Appendix I, CASA models

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Introduction

This Appendix describes the changes to the CASA model from that used in the 2018 benchmark (NEFSC 2018), and gives detailed CASA model results. For more details regarding the CASA model, see Hart et al. (2013) and NEFSC (2018), and in particular, its Appendix 6. Unless otherwise specified, the CASA models were configured as in the 2018 benchmark. There are three separate CASA models for the Mid-Atlantic, Georges Bank Open and Georges Bank Closed areas. These were separated to account for different life history parameters (especially between the Mid-Atlantic and Georges Bank), and different fishing mortality patterns (in particular between Georges Bank Closed and Open). The results of these models are combined to obtain estimates for the whole stock.

As in the 2018 benchmark, the scallops in the deep water (> 70 m) southeast portion of the Nantucket Lightship area were not included in any of the models. This is because these scallops are growing anomalously slowly and were not fished prior to 2020, and because there is no history of scallops in this area prior to settlement of the large 2012 year class. Biomass in this area is determined empirically, using the Habcam survey. We discuss each of the three CASA models in turn.

Model Configuration

CASA Model for Georges Bank Closed Areas

The model was tuned to the lined dredge survey (1979-2019), the SMAST large video drop camera survey (2003-2012, and 2014), the SMAST digital drop camera survey (2015 and 2017), the Habcam survey (2011-2019), and the unlined dredge survey (1975 and 1977). Neither the Habcam nor the SMAST survey covered all of this area in 2019, but they can be combined to obtain a complete survey; for time series purposes, this combined survey was considered to be part of the Habcam survey. Four fishery selectivity periods were used. The first two were as in the 2018 benchmark, with the first comprising the years prior to the fishery closures (1975-1994), and the second the period after the reopenings until 2017 (1998-2017). Selectivity changed in 2018 and 2019 due to the reopening of the Nantucket Lightship West area, which had less very large scallops than is typical in the closed areas. Selectivity was modeled separately for each of these two years. The 2019 period was modeled as domed (double logistic) selectivity, due to heavy fishing in the Nantucket Lightship West Area that targeted intermediate sized scallops. All the other periods were assumed to have logistic selectivity.

The four growth matrices used in the 2018 benchmark were also used for the 2020 model: matrix 1 for 1993-1996 and 2011-2019, matrix 2 for 2000-2006, matrix 3 for 1975-1992 and 1997-1999, and matrix 4 for 2007-2010. The growth matrices were based on a mixed-effects model that estimates von Bertalanffy parameters and their variation based on shell ring increments (Hart and Chute 2009). Based on survey size-frequencies, growth in recent years has been relatively slow, likely due to the slow growing large 2012 year class. For that reason, the matrix representing the slowest growth (matrix 1), was used to model growth from 2011-2019.

CASA Model for Georges Bank Open Areas

The model was tuned to the lined dredge survey (1979-2019), the SMAST large drop video camera survey (2003-2012, and 2014), the digital drop camera survey (2015, 2017, and 2019), the Habcam survey (2011-

2018), and the unlined dredge survey (1975 and 1977). As in the Georges Closed Area, neither the drop camera and Habcam surveys covered all portions of the Georges Bank Open areas in 2019, so these were combined to obtain a survey that covered all areas. For time series purposes, these data were considered to be a part of the digital drop camera survey.

As in the 2018 benchmark, there were three commercial fishery selectivity periods: 1975-1998, 1999-2004, and 2005-2019. Five discontinuous growth periods were used for Georges Bank open stock (period 1 from 1993-1996; period 2 from 2000-2006 period 3 from 1975-1992 and 1997-1999; period 4 from 2007-2011; and period 5 from 2012-2019). The growth matrices used for period 1-4 were as in the 2018 benchmark, whereas the matrix for period 5 were based on shell increment data from those years, much of it new.

CASA Model for Mid-Atlantic Areas

The Mid-Atlantic CASA model uses all the surveys employed in the Georges Bank models plus the NEFSC winter bottom trawl survey, which was conducted between 1992-2007. The fishery selectivity periods were the same as the 2018 benchmark (with two years added to the last period): 1975-1979, 1980-1997, 1998-2001, 2002-2004 and 2005-2019. The first period was modeled as domed (double logistic) selectivity, due to indications in the data of higher mortality on intermediate sized scallops. All the other periods were assumed to have logistic selectivity.

As in the 2018 benchmark, three discontinuous growth periods were used for the Mid-Atlantic region: 1975-1977, 1987-2003, and 2006 (matrix 1, slow growth), 1978, 1983-1986, 2004-2005, and 2007 (matrix 2, moderate growth), and 1979-1982 and 2008-2011 (matrix 3, fast growth). Growth matrix 1 were used for 2012-2019 based on the observed slow growth from surveys in those years.

Model Results

The models generally had good fit to the data, with only moderate retrospective patterns; Mohn's ρ ranged from 0.23 to 0.33 for biomass and from -0.03 to 0.41 for fishing mortality. Much of these retrospective patterns were due to anomalous natural mortalities associated with large year classes. Although the CASA models can estimate temporal variations in natural mortality, large mortality events that occur near the terminal year cannot be precisely estimated due to the lack of data. As more years of data are added, the M estimates become more stable and precise. In particular, there was a large decline in biomass and abundance in the Nantucket Lightship West area between $2018-2019$ beyond what could be accounted for by landings and mean natural mortality. With only a single year's data after the decline, the CASA model has insufficient information to estimate a large increase in M for those years. Additionally, the uncertainties surrounding estimated growth for recent years may be causing uncertainty in estimated biomass.

We present updates of all the CASA model tables and figures from the 2018 benchmark.

References

Hart DR, Chute AS. 2009. Estimating von Bertalanffy growth parameters from growth increment data using a linear mixed-effects model, with an application to the sea scallop *Placopecten magellanicus*. ICES J Mar Sci 66:2165-2175

Hart DR, Jacobson LD, Tang J. 2013. To split or not to split:Assessment of Georges Bank sea scallops in the presence of marine protected areas. Fish Res 144:74-83

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Tables

Table 1: CASA estimates for Georges Bank Closed Areas, excluding the Nantucket Lightship Deep South area.

Year	Abundance (millions)	CV	SSB (mt meats)	CV	Bms (mt meats)	CV	ExplBms (mt meats)	CV	F	CV
1975	716	0.11	6434	0.24	13744	0.11	12394	0.12	0.09	1.31
1976	624	0.10	6953	0.21	14968	0.10	14015	0.11	0.13	0.81
1977	594	0.09	6427	0.21	14294	0.09	13532	0.10	0.27	0.35
1978	587	0.09	5538	0.20	12577	0.09	11479	0.09	0.34	0.27
1979	398	0.09	4004	0.21	9515	0.09	9113	0.09	0.55	0.16
1980	458	0.10	3269	0.22	7557	0.10	6414	0.11	0.47	0.21
1981	408	0.11	2860	0.25	6732	0.11	5804	0.12	0.54	0.19
1982	369	0.12	2629	0.28	6100	0.12	5315	0.14	0.44	0.25
1983	306	0.14	2354	0.32	5455	0.14	4880	0.15	0.45	0.28
1984	372	0.13	2597	0.30	5716	0.14	4748	0.16	0.21	0.66
1985	366	0.13	2737	0.28	6146	0.13	5342	0.15	0.35	0.36
1986	507	0.11	2780	0.28	6445	0.12	4954	0.16	0.57	0.24
1987	558	0.12	2876	0.29	6738	0.12	5109	0.16	0.73	0.19
1988	771	0.11	3313	0.29	7765	0.12	5225	0.18	0.85	0.19
1989	1003	0.09	4469	0.20	10299	0.09	6999	0.13	0.67	0.21
1990	935	0.08	3826	0.20	9851	0.08	7287	0.11	1.37	0.08
1991	894	0.09	3212	0.24	8277	0.09	5521	0.14	1.52	0.07
1992	820	0.15	3337	0.36	8053	0.15	5516	0.22	1.19	0.12
1993	1490	0.16	6118	0.37	13506	0.17	8059	0.28	0.34	0.51
1994	1414	0.16	9775	0.34	20574	0.16	17232	0.19	0.04	3.46
1995	1744	0.14	13864	0.31	28967	0.15	25571	0.17	0.00	0.00
1996	1792	0.13	17579	0.28	36752	0.13	33884	0.14	0.00	0.00
1997	1848	0.12	20671	0.26	42926	0.12	40570	0.13	0.00	0.00
1998	2490	0.12	25210	0.24	52670	0.11	33938	0.18	0.00	60.73
1999	2267	0.11	28031	0.23	59234	0.11	39156	0.17	0.09	1.20
2000	2773	0.11	30590	0.23	64627	0.11	43609	0.16	0.07	1.41
2001	3039	0.10	34836	0.21	73266	0.10	48654	0.15	0.02	6.92
2002	2841	0.09	38266	0.19	80294	0.09	55666	0.13	0.00	0.00
2003	2931	0.08	40196	0.17	84597	0.08	63574	0.11	0.00	0.00
2004	2570	0.08	39073	0.16	83214	0.07	65846	0.09	0.06	1.37
2005	2194	0.07	34421	0.16	74590	0.07	61550	0.09	0.14	0.57
2006	1762	0.08	27515	0.17	60773	0.08	51390	0.09	0.24	0.36
2007	1733	0.08	23425	0.18	50835	0.08	41309	0.10	0.15	0.60
2008	1648	0.08	23133	0.18	49216	0.08	38124	0.11	0.07	1.41
2009	1833	0.08	23589	0.17	50159	0.08	37606	0.11	0.05	1.90
2010	1965	0.08	23444	0.16	50701	0.08	36388	0.11	0.09	0.97
2011	2201	0.07	22111	0.15	49352	0.07	32702	0.10	0.21	0.42
2012	1995	0.07	19596	0.15	43434	0.07	25951	0.11	0.31	0.29
2013	2026	0.07	21316	0.14	44065	0.07	25472	0.12	0.10	0.98
2014	4494	0.07	29570	0.14	61318	0.07	29932	0.14	0.07	1.34
2015	4845	0.06	40512	0.14	84923	0.06	36376	0.15	0.00	21.25
2016	4667	0.07	43755	0.14	95738	0.06	46250	0.13	0.00	29.75
2017	4709	0.06	42307	0.14	93750	0.06	52260	0.11	0.11	0.85
2018	3279	0.07	33197	0.17	77266	0.07	58515	0.10	0.23	0.47
2019	2697	0.09	26988	0.21	60587	0.09	22935	0.25	0.53	0.35

Table 2: CASA Estimates for Georges Bank Open Areas.

Year	Abundance (millions)	CV	SSB (mt meats)	CV	Bms (mt meats)	CV	ExplBms (mt meats)	CV	F	CV
1975	1423	0.03	12157	0.07	25788	0.03	23444	0.03	0.07	0.64
1976	1268	0.03	12305	0.07	26778	0.03	24981	0.04	0.16	0.29
1977	1095	0.04	10749	0.08	24032	0.04	23188	0.04	0.27	0.18
1978	1016	0.04	8924	0.09	20116	0.04	18761	0.04	0.31	0.16
1979	797	0.04	7017	0.09	16141	0.04	15174	0.04	0.41	0.12
1980	961	0.03	6062	0.09	13760	0.04	11915	0.05	0.39	0.14
1981	777	0.04	5088	0.08	12027	0.03	10631	0.04	0.56	0.08
1982	659	0.04	3641	0.10	8999	0.04	7978	0.04	0.77	0.06
1983	457	0.05	2811	0.12	6767	0.05	6004	0.06	0.64	0.09
1984	390	0.06	2415	0.14	5612	0.06	4984	0.07	0.50	0.14
1985	454	0.06	2229	0.15	5187	0.06	4191	0.08	0.60	0.14
1986	717	0.05	2228	0.15	5413	0.06	3478	0.09	1.08	0.09
1987	781	0.05	2856	0.12	6750	0.05	4636	0.07	0.75	0.10
1988	623	0.05	2865	0.14	6980	0.06	5728	0.07	0.79	0.09
1989	622	0.05	2730	0.14	6510	0.06	5192	0.08	0.72	0.12
1990	690	0.05	2567	0.12	6271	0.05	4597	0.07	0.96	0.08
1991	845	0.04	2466	0.09	6223	0.04	3995	0.06	1.30	0.05
1992	533	0.03	1939	0.09	5204	0.03	4041	0.04	1.39	0.04
1993	343	0.04	1644	0.11	4032	0.05	3433	0.05	0.79	0.07
1994	362	0.05	1677	0.12	3791	0.05	3003	0.07	0.48	0.14
1995	652	0.04	2219	0.09	4996	0.04	3202	0.07	0.54	0.13
1996	622	0.04	2481	0.09	5938	0.04	4289	0.05	0.79	0.07
1997	549	0.05	2340	0.11	5612	0.05	4455	0.06	0.78	0.08
1998	810	0.05	2934	0.11	6711	0.05	4562	0.07	0.63	0.11
1999	1188	0.04	4263	0.10	9680	0.04	3981	0.10	0.86	0.11
2000	1470	0.04	6373	0.08	14210	0.03	6968	0.07	0.54	0.14
2001	1649	0.03	8325	0.06	19073	0.03	11642	0.05	0.57	0.10
2002	1334	0.03	8183	0.07	19366	0.03	13924	0.04	0.68	0.07
2003	1332	0.03	7753	0.07	18063	0.03	13491	0.04	0.57	0.09
2004	1247	0.03	8586	0.06	19026	0.03	13957	0.04	0.30	0.17
2005	1234	0.03	9060	0.06	20221	0.03	13608	0.04	0.36	0.13
2006	1049	0.04	6779	0.08	16572	0.03	11329	0.04	0.94	0.05
2007	1460	0.03	6696	0.07	15484	0.03	8184	0.06	0.76	0.08
2008	1581	0.03	8341	0.07	19037	0.03	8544	0.07	0.73	0.09
2009	1697	0.03	9972	0.06	22643	0.03	12527	0.05	0.55	0.10
2010	1605	0.02	11939	0.05	26254	0.02	16875	0.04	0.28	0.18
2011	1515	0.02	13406	0.05	29196	0.02	21923	0.03	0.19	0.23
2012	1257	0.03	11836	0.05	27127	0.02	21968	0.03	0.44	0.09
2013	1225	0.04	7913	0.07	19055	0.03	14211	0.04	0.85	0.05
2014	2124	0.07	7830	0.11	19848	0.04	9208	0.09	0.48	0.11
2015	1343	0.04	7110	0.09	16505	0.04	8096	0.08	0.75	0.08
2016	1347	0.04	7808	0.10	17583	0.04	9141	0.09	0.51	0.13
2017	1287	0.04	9406	0.10	20276	0.05	12256	0.08	0.17	0.38
2018	1168	0.05	9082	0.12	20565	0.05	14506	0.08	0.44	0.15
2019	1662	0.06	8520	0.15	19692	0.06	12321	0.10	0.61	0.14

Table 3: CASA Estimates for Mid-Atlantic.

Year	Abundance (millions)	CV	SSB (mt meats)	CV	Bms (mt meats)	CV	ExplBms (mt meats)	CV	F	CV
1975	1022	0.05	5942	0.10	11803	0.05	4384	0.13	0.40	0.23
1976	771	0.05	6691	0.11	13354	0.06	5825	0.13	0.64	0.14
1977	813	0.05	6265	0.11	12485	0.06	3873	0.18	0.73	0.17
1978	651	0.04	5368	0.10	10711	0.05	3681	0.15	1.27	0.09
1979	395	0.05	4057	0.10	8101	0.05	2652	0.16	1.23	0.10
1980	367	0.05	3307	0.11	6598	0.06	5837	0.06	0.39	0.19
1981	401	0.05	3441	0.11	6868	0.05	5963	0.06	0.15	0.48
1982	419	0.05	3695	0.10	7369	0.05	6533	0.06	0.27	0.24
1983	480	0.05	3511	0.10	7002	0.05	5838	0.06	0.59	0.12
1984	430	0.06	2844	0.13	5645	0.07	4659	0.08	0.84	0.10
1985	758	0.07	3143	0.14	6214	0.07	3646	0.12	0.93	0.12
1986	1185	0.05	5218	0.11	10345	0.06	6341	0.09	0.56	0.17
1987	1493	0.04	6833	0.10	13582	0.05	9012	0.08	1.03	0.08
1988	1431	0.04	7492	0.10	14879	0.05	10844	0.07	0.69	0.11
1989	1488	0.04	7255	0.10	14403	0.05	10317	0.07	1.03	0.08
1990	1329	0.04	6930	0.08	13790	0.04	10026	0.06	0.87	0.08
1991	898	0.04	5407	0.08	10776	0.04	8787	0.05	1.10	0.06
1992	538	0.06	3454	0.12	6830	0.06	5789	0.07	1.14	0.06
1993	1226	0.05	4116	0.10	8105	0.05	3908	0.11	0.88	0.12
1994	1345	0.04	5579	0.09	11060	0.04	6602	0.07	1.26	0.07
1995	1197	0.04	5735	0.08	11415	0.04	7967	0.06	1.06	0.07
1996	722	0.05	5058	0.10	10086	0.05	8536	0.06	0.72	0.09
1997	697	0.07	4501	0.13	8876	0.07	7377	0.08	0.48	0.16
1998	2102	0.06	7377	0.11	14497	0.06	5533	0.15	0.61	0.19
1999	3587	0.05	15128	0.09	29994	0.05	10243	0.14	0.49	0.25
2000	4196	0.04	23546	0.08	46858	0.04	24307	0.07	0.42	0.24
2001	4500	0.03	28548	0.07	56890	0.03	36419	0.05	0.46	0.17
2002	4059	0.03	29746	0.06	59176	0.03	36790	0.05	0.50	0.14
2003	5682	0.07	31605	0.07	62870	0.04	37565	0.06	0.57	0.11
2004	4254	0.04	29583	0.06	58997	0.03	31327	0.06	0.80	0.08
2005	3794	0.03	29220	0.06	58299	0.03	30910	0.05	0.55	0.12
2006	3947	0.03	31557	0.05	62997	0.03	37670	0.04	0.25	0.24
2007	3454	0.03	29952	0.05	59711	0.03	36673	0.04	0.50	0.12
2008	4253	0.03	29108	0.05	58072	0.03	33852	0.04	0.57	0.11
2009	3493	0.02	30126	0.05	60186	0.02	33000	0.04	0.61	0.10
2010	2781	0.03	27436	0.05	54826	0.03	37840	0.04	0.53	0.11
2011	2004	0.03	22072	0.06	44012	0.03	33249	0.04	0.54	0.10
2012	3189	0.04	21381	0.07	42654	0.03	27147	0.05	0.43	0.14
2013	2791	0.03	22801	0.06	45413	0.03	22901	0.06	0.26	0.24
2014	4087	0.04	26282	0.07	51759	0.03	27964	0.06	0.33	0.19
2015	8053	0.06	37196	0.09	73834	0.04	29026	0.11	0.36	0.18
2016	5268	0.03	37862	0.07	75557	0.03	32845	0.08	0.40	0.16
2017	4564	0.03	39754	0.07	79415	0.04	45014	0.06	0.34	0.19
2018	3471	0.04	37853	0.08	75664	0.04	53443	0.05	0.17	0.37
2019	2735	0.04	33435	0.08	66795	0.04	54321	0.05	0.19	0.34

Table 4: CASA Estimates for Georges Bank and Mid-Atlantic combined, excluding scallops located in the deep water southeast portion of Nantucket Lightship Area.

Year	Abundance (millions)	CV	SSB (mt meats)	CV	Bms (mt meats)	CV	ExplBms (mt meats)	CV	F	CV
1975	3162	0.03	24533	0.07	51336	0.04	40223	0.05	0.14	0.04
1976	2662	0.03	25949	0.07	55100	0.03	44822	0.04	0.25	0.04
1977	2502	0.03	23441	0.07	50810	0.03	40592	0.04	0.33	0.04
1978	2253	0.03	19830	0.07	43404	0.03	33920	0.04	0.49	0.04
1979	1590	0.03	15079	0.08	33757	0.03	26939	0.04	0.57	0.04
1980	1786	0.03	12638	0.08	27915	0.04	24165	0.04	0.41	0.04
1981	1587	0.04	11390	0.08	25627	0.04	22398	0.04	0.46	0.04
1982	1447	0.04	9964	0.09	22468	0.04	19826	0.04	0.53	0.04
1983	1243	0.04	8676	0.10	19224	0.05	16721	0.05	0.57	0.05
1984	1192	0.05	7857	0.12	16973	0.05	14391	0.06	0.53	0.05
1985	1578	0.05	8109	0.12	17548	0.05	13179	0.07	0.61	0.06
1986	2409	0.04	10226	0.10	22203	0.05	14773	0.07	0.69	0.06
1987	2832	0.04	12566	0.09	27071	0.04	18758	0.06	0.88	0.05
1988	2826	0.04	13669	0.09	29624	0.04	21797	0.06	0.75	0.05
1989	3112	0.04	14454	0.08	31212	0.04	22507	0.05	0.84	0.05
1990	2953	0.03	13323	0.08	29912	0.03	21909	0.05	1.05	0.05
1991	2637	0.04	11085	0.08	25276	0.04	18303	0.05	1.28	0.04
1992	1891	0.07	8730	0.15	20087	0.06	15347	0.08	1.23	0.06
1993	3059	0.08	11878	0.20	25643	0.09	15400	0.15	0.57	0.10
1994	3122	0.07	17031	0.20	35425	0.09	26837	0.13	0.43	0.10
1995	3593	0.07	21818	0.20	45378	0.09	36740	0.12	0.34	0.09
1996	3136	0.08	25118	0.20	52776	0.09	46709	0.11	0.27	0.09
1997	3094	0.08	27512	0.19	57414	0.09	52402	0.10	0.18	0.09
1998	5402	0.06	35521	0.17	73878	0.08	44033	0.14	0.22	0.08
1999	7042	0.04	47422	0.14	98907	0.07	53380	0.12	0.30	0.08
2000	8439	0.04	60509	0.12	125695	0.06	74884	0.10	0.29	0.07
2001	9189	0.04	71709	0.11	149230	0.05	96715	0.08	0.32	0.05
2002	8233	0.04	76195	0.10	158836	0.05	106380	0.07	0.33	0.05
2003	9944	0.05	79554	0.09	165530	0.04	114630	0.06	0.32	0.05
2004	8071	0.03	77242	0.08	161237	0.04	111130	0.06	0.37	0.04
2005	7221	0.03	72700	0.08	153110	0.04	106068	0.05	0.33	0.04
2006	6758	0.03	65851	0.08	140342	0.04	100388	0.05	0.34	0.04
2007	6647	0.03	60074	0.07	126030	0.04	86167	0.05	0.40	0.04
2008	7482	0.02	60582	0.07	126325	0.03	80520	0.05	0.41	0.04
2009	7023	0.03	63687	0.07	132988	0.03	83134	0.05	0.41	0.04
2010	6351	0.03	62819	0.07	131781	0.03	91104	0.05	0.34	0.03
2011	5721	0.03	57588	0.06	122560	0.03	87874	0.04	0.34	0.03
2012	6440	0.03	52813	0.06	113215	0.03	75066	0.04	0.40	0.03
2013	6042	0.03	52029	0.07	108533	0.03	62584	0.06	0.35	0.04
2014	10705	0.04	63682	0.07	132925	0.03	67104	0.07	0.25	0.04
2015	14241	0.04	84818	0.08	175263	0.04	73498	0.09	0.26	0.04
2016	11282	0.03	89424	0.08	188878	0.04	88237	0.08	0.23	0.04
2017	10560	0.03	91467	0.07	193441	0.03	109529	0.06	0.23	0.04
2018	7918	0.03	80132	0.08	173494	0.04	126464	0.05	0.23	0.04
2019	7094	0.04	68943	0.09	147073	0.04	89577	0.07	0.34	0.06

Figures

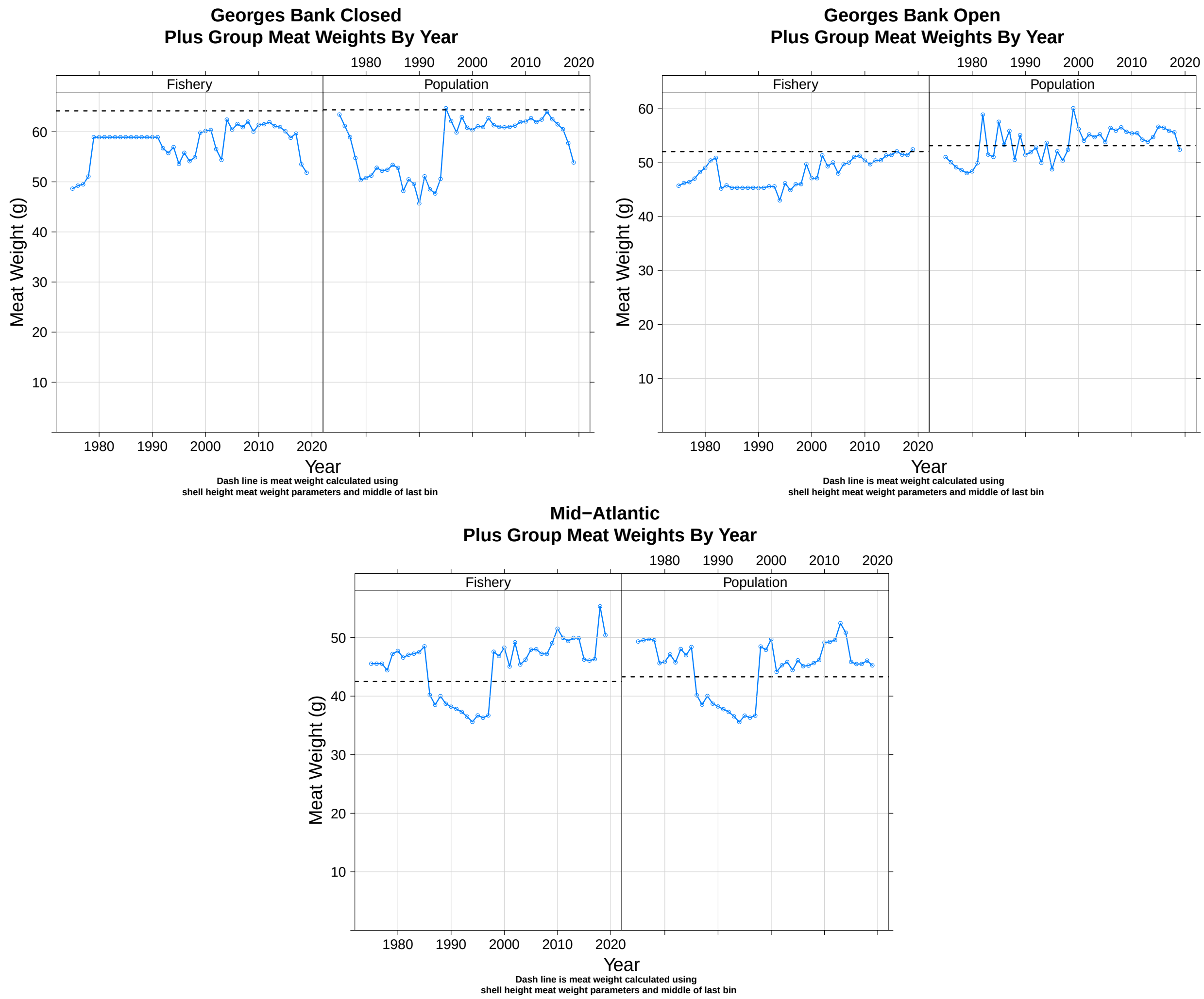


Figure 1: Estimated plus group meat weights for the population and fishery in the open and closed portions of Georges Bank, and in the Mid-Atlantic. The plus group represents scallops in the largest bin which contained L_∞. The dashed line is the meat weight for the last size bin calculated using the shell height meat weight parameters used in the CASA model.

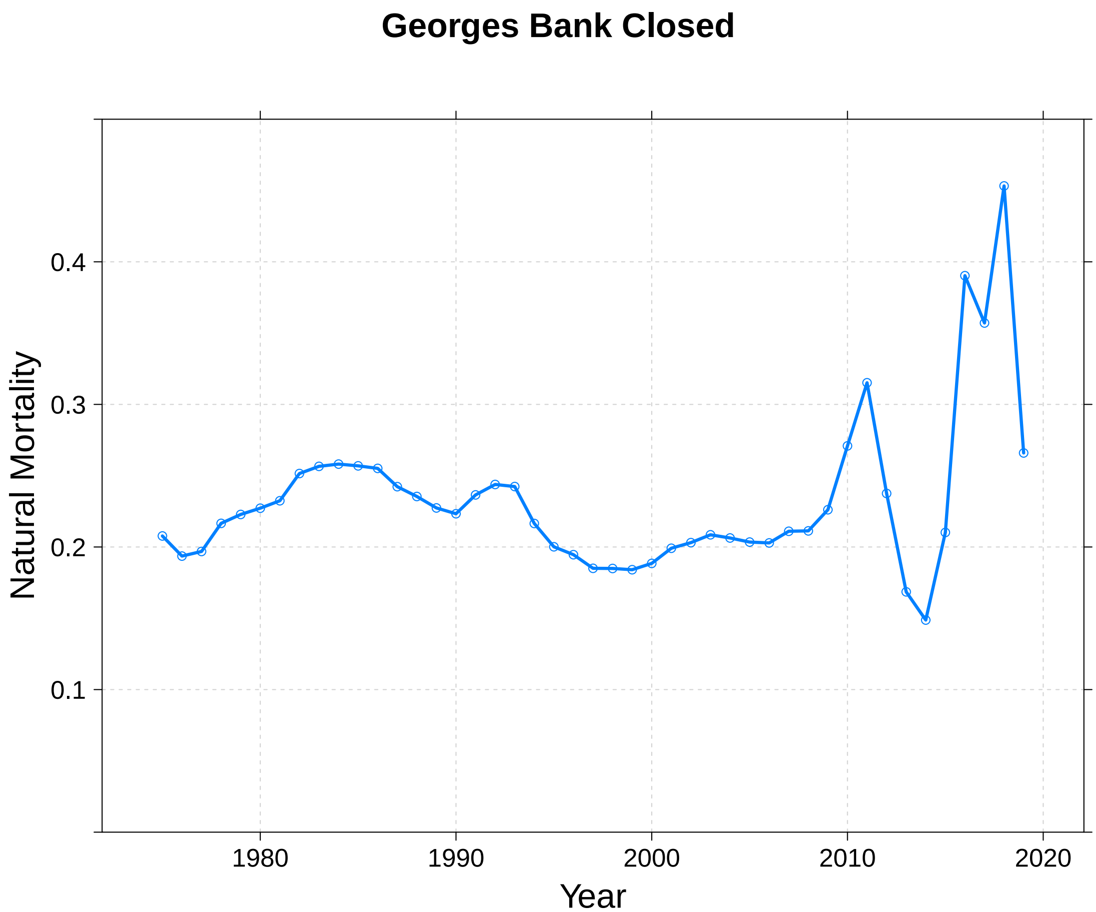


Figure 2: Estimated natural mortality from 1975 to 2019 for the Georges Bank closed areas.

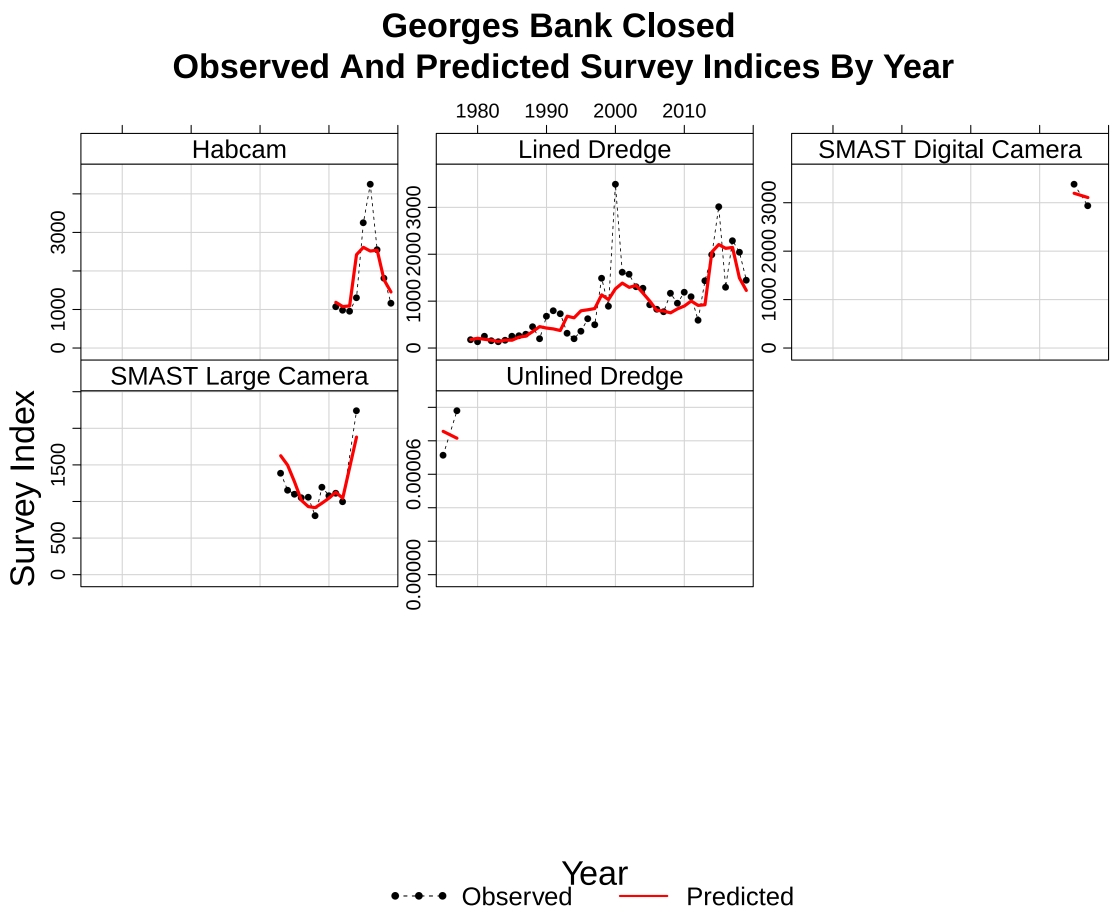


Figure 3: Observed survey trend (solid circles) and corresponding model estimates (lines) for the SMAST digital camera (top left), lined dredge (top middle), Habcam (top right), SMAST large camera (bottom left), and unlined dredge (bottom middle) surveys on Georges Bank closed areas.

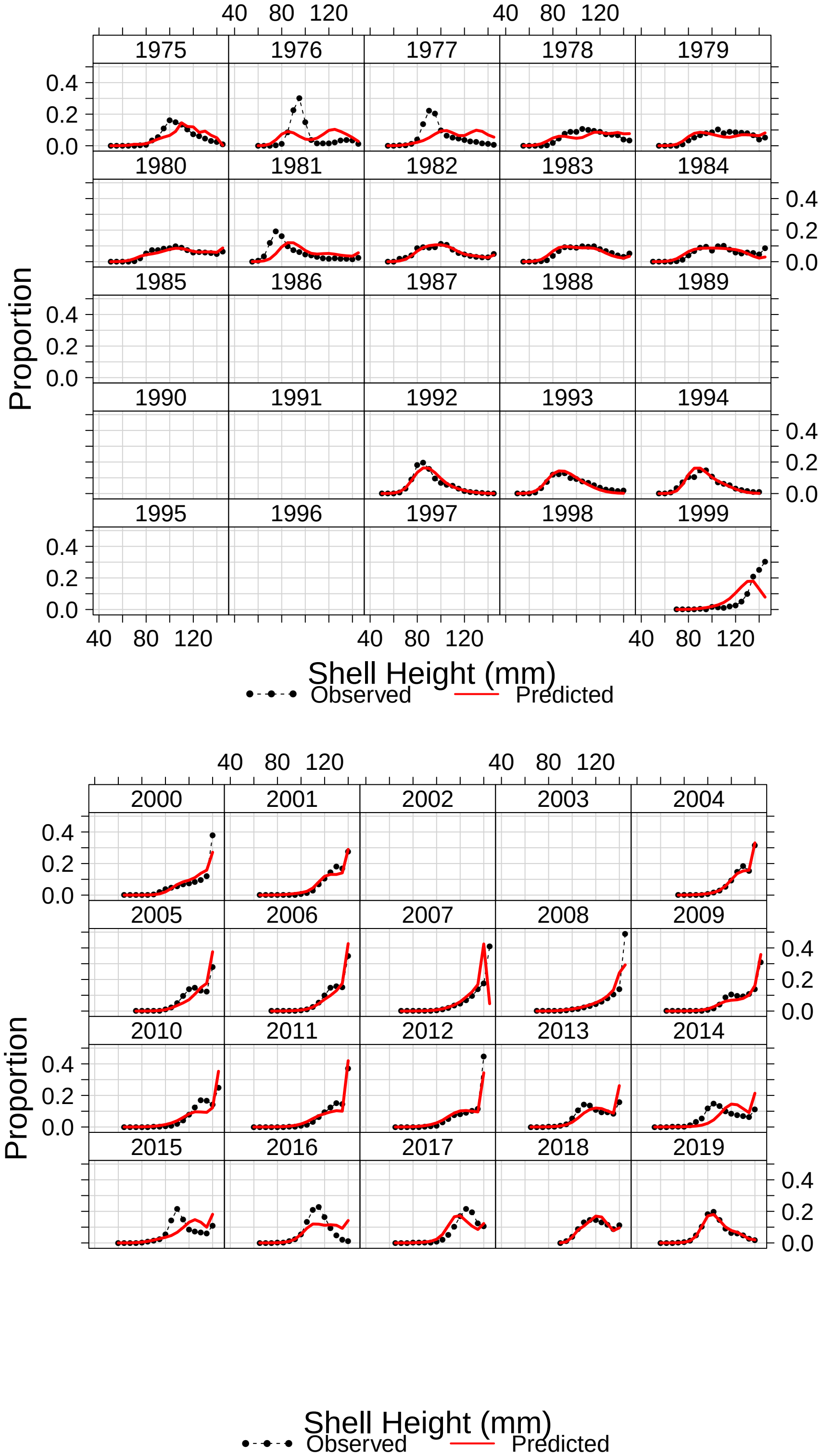


Figure 4: Comparison of observed fishery shell height proportions (solid circles) and model estimated fishery shell height proportions (lines) for Georges Bank closed areas.

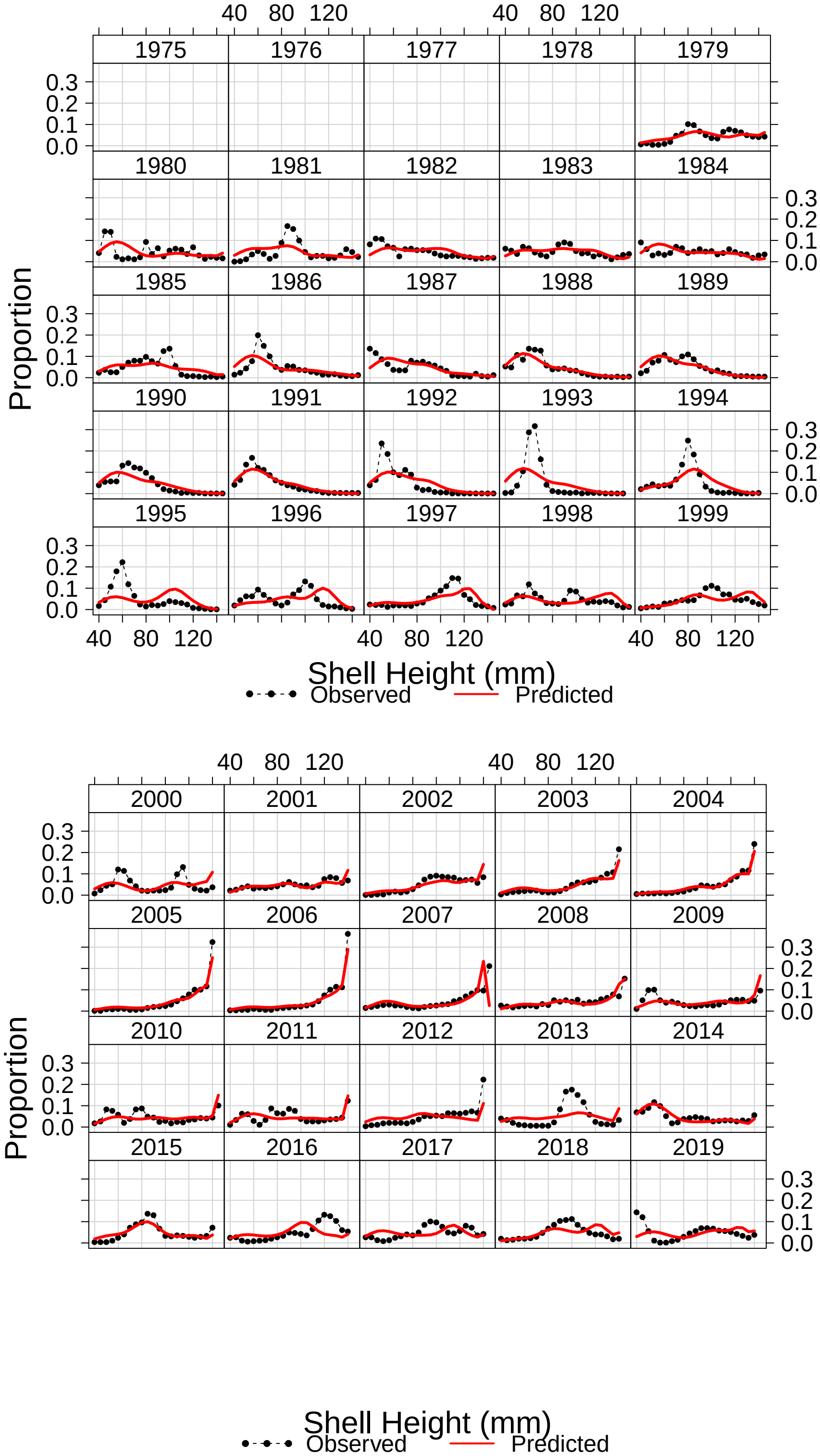
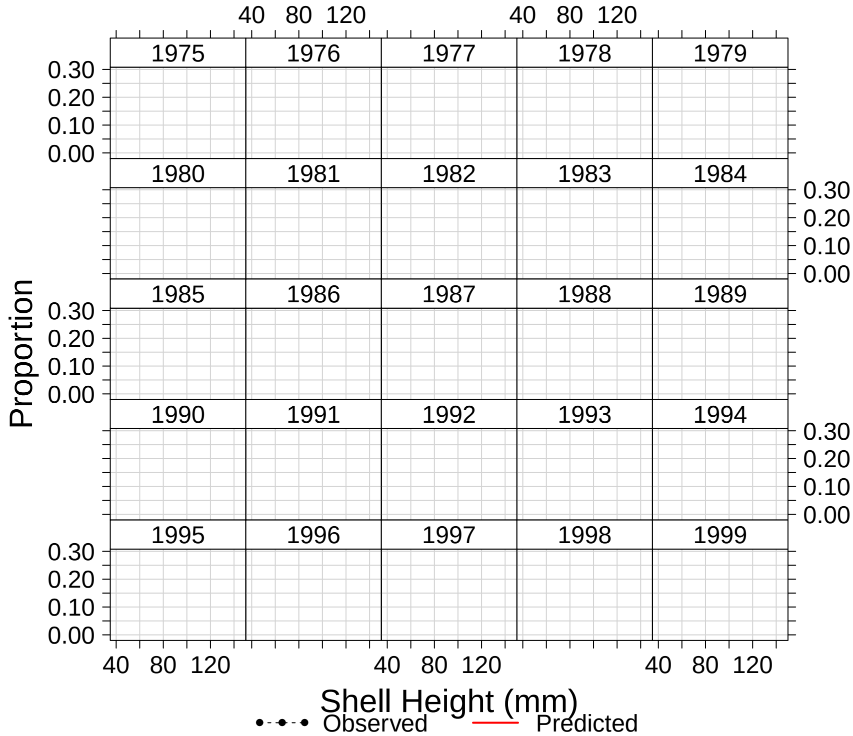


Figure 5: Comparison of lined dredge survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank closed areas.



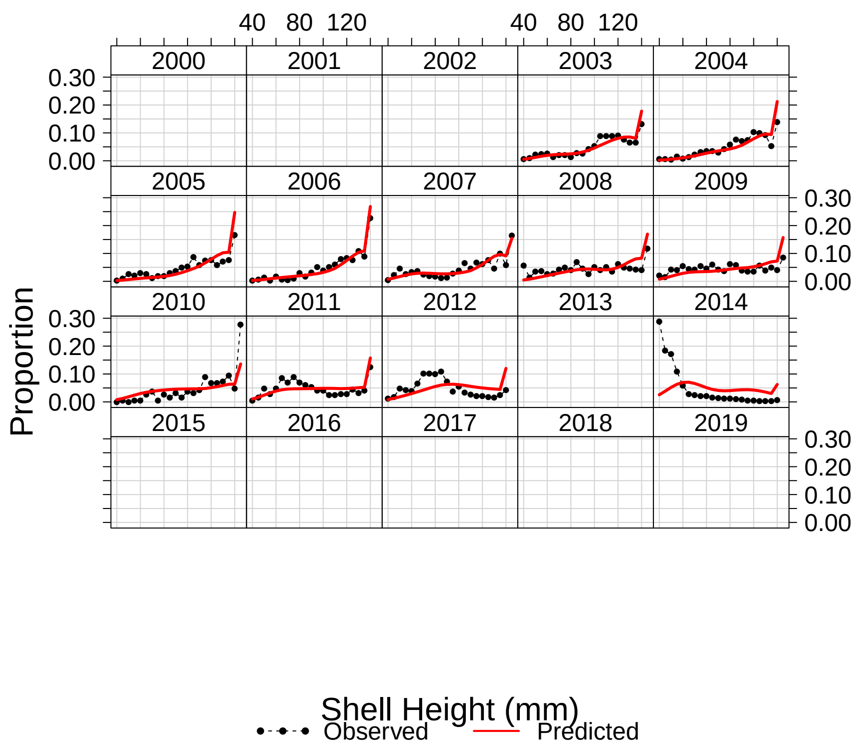


Figure 6: Comparison of SMAST large camera survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank closed areas.

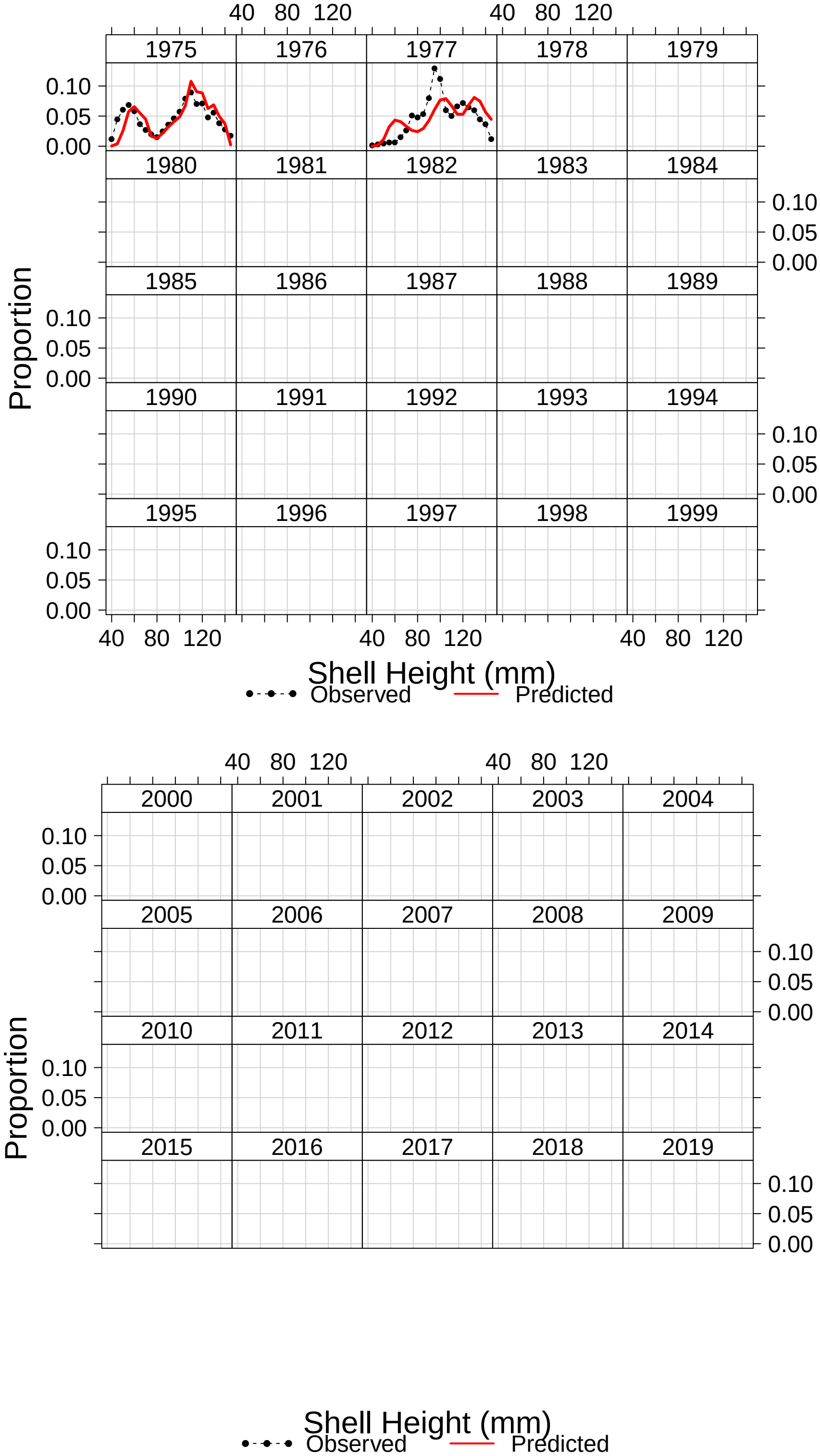
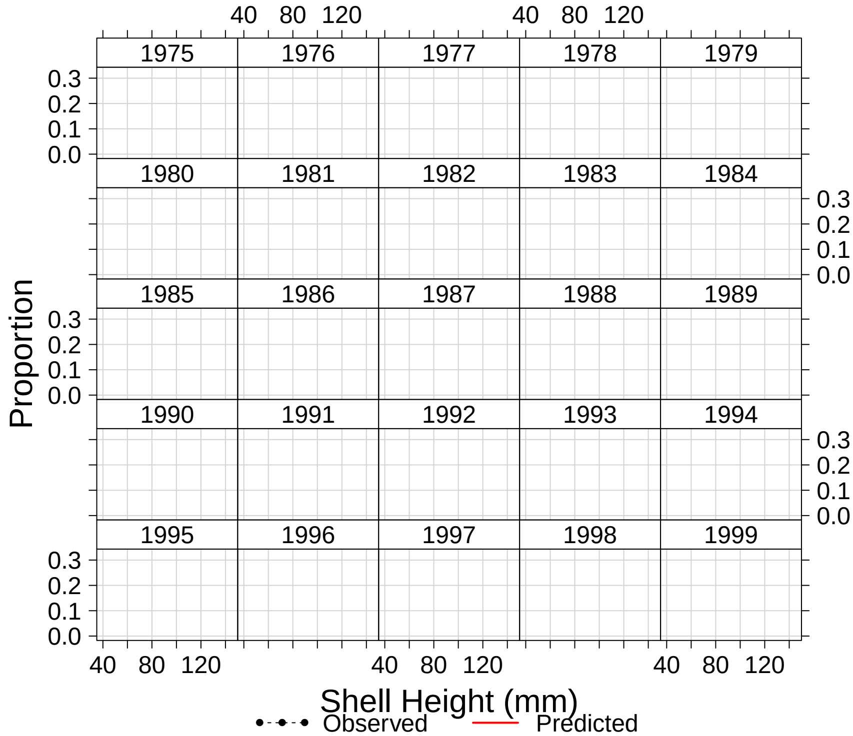


Figure 7: Comparison of unlined dredge survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank closed areas.



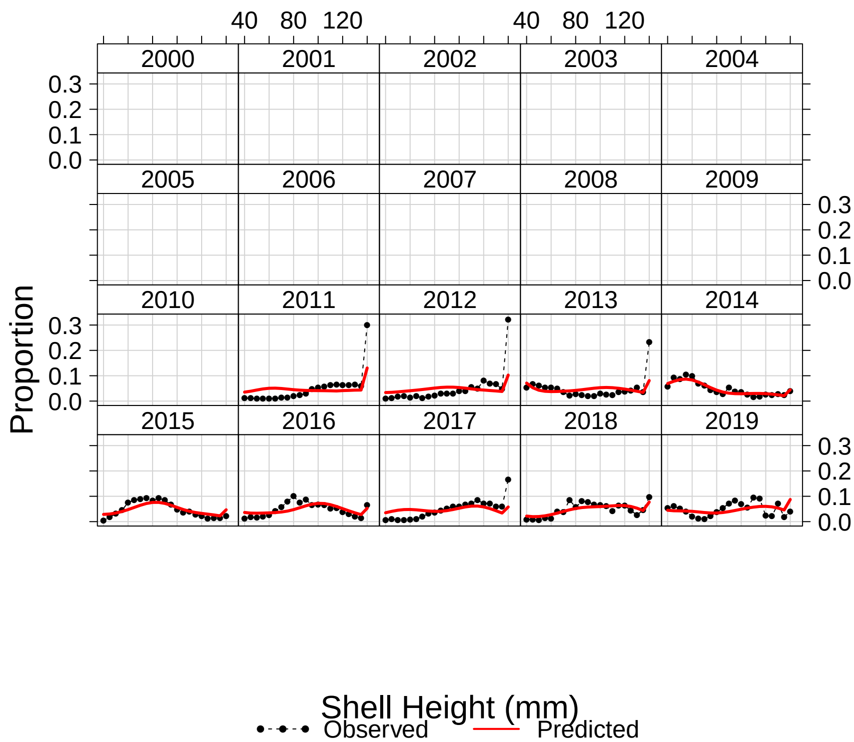


Figure 8: Comparison of Habcam survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank closed areas.

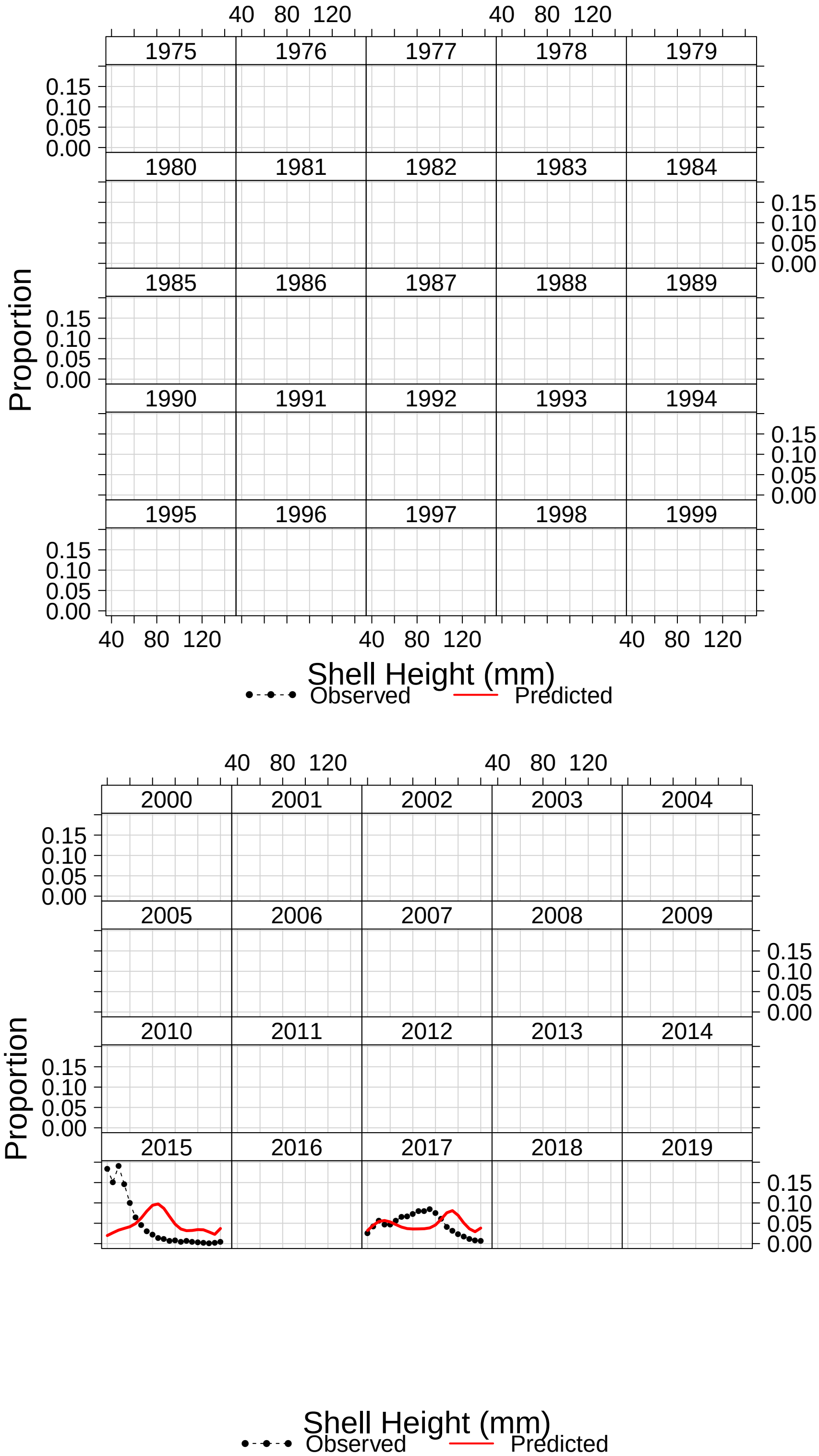


Figure 9: Comparison of SMAST digital camera survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank closed areas.

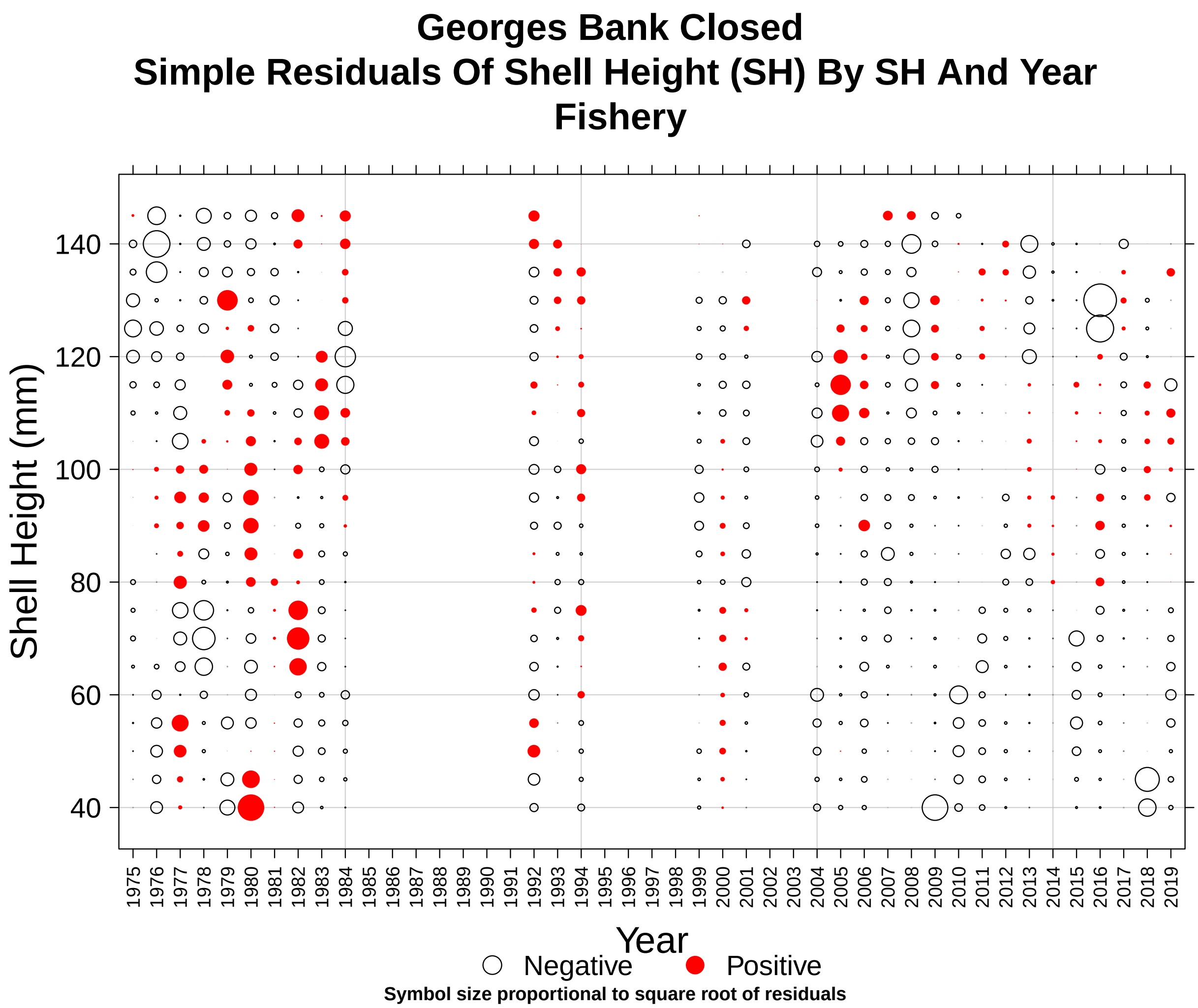


Figure 10: Simple residuals of fishery shell height proportions for Georges Bank closed areas. Symbol areas are proportional to residual.

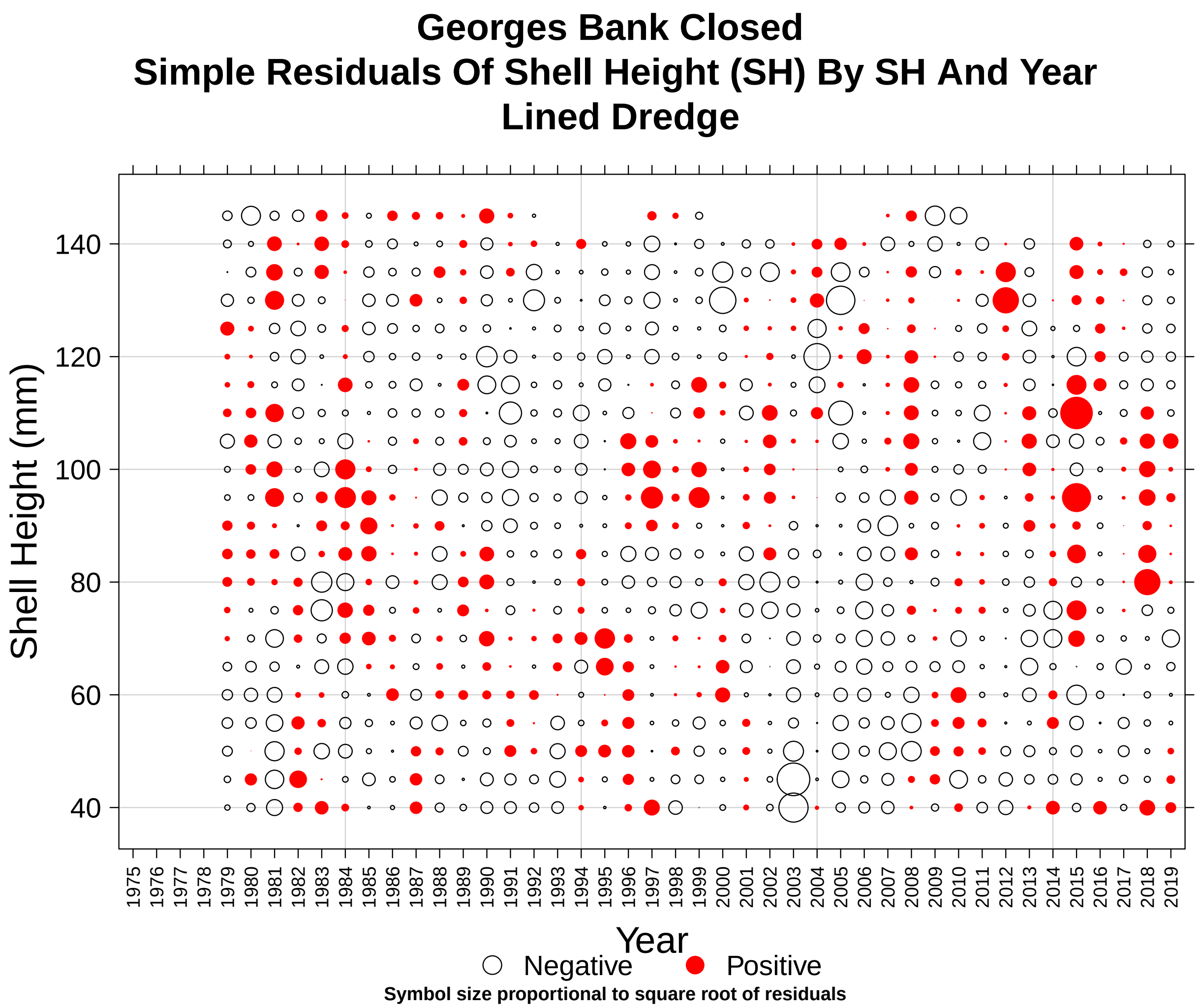


Figure 11: Simple residuals of lined dredge survey shell height proportions for Georges Bank closed areas. Symbol areas are proportional to residual.

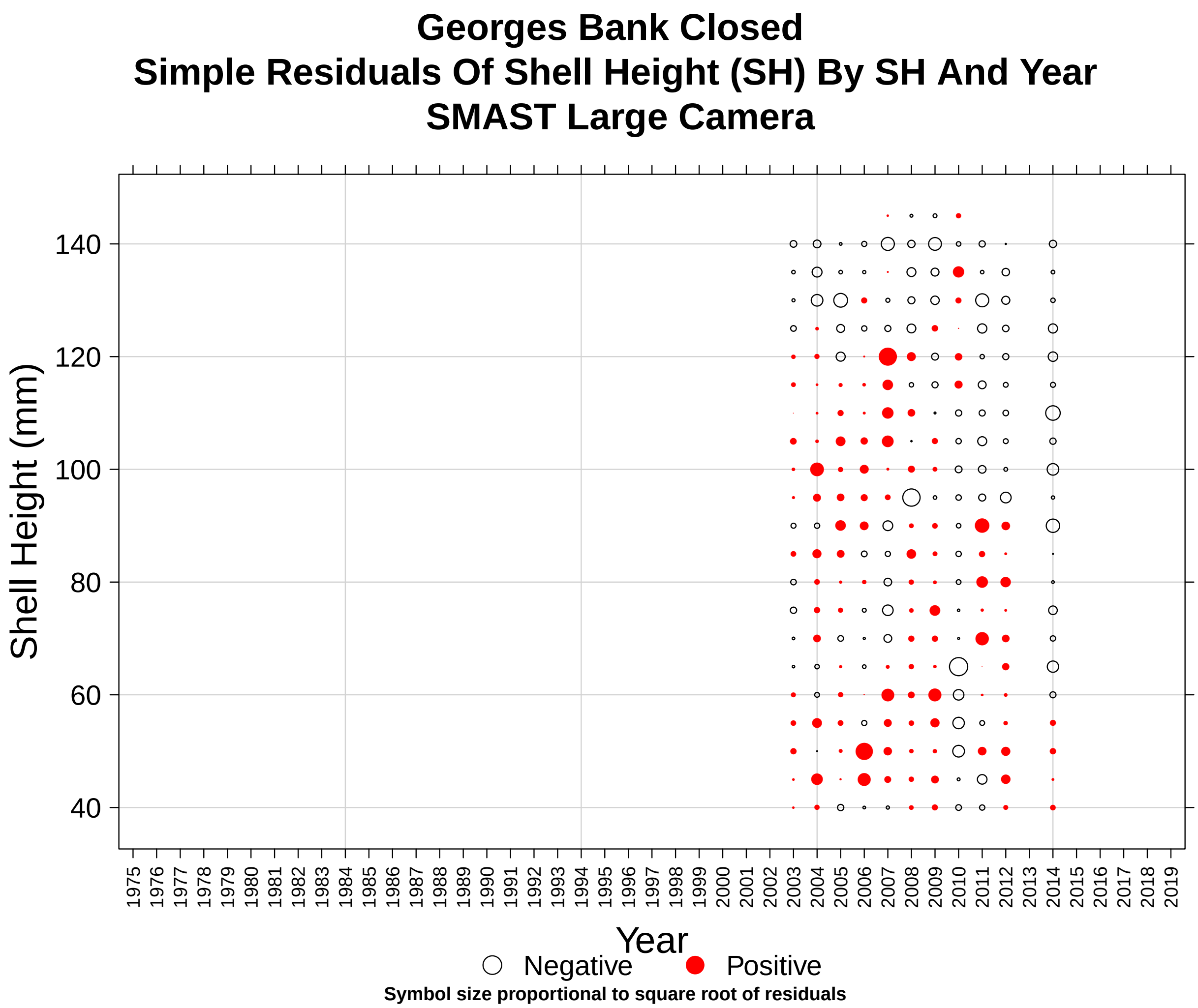


Figure 12: Simple residuals of SMAST large camera survey shell height proportions for Georges Bank closed areas. Symbol areas are proportional to residual.

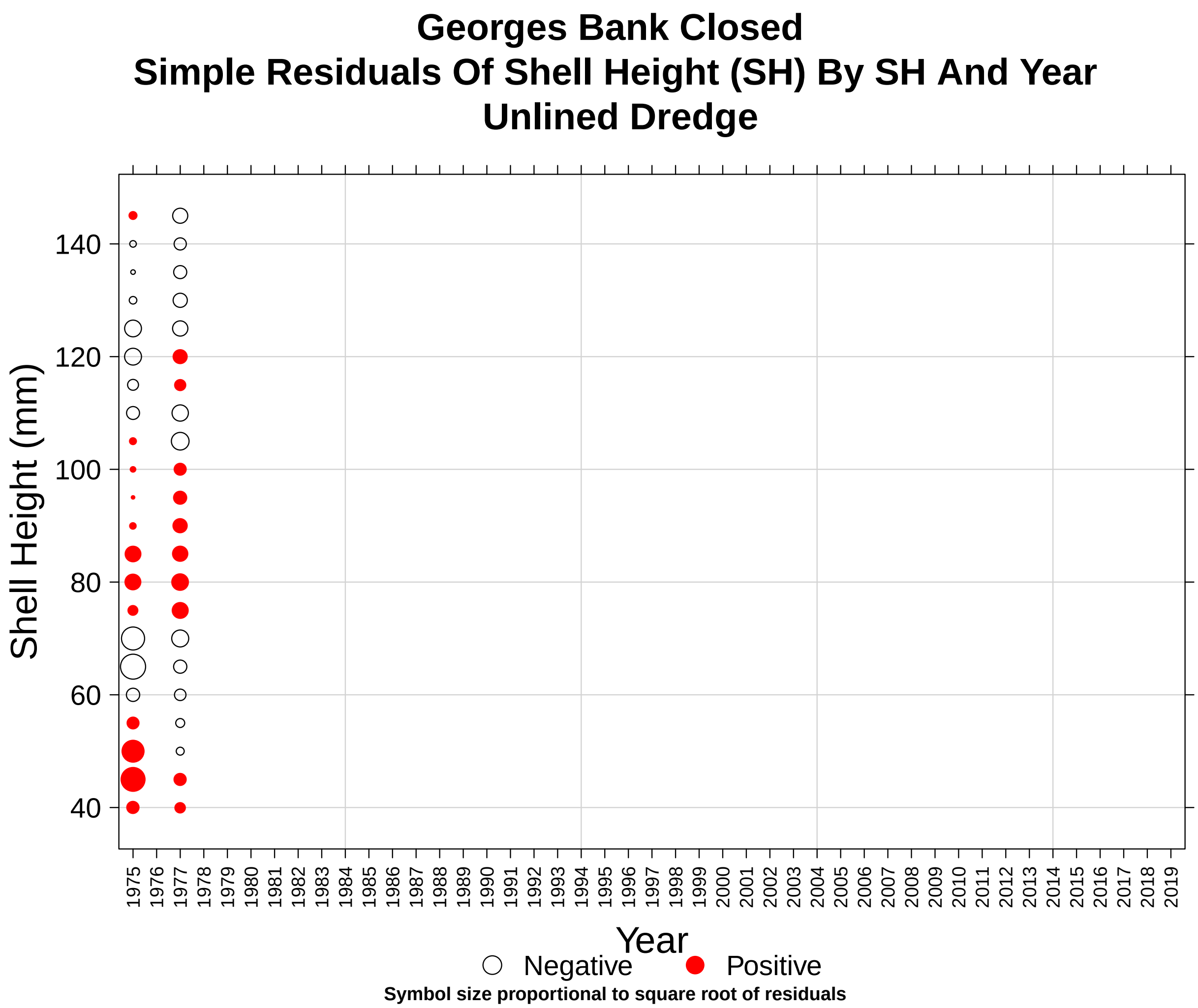


Figure 13: Simple residuals of unlined dredge survey shell height proportions for Georges Bank closed areas. Symbol areas are proportional to residual.

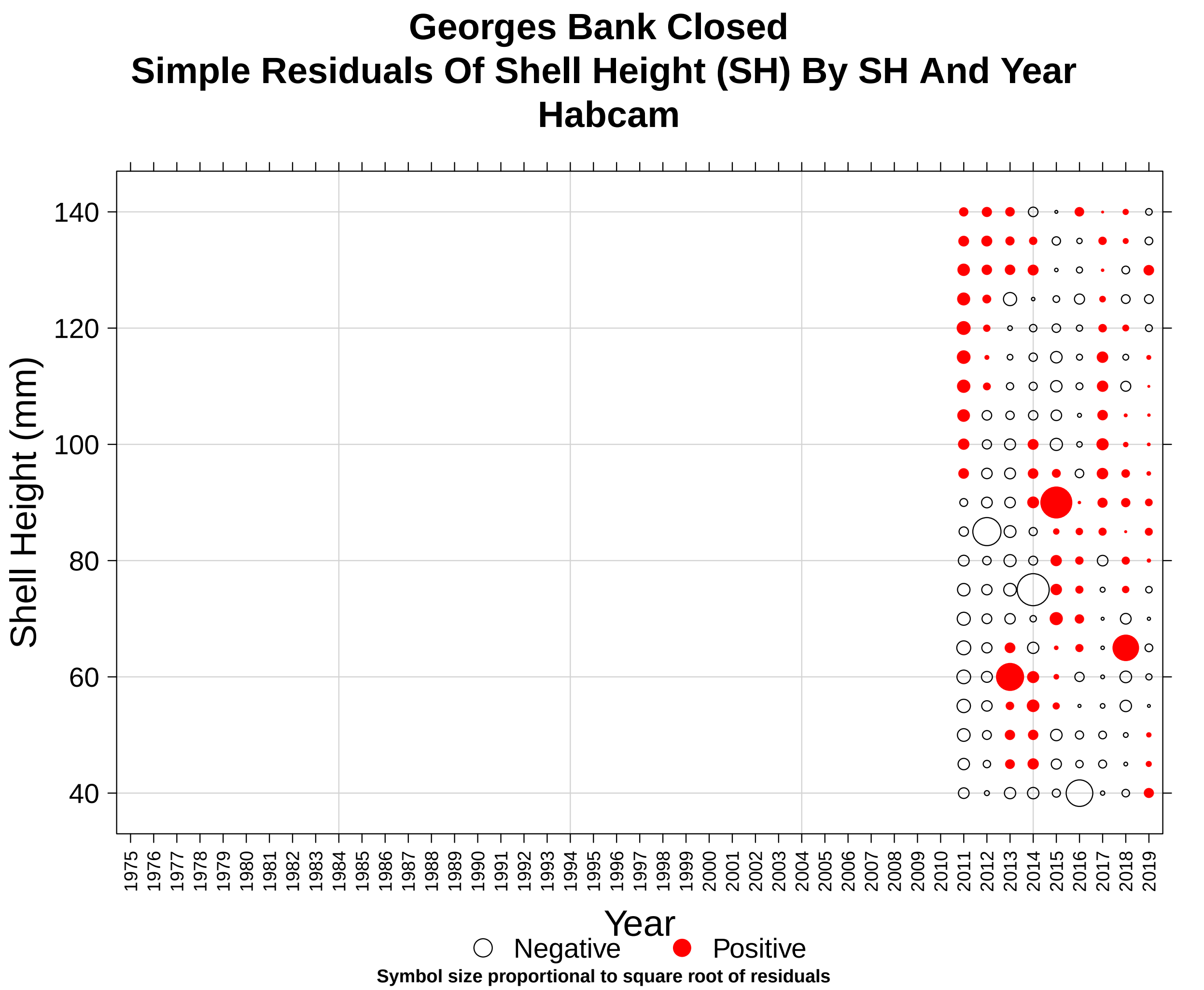


Figure 14: Simple residuals of Habcam survey shell height proportions for Georges Bank closed areas. Symbol areas are proportional to residual.

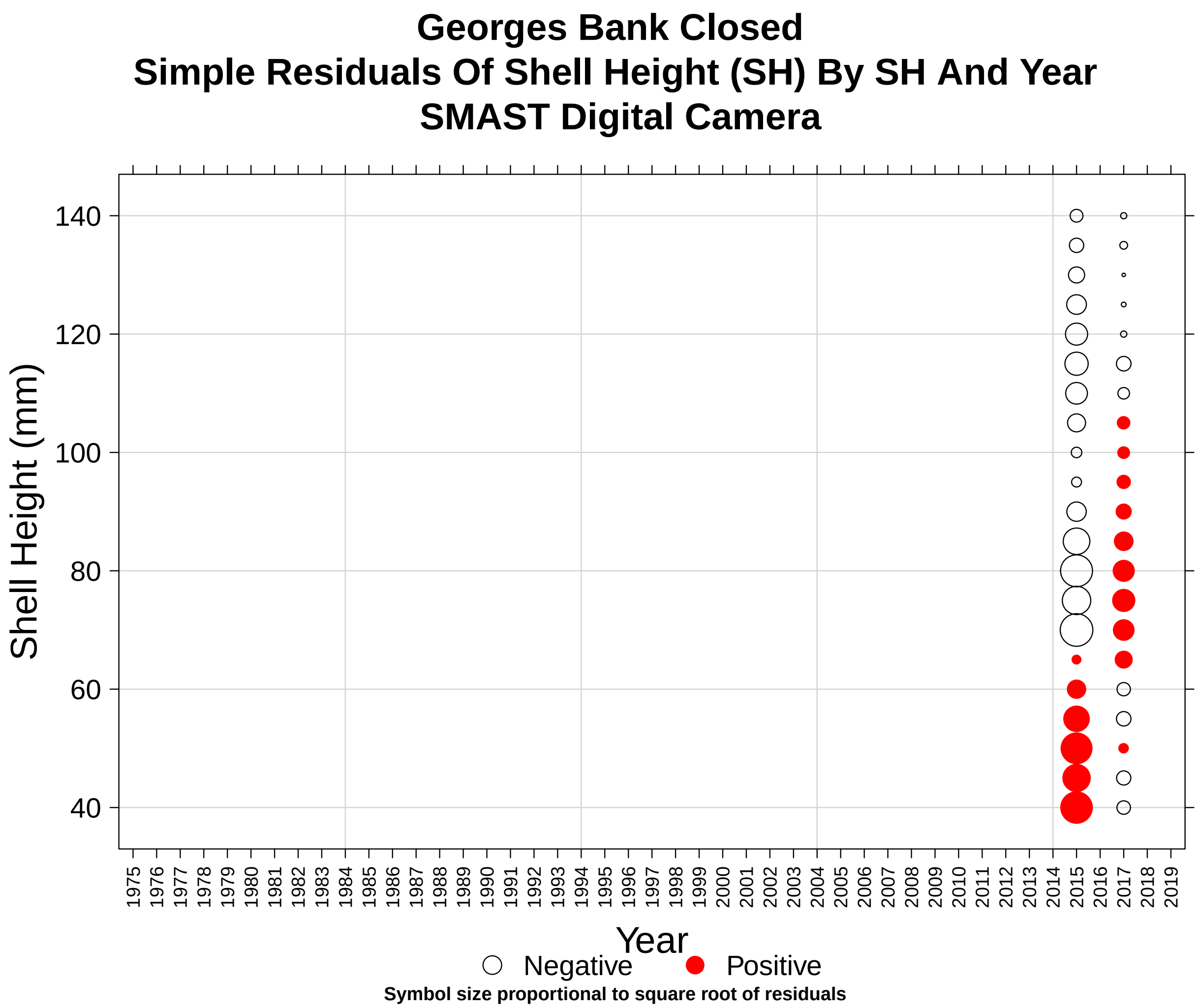


Figure 15: Simple residuals of SMAST digital camera survey shell height proportions for Georges Bank closed areas. Symbol areas are proportional to residual.

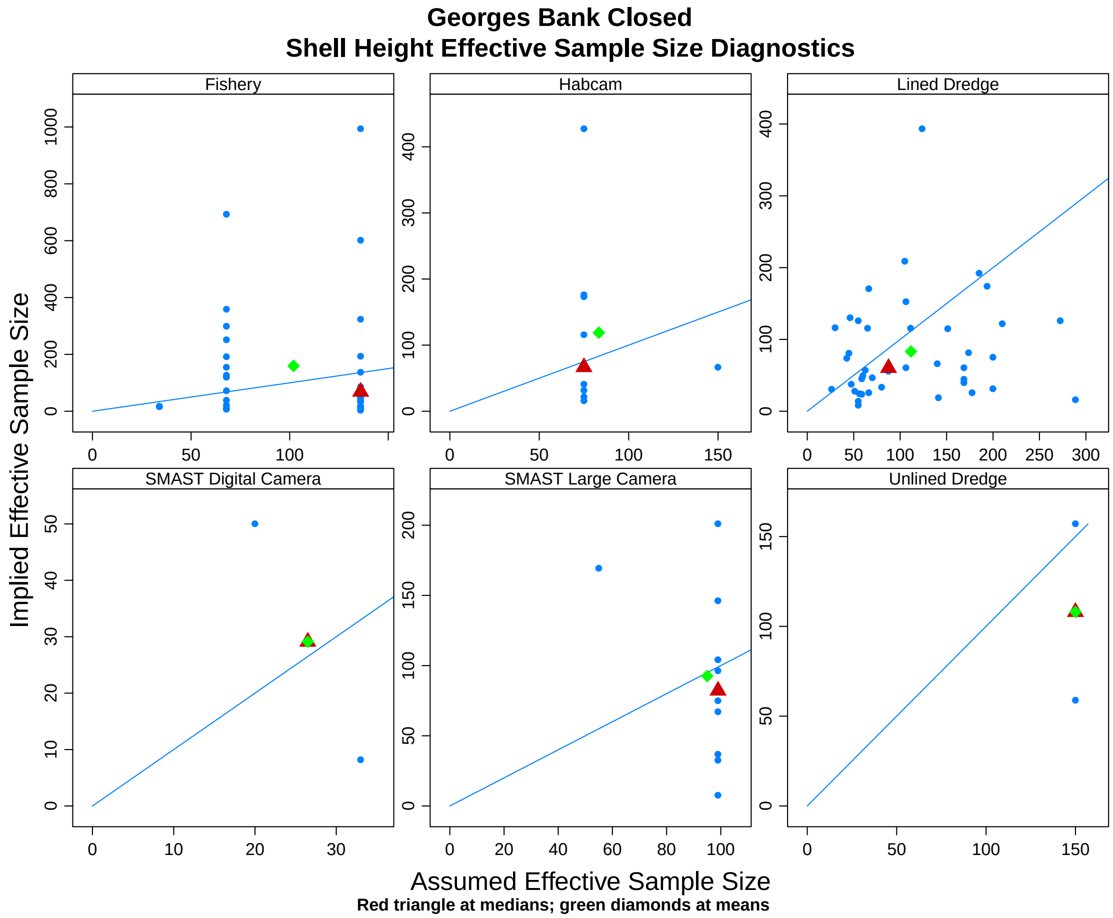


Figure 16: Assumed and model implied effective sample sizes for SMAST digital camera, lined dredge, Habcam, SMAST large camera, and unlined dredge surveys, and the fishery shell height compositions for Georges Bank closed areas. The triangle is the median and the diamond is the mean.

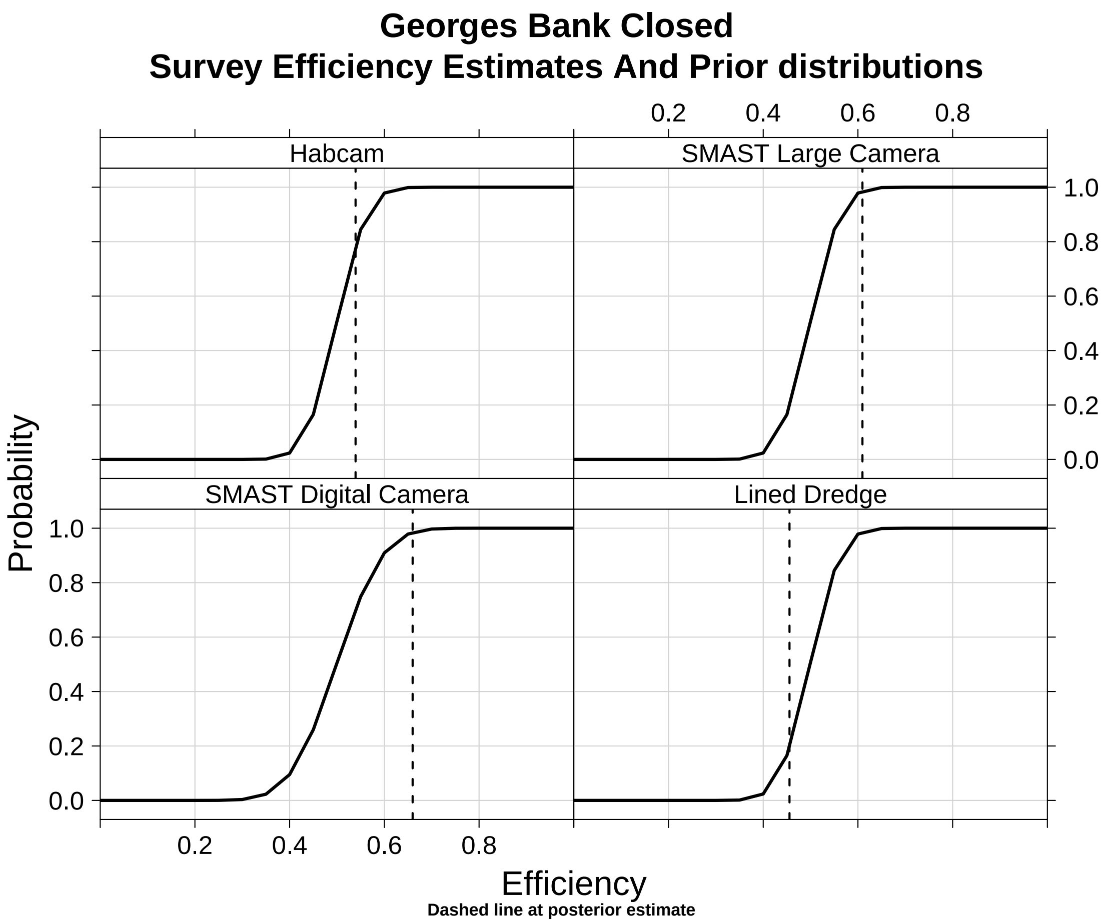
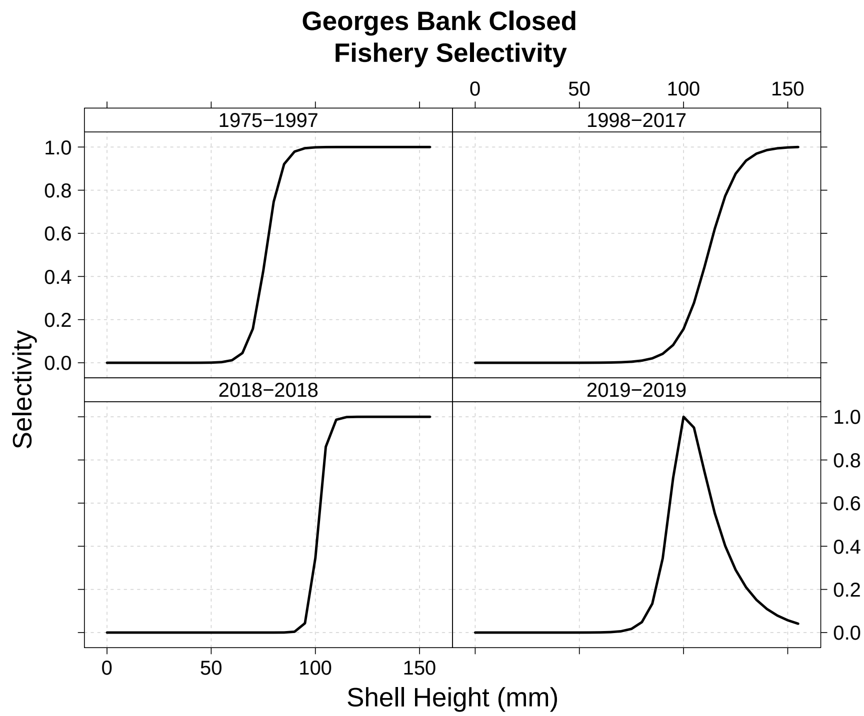


Figure 17: Prior cumulative distributions for catchability of Habcam, SMAST large camera, SMAST digital camera, and lined dredge surveys for Georges Bank closed areas. The dashed lines are the mean posterior estimate for survey catchability. For the purposes of this plot, the surveys were adjusted to have a mean prior catchability of 0.5.



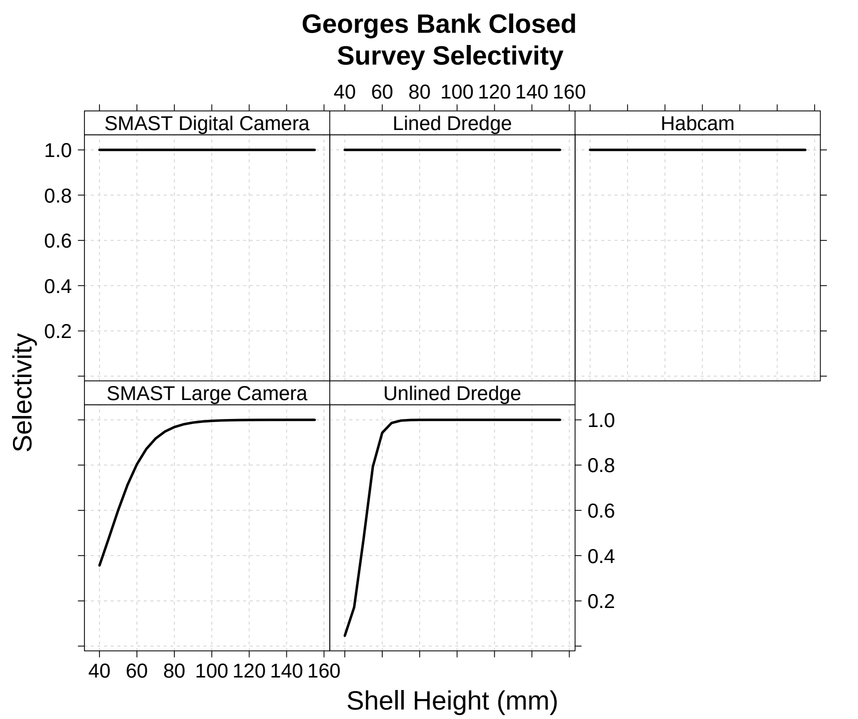


Figure 18: Estimated fishery selectivity curves (top) and assumed selectivity curves (bottom) for SMAST digital camera, lined dredge, Habcam, SMAST large camera, and unlined dredge surveys for Georges Bank closed areas.

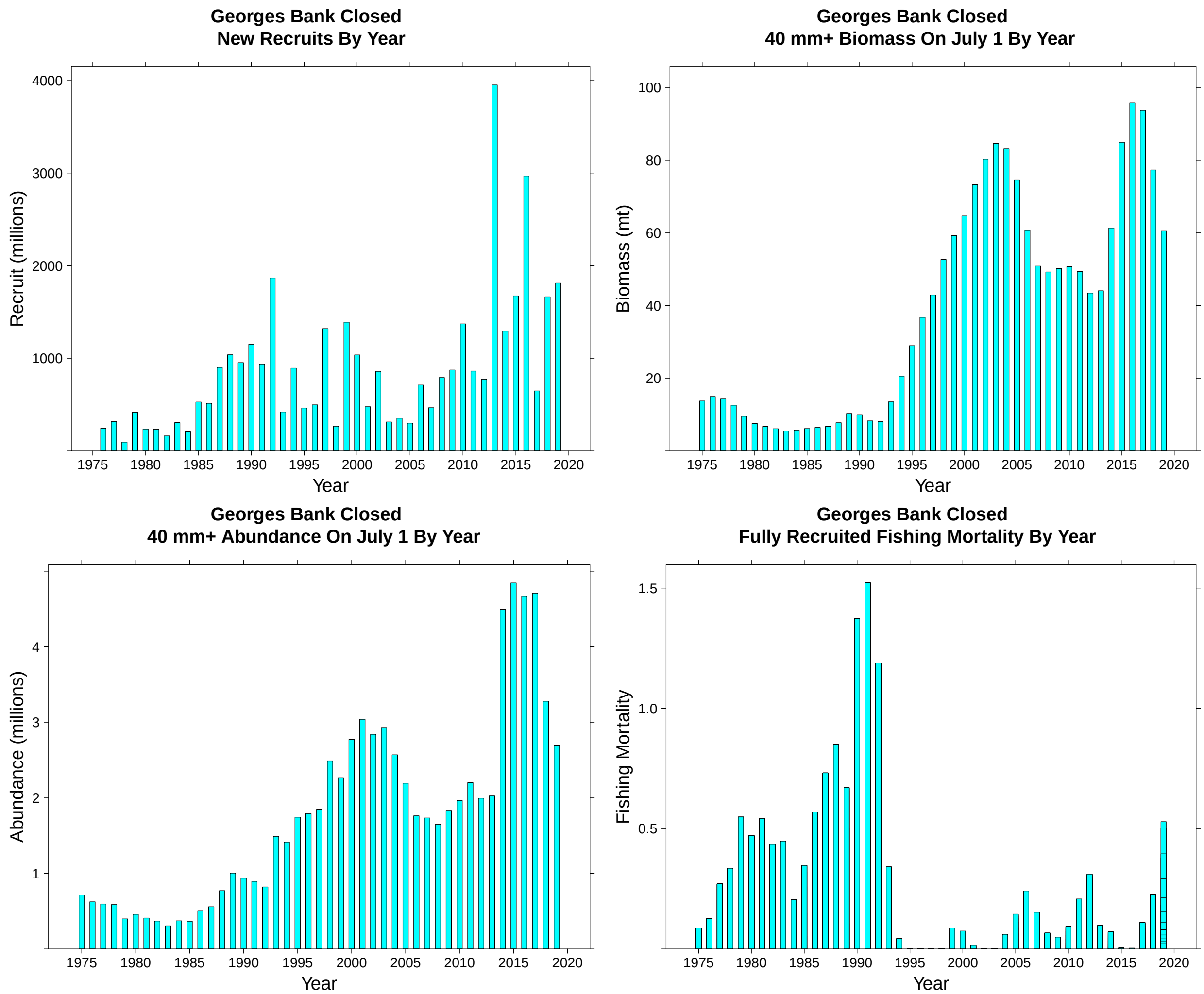


Figure 19: CASA model estimated recruitment (top left), July 1 biomass (top right), July 1 abundance (bottom left) and fully recruited fishing mortality (bottom right) for Georges Bank closed areas.

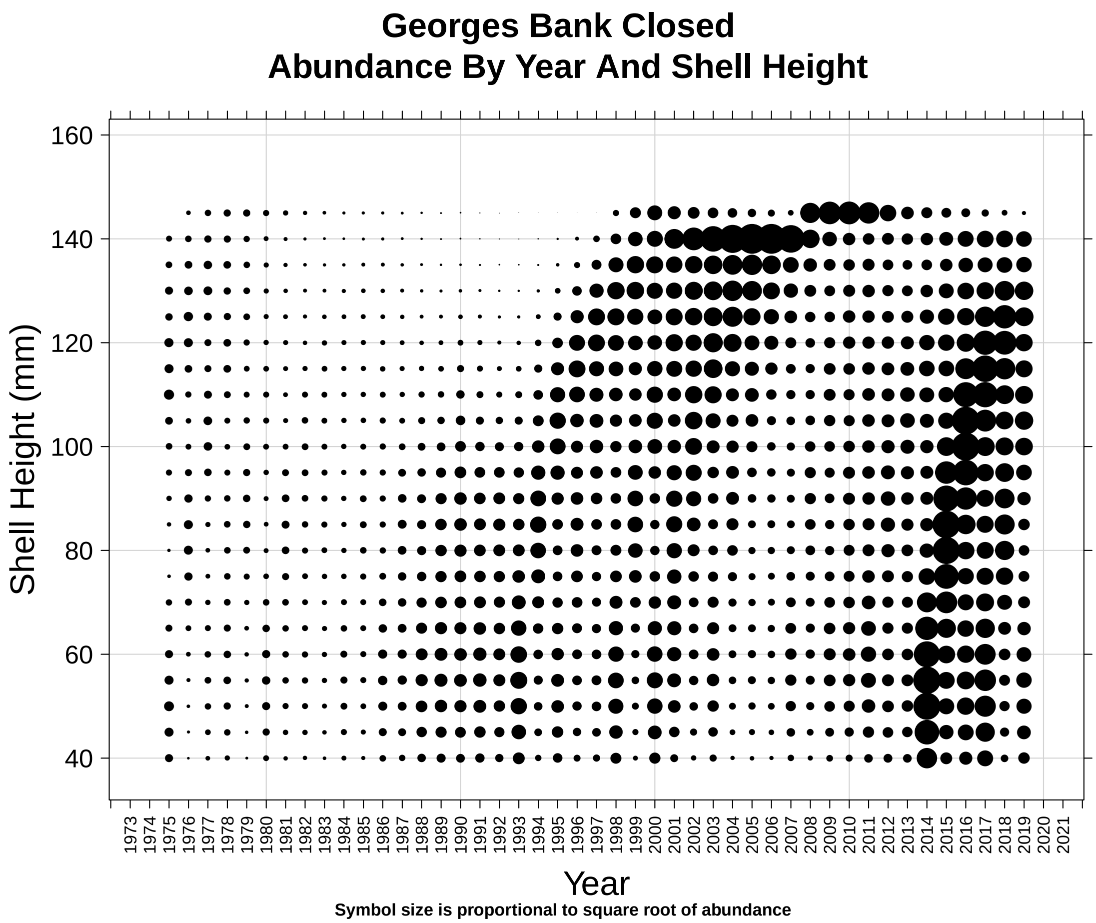


Figure 20: CASA model estimated abundances at shell height for Georges Bank closed areas. Symbol areas are proportional to abundance.

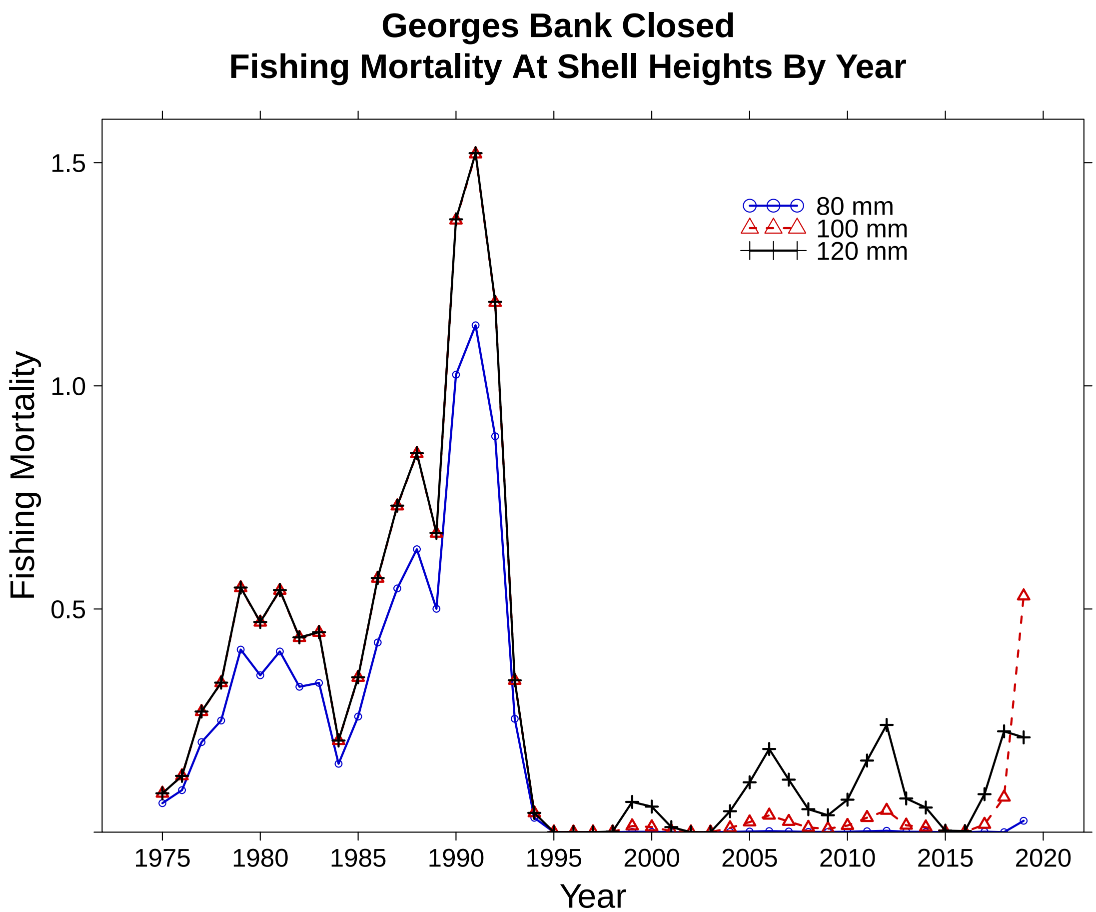


Figure 21: CASA model estimated fishing mortality at 80 mm (solid line with circles), 100 mm (dashed line with triangles), and 120 mm SH (dashed line with crosses) for Georges Bank closed areas.

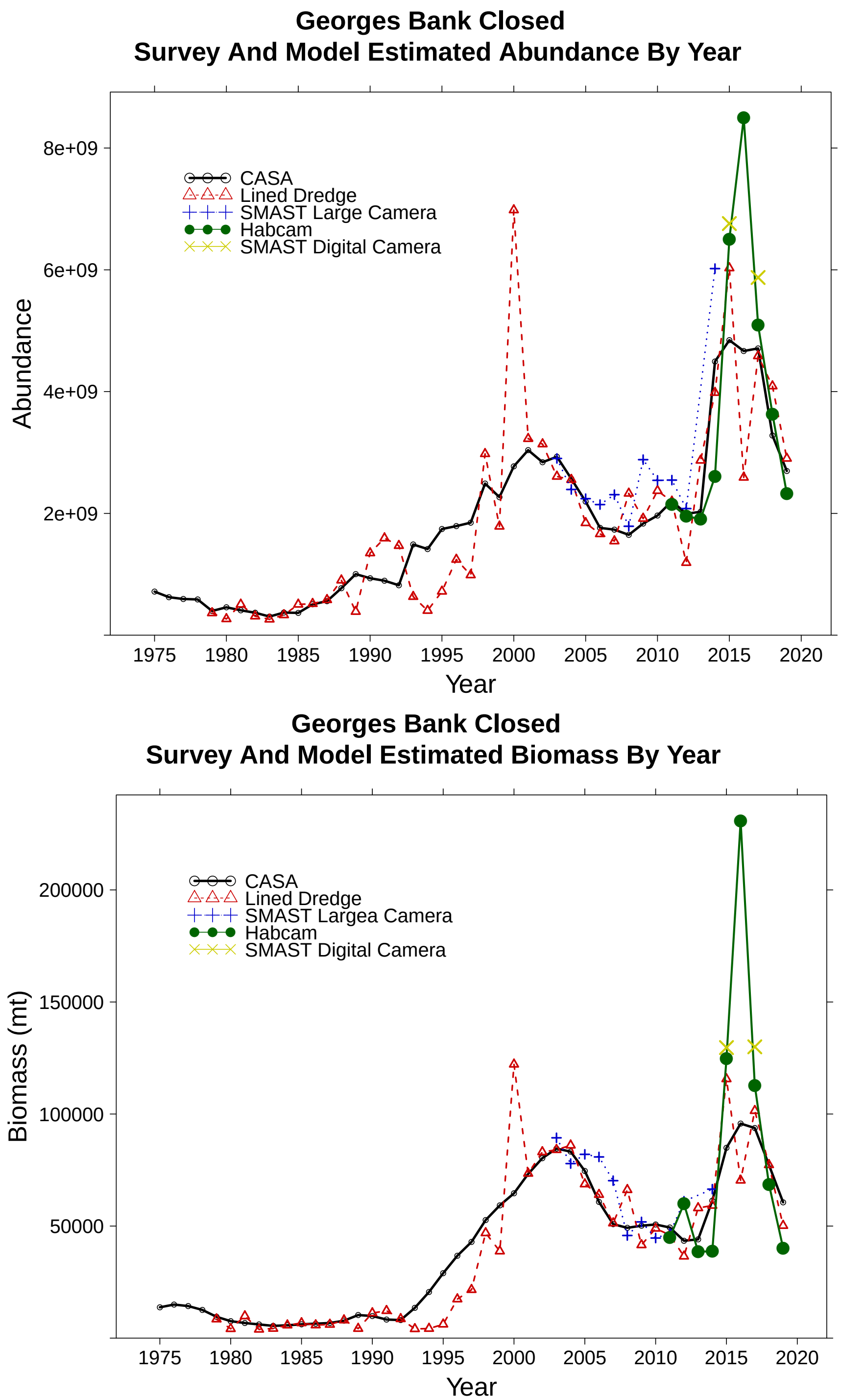


Figure 22: Comparison of CASA model estimated abundance (top) and biomass (bottom) with expanded estimates from the lined dredge (red), SMAST large camera (blue), HabCam (green), and SMAST digital camera (light green) for Georges Bank closed areas.

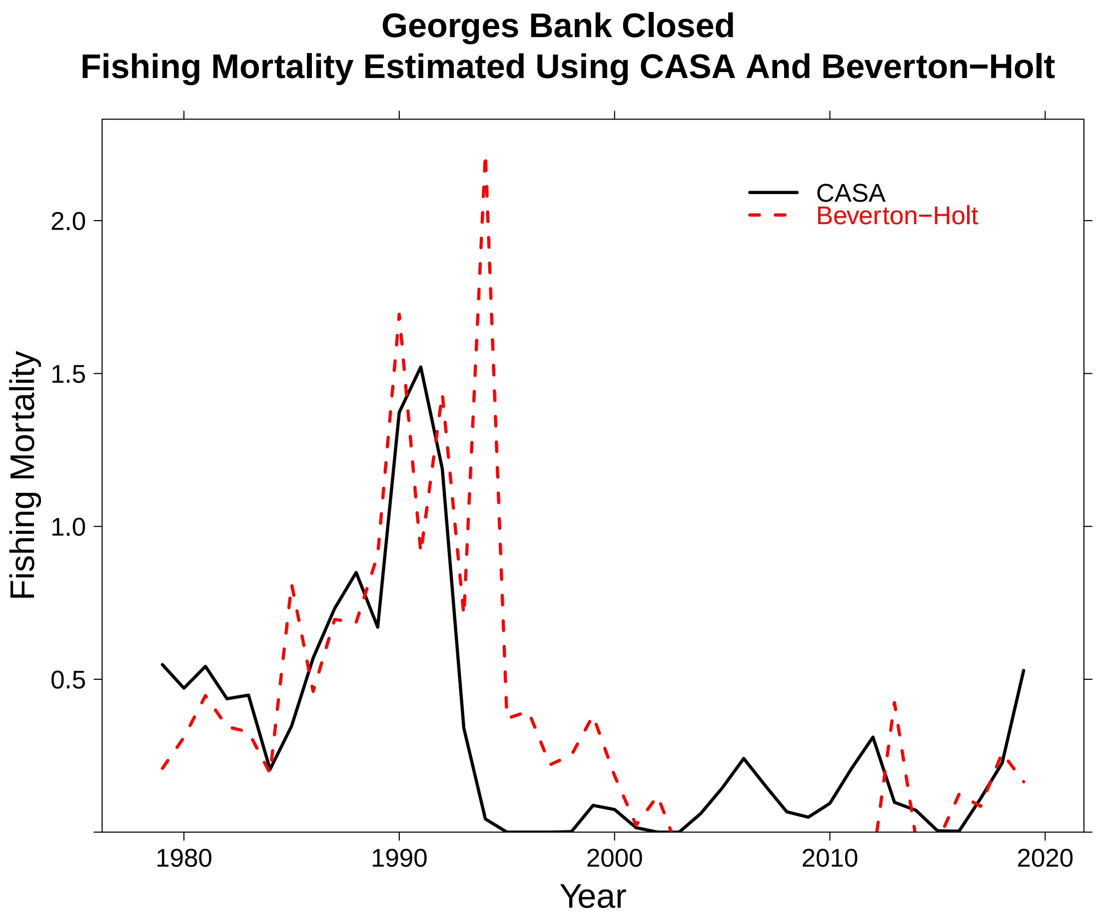


Figure 23: Comparison of fully recruited CASA fishing mortality with those calculated from the Beverton-Holt equilibrium length based estimator for Georges Bank closed areas.

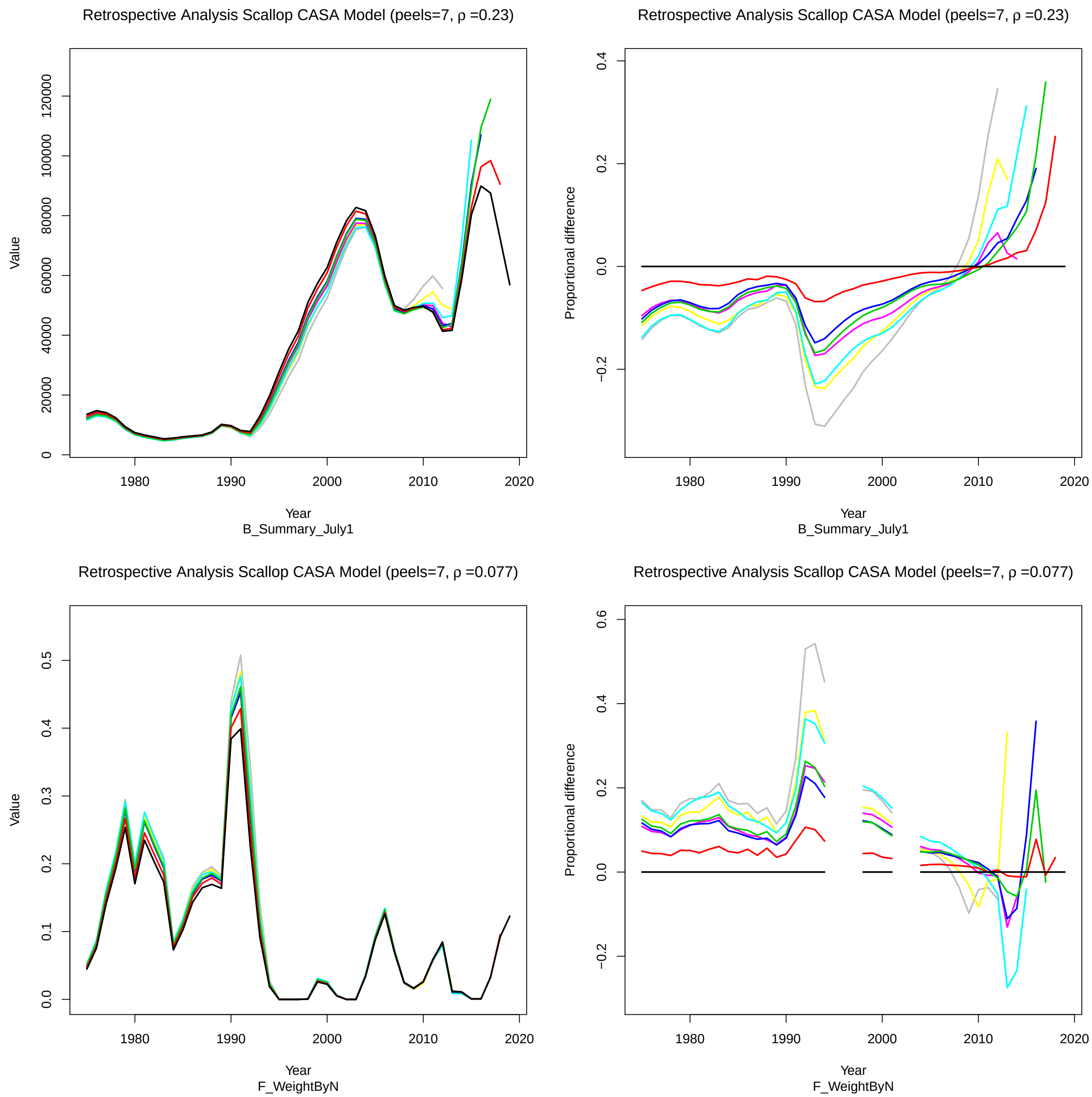


Figure 24: Retrospective plots for biomass and fishing mortality for Georges Bank closed areas. Retrospectives are shown on both absolute and relative scales.

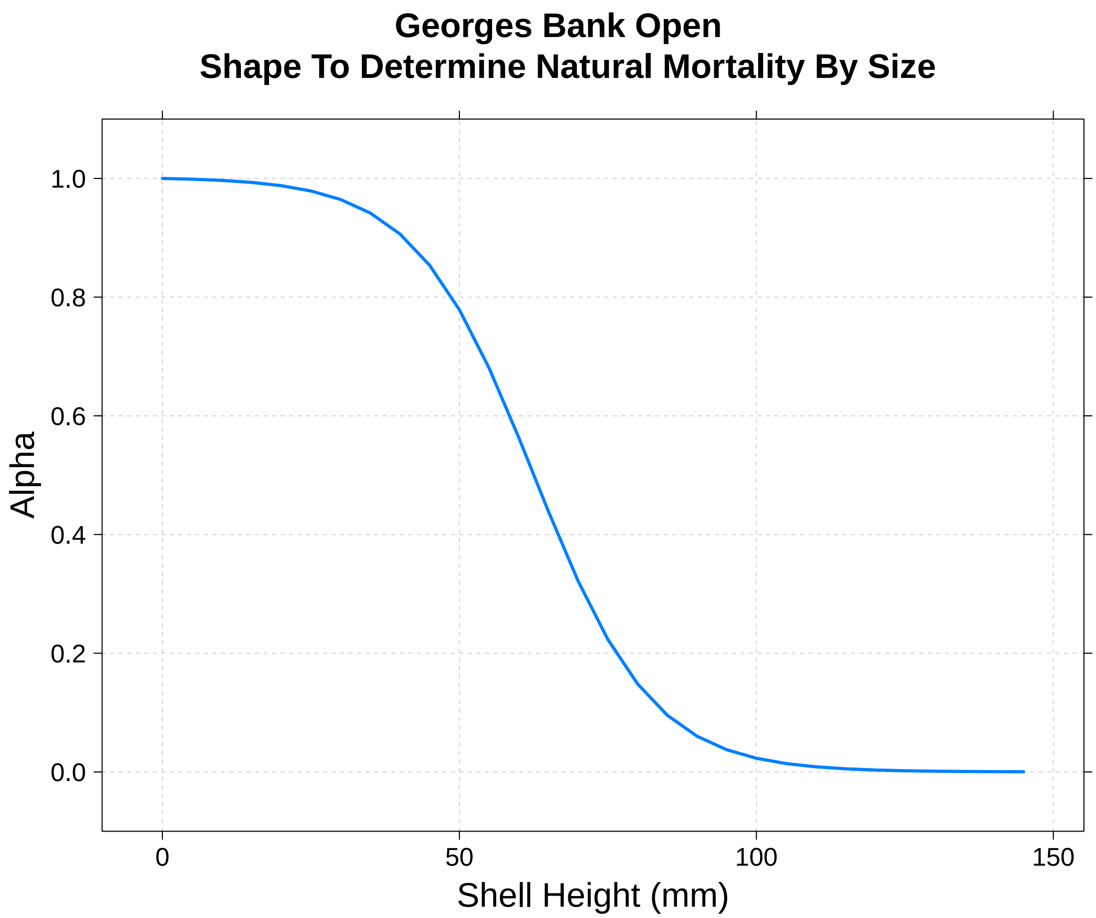


Figure 25: Logistic curve used to partition juvenile and adult natural mortality for Georges Bank open areas.

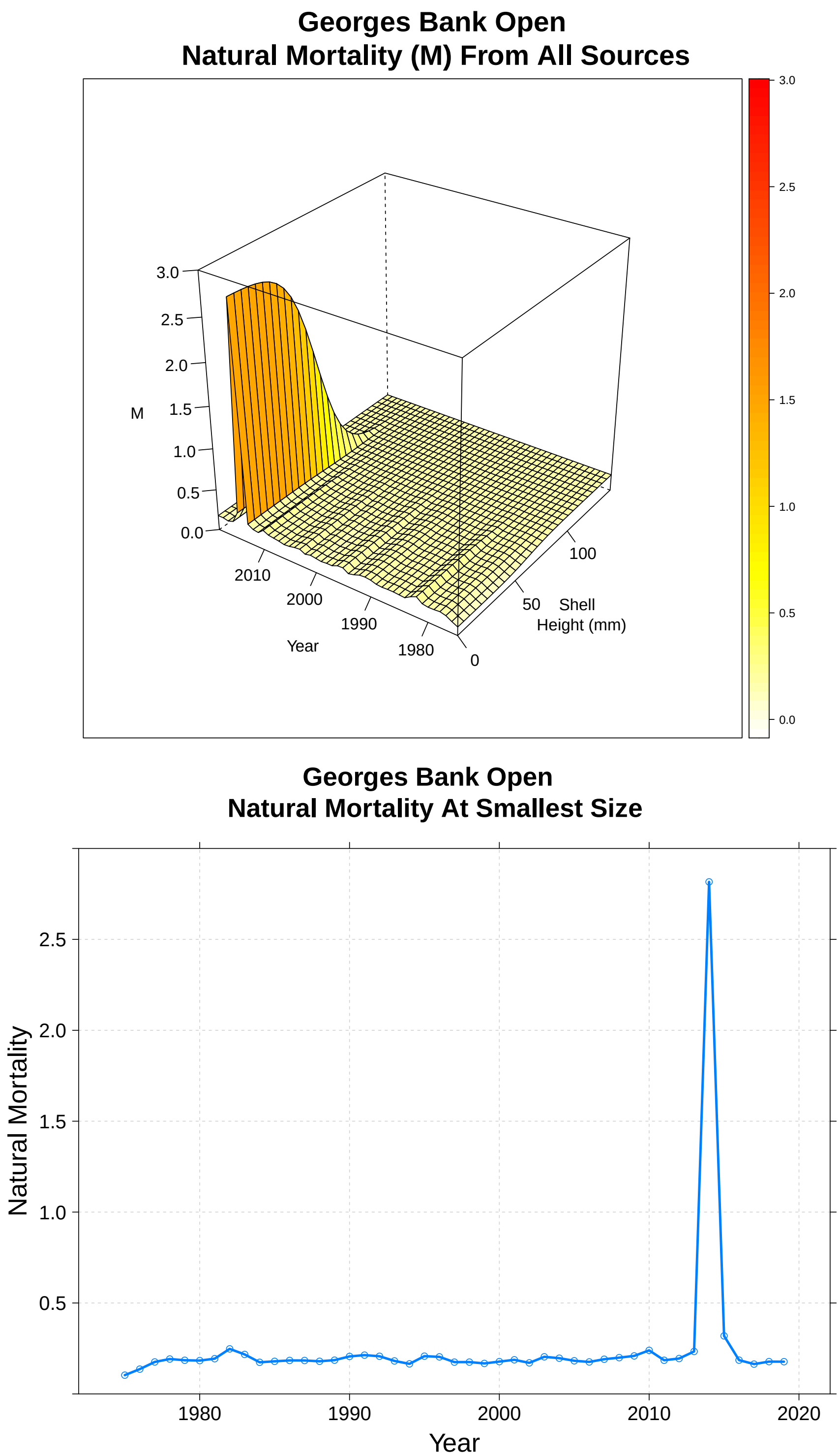


Figure 26: Estimated natural mortality by size (top) and for smallest size group (bottom) from 1975 to 2019 for Georges Bank open areas.

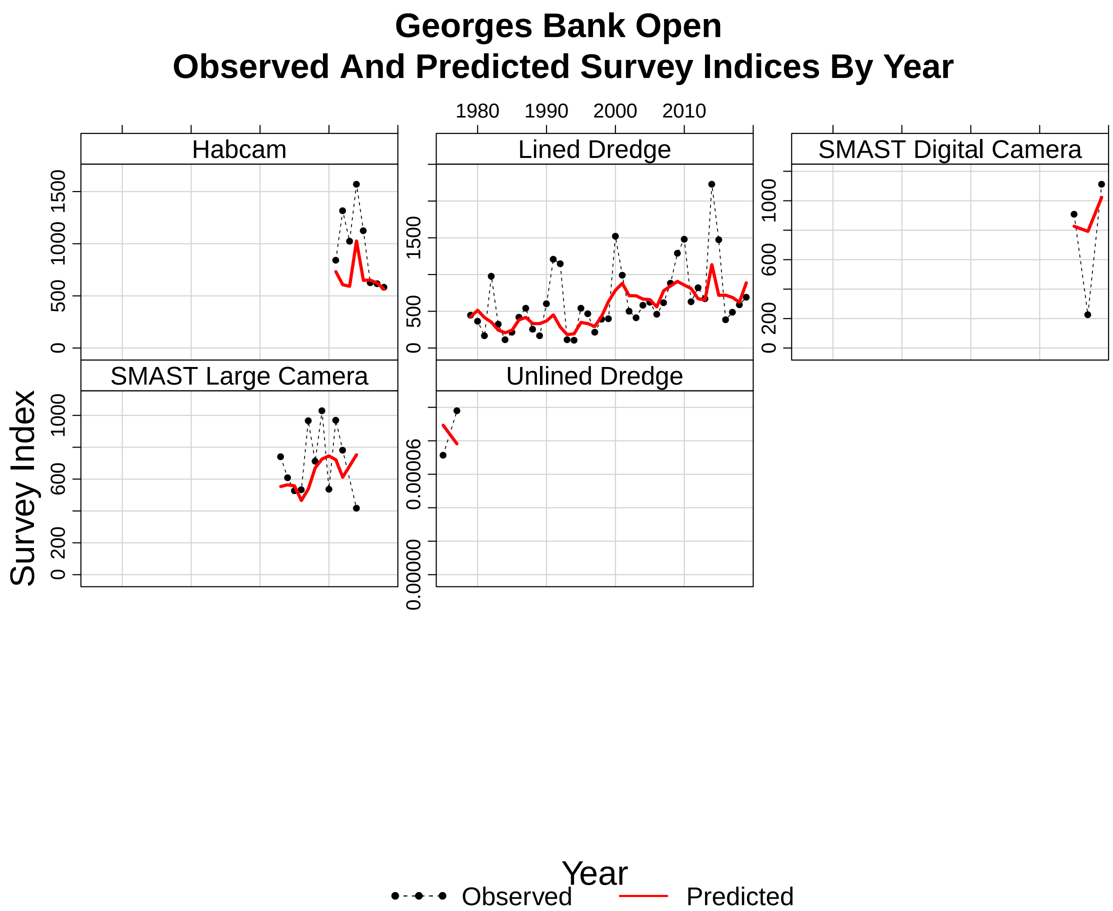


Figure 27: Observed survey trend (solid circles) and corresponding model estimates (lines) for the SMAST digital camera (top left), lined dredge (top middle), Habcam (top right), SMAST large camera (bottom left), and unlined dredge (bottom middle) surveys on Georges Bank open areas.

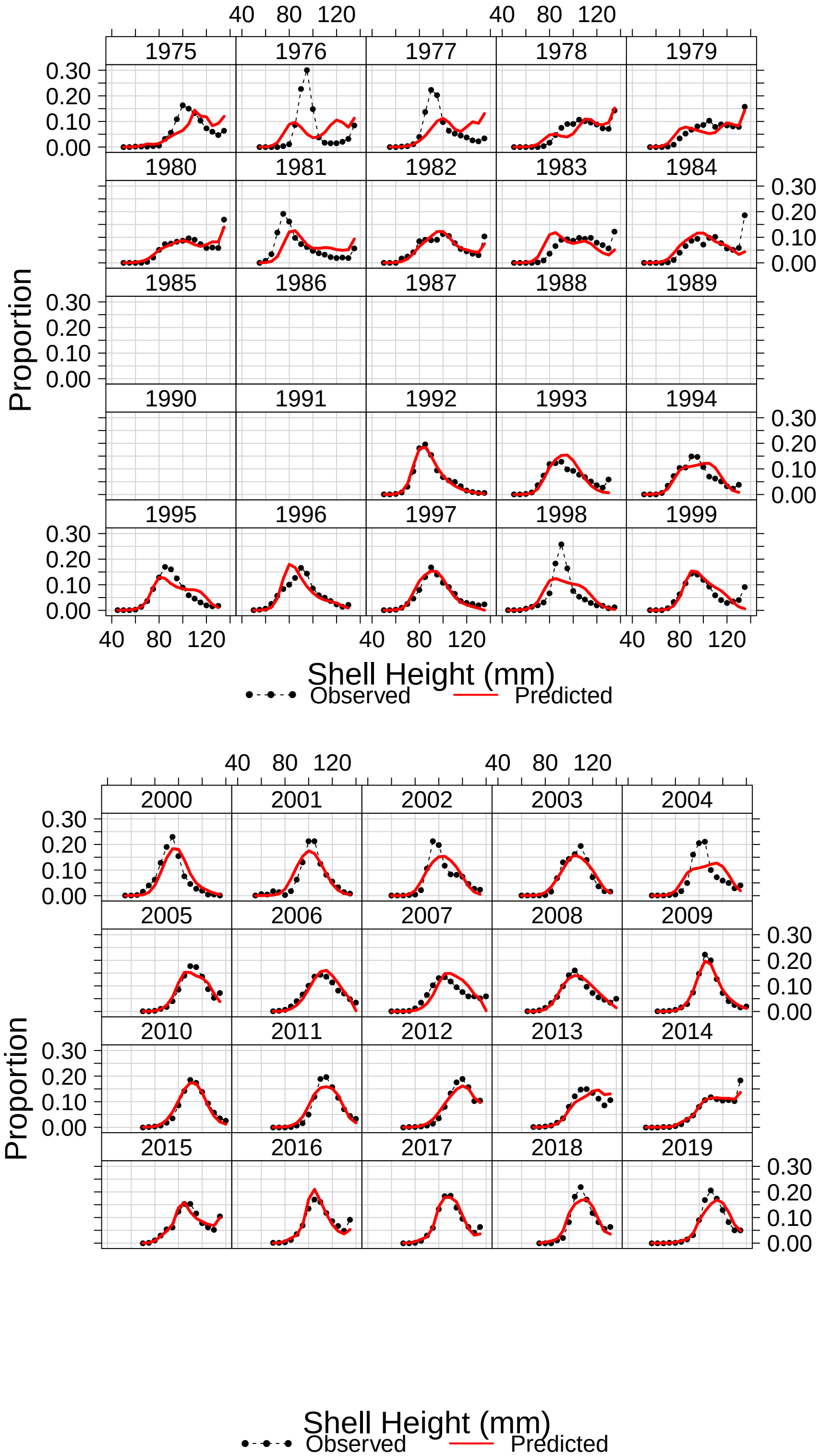


Figure 28: Comparison of observed fishery shell height proportions (solid circles) and model estimated fishery shell height proportions (lines) for Georges Bank open areas.

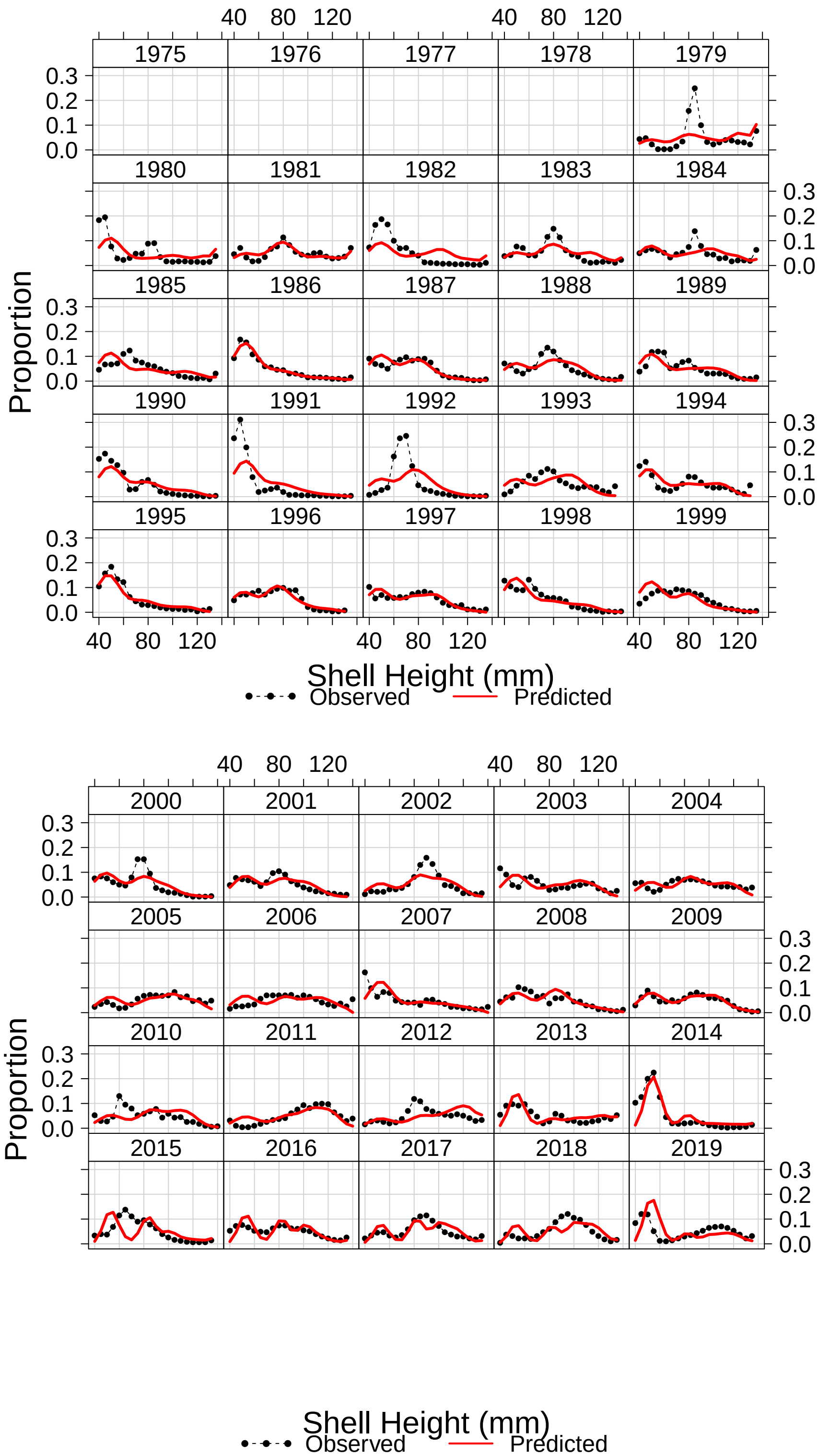


Figure 29: Comparison of lined dredge survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank open areas.

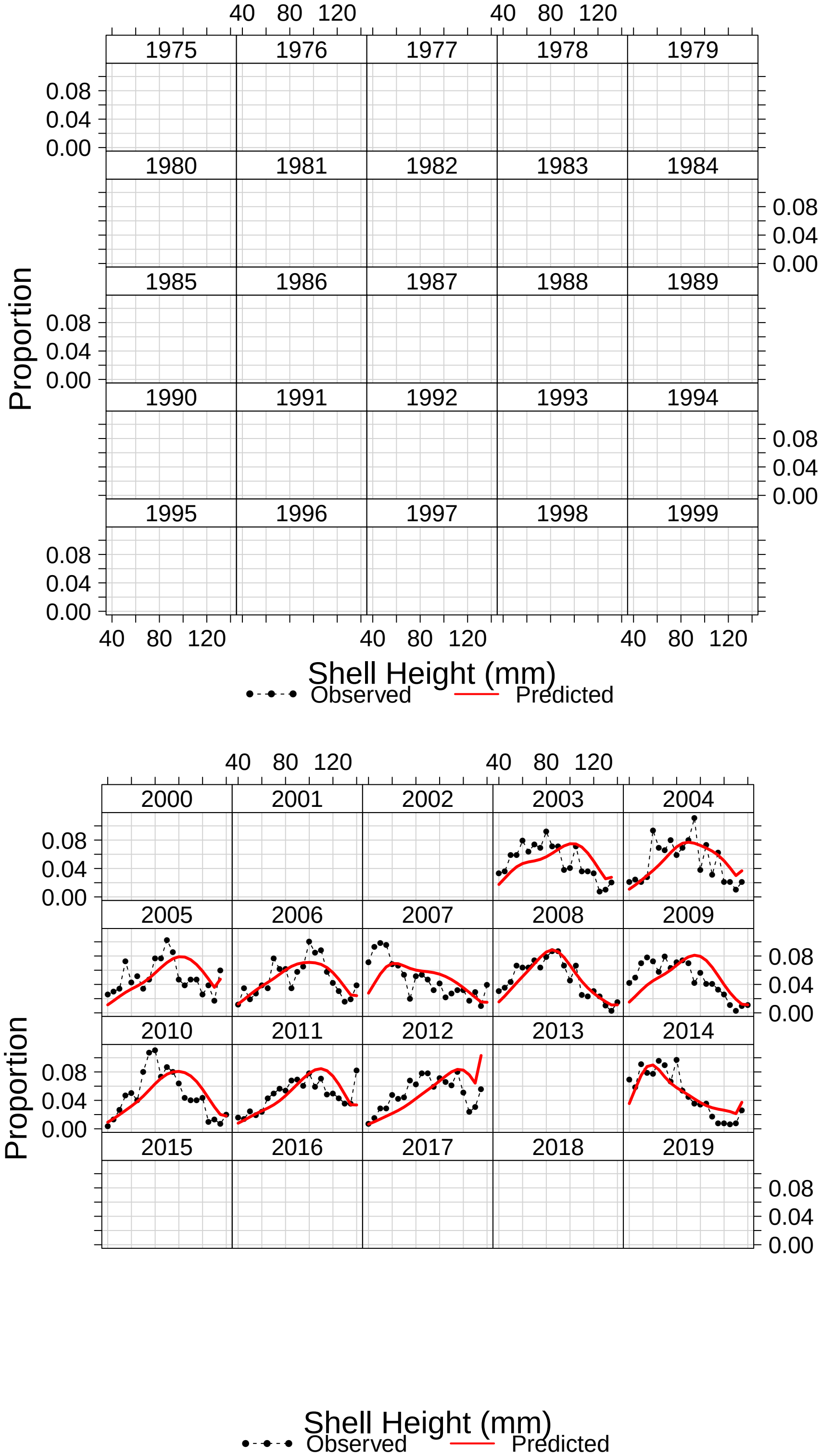
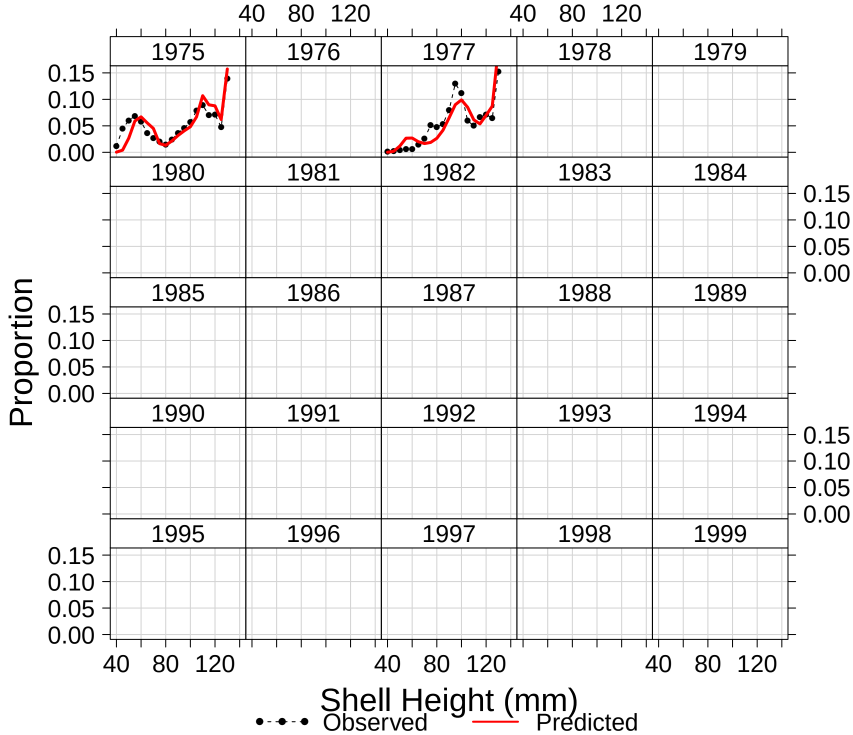


Figure 30: Comparison of SMAST large camera survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank open areas.



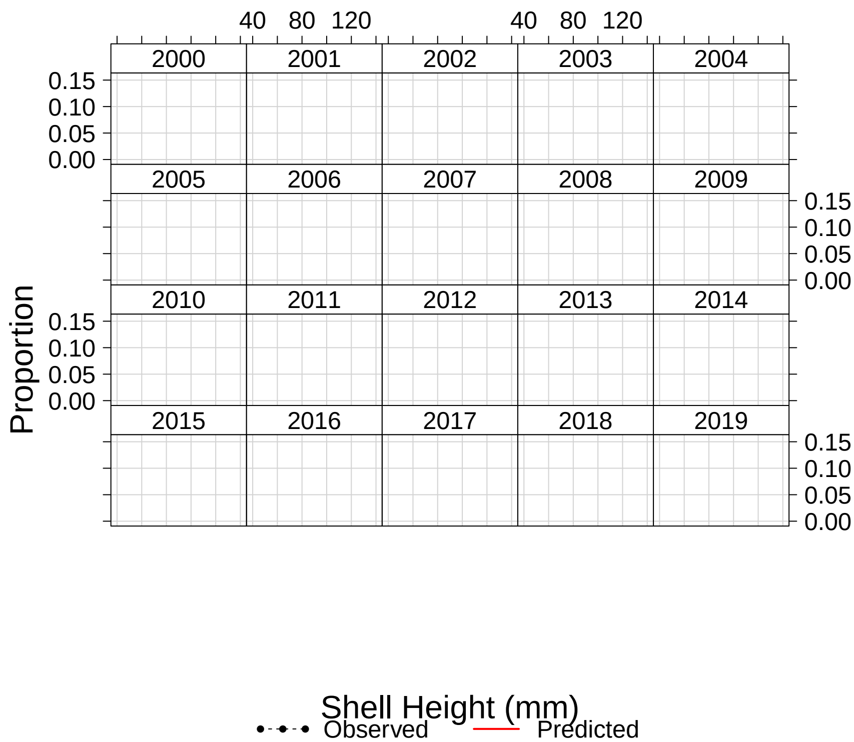


Figure 31: Comparison of unlined dredge survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank open areas.

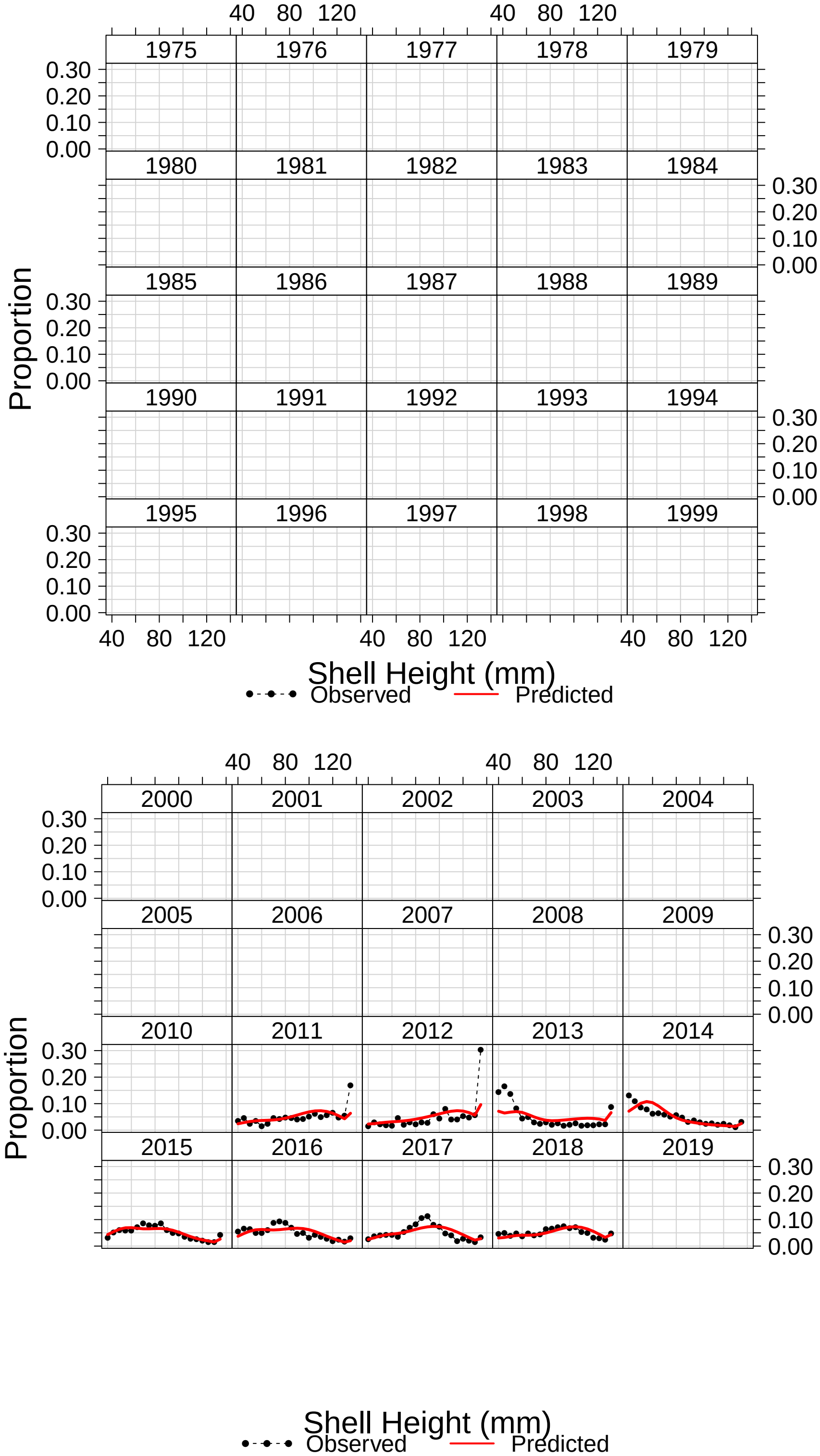


Figure 32: Comparison of Habcam survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank open areas.

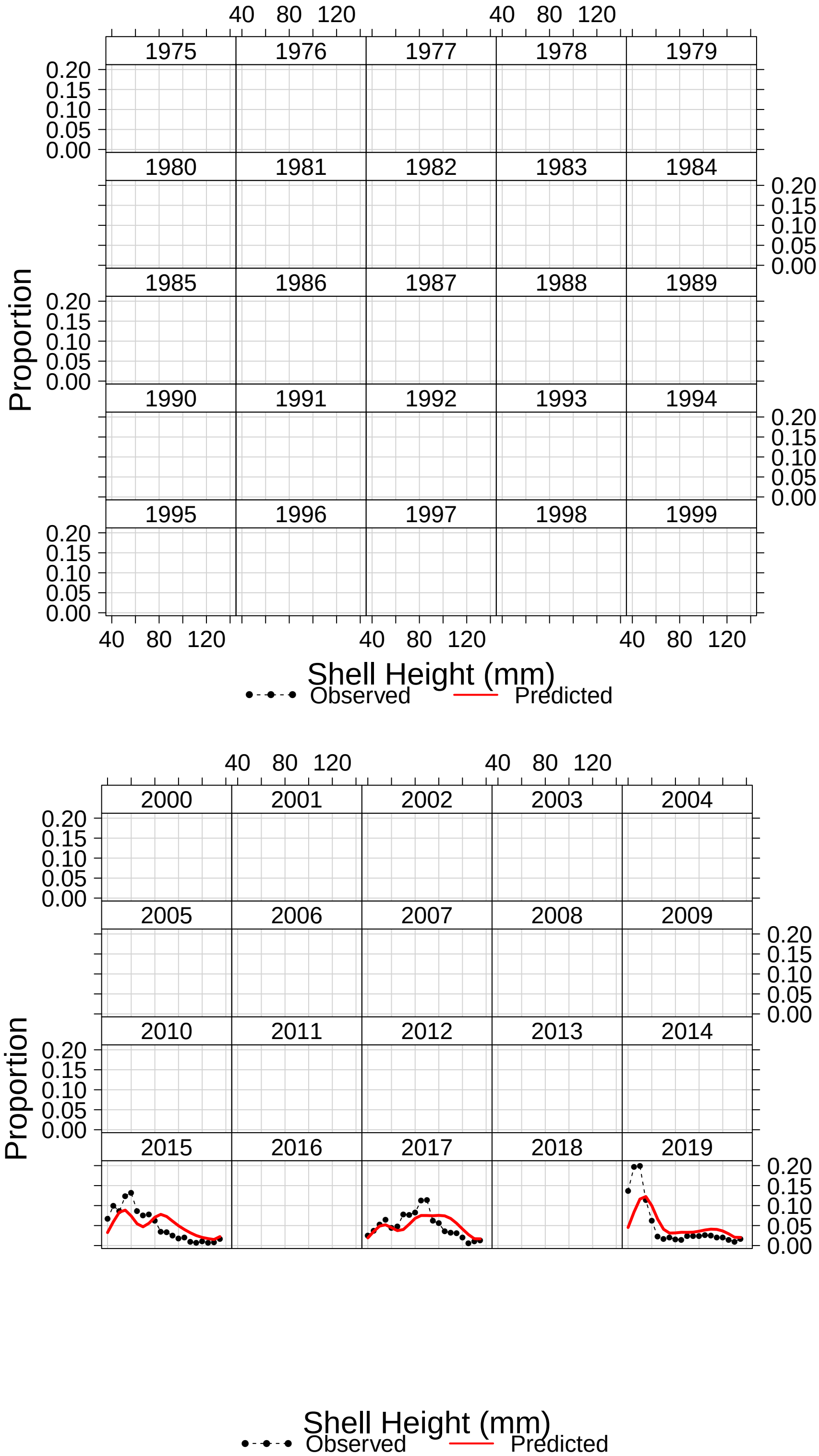


Figure 33: Comparison of SMAST digital camera survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank open areas.

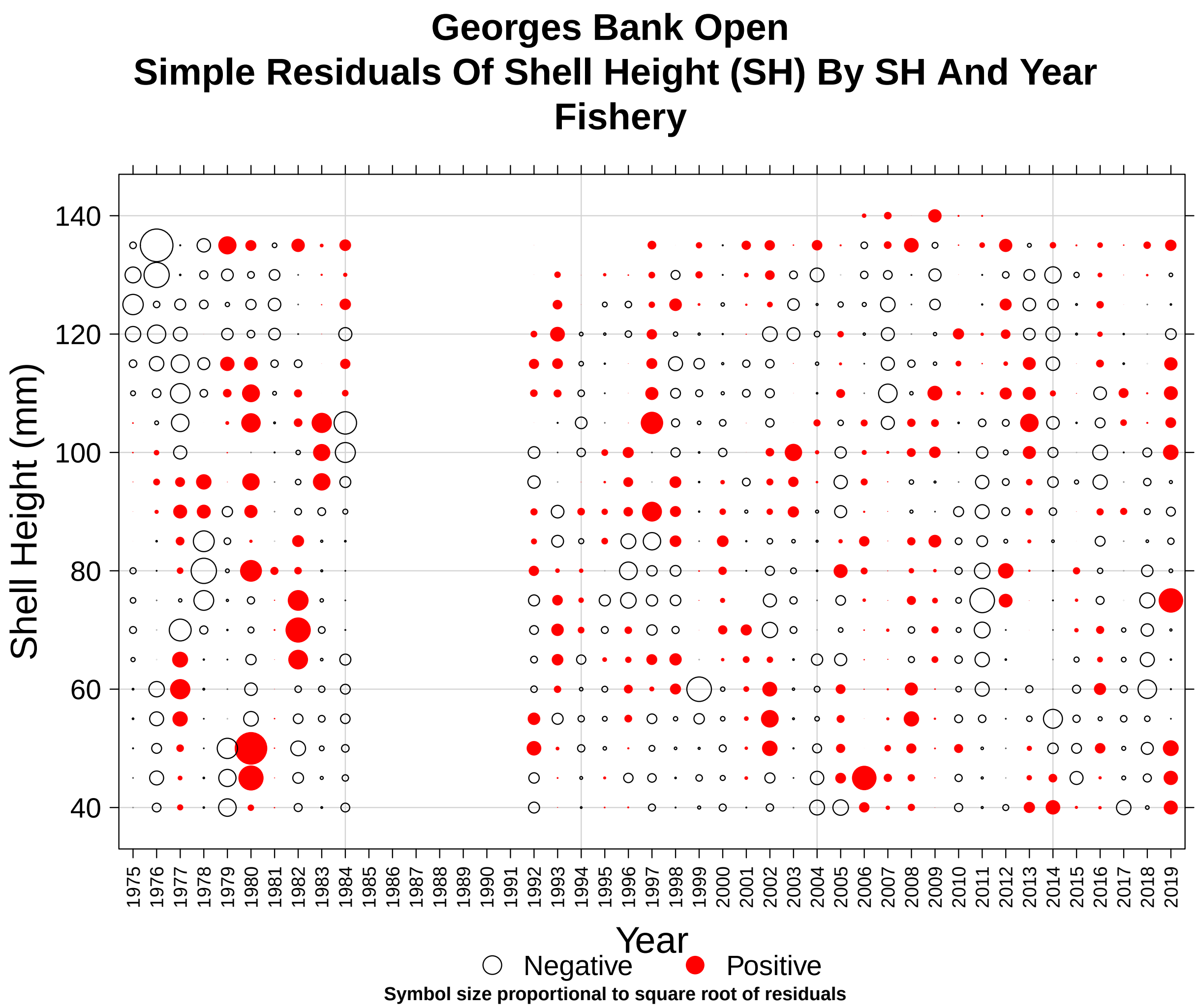


Figure 34: Simple residuals of fishery shell height proportions for Georges Bank open areas. Symbol areas are proportional to residual.

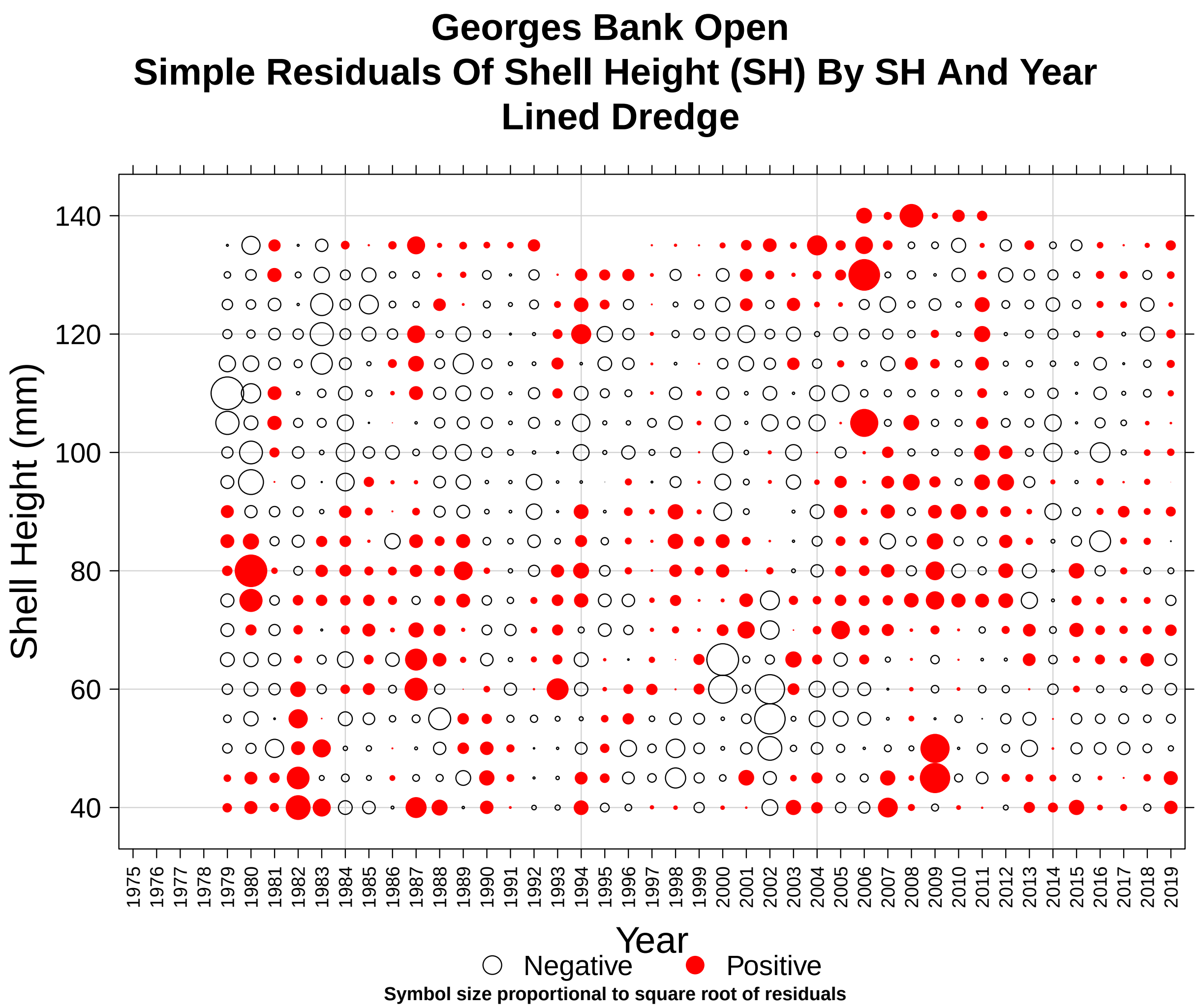


Figure 35: Simple residuals of lined dredge survey shell height proportions for Georges Bank open areas. Symbol areas are proportional to residual.

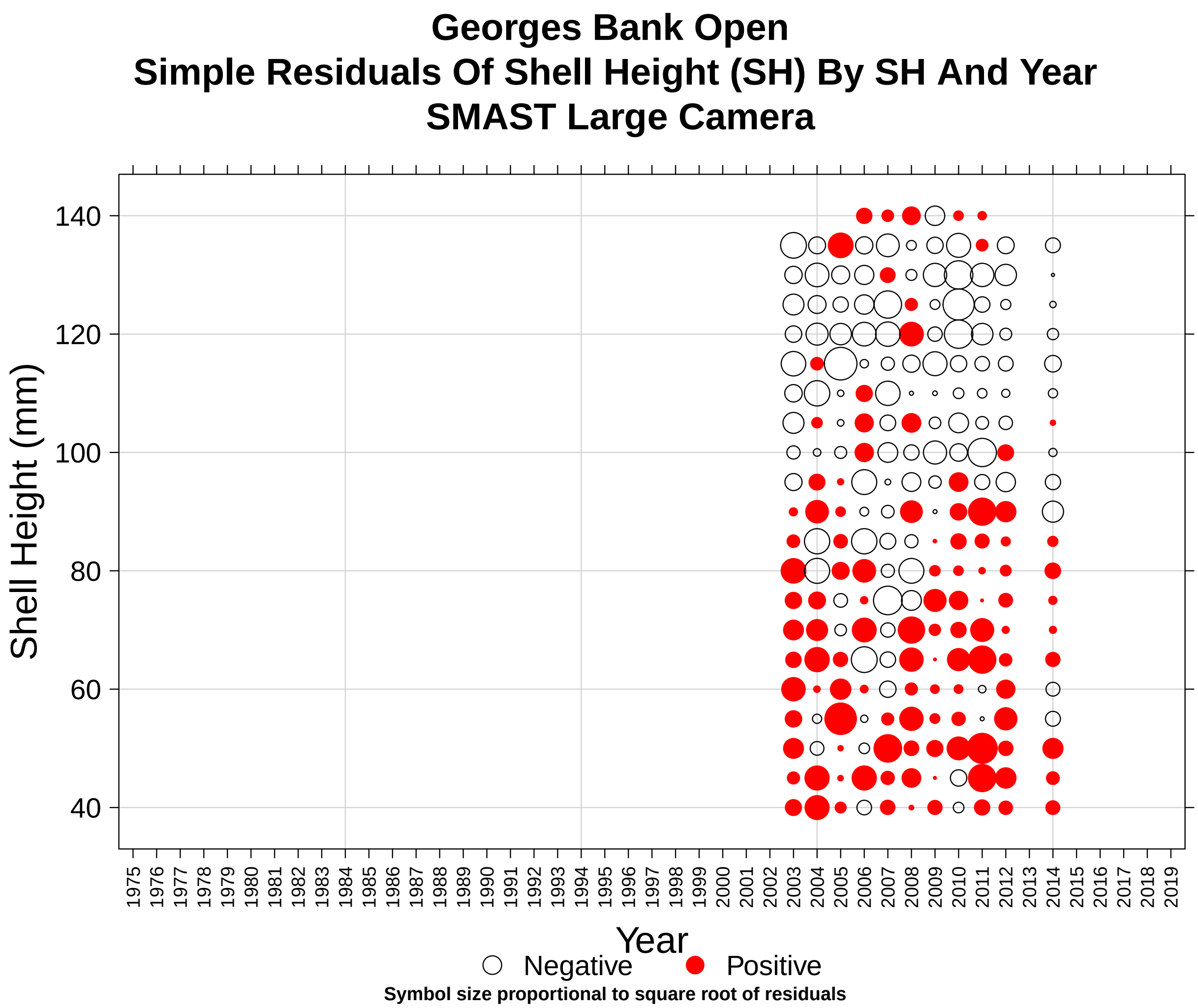


Figure 36: Simple residuals of SMAST large camera survey shell height proportions for Georges Bank open areas. Symbol areas are proportional to residual.

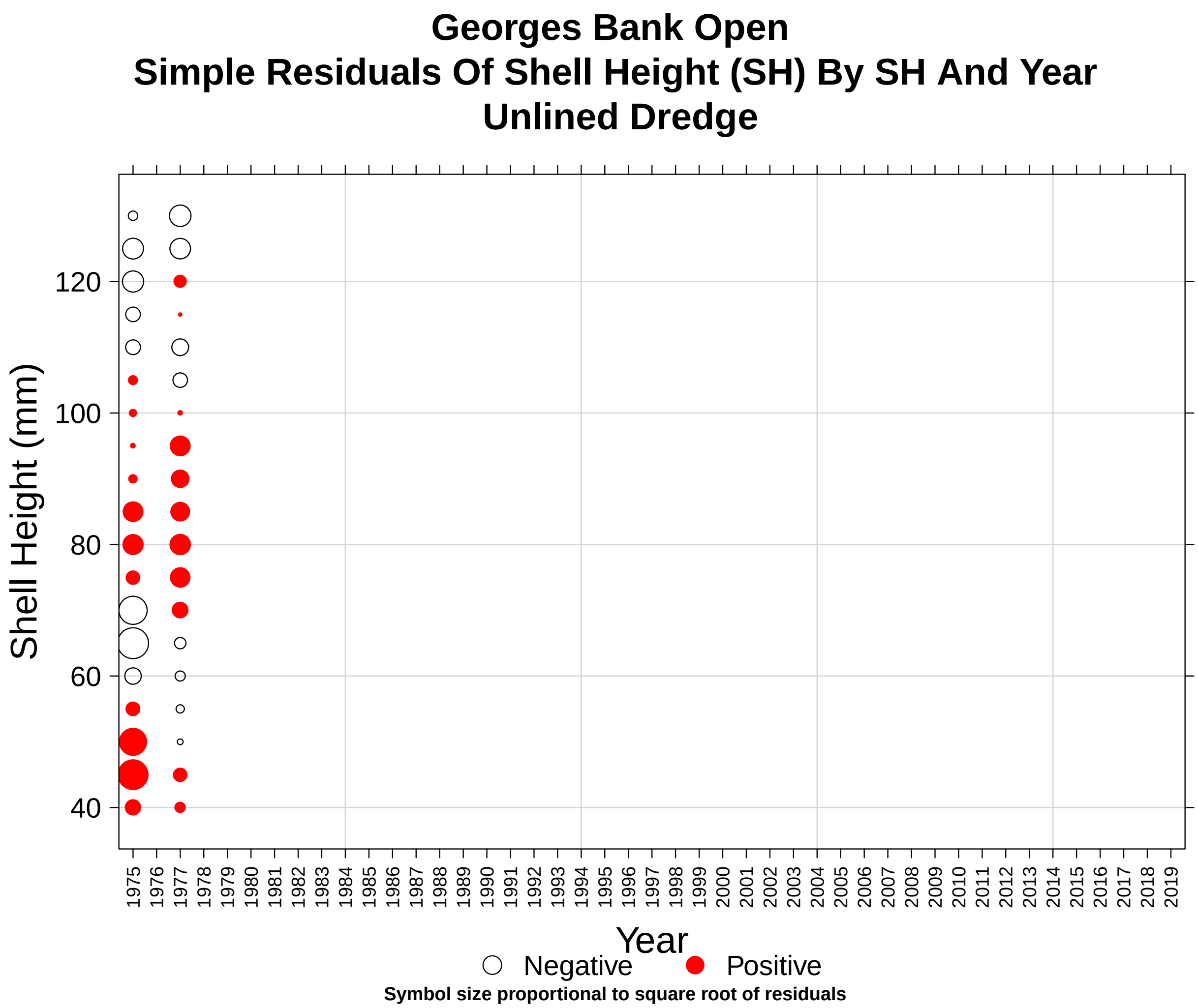


Figure 37: Simple residuals of unlined dredge survey shell height proportions for Georges Bank open areas. Symbol areas are proportional to residual.

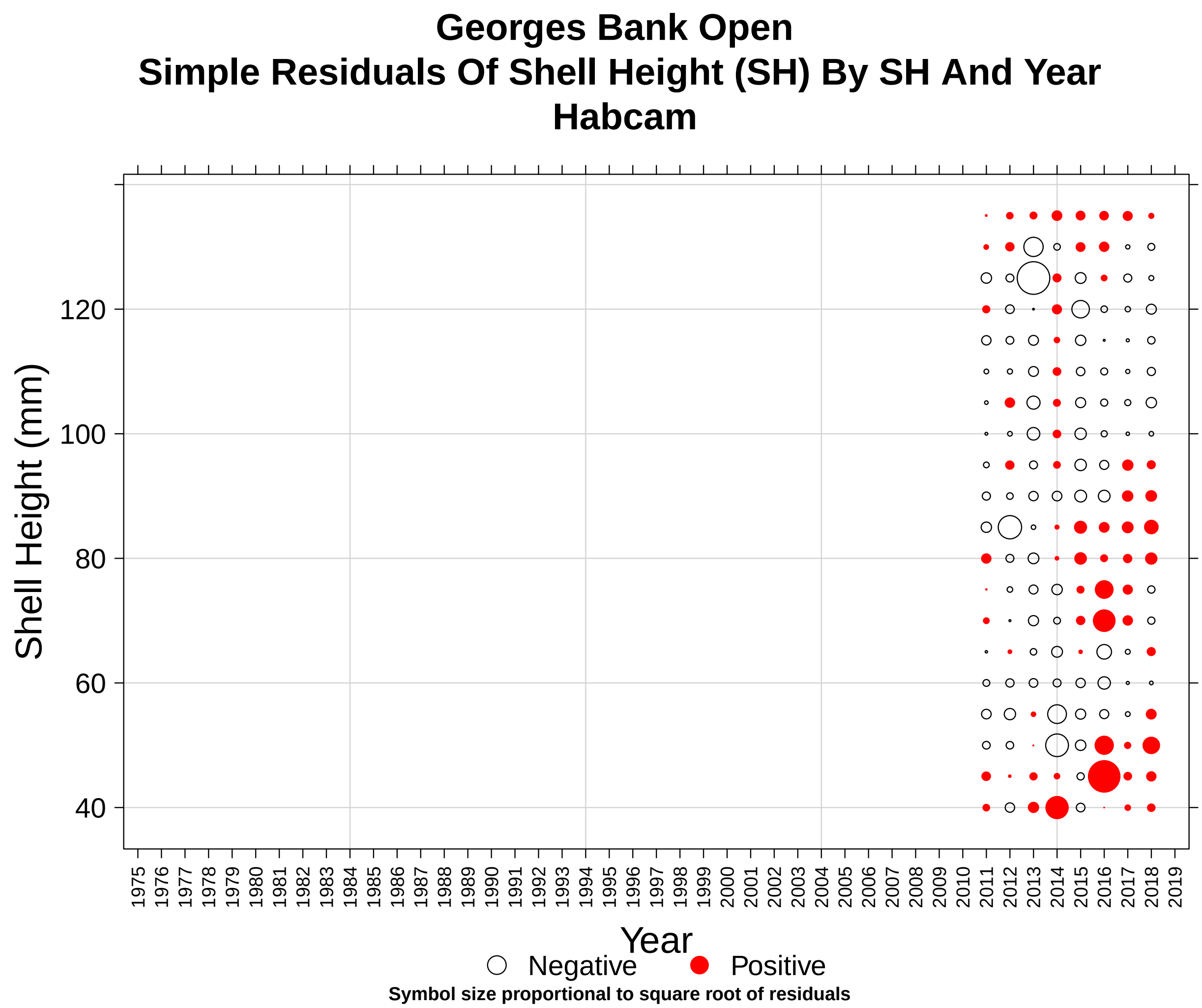


Figure 38: Simple residuals of Habcam survey shell height proportions for Georges Bank open areas. Symbol areas are proportional to residual.

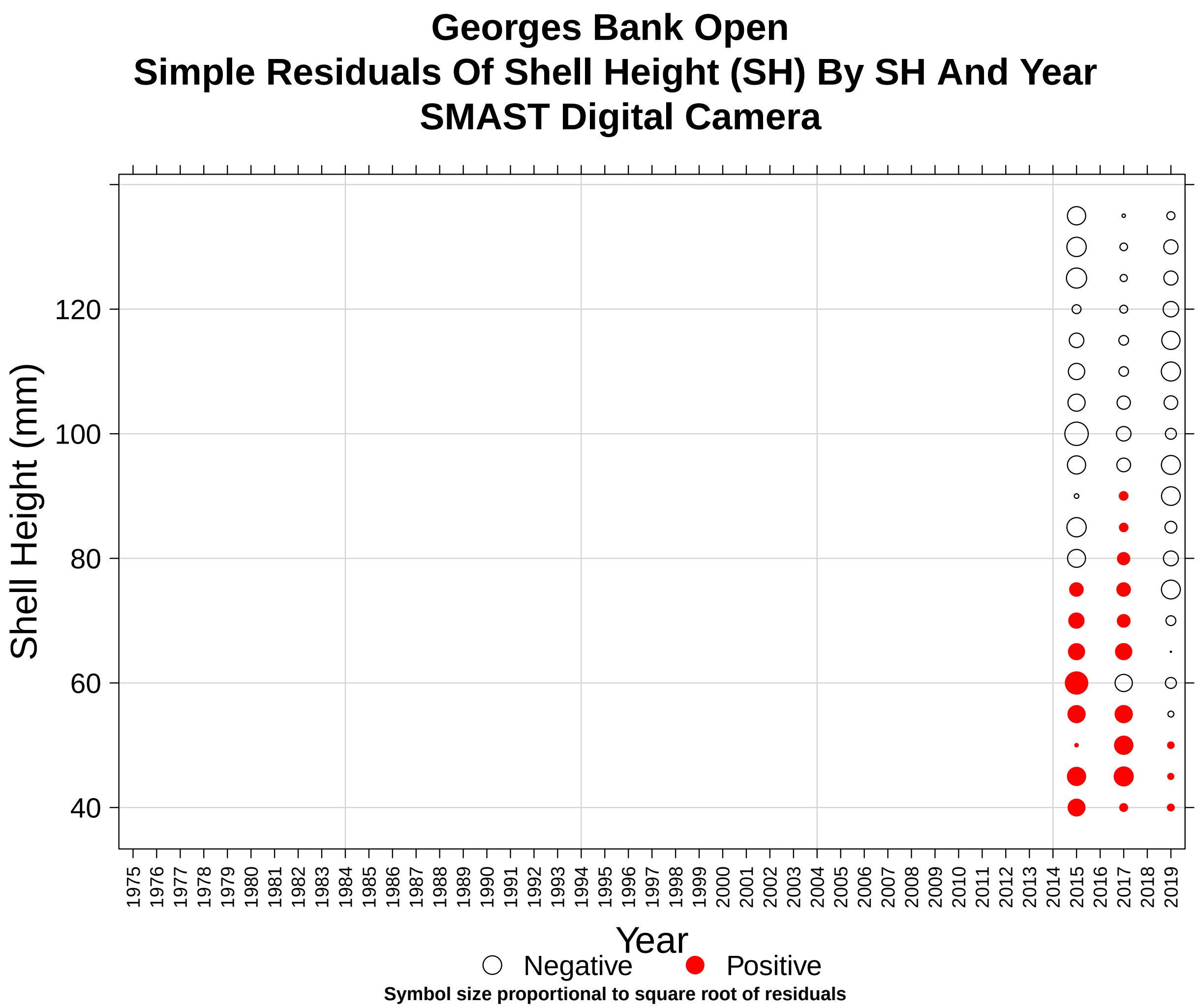


Figure 39: Simple residuals of SMAST digital camera survey shell height proportions for Georges Bank open areas. Symbol areas are proportional to residual.

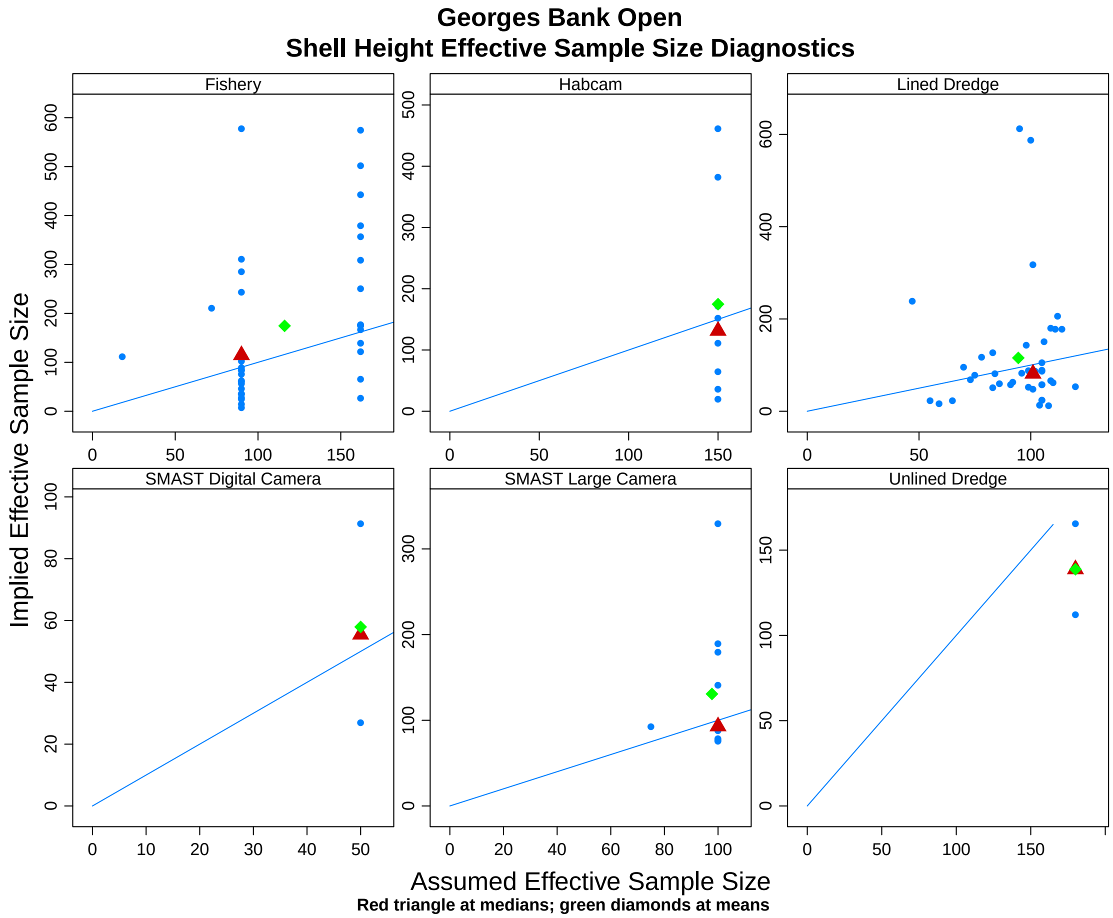


Figure 40: Assumed and model implied effective sample sizes for SMAST digital camera, lined dredge, Habcam, SMAST large camera, and unlined dredge surveys, and the fishery shell height compositions for Georges Bank open areas. The triangle is the median and the diamond is the mean.

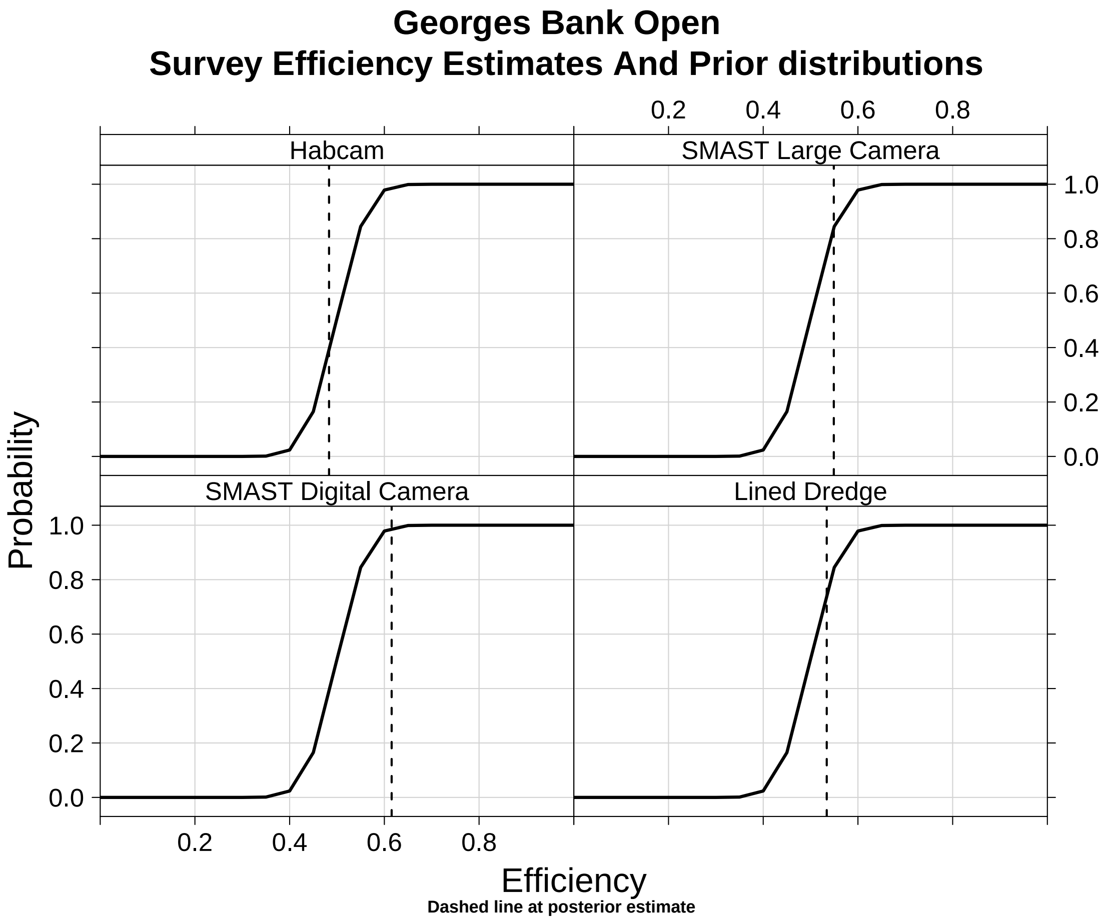


Figure 41: Prior cumulative distributions for catchability of Habcam, SMAST large camera, SMAST digital camera, and lined dredge surveys for Georges Bank open areas. The dashed lines are the mean posterior estimate for survey catchability. For the purposes of this plot, the surveys were adjusted to have a mean prior catchability of 0.5.

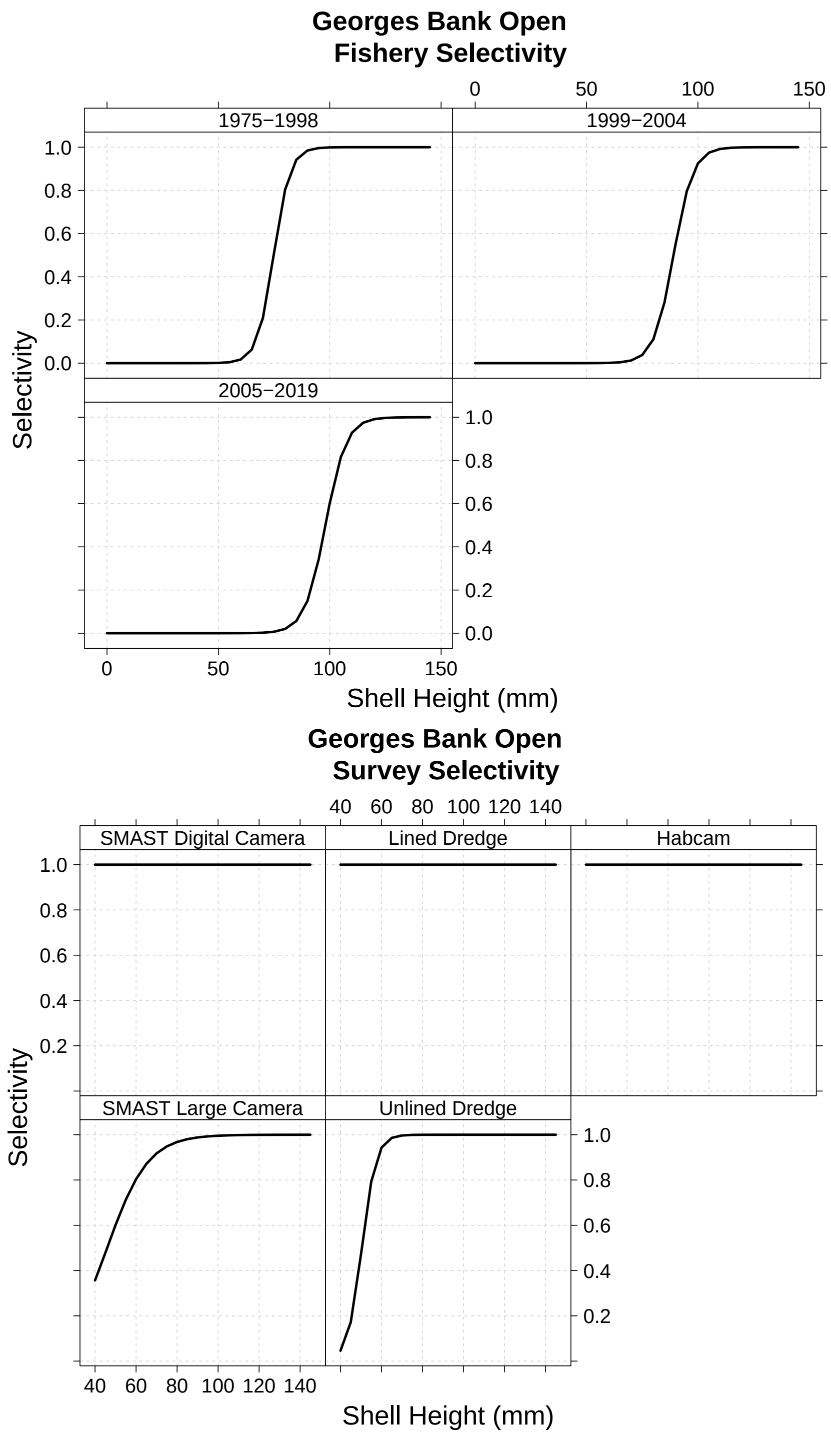


Figure 42: Estimated fishery selectivity curves (top) and assumed selectivity curves (bottom) for SMAST digital camera, lined dredge, Habcam, SMAST large camera, and unlined dredge surveys for Georges Bank open areas.

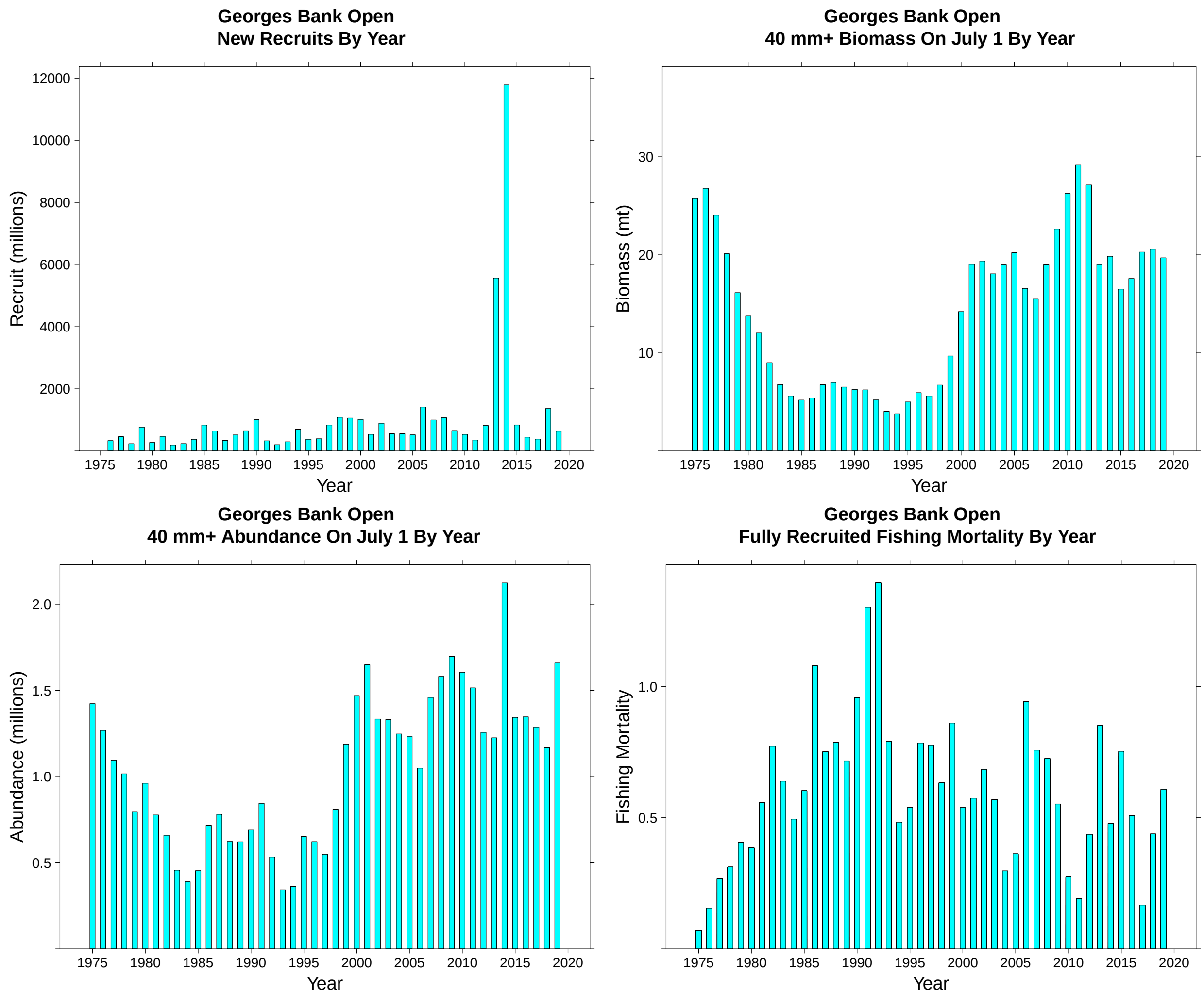


Figure 43: CASA model estimated recruitment (top left), July 1 biomass (top right), July 1 abundance (bottom left) and fully recruited fishing mortality (bottom right) for Georges Bank open areas.

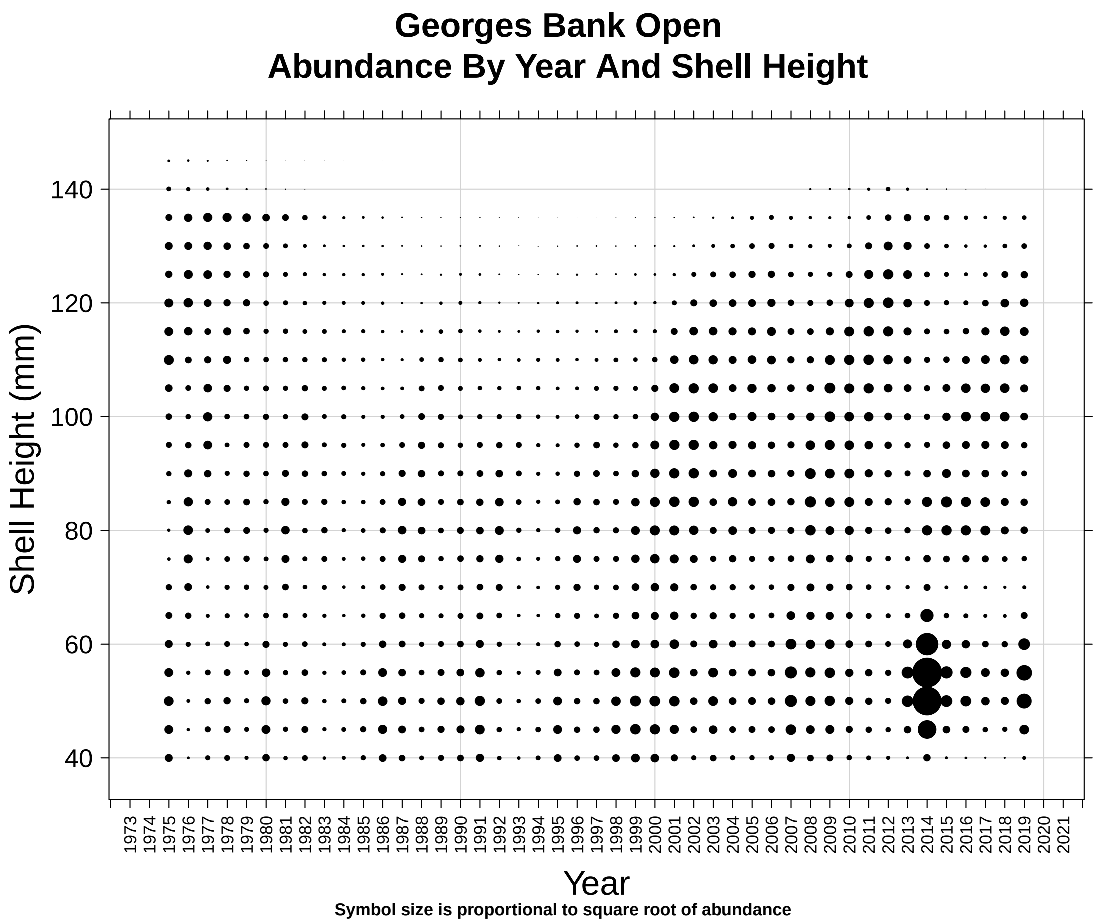


Figure 44: CASA model estimated abundances at shell height for Georges Bank open areas. Symbol areas are proportional to abundance.

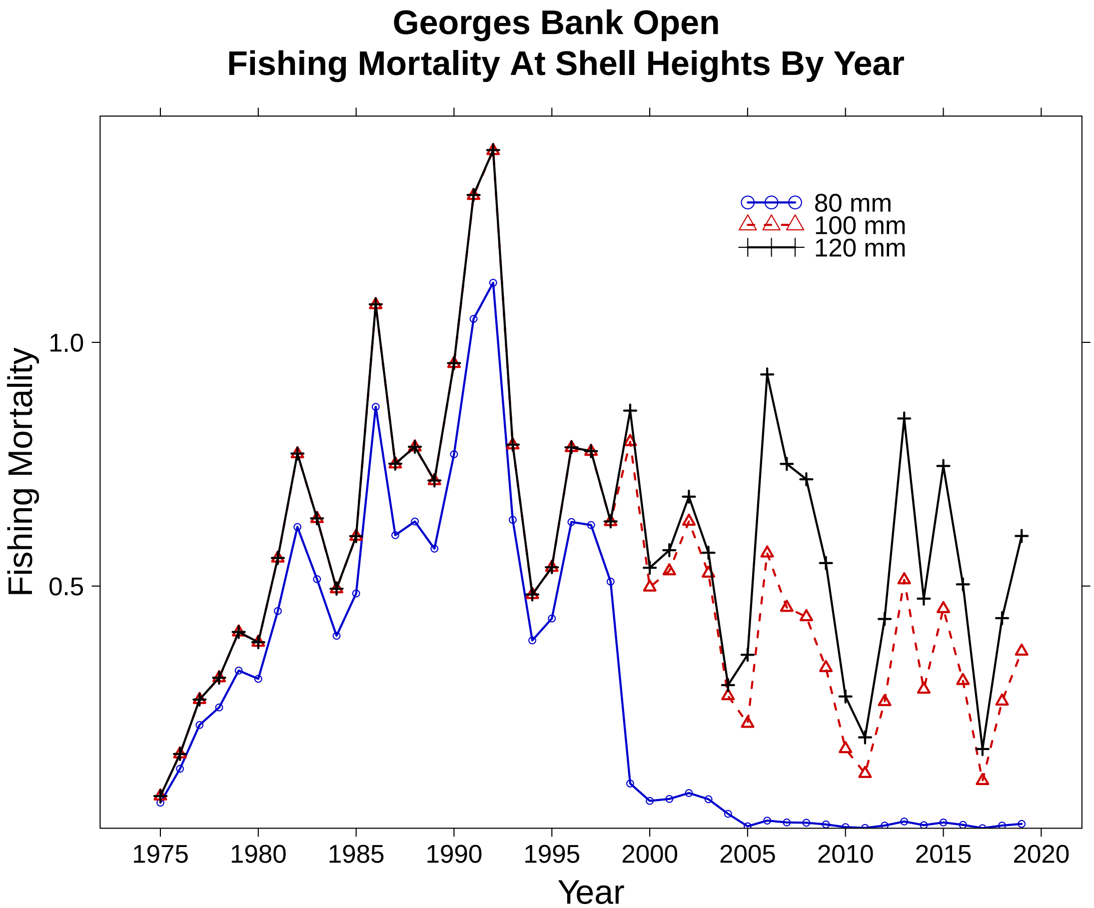
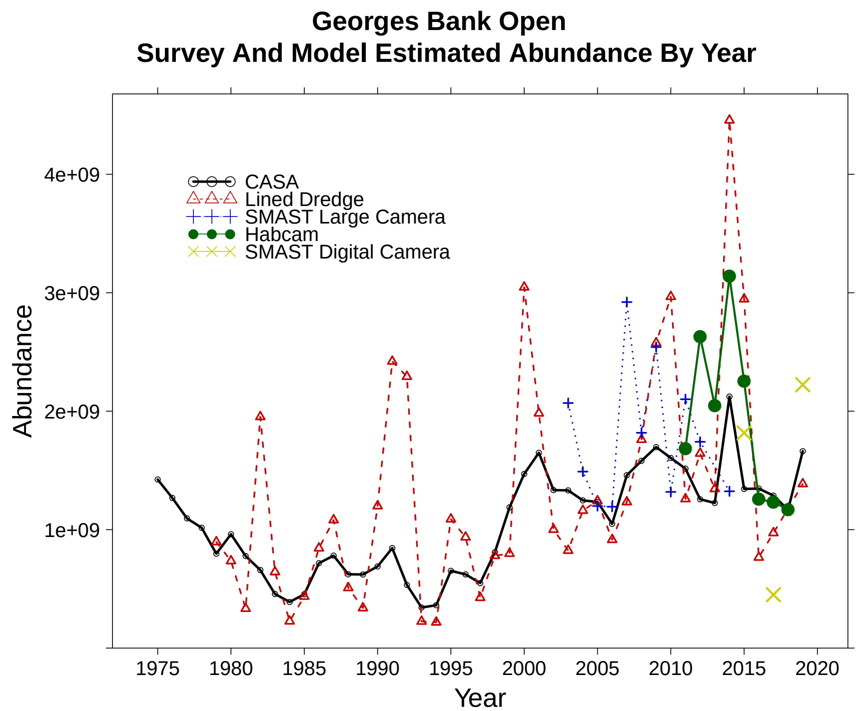


Figure 45: CASA model estimated fishing mortality at 80 mm (solid line with circles), 100 mm (dashed line with triangles), and 120 mm SH (dashed line with crosses) for Georges Bank open areas.



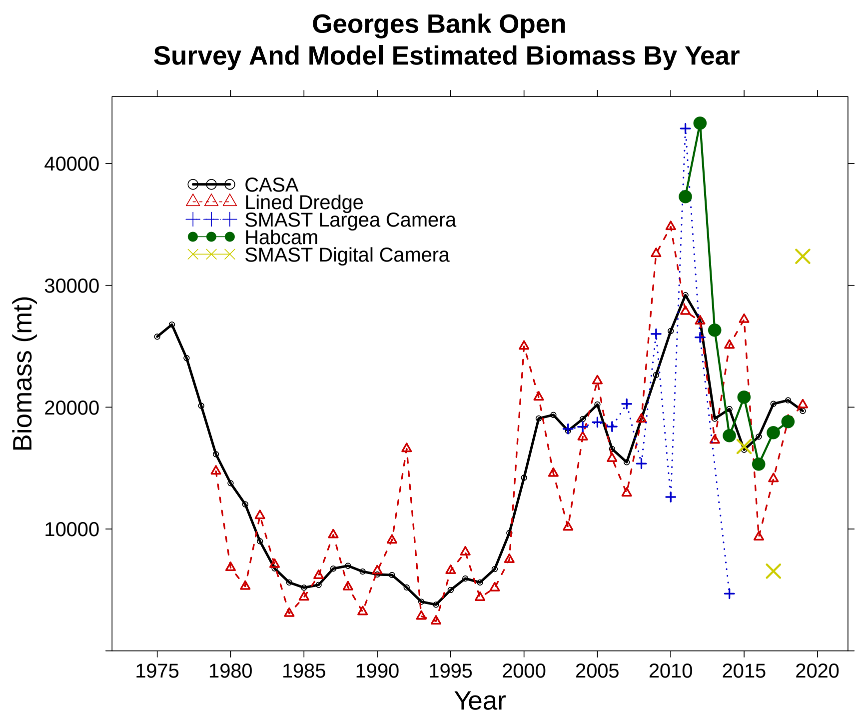


Figure 46: Comparison of CASA model estimated abundance (top) and biomass (bottom) with expanded estimates from the lined dredge (red), SMAST large camera (blue), HabCam (green), and SMAST digital camera (light green) for Georges Bank open areas.

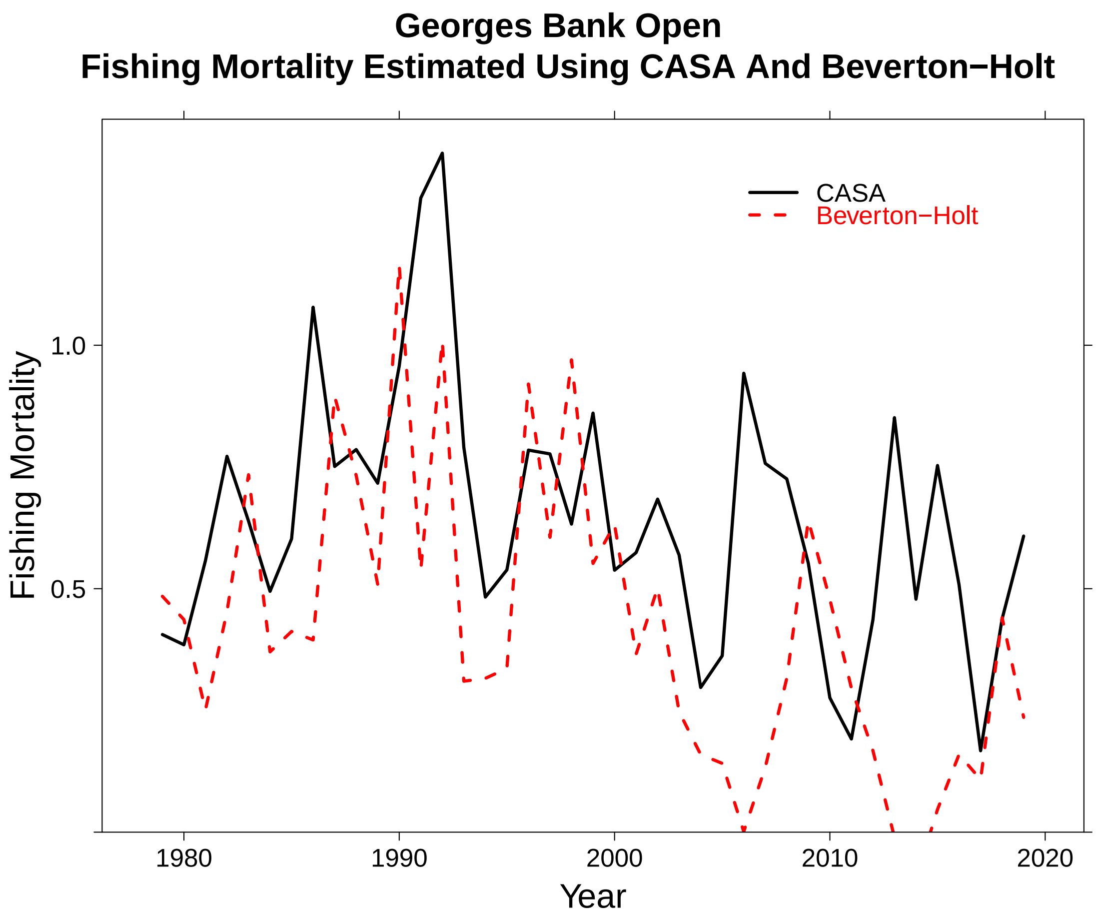


Figure 47: Comparison of fully recruited CASA fishing mortality with those calculated from the Beverton-Holt equilibrium length based estimator for Georges Bank open areas.

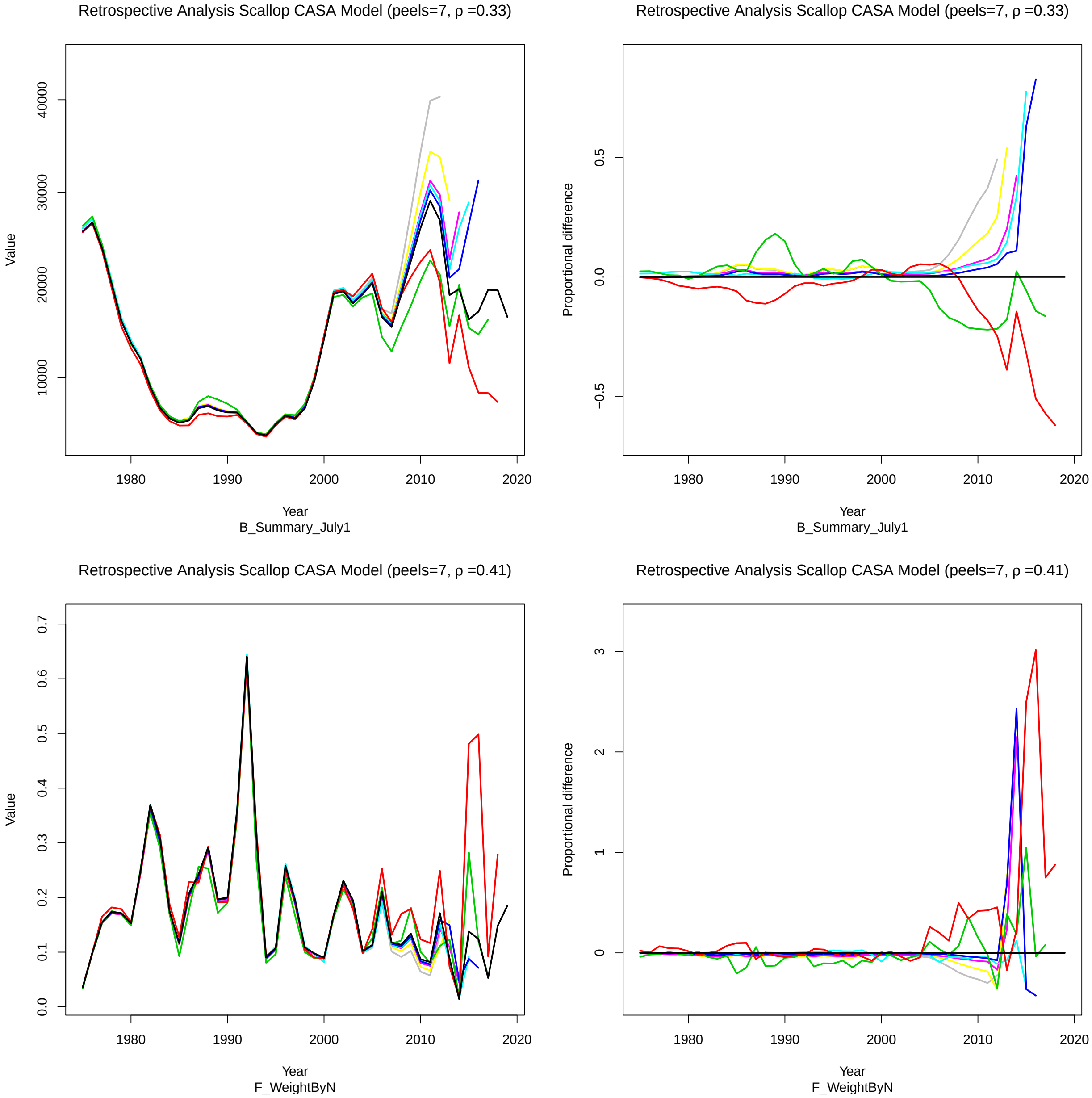


Figure 48: Retrospective plots for biomass and fishing mortality for Georges Bank open areas. Retrospectives are shown on both absolute and relative scales.

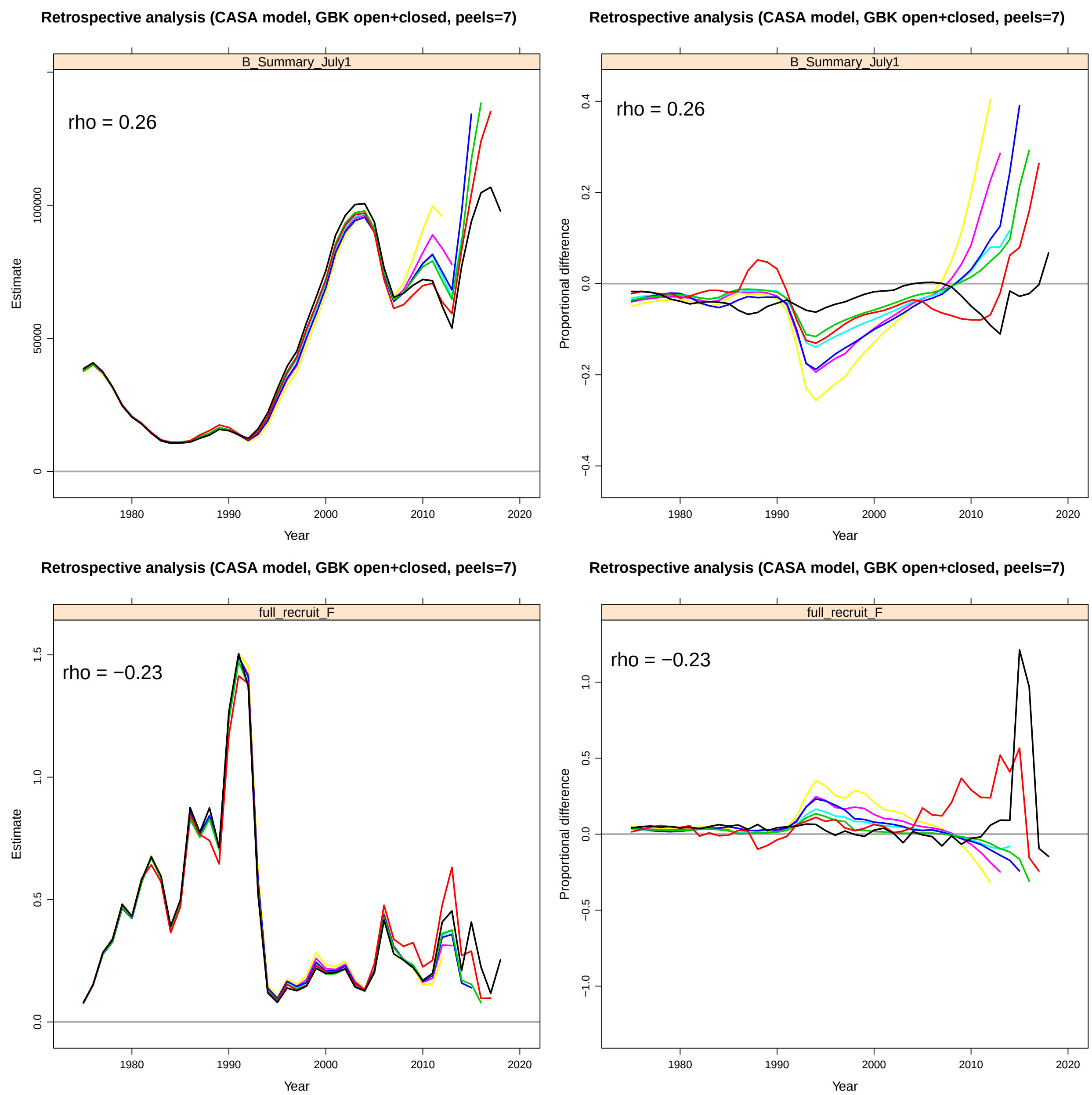


Figure 49: Retrospective plots for biomass and fishing mortality for the combined Georges Bank stock. Retrospectives are shown on both absolute and relative scales.

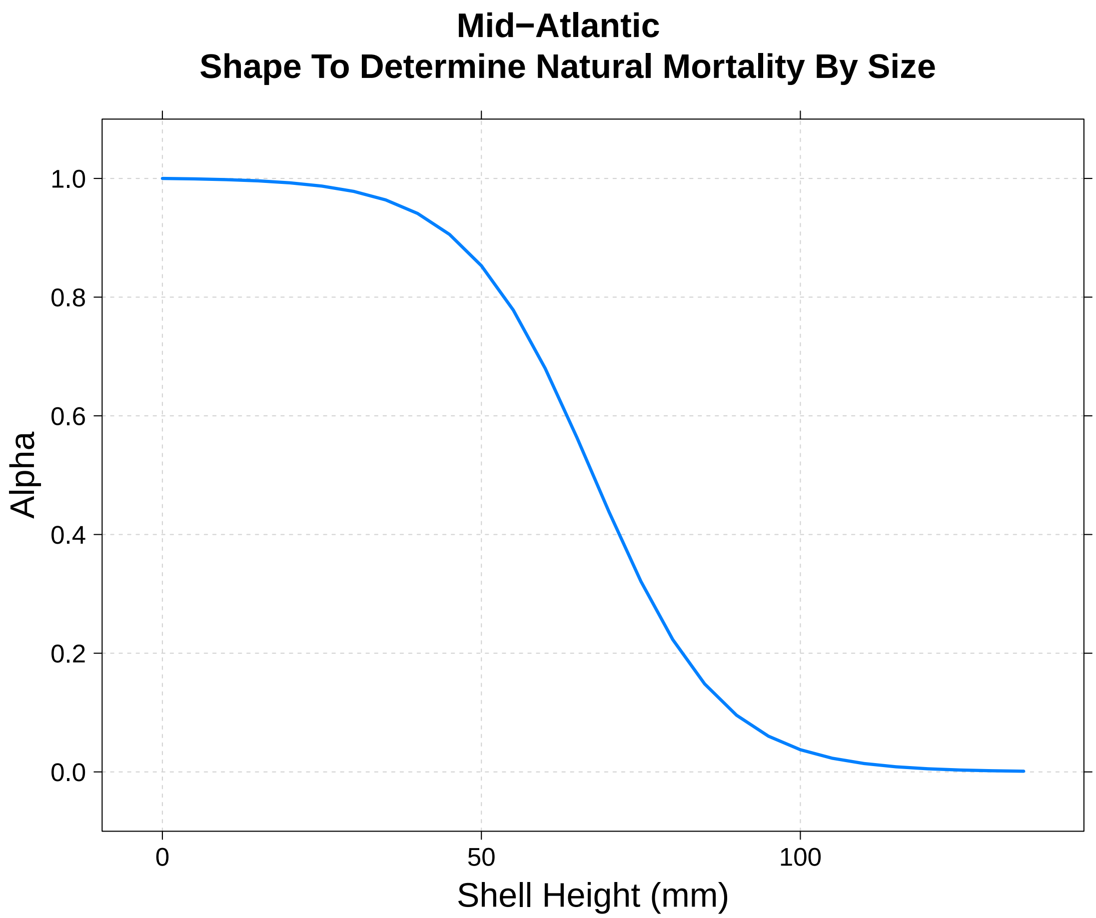
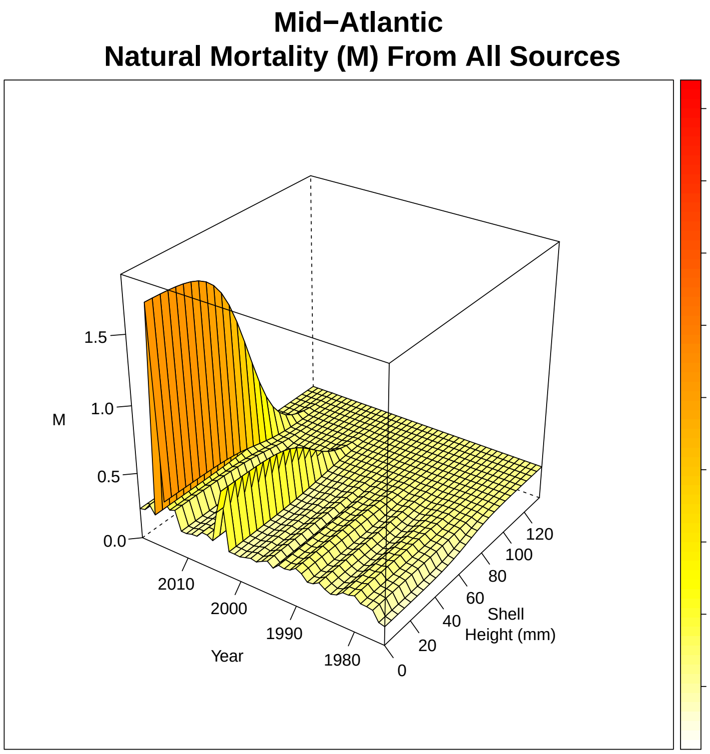


Figure 50: Logistic curve used to partition juvenile and adult natural mortality for Mid-Atlantic areas.



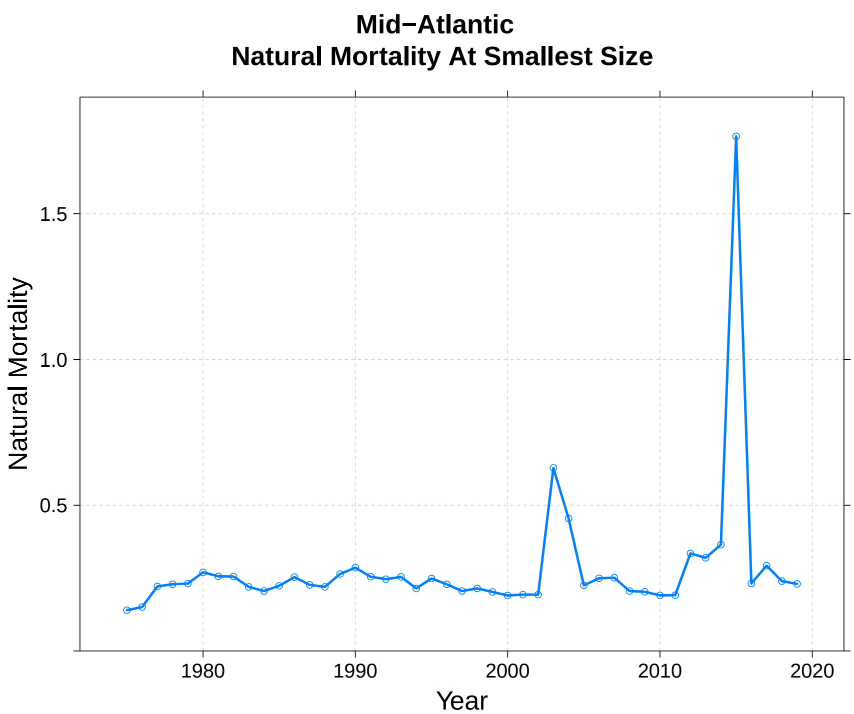


Figure 51: Estimated natural mortality by size (top) and for smallest size group (bottom) from 1975 to 2019 for Mid-Atlantic areas.

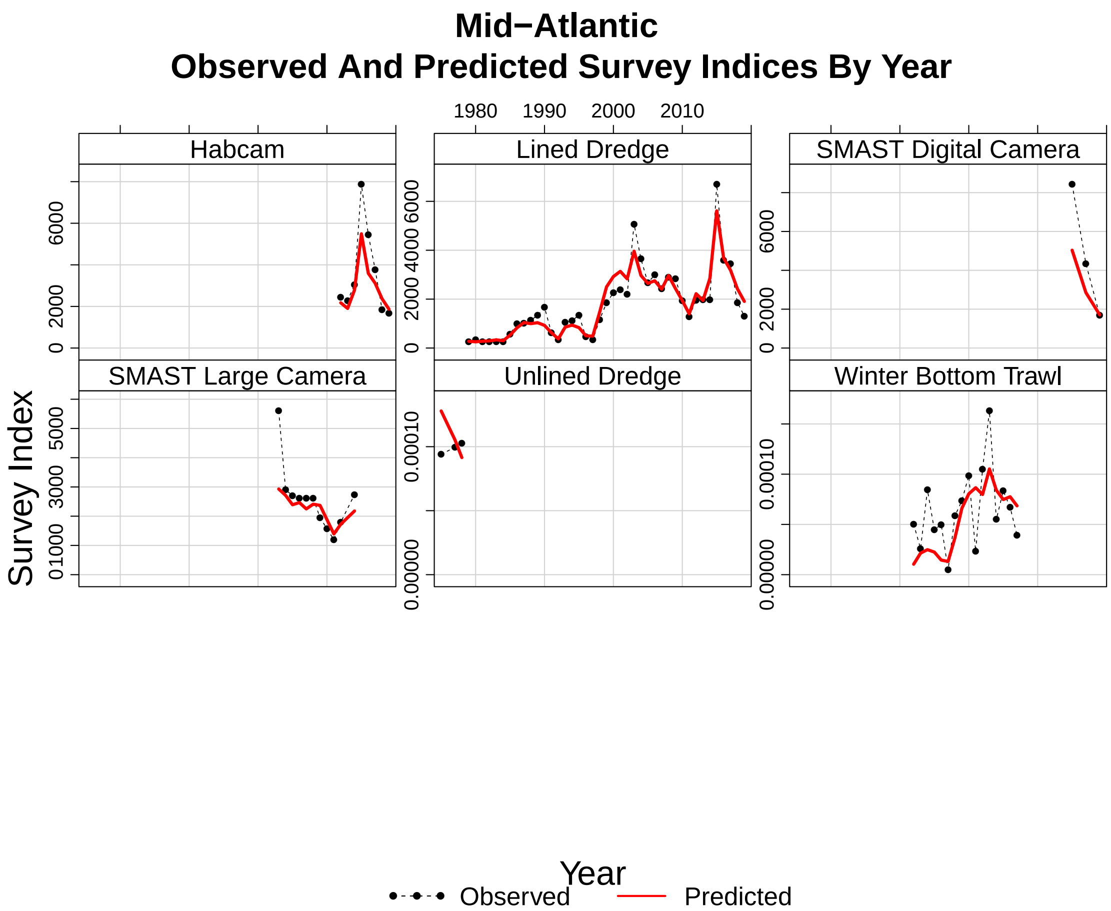
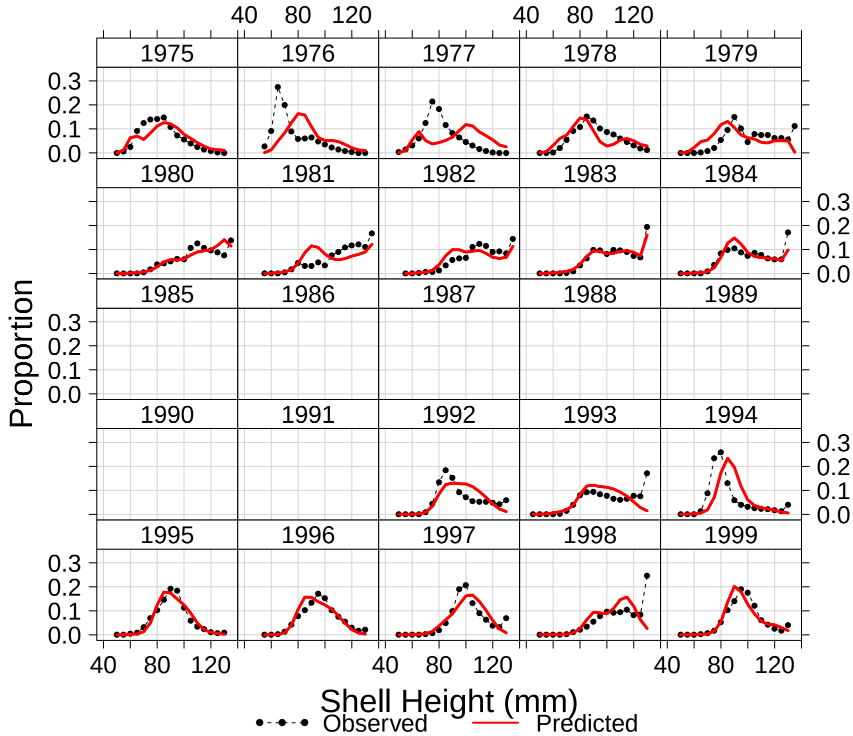


Figure 52: Observed survey trend (solid circles) and corresponding model estimates (lines) for the SMAST digital camera (top left), lined dredge (top middle), Habcam (top right), SMAST large camera (bottom left), unlined dredge (bottom middle), and winter bottom trawl (bottom right) surveys on Mid-Atlantic areas.



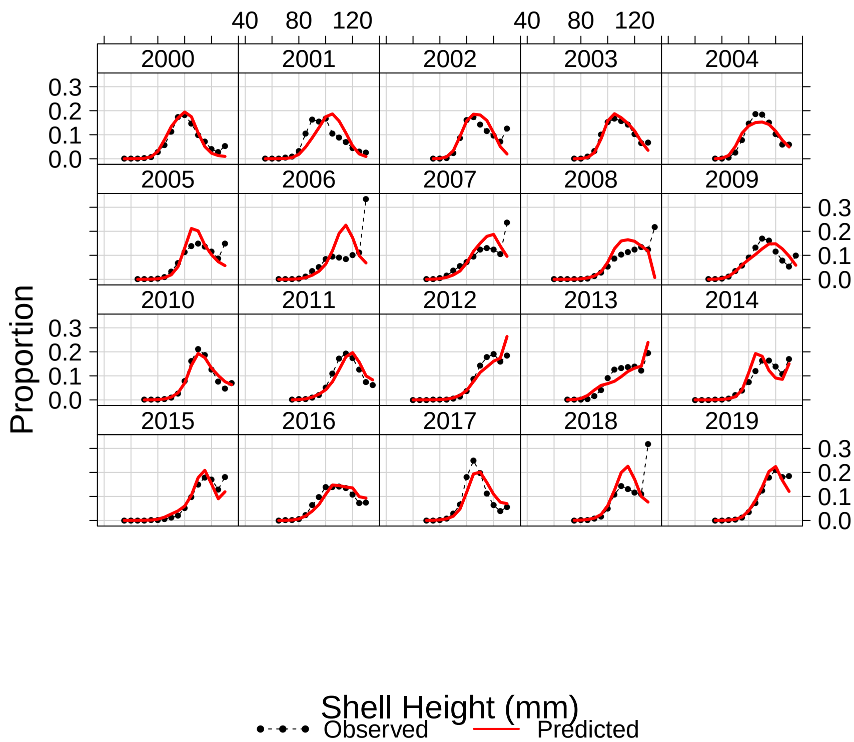


Figure 53: Comparison of observed fishery shell height proportions (solid circles) and model estimated fishery shell height proportions (lines) for Mid-Atlantic areas.

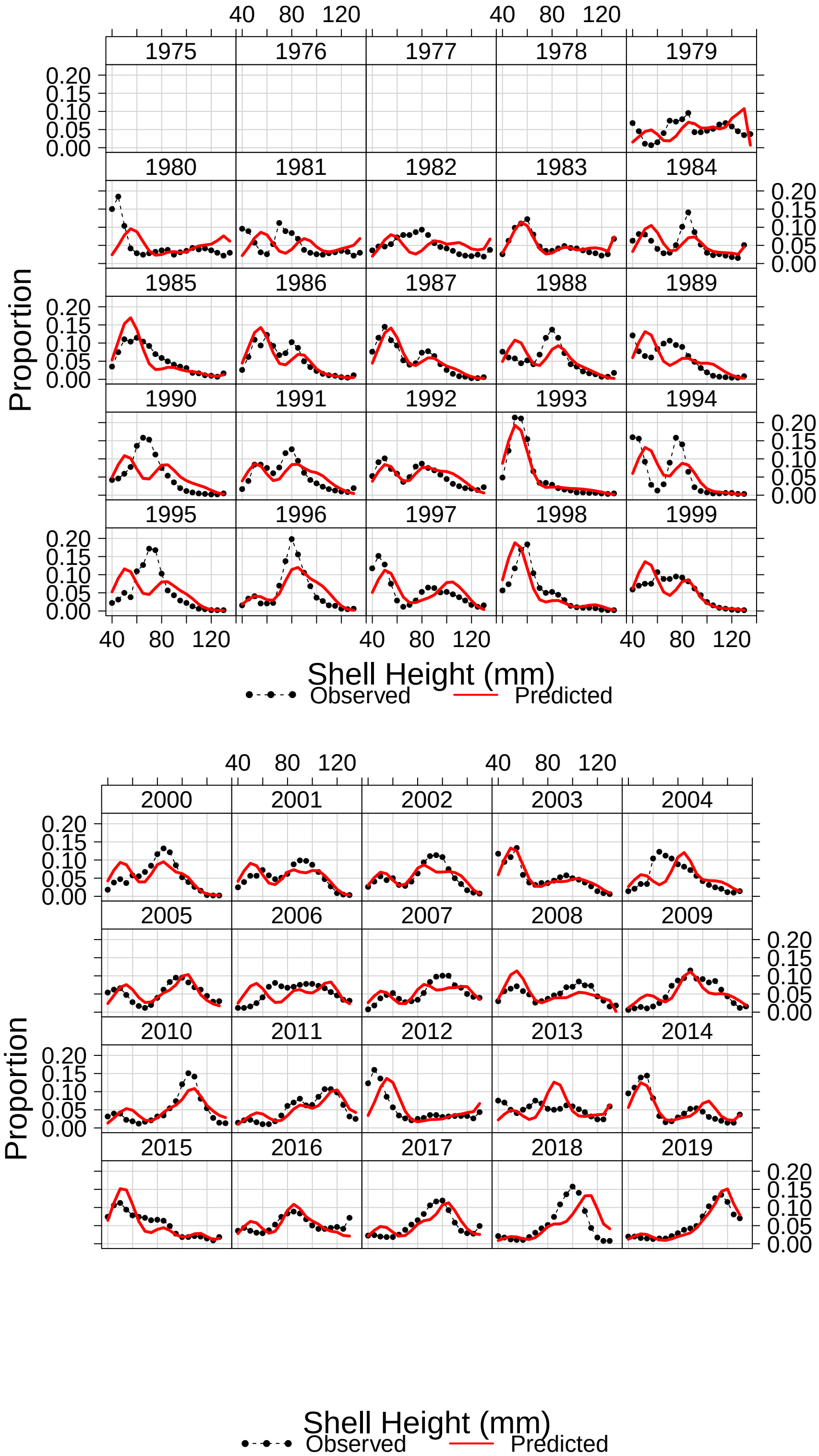
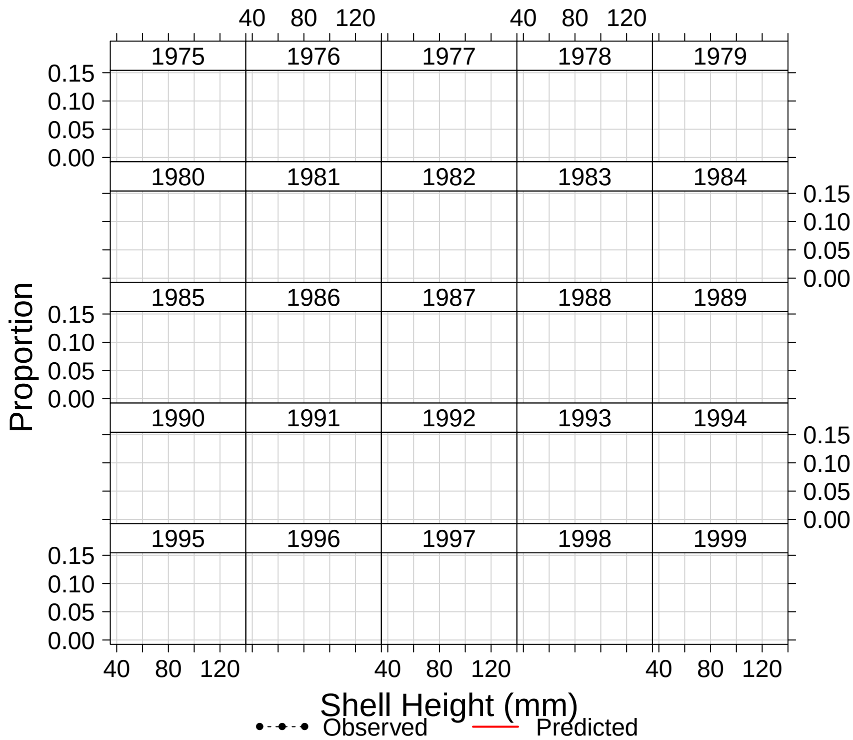


Figure 54: Comparison of lined dredge survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Mid-Atlantic areas.



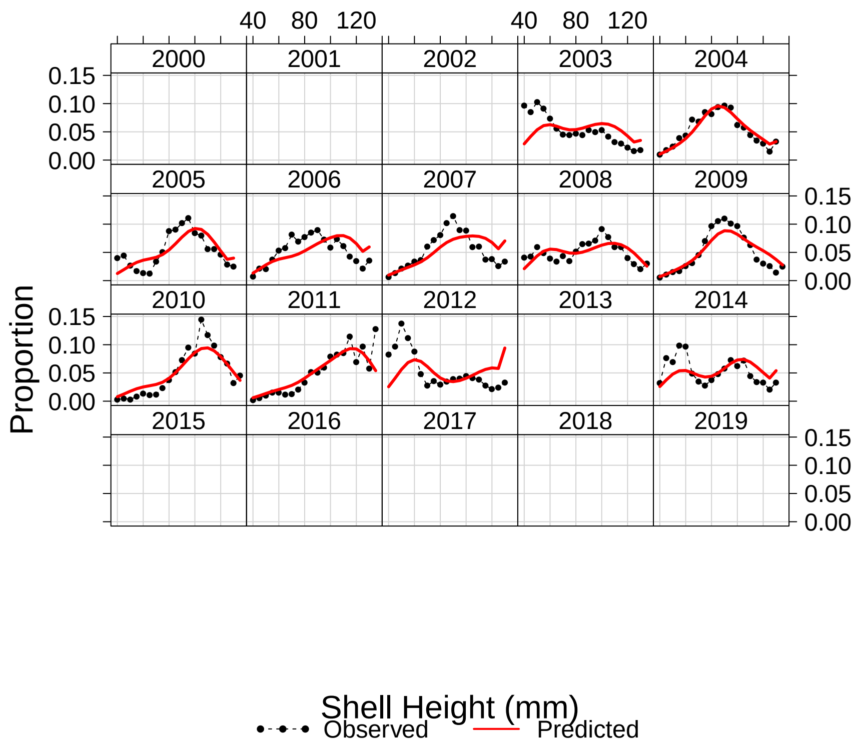


Figure 55: Comparison of SMAST large camera survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Mid-Atlantic areas.

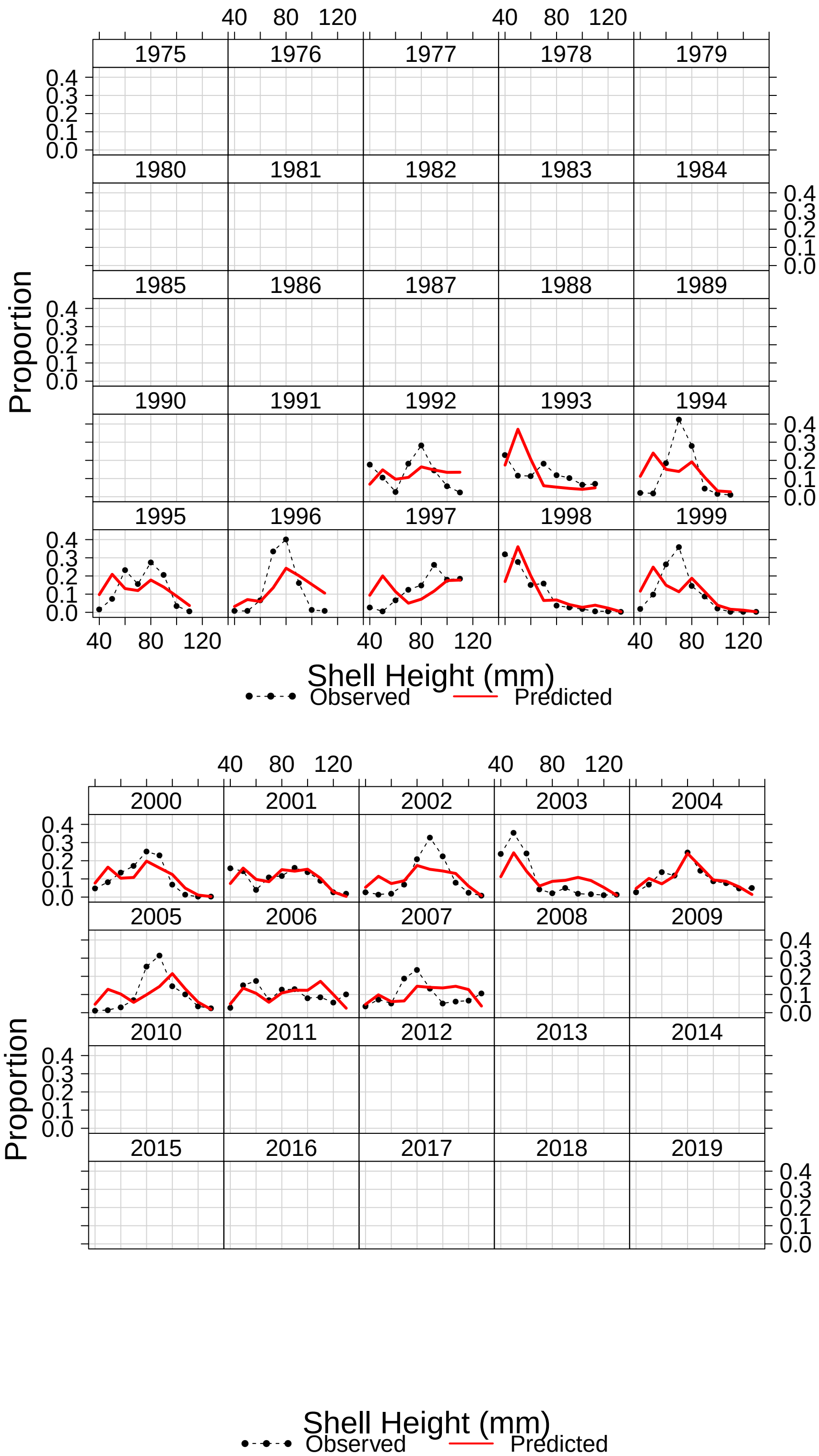
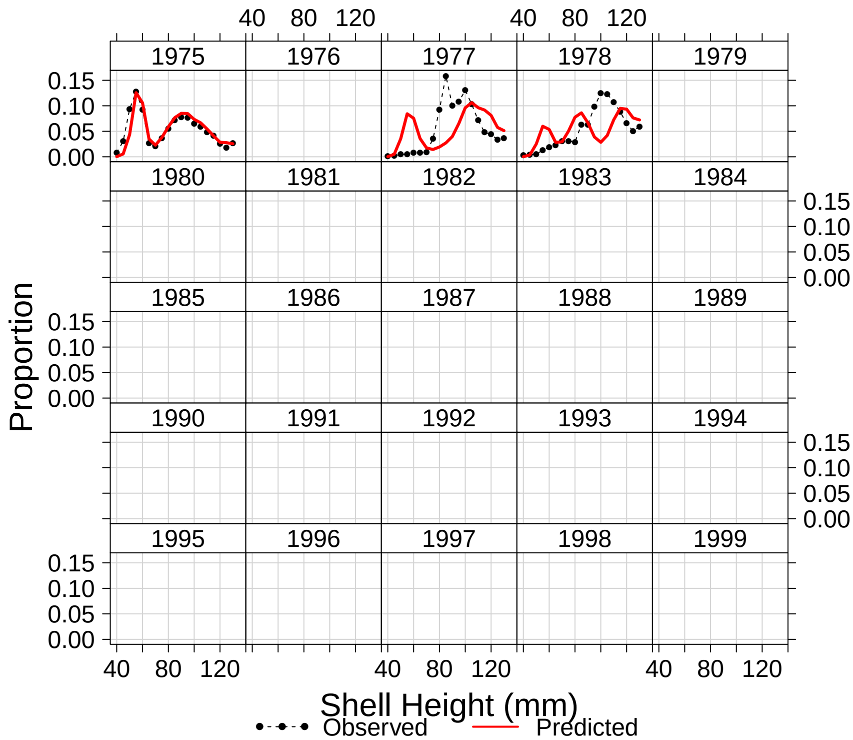


Figure 56: Comparison of winter bottom trawl survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Mid-Atlantic areas.



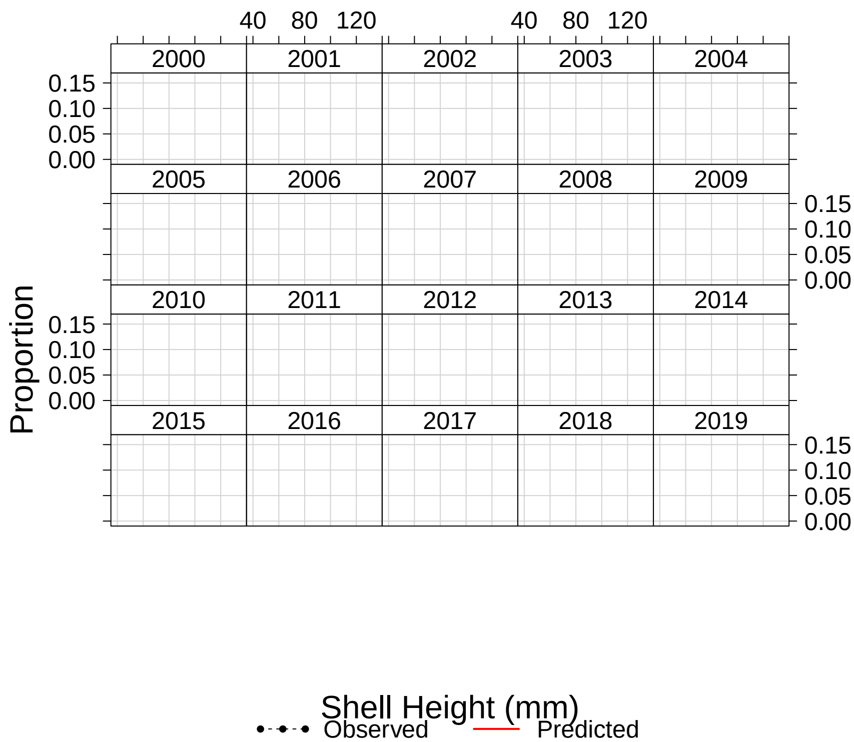
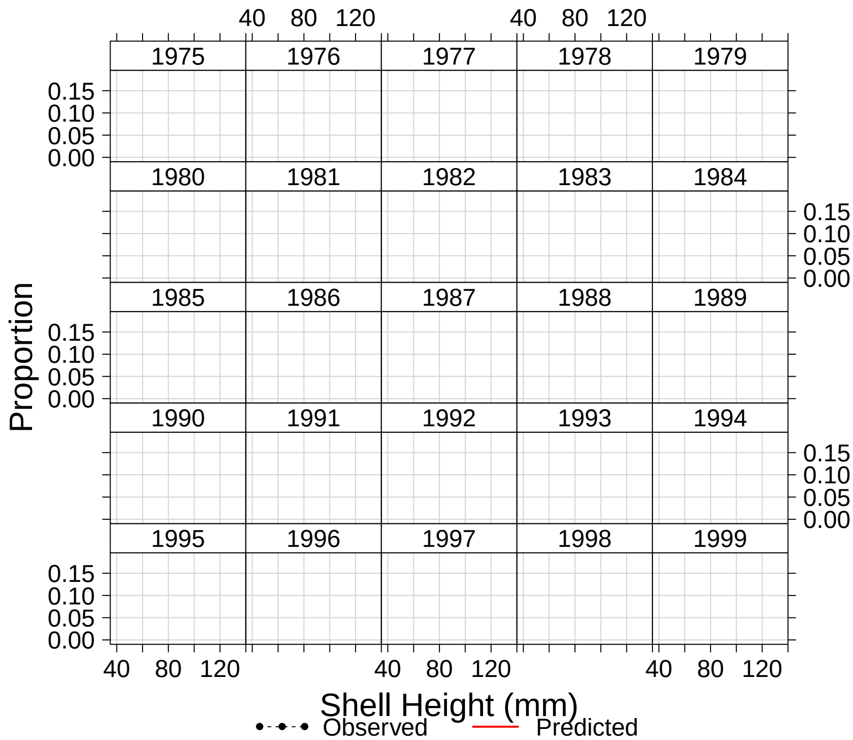


Figure 57: Comparison of unlined dredge survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Mid-Atlantic areas.



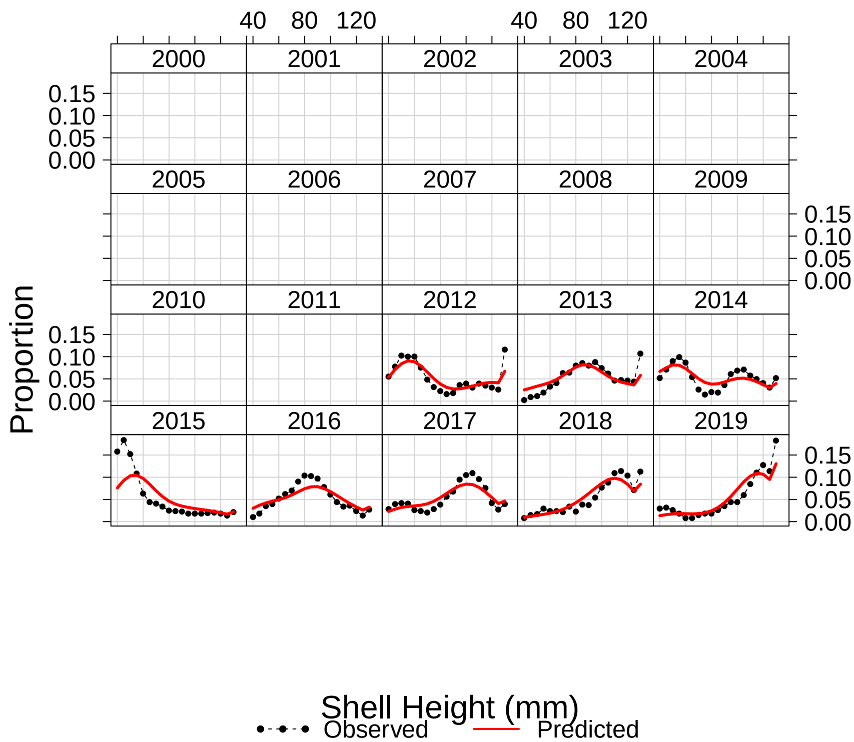


Figure 58: Comparison of Habcam survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Mid-Atlantic areas.

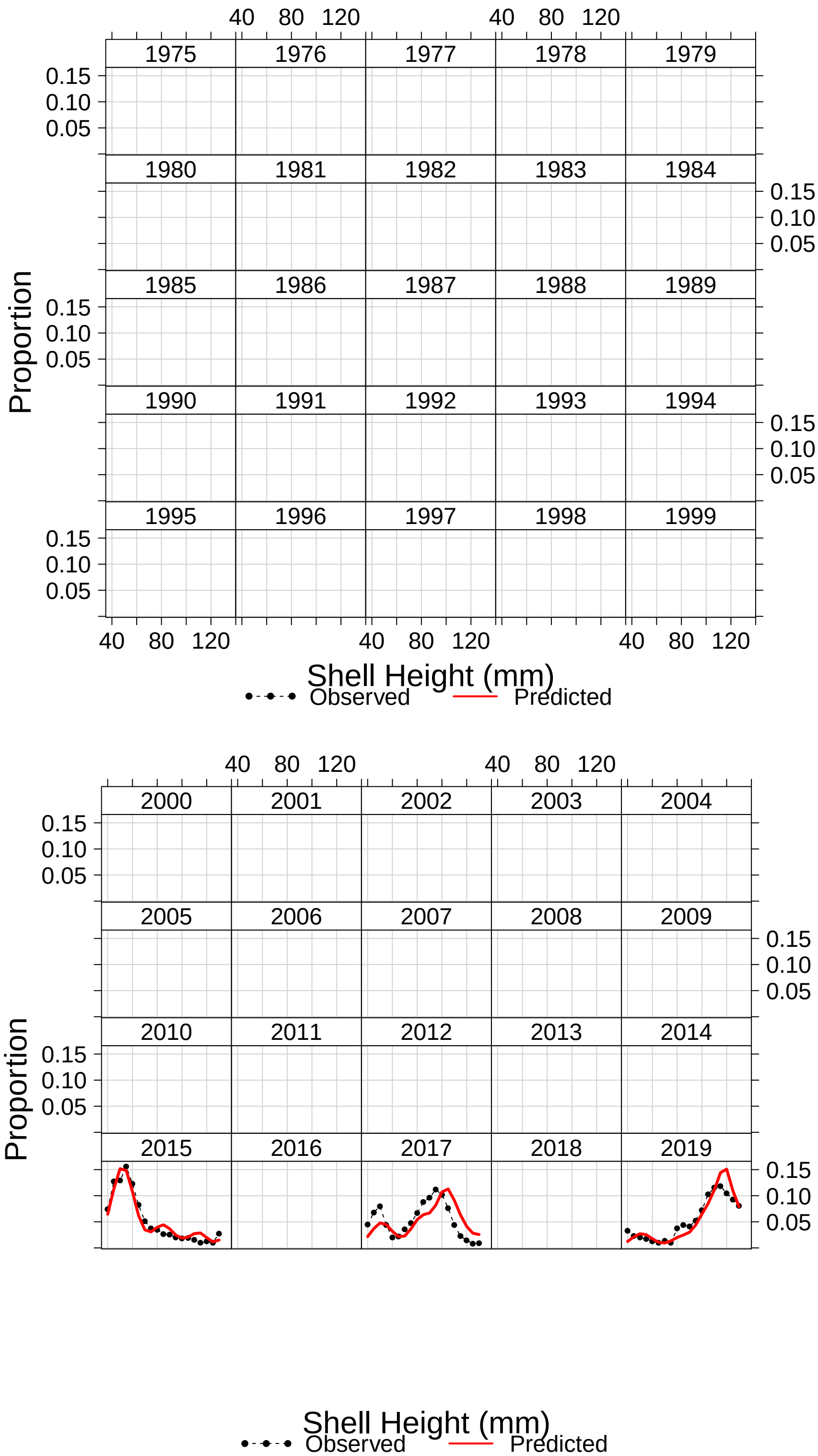


Figure 59: Comparison of SMAST digital camera survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Mid-Atlantic areas.

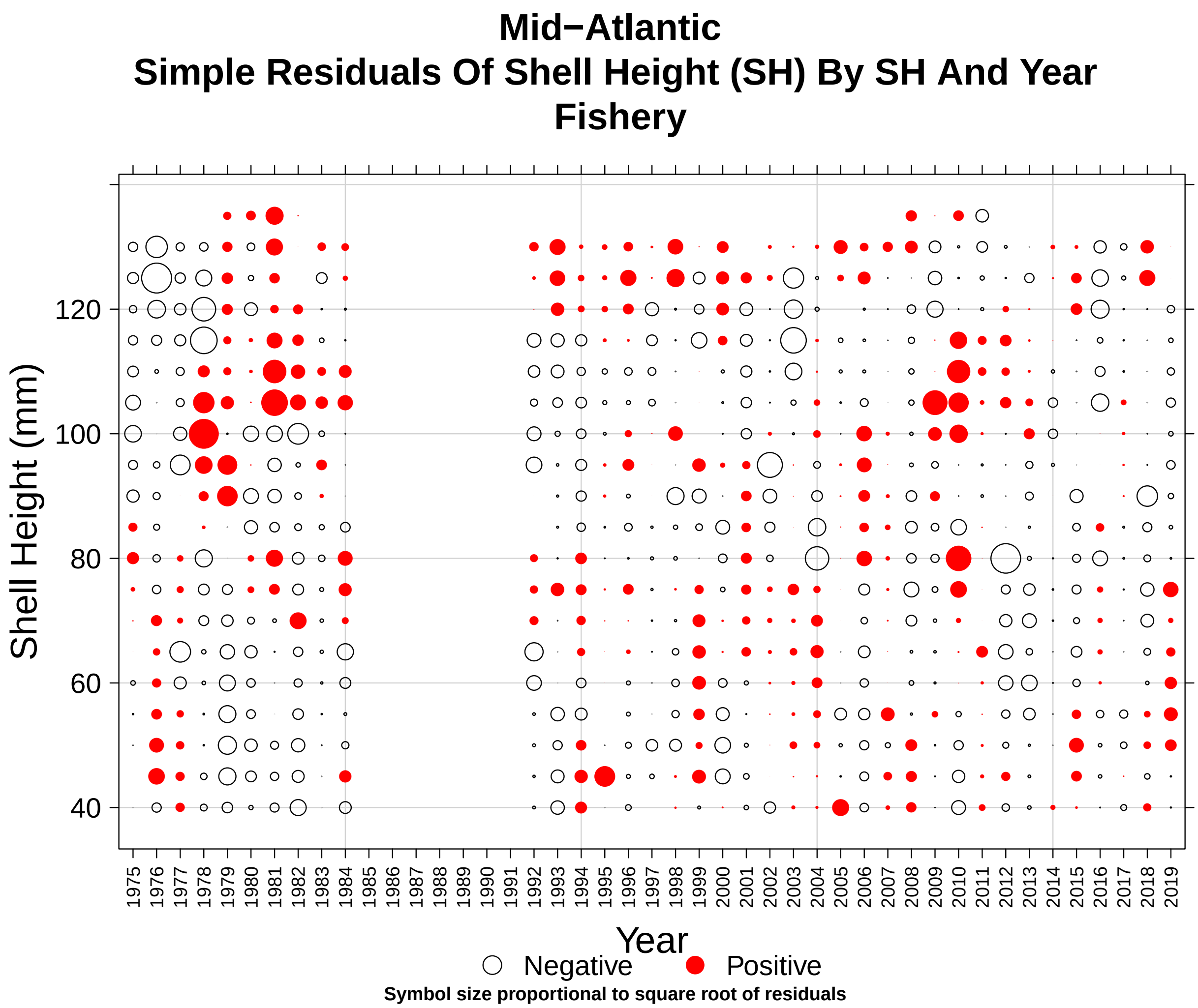


Figure 60: Simple residuals of fishery shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

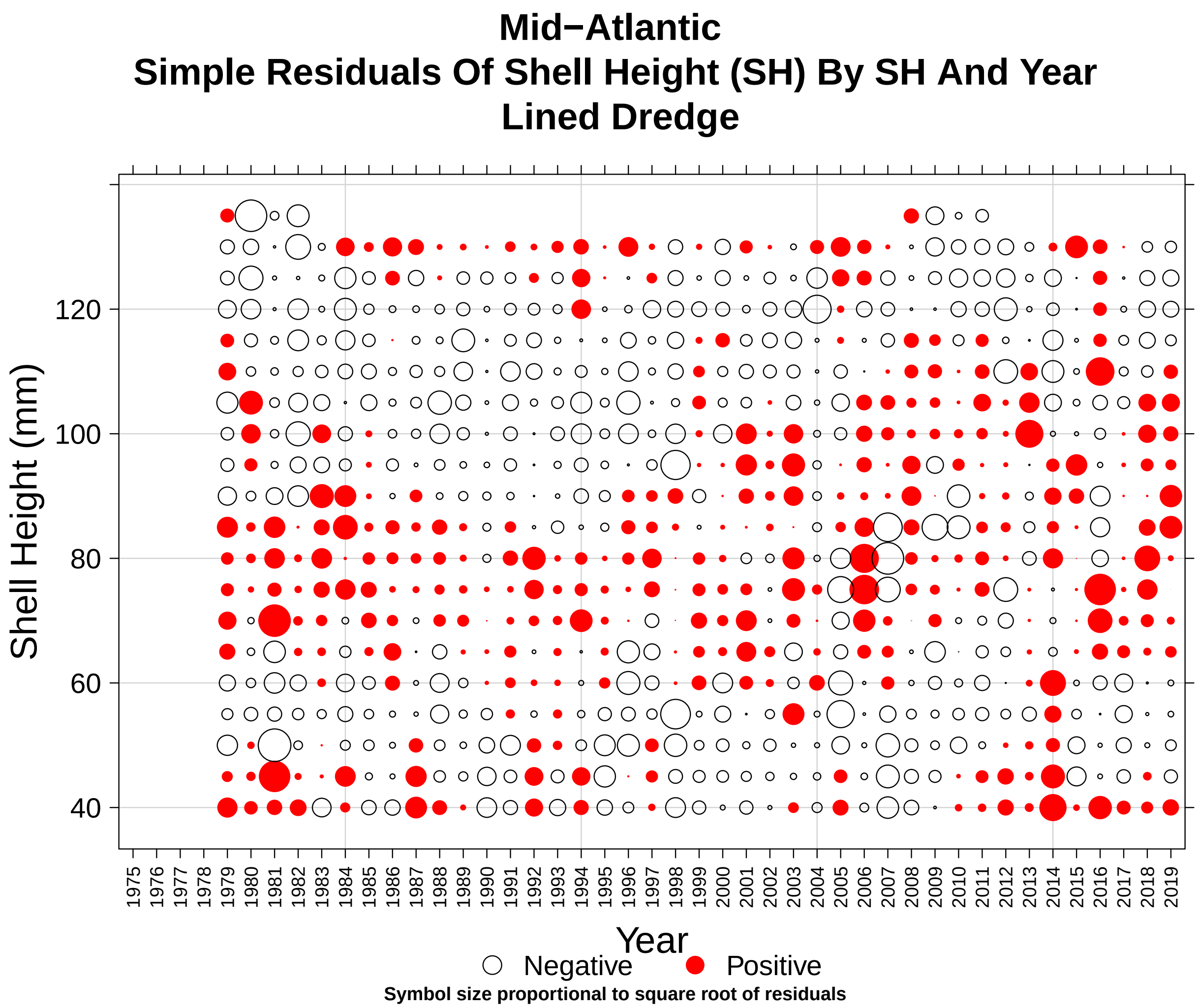


Figure 61: Simple residuals of lined dredge survey shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

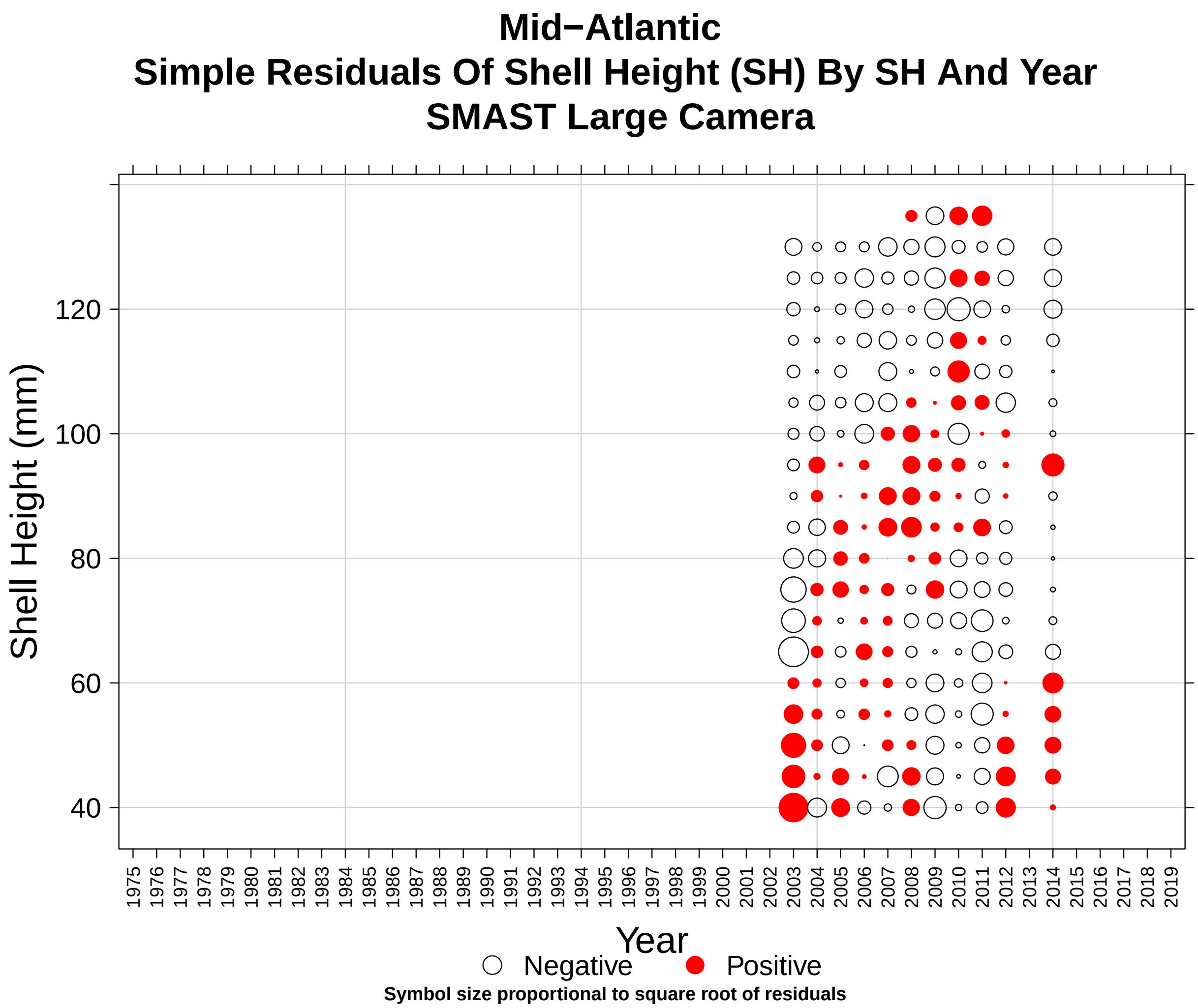


Figure 62: Simple residuals of SMAST large camera survey shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

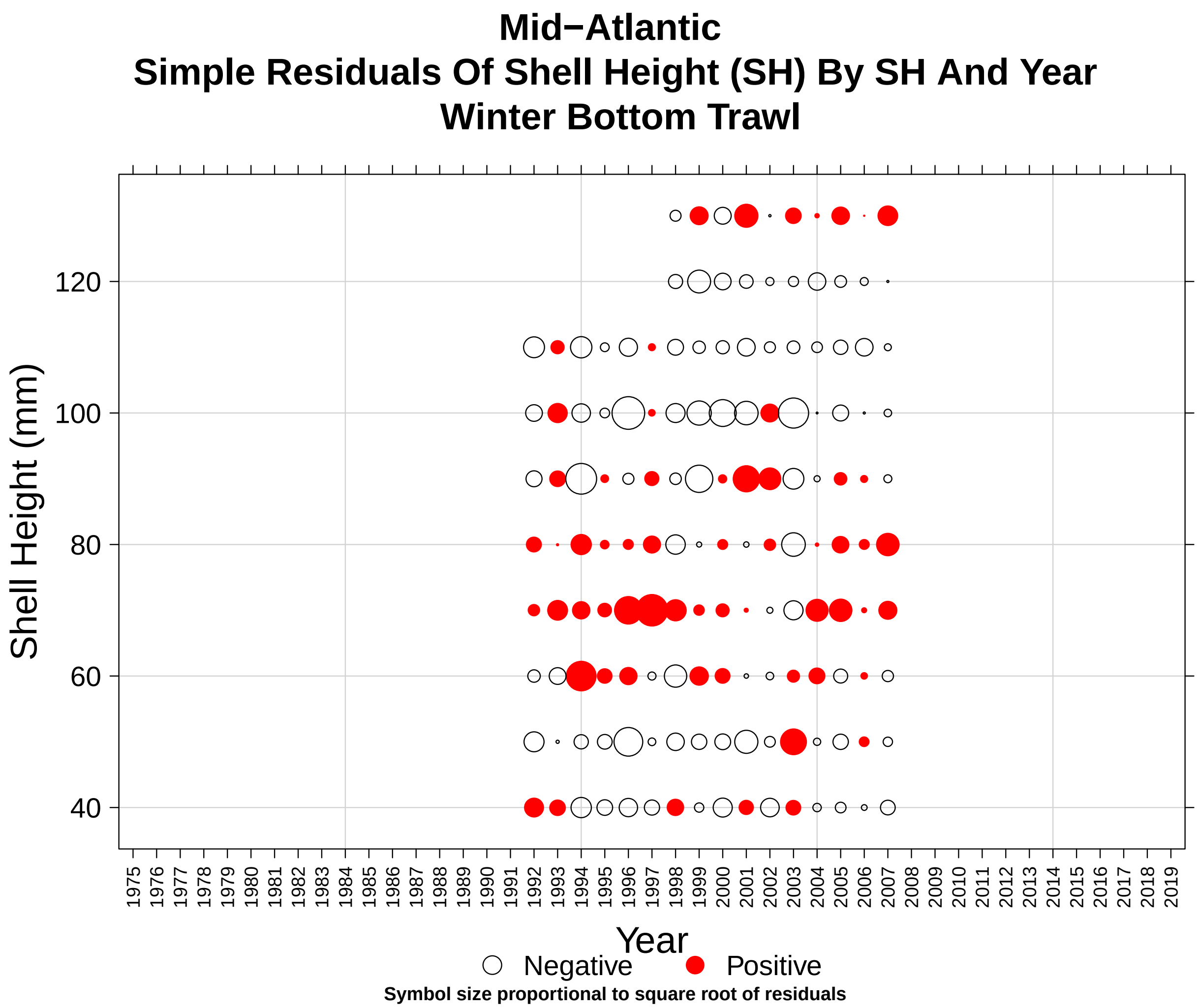


Figure 63: Simple residuals of winter bottom trawl survey shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

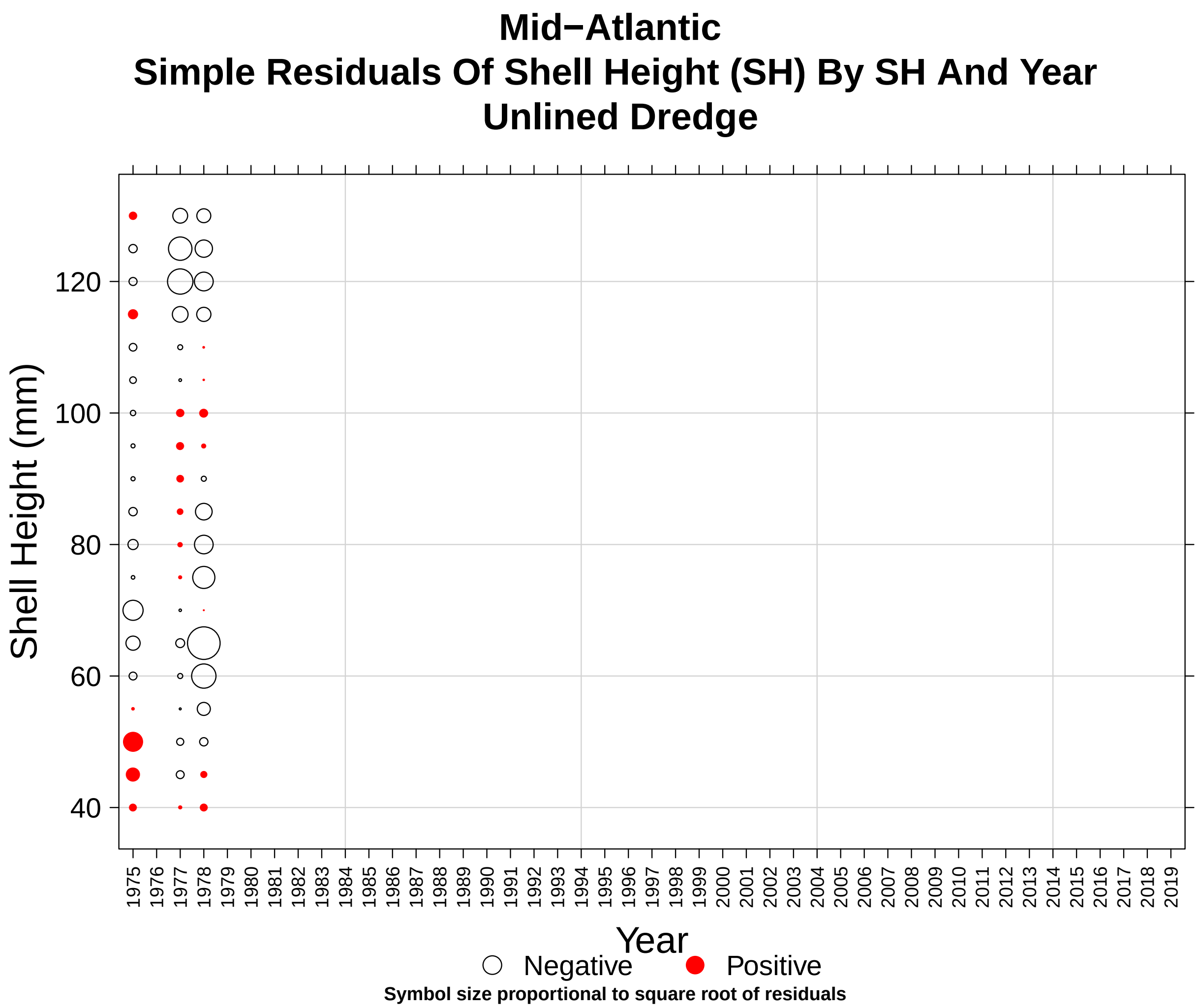


Figure 64: Simple residuals of unlined dredge survey shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

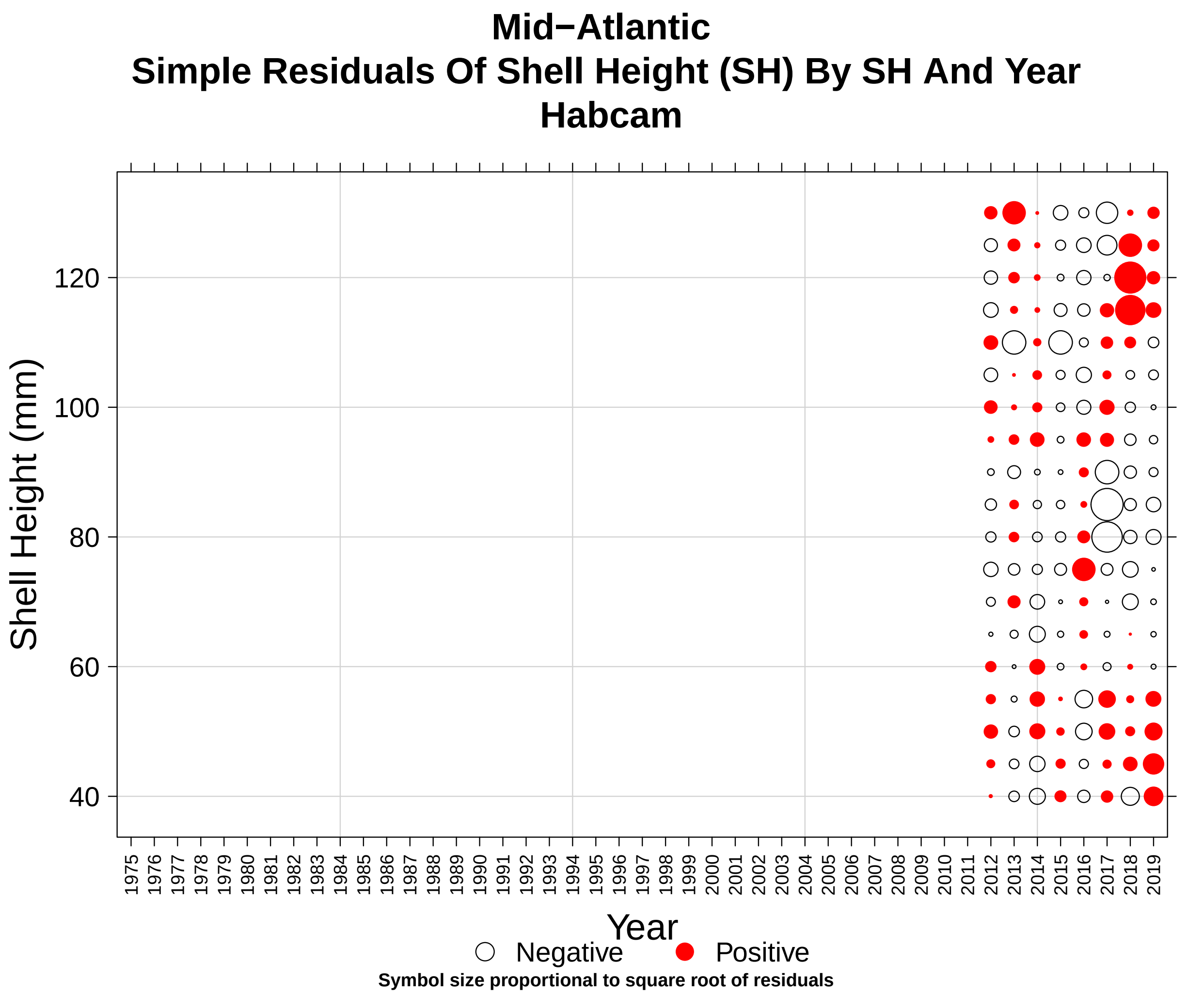


Figure 65: Simple residuals of Habcam survey shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

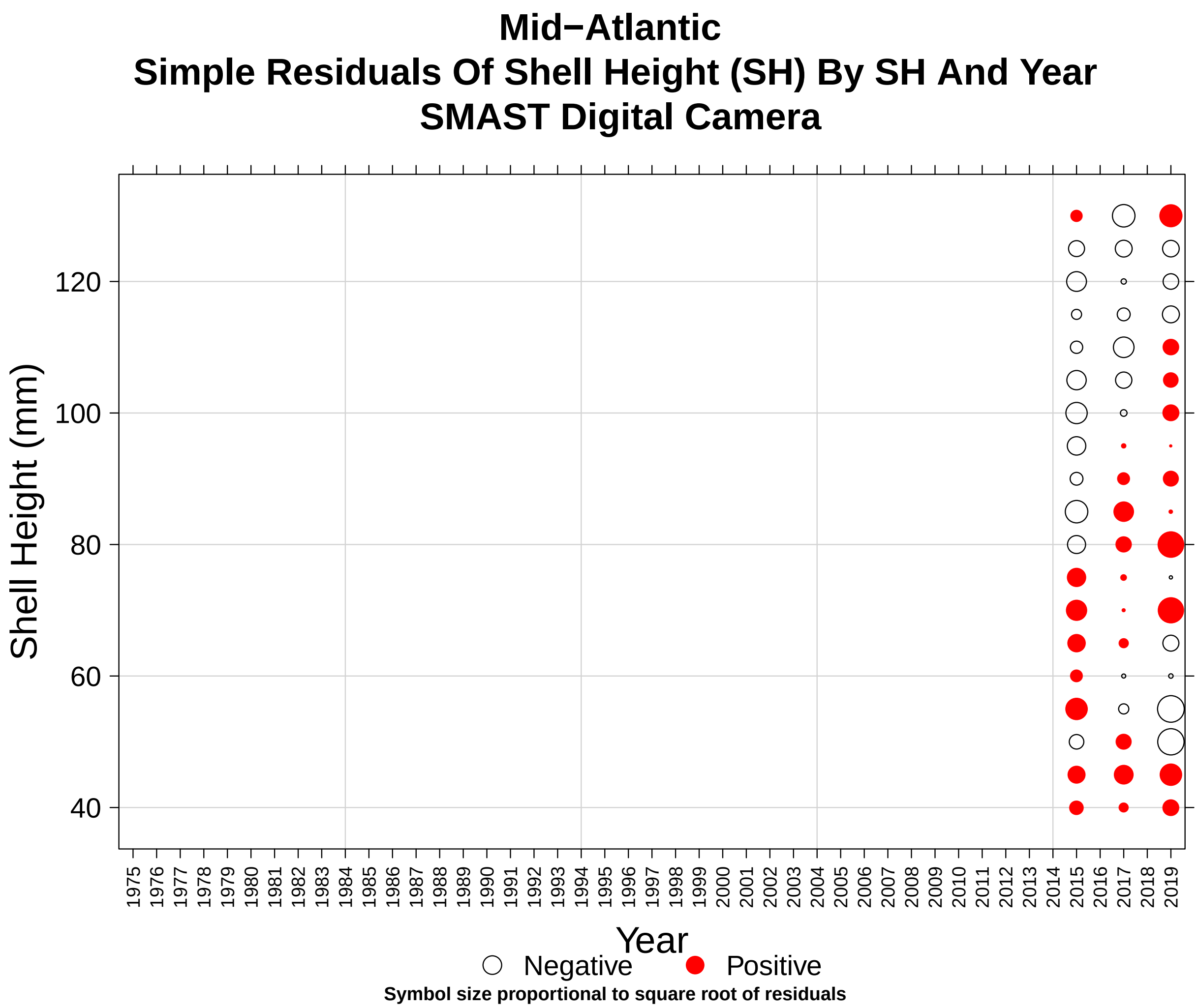


Figure 66: Simple residuals of SMAST digital camera survey shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

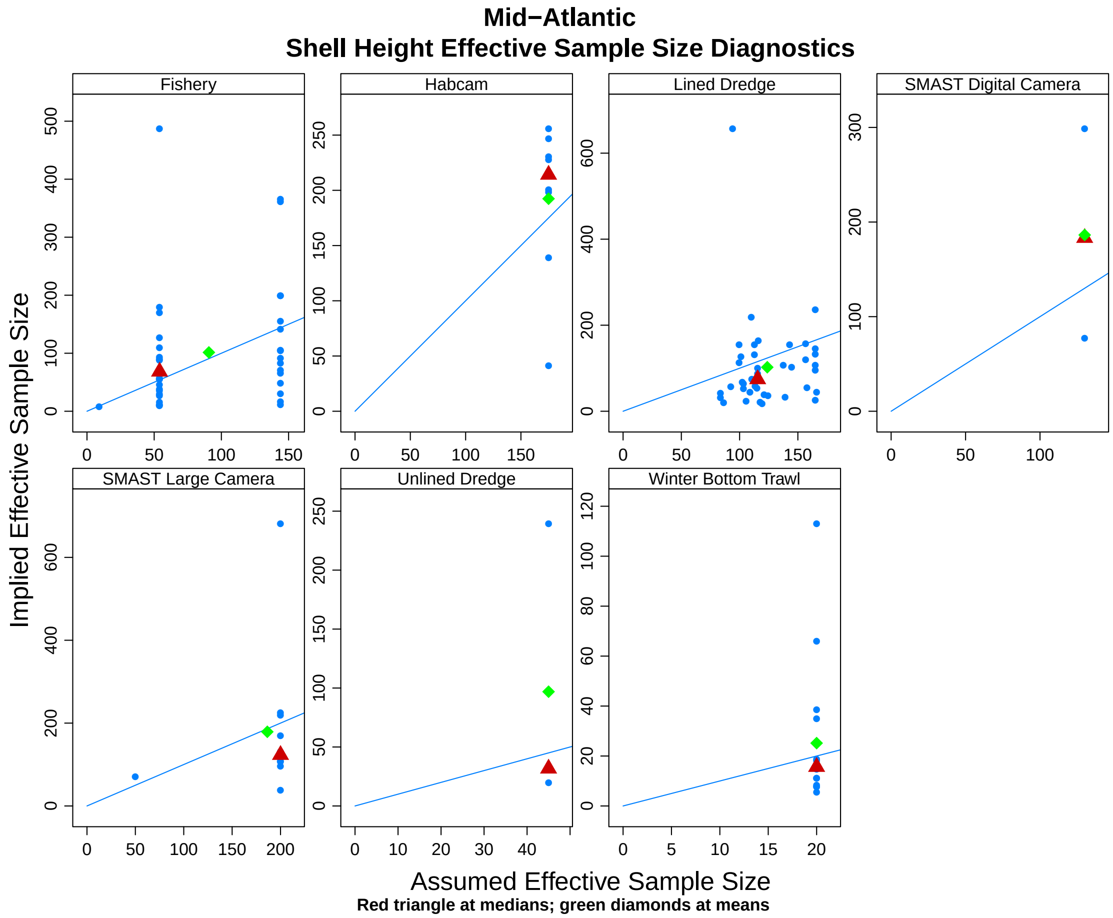


Figure 67: Assumed and model implied effective sample sizes for SMAST digital camera, lined dredge, Habcam, SMAST large camera, unlined dredge, and winter bottom trawl surveys, and the fishery shell height compositions for Mid-Atlantic areas. The triangle is the median and the diamond is the mean.

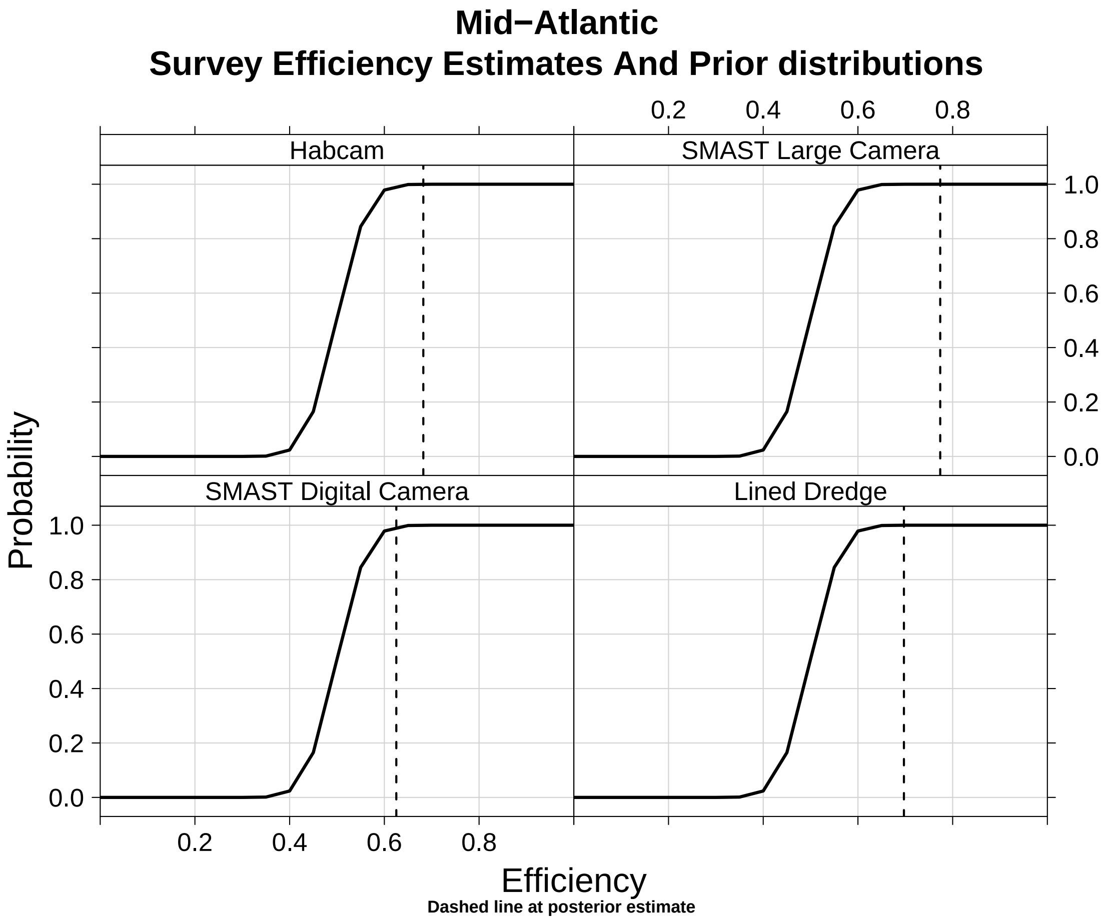


Figure 68: Prior cumulative distributions for catchability of Habcam, SMAST large camera, SMAST digital camera, and lined dredge surveys for Mid-Atlantic areas. The dashed lines are the mean posterior estimate for survey catchability. For the purposes of this plot, the surveys were adjusted to have a mean prior catchability of 0.5.

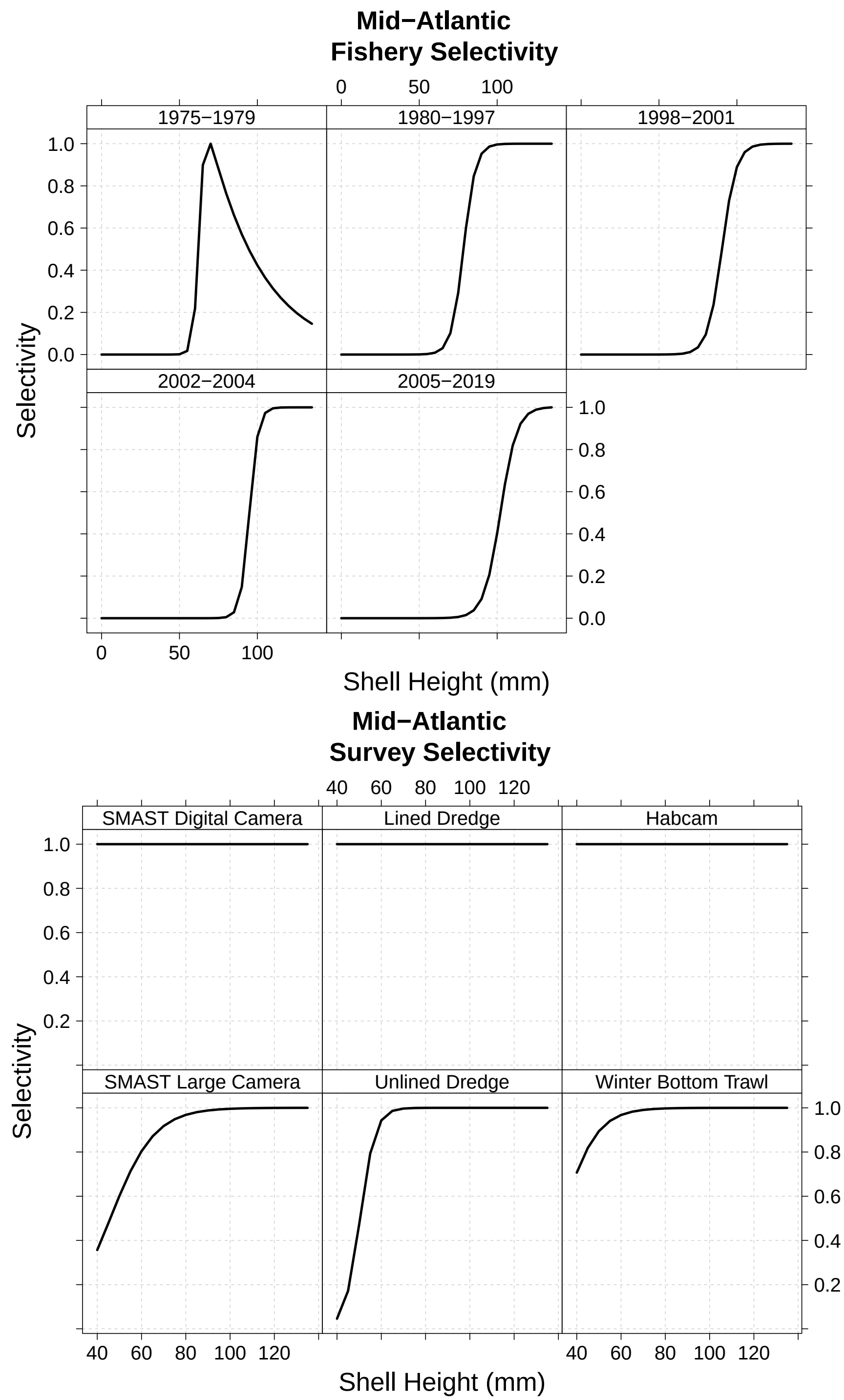


Figure 69: Estimated fishery selectivity curves (top) and assumed selectivity curves (bottom) for SMAST digital camera, lined dredge, Habcam, SMAST large camera, unlined dredge, and winter bottom trawl surveys for Mid-Atlantic areas.

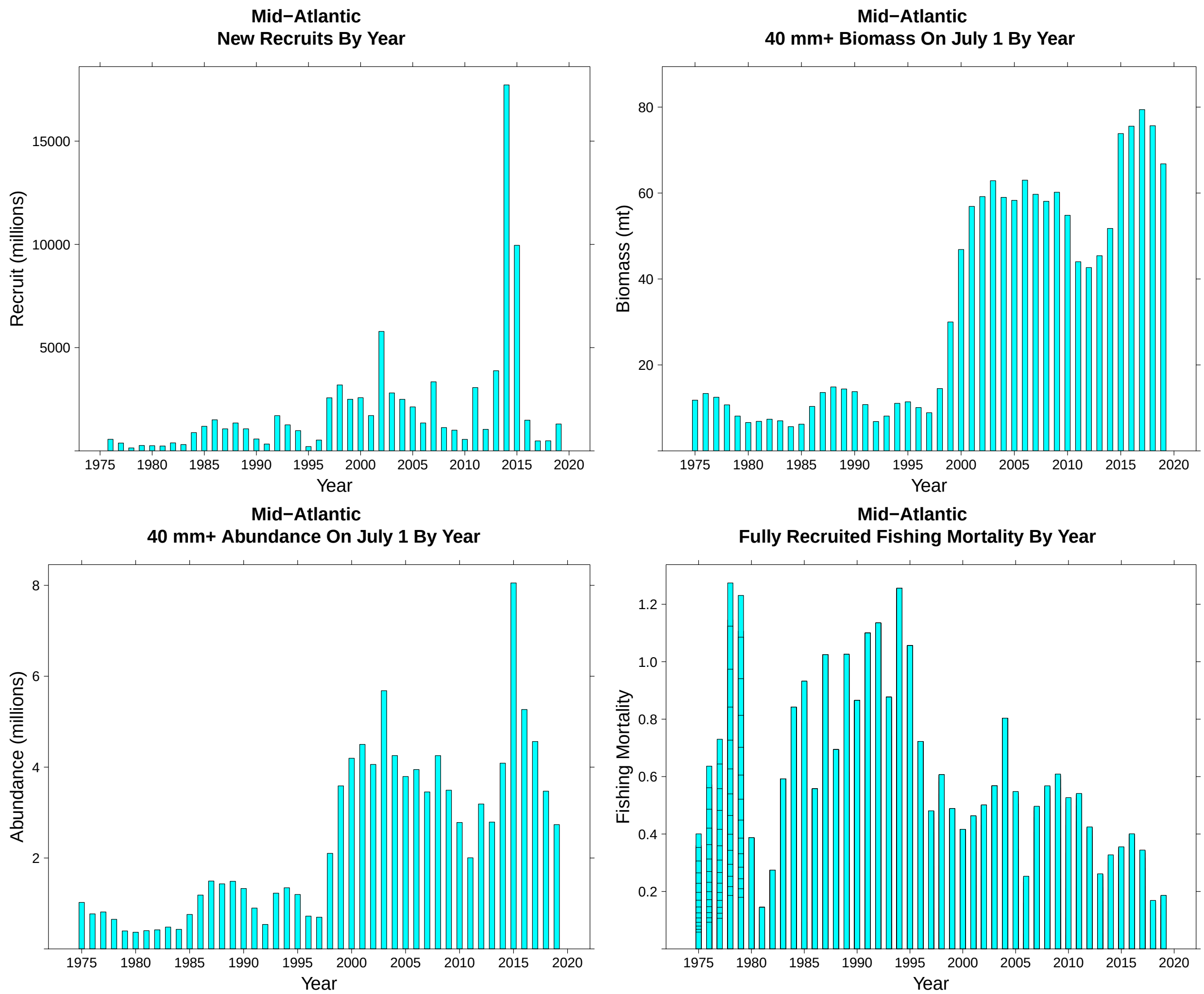


Figure 70: CASA model estimated recruitment (top left), July 1 biomass (top right), July 1 abundance (bottom left) and fully recruited fishing mortality (bottom right) for Mid-Atlantic areas.

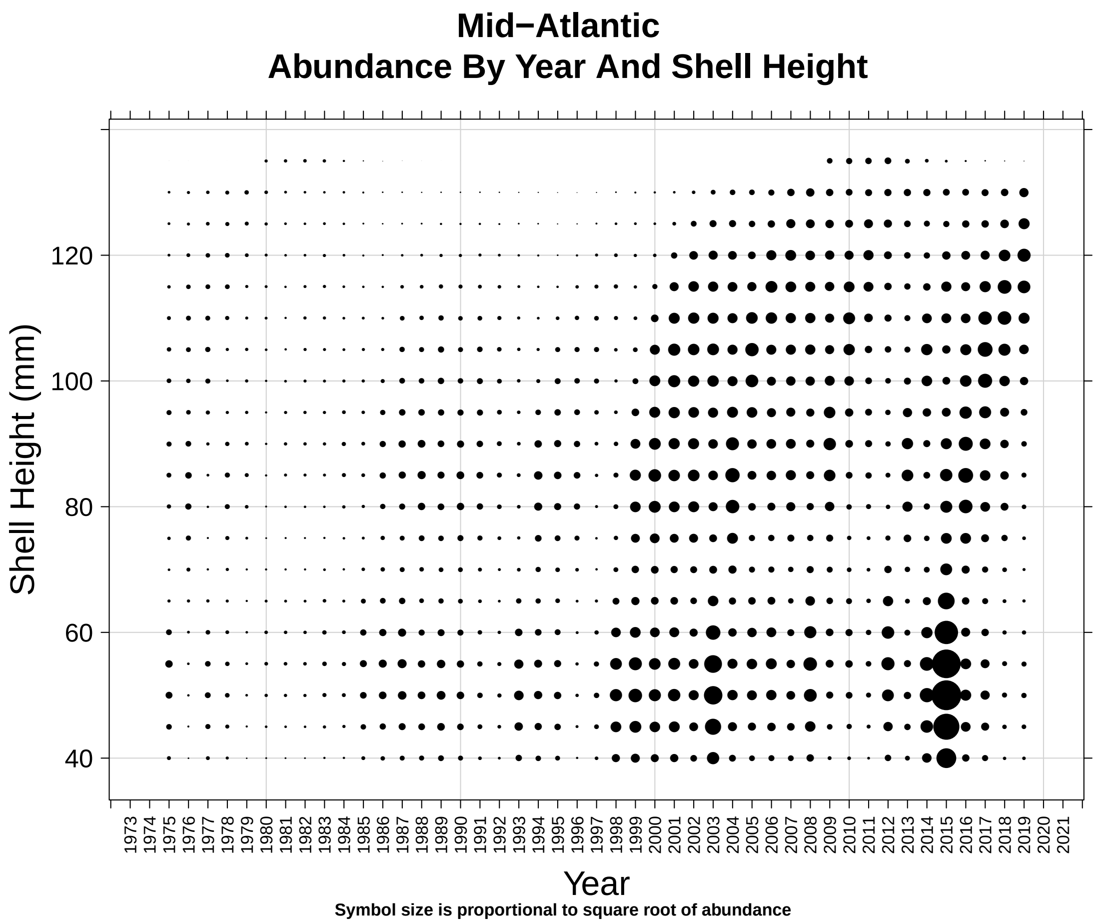


Figure 71: CASA model estimated abundances at shell height for Mid-Atlantic areas. Symbol areas are proportional to abundance.

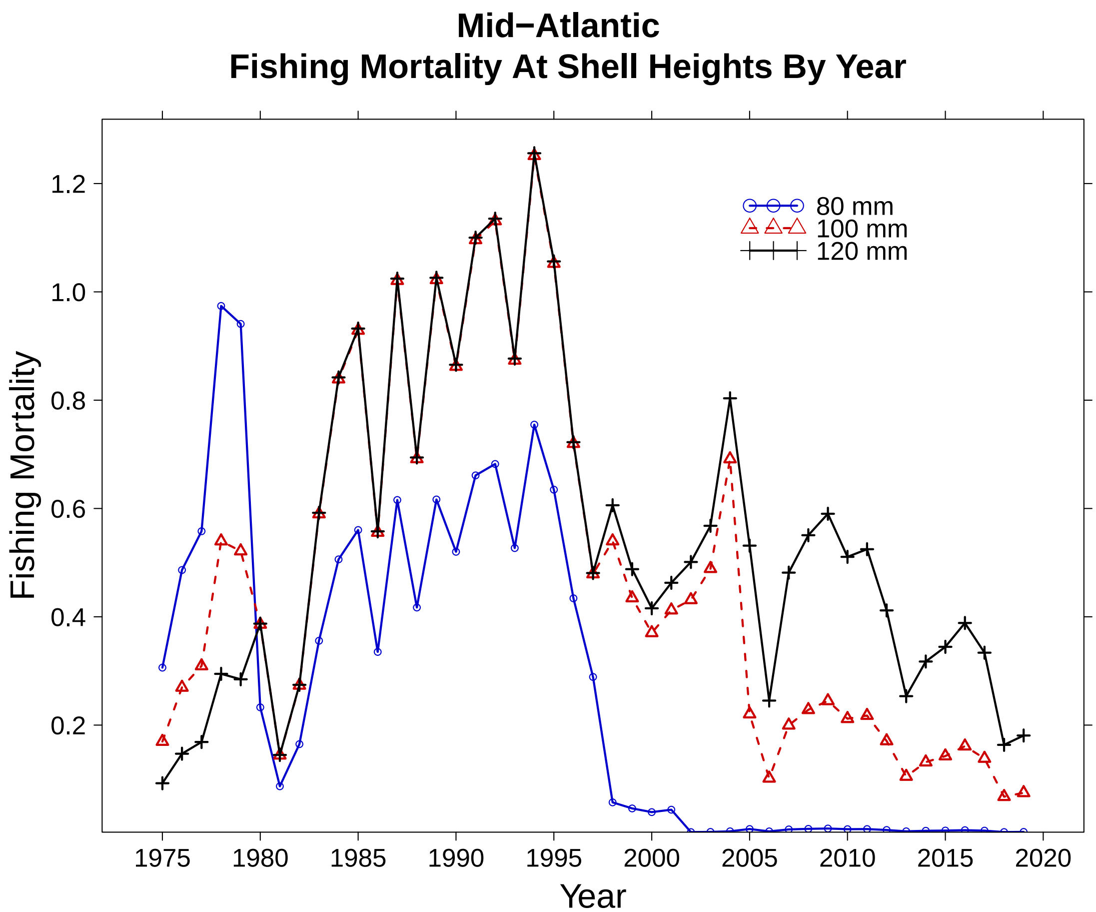


Figure 72: CASA model estimated fishing mortality at 80 mm (solid line with circles), 100 mm (dashed line with triangles), and 120 mm SH (dashed line with crosses) for Mid-Atlantic areas.

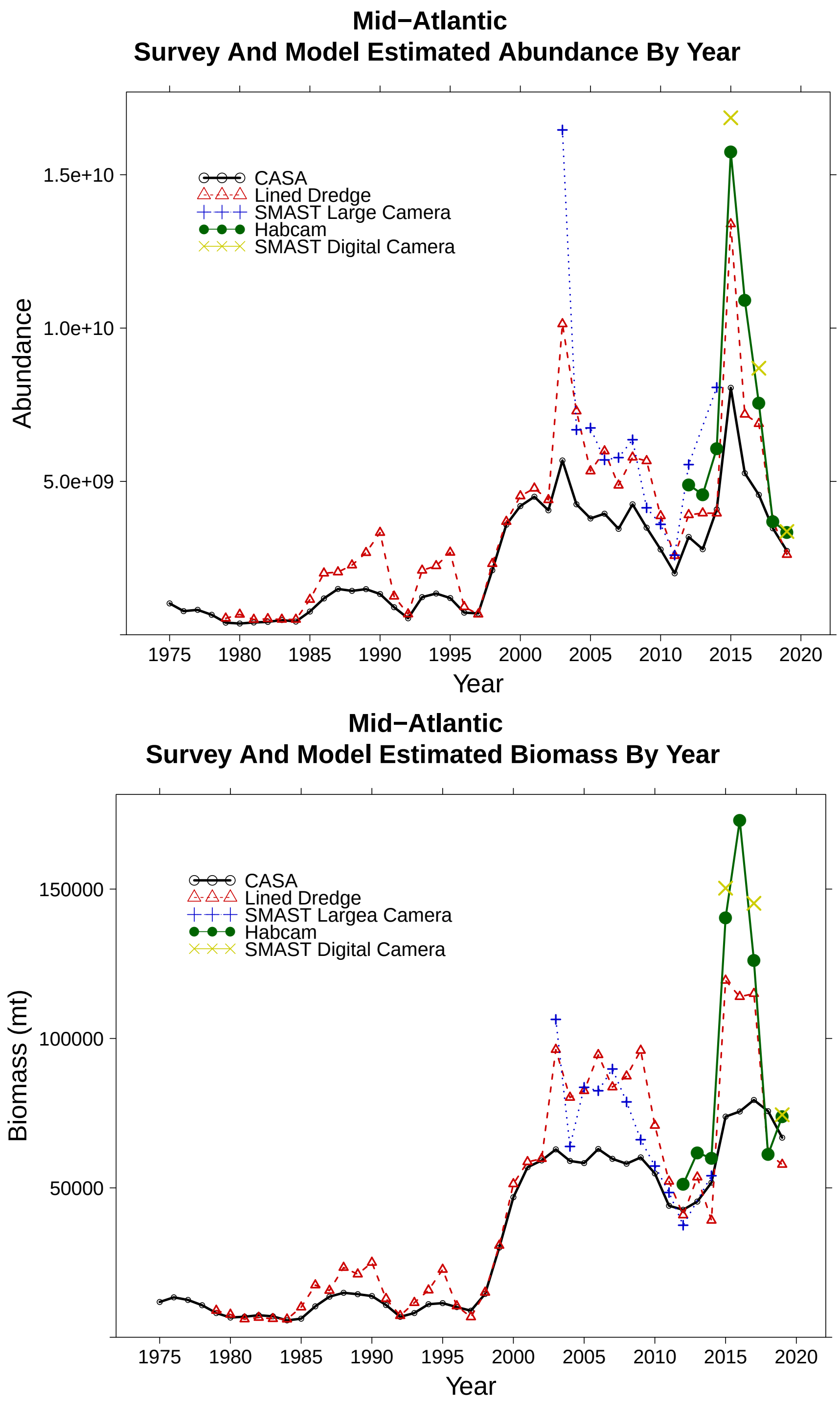


Figure 73: Comparison of CASA model estimated abundance (top) and biomass (bottom) with expanded estimates from the lined dredge (red), SMAST large camera (blue), HabCam (green), and SMAST digital camera (light green) for Mid-Atlantic areas.

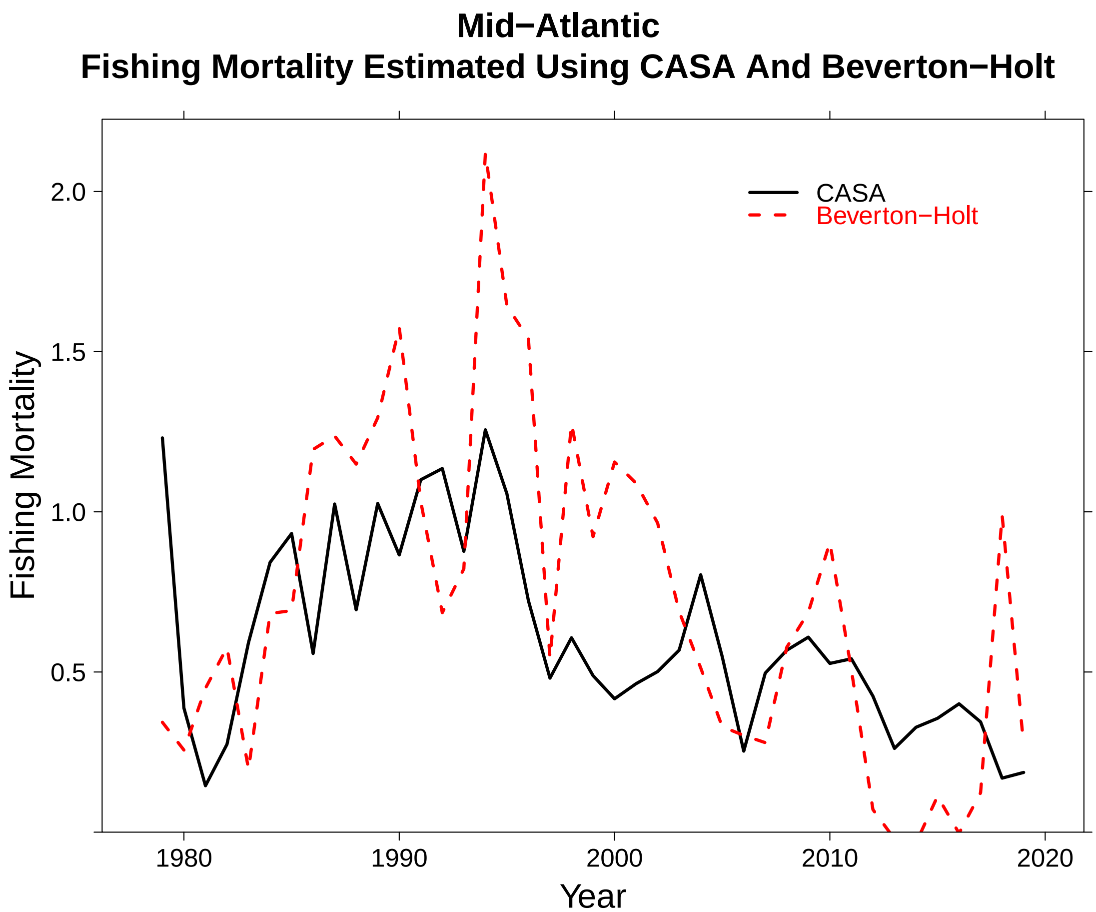


Figure 74: Comparison of fully recruited CASA fishing mortality with those calculated from the Beverton-Holt equilibrium length based estimator for Mid-Atlantic areas.

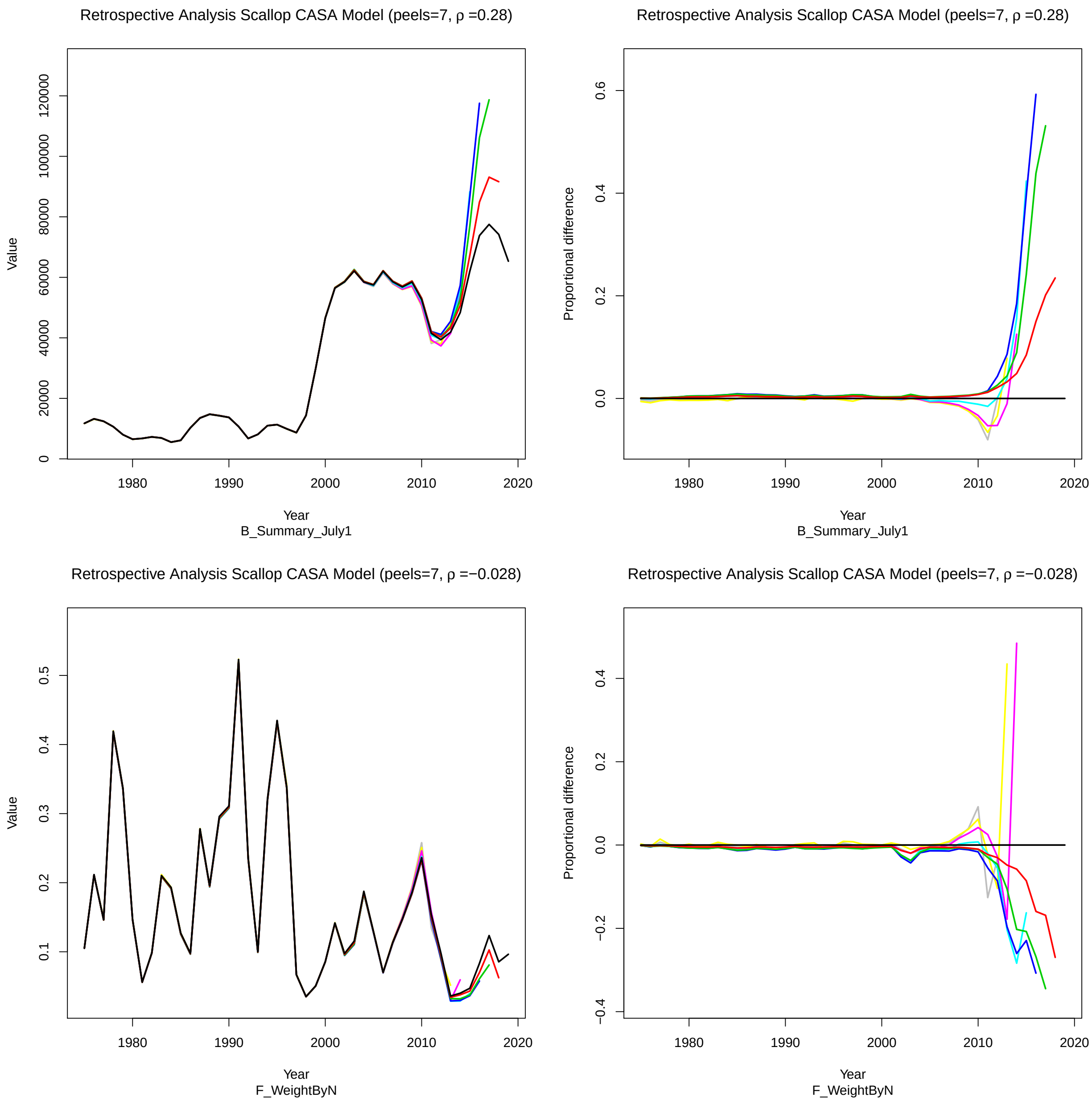


Figure 75: Retrospective plots for biomass and fishing mortality for Mid-Atlantic areas. Retrospectives are shown on both absolute and relative scales.

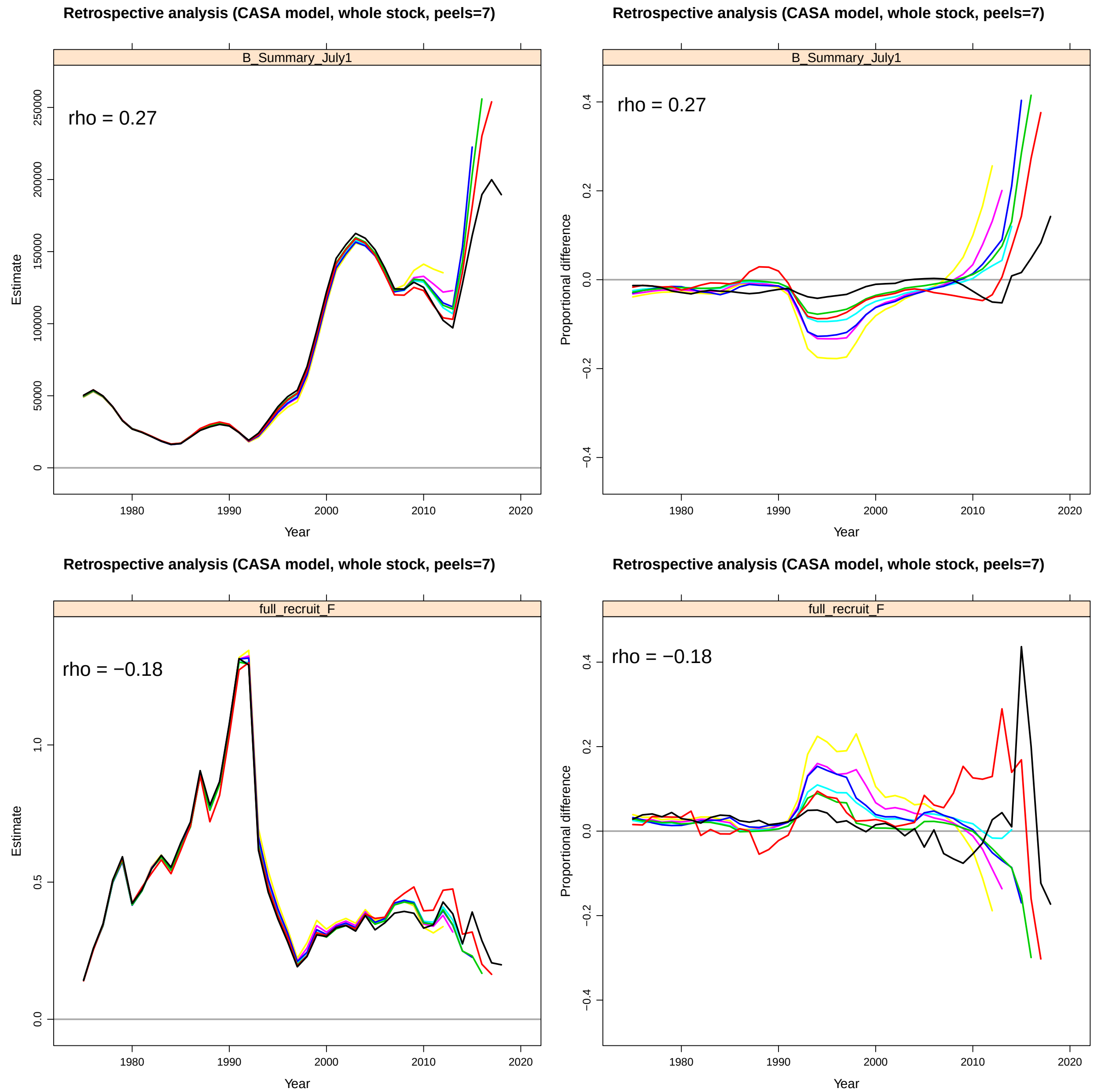


Figure 76: Retrospective plots for biomass and fishing mortality for all three stocks combined. Retrospectives are shown on both absolute and relative scales.

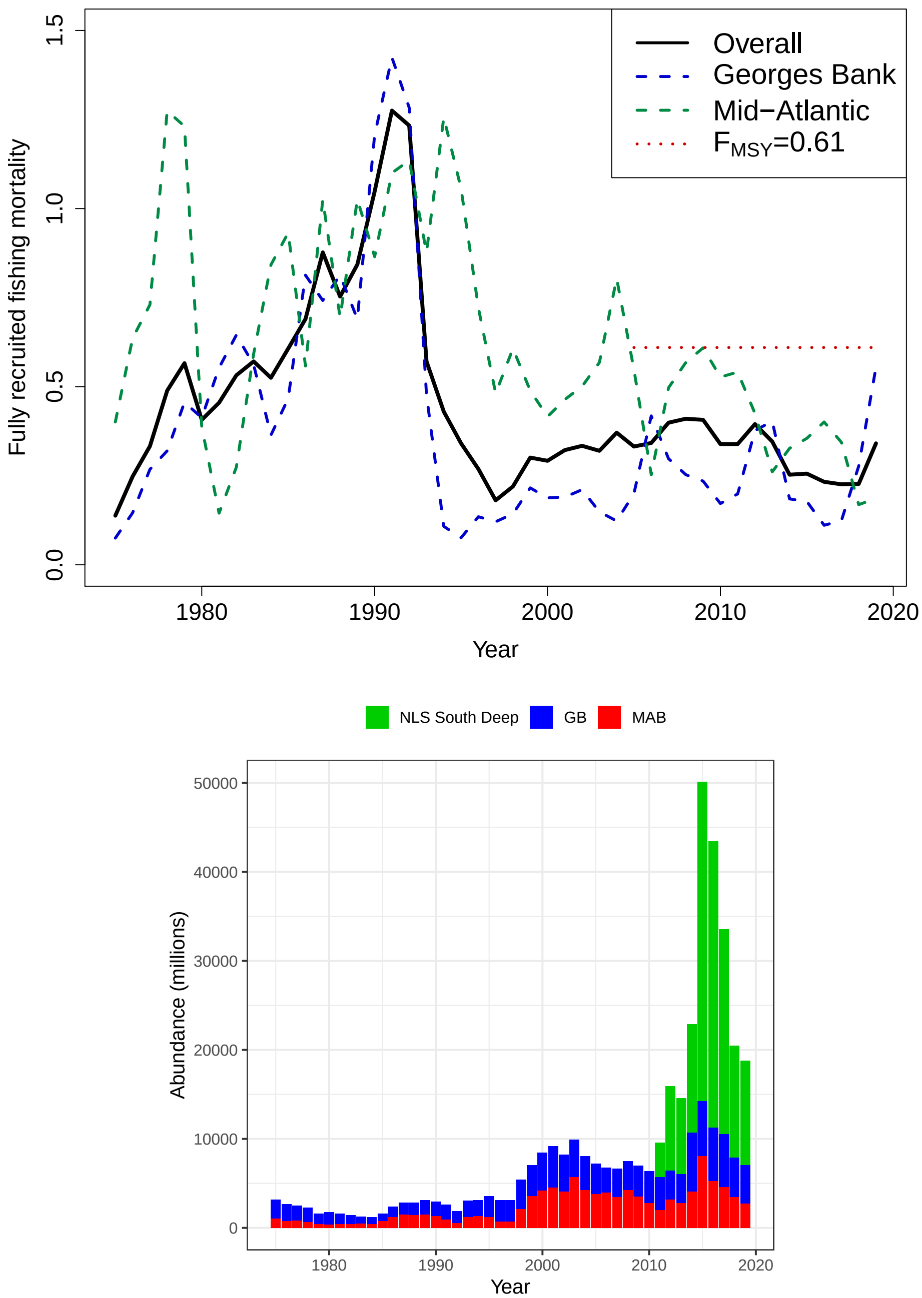


Figure 77: Estimated fully recruited fishing mortality (top), biomass (bottom left), and abundance (bottom right) for Georges Bank (open and closed combined) and Mid-Atlantic sea scallops, including Habcam biomass and abundance estimates of scallops located in the deep water southeast portion of Nantucket Lightship Area.

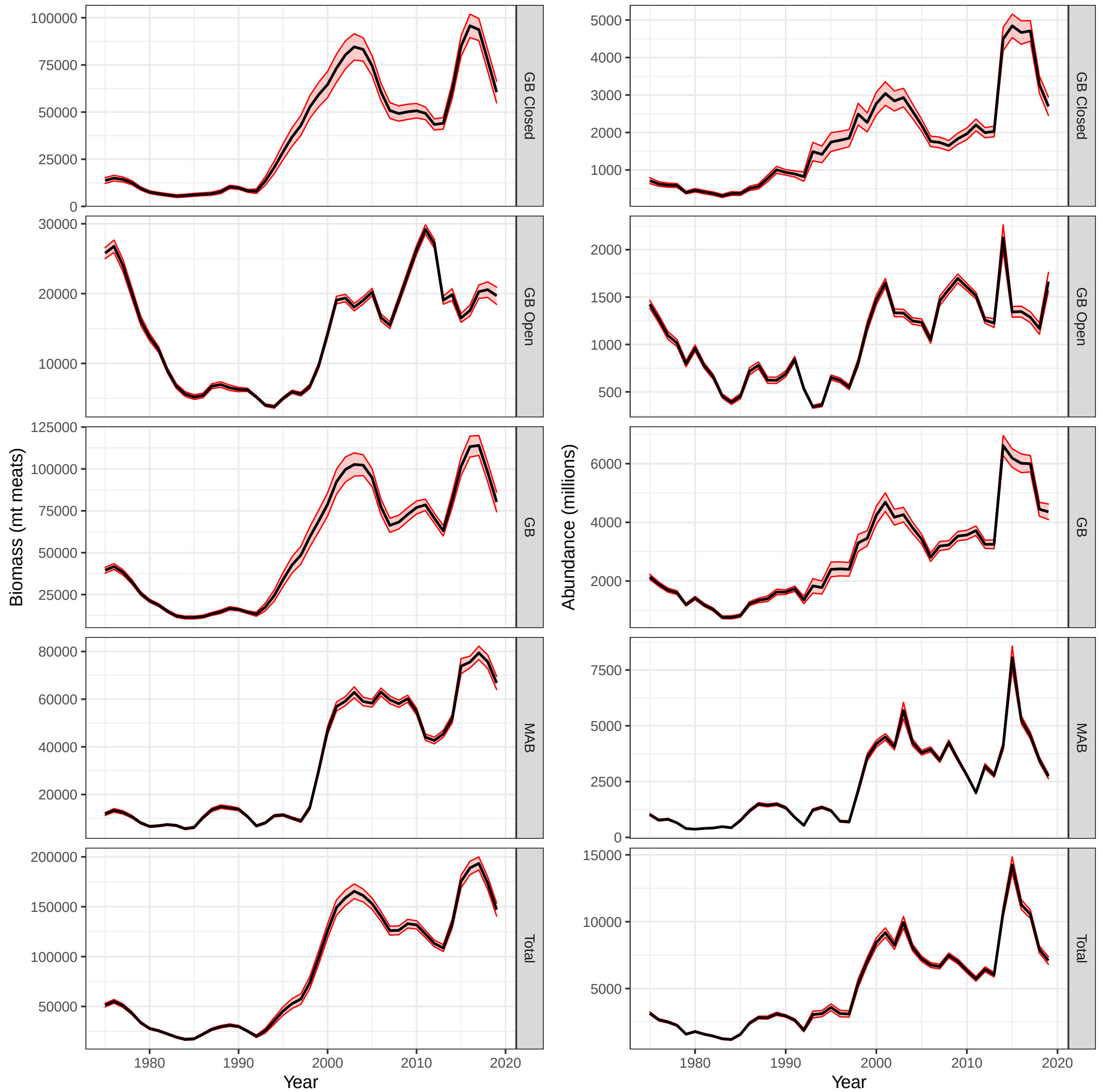


Figure 78: CASA estimated biomass and abundance with standard error for Georges Bank closed, Georges Bank open, Mid-Atlantic, and all three stocks combined.

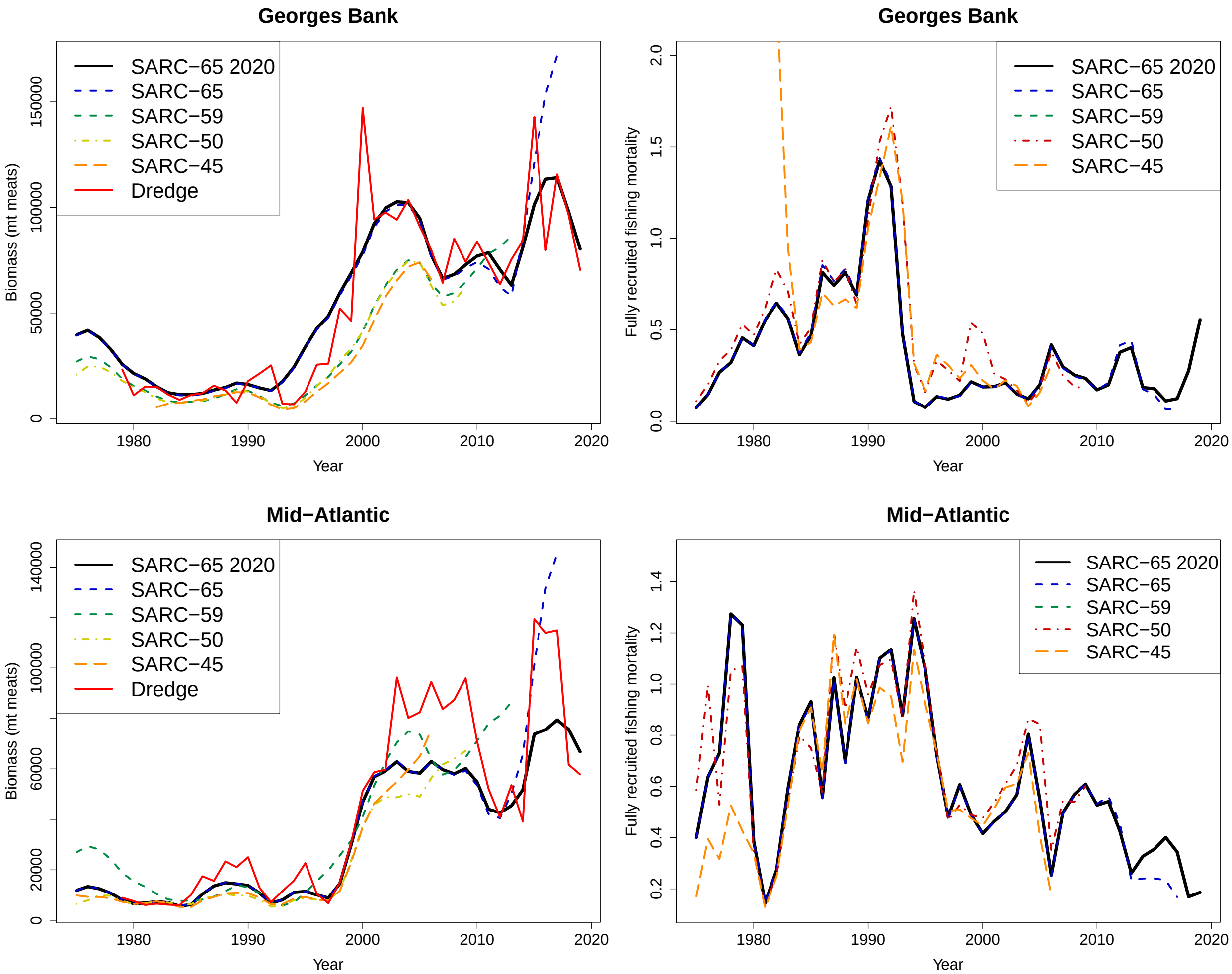


Figure 79: Comparison of current CASA model estimates of biomass (left) and fishing mortality (right) to previous CASA model estimates for Georges Bank (top) and Mid-Atlantic (bottom) sea scallops.