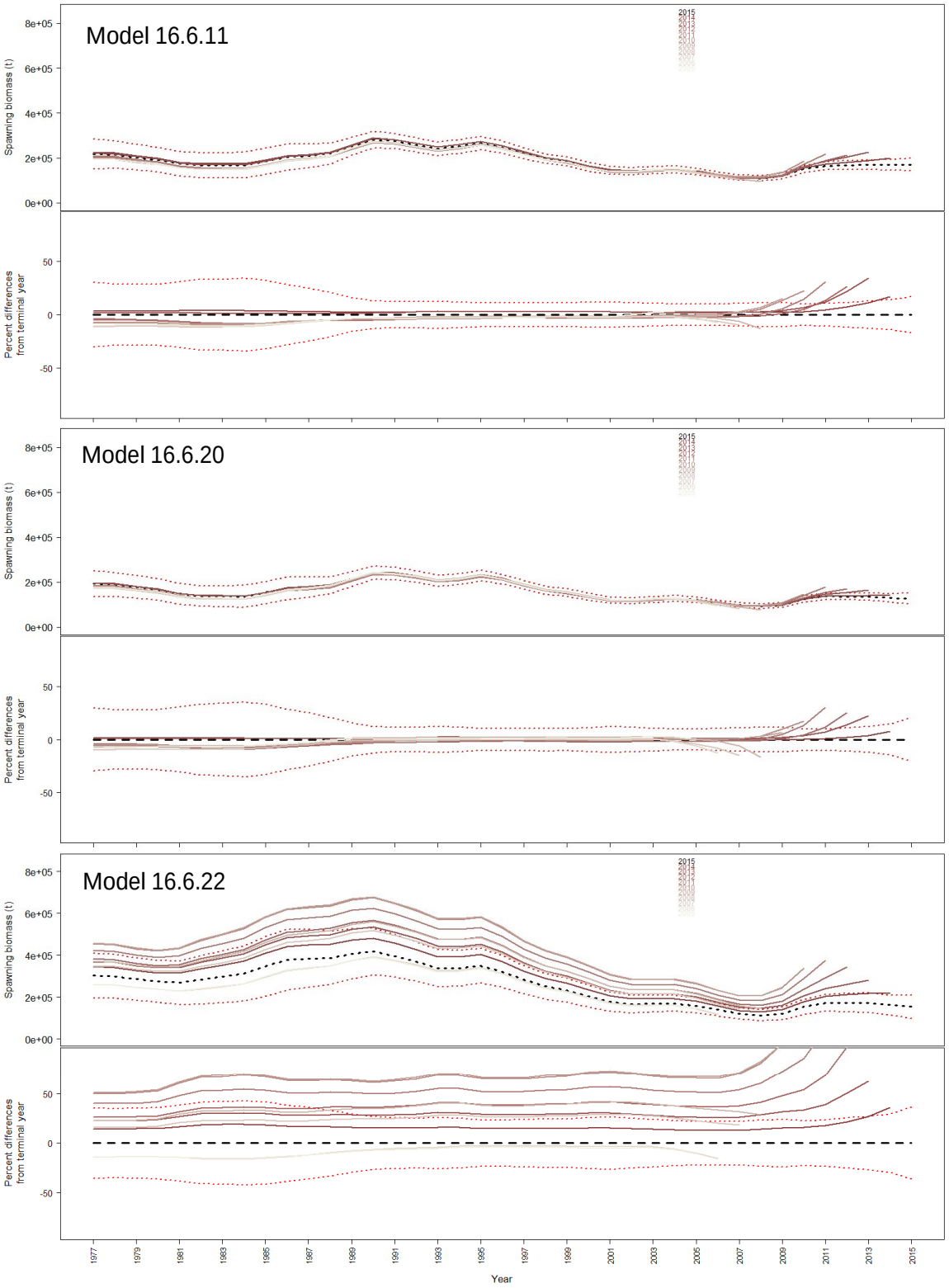

Figure 49 cont. Retrospective analysis of female spawning biomass (top of each pair) and percentage of difference in female spawning biomass (bottom of each pair).

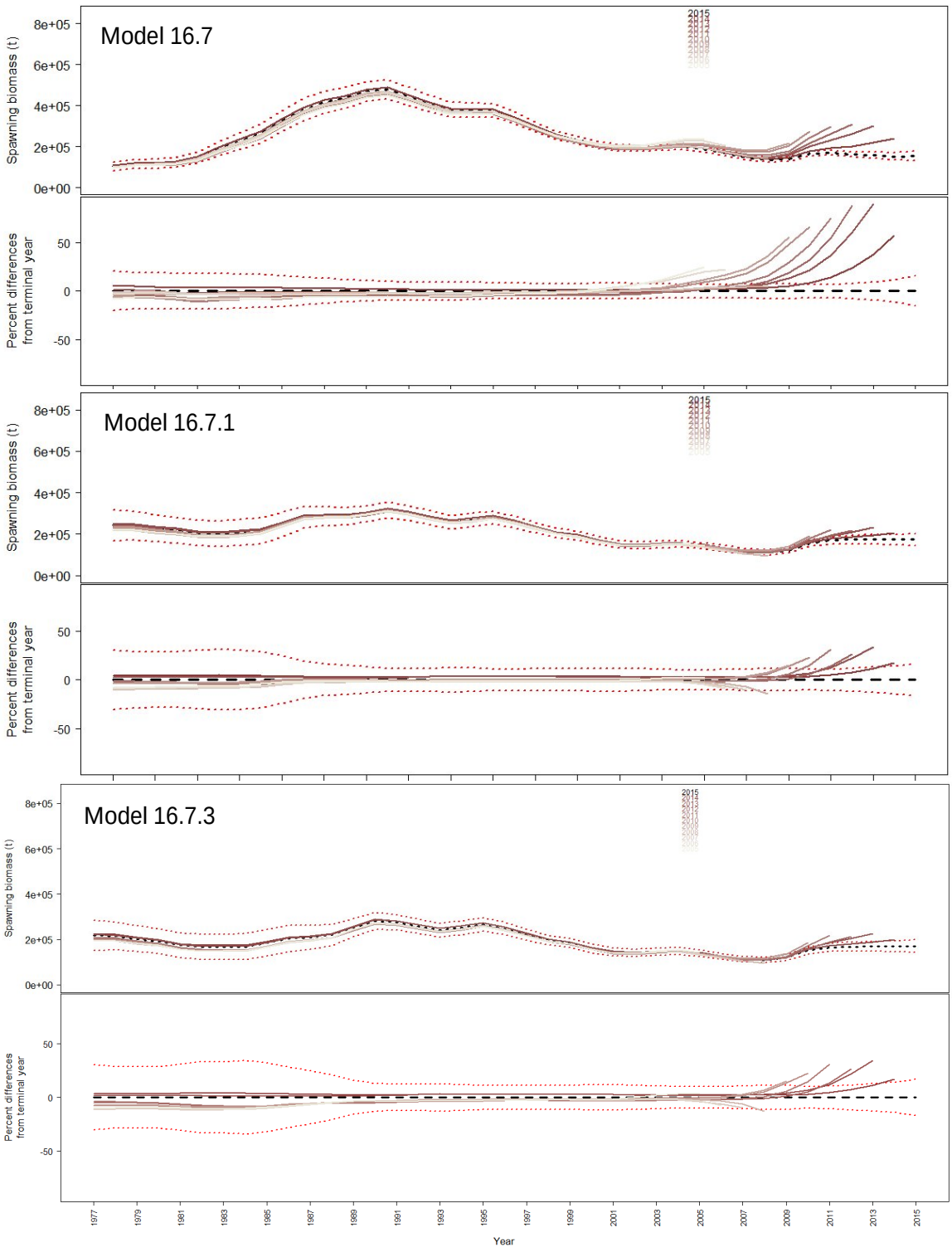

Figure 49 cont. Retrospective analysis of female spawning biomass (top of each pair) and percentage of difference in female spawning biomass (bottom of each pair).

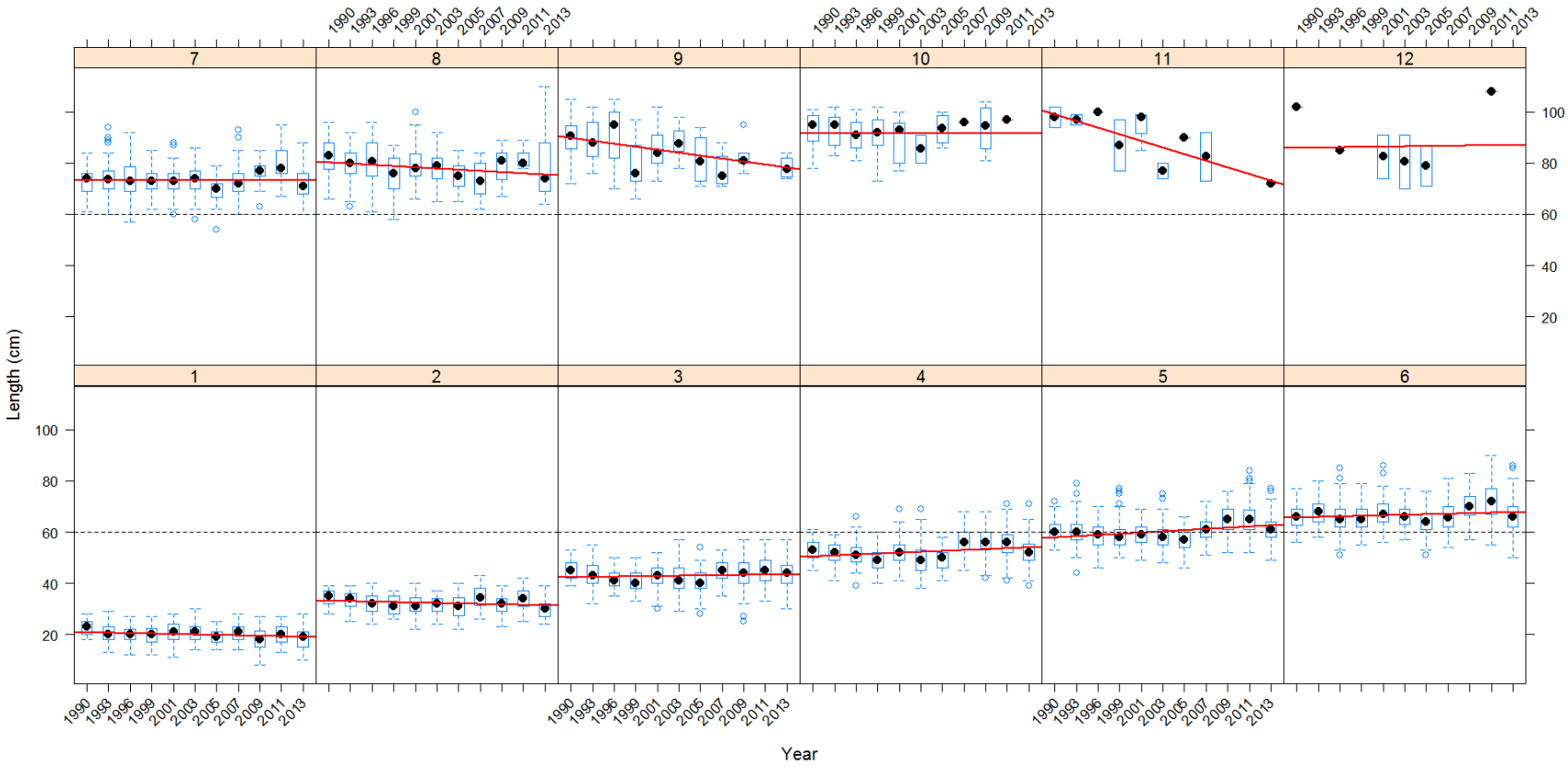

Figure 50. Pacific cod length (cm) at age from the 1990 – 2013 bottom trawl survey data. Red line is a linear model fit to each age across time, black checkered line is a flat line at 60 cm for reference.