Working Paper 3.3
April 15, 2008
(April 16, 2008 - WP # changed).

Estimates of aggregate surplus production for the GARM and other stocks groups for the US Northeast Shelf LME.

(GARM3 System Capacity Analyses)

W.J. Overholtz, M. Fogarty, J.S. Link, C. Legault, and L. Col

Introduction:

This Working paper addresses TOR 3 of section F: Ecosystem Data for use in stock assessments, (3. Identify candidate measures of system-level productivity). It provides analyses to determine the productivity of commercial stocks of the Northeast Shelf LME (Large Marine Ecosystem). The purpose of this working paper is to estimate aggregate biological reference points (BRPs) for the GARM stocks and other commercial fish stocks on the Northeast Shelf LME. The technical basis for estimating aggregate BRPs for demersal and pelagic stocks is based on the following observations.

1. The energy available to demersal and pelagic fish from lower trophic levels is limited and shared by the entire community (Pauly and Christensen 1995; Pauly et al. 1998; Pauly et al. 2002), therefore an aggregated approach may be warranted.

2. Fish stocks have different productivities, making it difficult to attain single stocks objectives, therefore an average or aggregate quota may be more appropriate (May 1975).

3. Due to biological and or technological interactions, an aggregate quota may be more appropriate for managing suites of stocks (May 1975; Pope 1975; Fukuda 1976; Pope 1979; Mayo et al. 1992).

4. In mixed stock fisheries the effective catchability of each stock is different, therefore aggregate approaches are probably justified (Garrod 1973).

5. If fishing effort is relatively high, incidental catches are important and species overlap, then “the consideration of total yield from the total stock of available species is, therefore appropriate” (Au 1973)

6. If stocks are in different relative proportions, the results for grouping will be necessarily different than for separate stocks (Horwood1975).

7. Maintaining the resilience of fish stocks is an important deterrent to environmental adversity and climate change (Hilborn et al. 2003), this may necessitate a harvest approach that conserves all the components of the fisheries system, hence an aggregate approach may be useful.

Information is summarized for the GARM, pelagic, elasmobranch, and GARM-Pelagic-Elasmobranch components of the LME. Aggregate surplus production models will be fit using the ASPIC production model for all 19 groundfish stocks and other commercially targeted stocks as one "mega" stock and associated fishery. Additionally aggregate models will also be estimated for the GARM and pelagic stocks with methodology similar to Mueter and Megrey (2006). These approaches will provide an estimate of the overall carrying capacity for this group of stocks as a whole, emphasizing the GARM stocks. Estimates of BRPs (e.g., aggregate carrying capacity, B_{MSY}, MSY, Fmsy) will be calculated for groups of commercial stocks and for the entire complex of stocks. The aim will be to calculate aggregate BRPs to compare to summations of single stocks BRPs.

Methods

Aggregate data for the 19 GARM stocks, 3 pelagic stocks, and elasmobranchs (Spiny dogfish and 7 skate stocks) were assembled from available information on landings for individual stocks and for aggregate spring and autumn indices of abundance. Landings data were compiled from stock assessments (NEFSC 2007) and the total landings for the GARM, pelagic, and elasmobranch stocks were calculated during 1950-2005 (Tables 1,2,3). Indices of abundance were calculated for groups of stocks using software designed for this purpose (NEFSC, SAGA 2007). Aggregate biomass indices (catch per tow (kg)) were calculated for the spring (1968-2005) and autumn (1963-2005) time series for each group. These data were used in ASPIC runs to estimate BRPs for the various groups.

Another analysis required biomass estimates for the GARM stocks by using data from either previous stock assessments or by using catchability coefficients available from other sources (Link et al 2006) and applying them to survey area swept biomass estimates (Table 4). For a few GARM stocks a 5-year average of the most recent biomass years was used as an estimate of biomass to fill in missing years. These instances were few and resulted in only minor changes in the estimate of total biomass for the GARM stocks. Biomass estimates for the three pelagic stocks were available from previous stock assessments (Table 5).

This analysis followed the methods described in Mueter and Megrey (2006). In the analysis, surplus production for each group was calculated as:

$$SP = B_{t+1} - B_t + \gamma C_t$$

Where SP is surplus production, B is biomass, C is the catch and gamma is a correction parameter, assumed equal to 1 in this exercise.

The aggregate biomass and surplus production trajectories were used to estimate biological reference points for the GARM and Pelagic stocks. The equation used for estimating the management parameters was:

$$SP = r e^{g x_t} B(1 - B/K)$$

Where r is the intrinsic rate of increase, B is the annual biomass K is the carrying capacity, x is an environmental covariate index and g is a scaling parameter. The base case for each group was a no covariate model. Subsequent model fits included an environmental covariate. The covariates used in this study were March sea surface temperature (MSST), the March-August range in SST (RSST), production of CO2 from North America (CO2), spring bottom trawl survey temperature (BTEMP), and average salinity during March-April on Georges Bank (Table 6). Each covariate was converted to a standardized form so that it was a (0,1) index. The covariates were all from data collected in the Northeast LME; we felt that these environmental variables might have an influence on the productivity of the GARM and pelagic stocks.

Results and Discussion

Landings of GARM stocks ranged from 37,000 mt to 272,000 mt during 1950-2005 (Table 1). Since landings either did not occur or were not recorded for several stocks during 1950-1959, only landings from 1960-2005 were used in the ASPIC analysis. Spring survey indices for the GARM stocks showed a major decline from over 80 kg/tow in 1973 to a series low of 10 kg/tow in 1994, recovering to over 50kg/tow in 2002 (Figure

1). Most of the GARM stocks, although experiencing some declines from the 1970s to the early 1990s, were well represented in the survey catch during spring (Figure 2). Autumn survey indices also showed a pronounced decline during the late 1960s through the early 1990s, ranging from 110 kg/tow in 1964 to a series low of about 12 kg/tow in 1994 (Figure 3). GARM stocks were also well represented in the autumn survey catch in the 1963-2005 time-series (Figure 4).

These data were used in a series of ASPIC runs to estimate starting values for B1/K, MSY, and K. Specifically B1/K ratios were varied systematically from 0.3-1.0 and appropriate values and diagnostics were recorded for each run (Table 7). Based on MSE values, residual patterns, trends in biomass, and the estimate of K, a set of initial values for B1/K (1.0), MSY (126 kt), and K(1514 kt) were determined. When these values were used to start a final ASPIC run, the model converged rapidly to a B1/K value of 1.0, an MSY of 126, and a K value of 1513 (Tables 7,12). Residuals for both the spring and autumn series for this ASPIC run were reasonable and the biomass trajectory during 1960-2006 appeared plausible (Figures 5-7). Estimates of biological reference points were MSY = 126,000 mt, Bmsy = 758,000 mt, and Fmsy = 0.17 (Table 12).

A similar approach was used to estimate BRPs for the pelagic stocks (Herring, mackerel, and butterfish). Landings for the pelagic stocks were much larger than for the GARM stocks, especially during the late 1960s through the mid 1970s (Table 2). Landings ranged from 75,000 mt in 1983 to 730,000 mt in 1973 (Table 2). Spring catch per tow (kg) dropped to its lowest point in the time-series during the late 1970s and then gradually increased through 2006 (Figure 8). All three members of the pelagic stock complex were represented in the spring series (Figure 9). Catch per tow in the autumn survey series was flat in the 1960s and 1970s, increased in the 1980s and 1990s and dropped somewhat during 2000-2006 (Figure 10). Only butterfish and herring were relatively consistently present in the survey area during autumn (Figure 11). Herring were at very low abundance during the 1980s and part of the mackerel stock is in Canada during this time period, while the rest is dispersed inshore or else not generally available to the survey trawl gear (NEFSC 2007).

Landings during 1960-2005 for the pelagic stocks and the spring survey index were used to fit an ASPIC model. Again, a series of B1/K values were used to determine a set of starting values for the initial parameters (B1/K, MSY, K) (Table 8). Based on MSE values, residual patterns, trends in biomass, and the estimate of K, a set of initial values for B1/K (0.3), MSY (358), and K (5000) were determined (Table 8). These values were used as initial parameter estimates and a final ASPIC run was completed (Tables 8, 11). The model estimated B1/K=.246, MSY=422, and K=5943. Residuals for the spring survey were reasonably distributed and the biomass trajectory for this run was plausible (Figures 12; 13). BRPs for the aggregated pelagic stocks were MSY=422,000 mt, Bmsy = 2,942,000 mt, and Fmsy= 0.14 (Table 11).

Landings for the elasmobranch stocks ranged between 235 mt in 1962 to a peak of 42,000 mt in 1996 (Table 3). Survey catch per tow in the spring increased until the early 1990s and then declined (Figure 14). This aggregate measure of abundance is composed mostly of spiny dogfish, winter skate, little skate, and thorny skate (Figure 15). Autumn survey indices declined in the 1960s, remained flat through the 1980s, and increased from 1996 onward (Figure 16). Spiny dogfish, and winter, little, and thorny skates were most abundant in the survey (Figure 17).

Landings data during 1962-2005 and the two survey time-series were used to fit an aggregate ASPIC model for the elasmobranchs. Another systematic approach, using equally spaced values of B1/K between 0.3 and 1.0, was used to determine appropriate starting values for the parameters (Table 9). The starting set was determined as B1/K=0.3, MSY=22.5 kt, and K=1120 kt (Table 9). The model converged to final values of B1/K=0.068, MSY=58.66 kt, and K=3790 kt (Table 9). Residuals for the spring series were patterned indicating that the model fit to these data was not very good (Figure 18). The distribution of residuals for the autumn time series were better, but there was still some patterning (Figure 19). The biomass trajectory for the elasmobranch stocks seemed reasonable, albeit somewhat low (Figure 20). The BRP estimates from the final run were MSY=58,660 mt, Bmsy=1,895,000 mt, and Fmsy = 0.31 (Table 12).

A trial run with all three groups was completed, but BRPs and diagnostics from this run were poor. One of the reasons that this run was unsuccessful is because the combined survey index for this complex of stocks is relatively flat over the entire time series, making it difficult for the ASPIC model to estimate a useful solution (Figure 21).

Since pelagic fishes are by far the most abundant in the region, the spring survey indices for the GARM, pelagic, and elasmobranch stocks were scaled with their respective q's to allow for a more balanced index (Figure 22). A final ASPIC model run, with GARM, Pelagic, and Elasmobrnach stocks included, was used to estimate BRPs. A sensitivity analysis was used to determine starting values for parameters and final ASPIC run was completed (Table 10). Residuals from this model were well behaved and biomass trends seemed feasible (Figures 23; 24). Final parameters for this model were B1/K=.432, MSY=579, and K=10700 (Table 10). The BRP estimates for the 3-group model were MSY=579,000 mt, Bmsy=5,350,000 mt, and Fmsy=0.11 (Table 11).

Estimates of MSY from ASPIC runs are roughly similar to management targets for the single stock groups, with the GARM estimates being lower and the pelagic, elasmobranch, and GARM-Pelagic-Elasmobranch estimates slightly higher (Table 12). The Bmsy estimates from the ASPIC analyses are all higher except for the GARM stocks (Table 12). Overall, ASPIC results suggest that Bmsy biomasses that are larger than current management targets and lower fishing mortalities are appropriate for this system as a whole, except for the GARM stocks where the Bmsy target was lower (Tables 11; 12).

Estimates of management parameters from multispecies surplus production models with environmental covariates were in agreement with ASPIC results for the GARM and Pelagic stocks. A relatively long time-series of information is available for fitting these models and there is a relatively good level of contrast in the data (Figure 25; 26). Landings and surplus production have declined over time for the GARM stocks (Figure

25). Estimates of MSY for the GARM stocks ranged between 110-125 thousand mt (single species target, 197,000 mt) (Table 13). The model with no covariates had an estimated MSY of 124,000 mt, while the best covariate model estimated MSY as 114,000 mt (Table 13). Residuals from the no-covariate model had some minor patterning with a group of larger positive residuals in the 1960s and smaller negative residuals in the later part of the series (Figure 27). Estimates of Bmsy for the GARM stocks ranged from 509,000-525,000 mt (single species target, 1,424,000 mt) (Table 13). The model with no covariates had an estimated Bmsy of 522,000 mt while the best covariate model (CO2) had an estimate of 509,000 mt (Table 13). Fmsy values from the various models ranged between 0.108-0.130.

The pelagic stocks had MSYs ranging between 363,000-445,000 mt with the no covariate model at 368,000 mt and the best covariate model (March SST) at 363,900 mt (Table 13). Estimates of Bmsy for the pelagic stocks ranged between 2,814,000-4,132,700 mt with the no covariate model at 2,849,000 mt and the March SST model at 2,796,000 mt. Fmsy values ranged between 0.108-0.130 for all the pelagic stock models (Table 13).

Overall the results from both surplus production modeling approaches suggest that the expected aggregate yield is lower, the Bmsy biomass is lower and the overall fishing mortality rate should be lower for the GARM stocks as a whole than is suggested from the single species results. The expected yield for the pelagic complex is similar or slightly higher, the Bmsy biomass is higher, and the overall fishing mortality rate is lower than suggested from the single species target results. This suggests the need for an overall 2nd layer of consideration for the GARM stocks as a whole, and managing the pelagic stocks at a higher level of biomass than suggested by the single species results.

References

Au, D.W.K. 1973. Total sustainable yield from Subareas 5 and 6 based on yield per recruit and primary production consideration. ICNAF Research Document 73/10. Serial No. 2912. Annual Meeting 1973.

Fukuda, Y. 1976. A note on yield allocation in multistock fisheries. ICNAF Research Bulletin 12:83-87.

Garrod, D.J. 1973. Memorandum on the mixed fishery problem in Subarea 5 and Statistical Area 6. ICNAF Research Document. 73/6.

Hilborn, R., T.P. Quinn, D.E. Schindler, and D.E. Rogers. 2003. Biocomplexity and fisheries sustainability. PNAS. 100:6564-6568.

Horwood, J.W. 1975. Interactive fisheries: a two stocks Schaefer model. ICNAF Research Document 75/IX/125.

Link, J. S., C.A. Griswold, E.T. Methratta, and J. Gunnard, editors. 2006 Documentation for the energy modeling and analysis exercise (EMAX). Northeast Fisheries Science Center Reference Document 06-15.

May, A.W. 1975. Report of standing committee on research and statistics. ICNAF Seventh Special Commission Meeting – September 1975.

Mayo, R.K., M.J. Fogarty, and F.M. Serchuk. 1992. Aggregate fish biomass and yield on Georges Bank, 1960-87. JNAFS. 14:59-78.

Mueter, F.J., and B.A. Megrey. 2006. Using multi-species surplus production models to estimate ecosystem-level maximum sustainable yields. Fisheries Research. 81:189-201.

NEFSC. 2007. Status of Fishery Resources off the Northeastern United States. NOAA's National Marine Fisheries Service. Northeast Fisheries Science Center. http://www.nefsc.noaa.gov/sos/

Pauly, D., and V. Christensen. 1995. Primary production required to sustain global fisheries. Nature 374:255-257.

Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, F.Torres. 1998. Fishing down marine food webs. Science. 279:860-863.

Pauly, D., V. Christensen, S. Guenette, T.J. Pitcher, U. R. Sumaila, C.J. Walters, R. Watson, and D. Zeller. 2002. Towards sustainability in world fisheries. Nature 418:689-695.

Pope, J.G. 1975. The application of mixed fisheries theory to the cod and redfish stocks of subarea 2 and division 3K. ICNAF Research Document. 75/IX/126.

Pope, J. 1979. Stock assessment in multistock fisheries, with special reference to the trawl fishery in the Gulf of Thailand. SCS/DEV/79/19. FAO. Manila, Philippines. June 1979.

Table 1. Landings (000s mt) of GARM stocks during 1950-2005.

Year	GOM cod	GB cod	GOM hadd	GB hadd	Yt	Window	Winter	Witch	Pollock	Redfish	O-pout	White_hake	Halibut	Total
1950	5062	15400		41273	11590					34307			116	107748
1951	3567	14800		47318	9560					30077			154	105476
1952	3011	10900		43252	9040					21377			123	87703
1953	3121	8100		35926	7040					16791			104	71082
1954	3411	8800		46388	6710					12988			125	78422
1955	3171	9300		40851	7720					13914			74	75030
1956	2693	10500	7307	51144	7730					14388			62	93824
1957	2562	10400	6166	48561	11730					18490			80	97989
1958	4670	11100	7367	37322	17240					16047			73	93819
1959	3795	12100	4660	36051	15260					15521			59	87446
1960	3577	10900	4924	40877	16240			1255		11375			63	89211
1961	3234	14700	5409	46650	20520			1024		14101			84	105722
1962	3072	23500	5110	54004	23100			977		14134	0		146	124043
1963	2731	27200	4789	54846	37290			1374	6241	10046	20		183	144720
1964	3251	25200	5453	64086	38580		10072	1418	9008	8313	2123	3045	236	170785
1965	3928	38300	4363	150362	39080		11030	2664	9000	8057	877	2617	299	270577
1966	4392	53100	5704	121274	36010		14959	3314	9847	8569	13380	1563	282	272394
1967	5973	36800	5496	51469	36540		12630	3682	8534	10864	7361	1142	514	181005
1968	6421	43100	3557	40923	41670		9933	3054	5222	6777	13061	1295	270	175283
1969	8484	37900	2713	22252	43780		11600	3852	9822	12455	26972	1383	168	181381
1970	8684	25700	1562	11300	38540		12411	3261	11976	16741	7172	2133	138	139618
1971	7662	28200	1306	10862	30070		12663	6115	15203	20034	5910	2897	119	141041
1972	6917	25100	936	5866	35460		10787	5515	13013	19095	3351	3145	108	129293
1973	6146	28900	558	5429	30370		9629	3162	13076	17360	5370	3401	89	123490
1974	7764	27300	829	4450	26060		7362	2140	12393	10471	3732	4005	76	106582
1975	9015	25000	1263	5606	19370	1980.7	8100	2357	13871	10572	277	3818	106	101336
1976	10188	20000	1956	4484	17040	2083.8	6623	1882	13382	10696	678	4299	91	93403
1977	12426	27400	3322	10994	16540	1746	10168	2493	16273	13223	1059	5484	81	121209
1978	12426	35500	5179	22516	11720	1821	11771	3525	22305	14083	1035	5053	134	147068
1979	11680	38700	4879	19647	15390	1489.2	8628	2895	18452	14755	672	4299	154	141640
1980	13528	48100	7473	27638	18440	940	17039	3147	23539	10183	350	5053	168	175598
1981	12534	42400	6239	25011	15160	1295.5	17594	3449	22068	7915	251	6423	198	160538
1982	13582	57200	6923	17627	25010	1061.9	15211.431	4915	19466	6903	321	6945	201	175366
1983	13981	48900	7597	12009	32170	1257.8	14662.69	6045	17816	5328	408	7218	203	167595
1984	10806	38700	4038	10394	17230	1830.5	14512.406	6675	20633	4793	1324	7770	137	138843
1985	10693	37300	3015	7943	7280	4206	10797.388	6431	21069	4282	1504	8306	118	122944
1986	9664	25900	1668	6846	7850	3222.8	7903.673	5216	26507	2929	802	7065	76	105649
1987	7527	30900	829	6997	5930	2282.7	8981.005	3819	22347	1894	2185	6373	50	100115
1988	7958	39200	436	6689	4200	2549	8420.913	3665	17304	1177	1811	5317	128	98855
1989	10397	33100	264	4627	5190	2698	6813.825	2378	11903	637	1314	5131	78	84531
1990	15145	42500	433	5469	14240	1967.8	7301.208	1479	11201	601	1312	5474	74	107197
1991	17781	37600	431	6958	7710	3678.5	7658.673	1784	9600	525	1424	6159	88	101397
1992	10891	28600	312	6196	5600	2102.5	6489.614	2234	10225	849	474	9582	69	83624
1993	8287	23100	193	4528	4230	1681.3	5304.443	2611	9873	800	232	9147	65	70052
1994	7877	15200	328.76	2743	5420	500	3683.018	2699	7099	440	196	5692	46	51924
1995	6798	7900	181.57	2351	2390	800	4189.984	2220	4362	440	65	4814	19	36531
1996	7194	8900	1061.32	4008	2850	900	4716.703	2097	4164	322	51	3659	25	39948
1997	5421	10400	613.19	3570	3670	525	5482.449	1778	5483	251	33	2515	28	39770
1998	4156	8832	1037.12	5314	4820	519	5193.042	1858	7441	320	17	2592	17	42116
1999	1636	9880	913.32	6504	6330	162	4743.632	2140	5591	353	18	2798	20	41089
2000	3730	9189	773.71	8797	9920	268	6020.073	2492	5240	319	19	3214	18	50000
2001	4423	12778	1195.66	11505.13	10250	173	7432.51	3051	5680	360	17.6	3685	24	60575
2002	4096	10274	1211.14	12993.85	7940	97	6121.18	3222	5170	368	12.1	3424	23	54952
2003	4028	7963	1221.33	12576.3	7670	64	6208.2	3154	6215	361	25.6	4563	34	54083
2004	3798	4583	1020.58	17583.52	7310	69	5057.19	2917	7108	398	5.4	3595	30	53475
2005	3909	3048	1435	20597	4130	67	3740	2652	8269	564	3.6	2668	35	51118

Table 2. Landings (000s mt) of pelagic stocks during 1960-2005.

Year	Mackerel	Herring	Butterfish	Total
1960	9762	94954		104.7
1961	6841	101555		108.4
1962	8078	243149		251.2
1963	9081	195343		204.4
1964	13405	188444		201.8
1965	20825	110957	4.9	136.7
1966	23496	211037	7.3	241.9
1967	34181	284963	5.8	324.9
1968	90530	469535	8.0	568.1
1969	137189	393014	18.8	549.0
1970	251958	306146	14.9	573.0
1971	382794	334605	11.3	728.7
1972	415831	271272	13.3	700.4
1973	436698	259244	34.3	730.2
1974	367534	210601	19.4	597.5
1975	315145	218338	16.3	549.8
1976	259052	123764	16.8	399.6
1977	80719	76708	6.1	163.5
1978	28345	91411	5.6	125.3
1979	36630	103962	4.0	144.6
1980	27910	98690	6.6	133.2
1981	30890	84841	6.2	121.9
1982	27026	60912	10.0	97.9
1983	32588	36358	5.8	74.8
1984	41689	42798	12.6	97.1
1985	72933	55545	5.9	134.4
1986	71097	57063	4.7	132.8
1987	80458	67764	4.5	152.7
1988	83434	74661	2.0	160.1
1989	74383	97194	3.2	174.8
1990	86891	93870	2.3	183.1
1991	71309	79973	2.1	153.4
1992	38843	93196	2.8	134.8
1993	31955	88677	4.6	125.2
1994	31195	76831	3.6	111.7
1995	27378	103787	2.1	133.2
1996	37917	127002	3.5	168.5
1997	38444	119729	2.8	161.0
1998	34419	125829	2.0	162.2
1999	29922	124251	2.1	156.3
2000	20477	125958	1.4	147.9
2001	37742	133204	4.4	175.3
2002	62140	106569	0.9	169.6
2003	79491	109718	0.5	189.7
2004	105683	115059	0.5	221.3

Table 3. Landings (000s mt) of Spiny Dogfish and Skates during 1962-2005.

Year	Dogfish	Skates	Total
1962	235		235
1963	611		611
1964	746	4083	4829
1965	695	2363	3058
1966	10006	2844	12850
1967	2714	4898	7612
1968	4562	6483	11045
1969	9303	9462	18765
1970	5765	4128	9893
1971	11643	5905	17548
1972	24063	8823	32886
1973	18902	7963	26865
1974	24676	3651	28327
1975	22671	3968	26639
1976	17341	1212	18553
1977	8131	1418	9549
1978	1534	1353	2887
1979	6271	1360	7631
1980	5354	1581	6935
1981	9896	847	10743
1982	6798	878	7676
1983	5428	3603	9031
1984	4937	4157	9094
1985	5142	3984	9126
1986	3319	4253	7572
1987	3428	5078	8506
1988	4111	7264	11375
1989	5332	6717	12049
1990	16618	11403	28021
1991	13834	11332	25166
1992	17969	12525	30494
1993	22201	12904	35105
1994	20775	8783	29559
1995	23737	7217	30954
1996	27927	14213	42139
1997	19076	10945	30021
1998	22352	13829	36182
1999	17934	11684	29618
2000	12440	13360	25800
2001	5818	13120	18939
2002	6487	13004	19491
2003	3157	15005	18162
2004	3759	16073	19833
2005	3016	13895	16911

Table 4. Landings (mt), biomass and surplus production (thousand mt) for the GARM stocks during 1963-2003

Year	Landings	B (t mt)	SP (t mt)
1963	144720	1129.444	-195.7149
1964	170785	789.0094	191.635
1965	270577	809.8595	310.6725
1966	272394	849.955	161.4533
1967	181005	739.0143	188.8191
1968	175283	746.8284	260.9006
1969	181381	832.446	112.7172
1970	139618	763.7821	-4.68013
1971	141041	619.484	316.5414
1972	129293	794.9844	56.10064
1973	123490	721.7921	-128.0025
1974	106582	470.2995	86.08113
1975	101335.7	449.7987	315.2127
1976	93402.8	663.6757	148.9303
1977	121209	719.2032	178.5958
1978	147068	776.59	47.22736
1979	141640.2	676.7494	233.7663
1980	175598	768.8755	117.3507
1981	160537.5	710.6281	-31.7181
1982	175366.3	518.3725	206.5677
1983	167595.5	549.5738	109.2545
1984	138842.9	491.2328	161.7936
1985	122944.4	514.1836	105.3061
1986	105649.5	496.5453	-0.137173
1987	100114.7	390.7587	123.9443
1988	98854.91	414.5883	70.6431
1989	84530.83	386.3764	151.4986
1990	107197	453.3442	58.53014
1991	101397.2	404.6774	36.68818
1992	83624.11	339.9684	81.98199
1993	70051.74	338.3263	-10.461
1994	51923.78	257.8135	90.34029
1995	36530.55	296.23	52.27165
1996	39948.02	311.9711	30.84666
1997	39769.64	302.8698	82.16454
1998	42116.16	345.2647	104.1201
1999	41088.95	407.2686	147.6518
2000	49999.78	513.8315	154.2849
2001	60574.9	618.1166	8.766964
2002	54952.27	566.3087	85.65001
2003	54083.43	597.0064	-3.872926

Table 5. Catch, biomass and surplus production (thousand mt) for the pelagic stocks during 1968-2003

Year	Landings	B(t mt)	SP (t mt)
1968	568.076	2138.105	807.2632
1969	548.987	2377.292	575.0289
1970	572.992	2403.334	513.8175
1971	728.748	2344.159	635.6133
1972	700.436	2251.025	407.1277
1973	730.208	1957.716	263.1308
1974	597.537	1490.639	222.1525
1975	549.813	1115.255	333.9878
1976	399.622	899.4294	328.6061
1977	163.482	828.4135	286.9439
1978	125.338	951.8754	169.145
1979	144.63	995.6824	179.4038
1980	133.22	1030.456	54.9983
1981	121.931	952.2345	100.5755
1982	97.905	930.879	158.9441
1983	74.757	991.9181	348.0841
1984	97.076	1265.245	391.7102
1985	134.373	1559.879	123.3487
1986	132.814	1548.855	-33.88
1987	152.73	1382.161	78.2636
1988	160.096	1307.695	118.3593
1989	174.781	1265.958	306.1557
1990	183.059	1397.333	509.9805
1991	153.431	1724.254	339.9825
1992	134.791	1910.806	208.9426
1993	125.236	1984.957	-17.5416
1994	111.657	1842.18	97.3157
1995	133.245	1827.838	256.5862
1996	168.466	1951.18	384.3423
1997	160.957	2167.056	228.0664
1998	162.2044	2234.165	247.0624
1999	156.276	2319.023	358.2267
2000	147.8574	2520.974	764.4378
2001	175.342	3137.554	366.4189
2002	169.5764	3328.631	236.4864
2003	189.7406	3395.541	150.7706

Table 6. Environmental covariates used in surplus production modeling, March Sea Surface Temperature (MSST, C), The range in SST between March and August (RSST, C), CO2 production in North America (million mt), and average bottom temperature from NEFSC bottom trawl surveys (BTEMP, C) during 1963-2003.

Year	MSST	RSST	CO2	BTEMP
1963	2.98	14.78	866.683	
1964	2.59	13.77	902.394	
1965	2.38	14.96	940.91	
1966	2.83	14.48	988.857	
1967	2.9	14.53	1028.564	
1968	2.81	14.81	1068.013	5.65
1969	3.2	14.76	1119.151	5.97
1970	2.74	15.61	1156.871	6.78
1971	2.63	15.08	1162.393	6.29
1972	3.49	13.91	1211.928	7.18
1973	3.45	15.37	1263.643	7.26
1974	4.15	14.59	1213.915	8.19
1975	3.76	14.23	1167.855	7.14
1976	3.87	14.36	1238.157	7.62
1977	3.32	14.21	1255.274	6.36
1978	2.03	16.39	1299.052	5.73
1979	2.95	14.66	1313.359	6.18
1980	3.22	15.16	1262.744	6.79
1981	3.28	14.4	1216.628	6.63
1982	2.58	14.78	1155.139	6.1
1983	3.8	13.97	1161.816	6.94
1984	3.05	16.45	1201.975	7.01
1985	3.52	14.68	1208.067	6.91
1986	3.7	14.65	1209.394	7.77
1987	2.93	15.04	1252.563	6.79
1988	2.66	15.86	1321.103	6.59
1989	2.58	15.44	1336.439	6.78
1990	3.46	15.87	1315.008	6.73
1991	3.57	14.58	1317.751	7.24
1992	2.16	15.08	1311.226	6.66
1993	2.78	15.07	1393.487	5.71
1994	2.65	15.56	1420.718	6.95
1995	3.13	15.1	1420.827	7.42
1996	2.58	14.46	1450.29	6.64
1997	2.73	14.57	1560.577	7.19
1998	2.67	15.51	1545.558	6.2
1999	3.13	15.88	1570.776	7.42
2000	4.23	14.11	1626.136	7.69
2001	3.17	15.05	1603.092	6.81
2002	4.1	15.21	1627.037	8.02
2003	2.34	16.54	1621.634	5.74

Table 7. Results of B1/K sensitivity analysis for estimating initial parameters for GARM stocks.

fix B1/K, starting guess for MSY=200,K 1500

trial run	B1/K	MSY	Bmsy	Fmsy	MSE	K	Resid Spr	Resid Fall	Biomass
1	0.3	500	605	0.8265	25.412	1209	highly patterened	highly patterened	constant 1100
2	0.4	500	695	0.7195	25.3996	1391	highly patterened	highly patterened	constant 1300
3	0.5	500	806	0.6205	25.3843	1613	highly patterened	highly patterened	constant 1500
4	0.6	137	855	0.16	4.8245	1711	good	good	down,up trend
5	0.7	132	816	0.162	4.6877	1633	good	good	down,up trend
6	0.8	129	790	0.164	4.5893	1580	good	good	down,up trend
7	0.9	127	771	0.165	4.5173	1542	good	good	down,up trend
8	1	126	757	0.166	4.4638	1514	good	good	down,up trend
final assume B1/K=1, MSY=126, K=1514									
1	1	126	758	0.166	4.4637	1513	good	good	down,up trend

Table 8. Results of B1/K sensitivity analysis for estimating initial parameters for pelagic stocks.

fix B1/K, starting guess for MSY=300,K 2000

trial run	B1/K	MSY	Bmsy	Fmsy	MSE	K	Resid Spr	Biomass
1	0.3	358	2500	0.159	9.8632	5000	good	up,down,up
2	0.4	373	2384	0.156	9.999	4769	good	up,down,up
3	0.5	365	2228	0.165	10.1295	4455	some pattern	up,down,up
4	0.6	361	2139	0.169	10.2186	4279	pattern	down,up
5	0.7	360	2085	0.173	10.2808	4169	pattern	down,up
6	0.8	359	2047	0.175	10.326	4095	pattern	down,up
7	0.9	358	2021	0.177	10.36	4042	pattern	down,up
8	1	358	2001	0.179	10.3866	4003	pattern	down,up
final assume B1/K=.3, MSY=358, K=5000								
1	0.2457	422	2971	0.142	9.78	5943	good	up,down,up

Table 9. Results of B1/K sensitivity analysis for estimating initial parameters for elasmobranch stocks.

fix B1/K, starting guess for MSY=20,K 1000

trial run	B1/K	MSY	Bmsy	Fmsy	MSE	K	Resid Spr	Resid Fall	Biomass
1	0.3	22.5	559	0.0402	16.752	1120	pattern	good	up,down
2	0.4	23.86	641	0.0372	16.94	1283	pattern	ok	up, down slightly
3	0.5	28.54	865	0.033	17.15	1730	pattern	ok	up, down slightly
4	0.6	38.1	1250	0.0305	17.3499	2500	pattern	ok	up,level
5	0.7	43.75	1250	0.035	17.593	2500	pattern	ok	up,down
6	0.8	70.76	200	0.0353	18.07	400	pattern	ok	not feasible
7	0.9	62.72	200	0.0314	18.002	400	pattern	ok	not feasible
8	1	61.3	215	0.0285	17.943	430.6	pattern	ok	not feasible
final assume B1/K=.3, MSY=22.5,K=1120									
1	0.0678	58.66	1895	0.031	16.596	3790	pattern	ok	up,down,up,down

Table 10. Results of B1/K sensitivity analysis for estimating initial parameters for combined GARM-Pelagic-Elasmobranch stocks.

fix B1/K, starting guess for MSY=500,K 10000

trial run	*B1/K*	*MSY*	*Bmsy*	*Fmsy*	*MSE*	*K*	*Resid Spr*	*Biomass*
1	0.3	717	4057	0.18	3.19	8113	ok	up, small dip, up
2	0.4	663	5371	0.12	3.053	10740	ok	up, small dip, up
3	0.5	599	5711	0.11	2.98	11420	ok	up,down,up
4	0.6	567	4989	0.114	2.981	9977	ok	up,down,up
5	0.7	556	4436	0.125	3	8872	ok	up,down,up
6	0.8	554	4094	0.135	3.02	8187	ok	up,down,up
7	0.9	554	3875	0.143	3.04	7750	ok	up,down,up
8	1	555	3728	1.49	3.05	7456	ok	up,down,up
final assume B1/K=.5, MSY=599, K=11420								
1	0.432	579	5350	0.11	2.978	10700	good	up,down,up

Table 11. Final ASPIC results for MSY, Bmsy, and K (000s mt), Fmsy for the GARM, pelagic, elasmobranch stocks, and combined GARM-Pelagic-Elasmobranch stocks.

GROUP	*MSY*	*Bmsy*	*Fmsy*	*K*
GARM	126	758	0.17	1513
Pelagic	422	2971	0.14	5943
Elasmobranch	59	1895	0.03	3790
GARM-Pelagic-Elasmobranch	579	5350	0.11	10700

Table 12. Aggregate BRP estimates from ASPIC analyses for GARM, pelagic, elasmobranch, and combined GARM-Pelagic-Elasmobranch stocks, with summed management target estimates from single-species results for comparison.

	ASPIC Estimates (000s mt)		**Target Estimates (000s mt)**	
GROUP	**MSY**	**Bmsy**	**MSY**	**Bmsy**
GARM	126	758	197	1424
Pelagic	422	2971	354	1295
Elasmobranch	59	1895	18	1156
GARM-Pelagic-Elasmobranch	579	5350	569	3875

Table 13. Aggregate BRP estimates from surplus production analyses for GARM and Pelagic stocks with and without environmental covariates and including various diagnostics.

GARM Stocks	MSY (t mt)	Bmsy (t mt)	Fmsy	F value	P	Residuals, comments
No Covariates	124.3	522.1	0.238	23.7	<.001	ok, some pattern in early years
March SST	124.7	525.3	0.237	15.8	<.001	pattern
SST Range	122.6	516.1	0.237	17.3	<.001	ok, some patterning in early years
CO2 North America	114.1	509.0	0.224	28.9	<.001	good
Bottom Temperature	110.0	529.0	0.208	13.8	<.001	ok
Salinity						
Pelagic Stocks						
No Covariates	368.0	2849.6	0.129	46.7	<.0001	good
March SST	363.9	2796.9	0.130	31.9	<.0001	good
SST Range	445.0	4132.7	0.108	33.7	<.0001	pattern, solution not feasible
CO2 North America	456.8	4051.0	0.113	52.9	<.0001	pattern, solution not feasible
Bottom Temperature	366.2	2814.0	0.130	30.4	<.0001	good
Salinity						

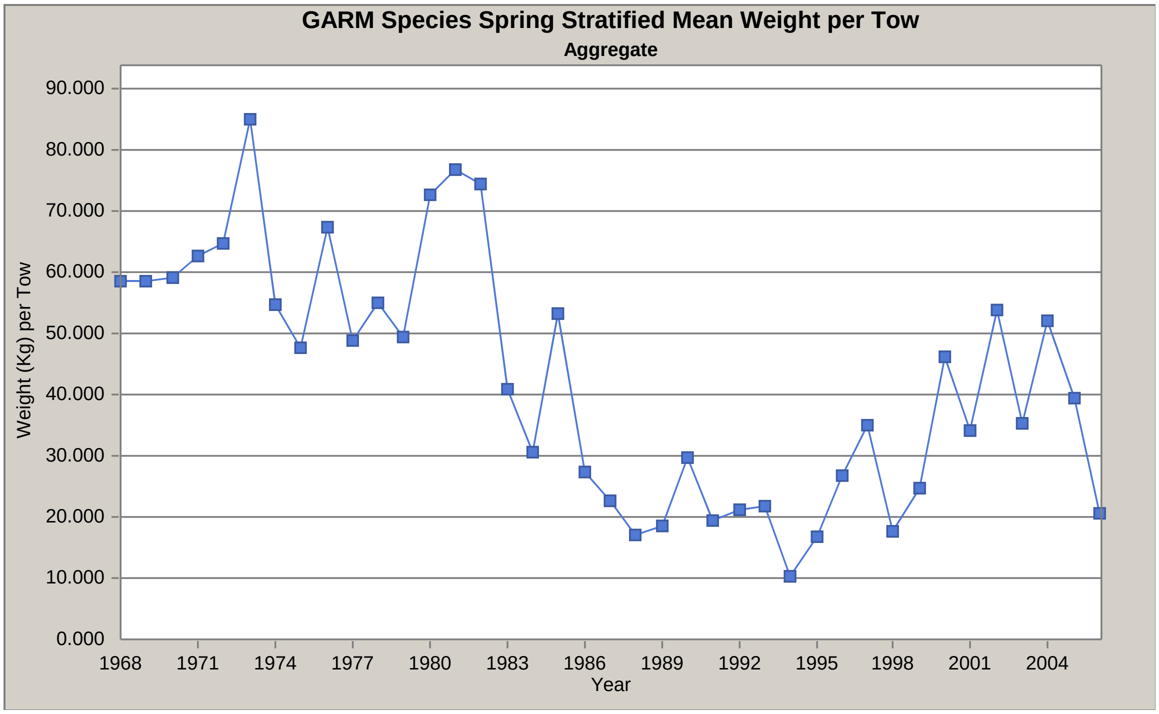

Figure 1. Spring stratified mean weight per tow (kg) for all GARM stocks during 1968-2006.

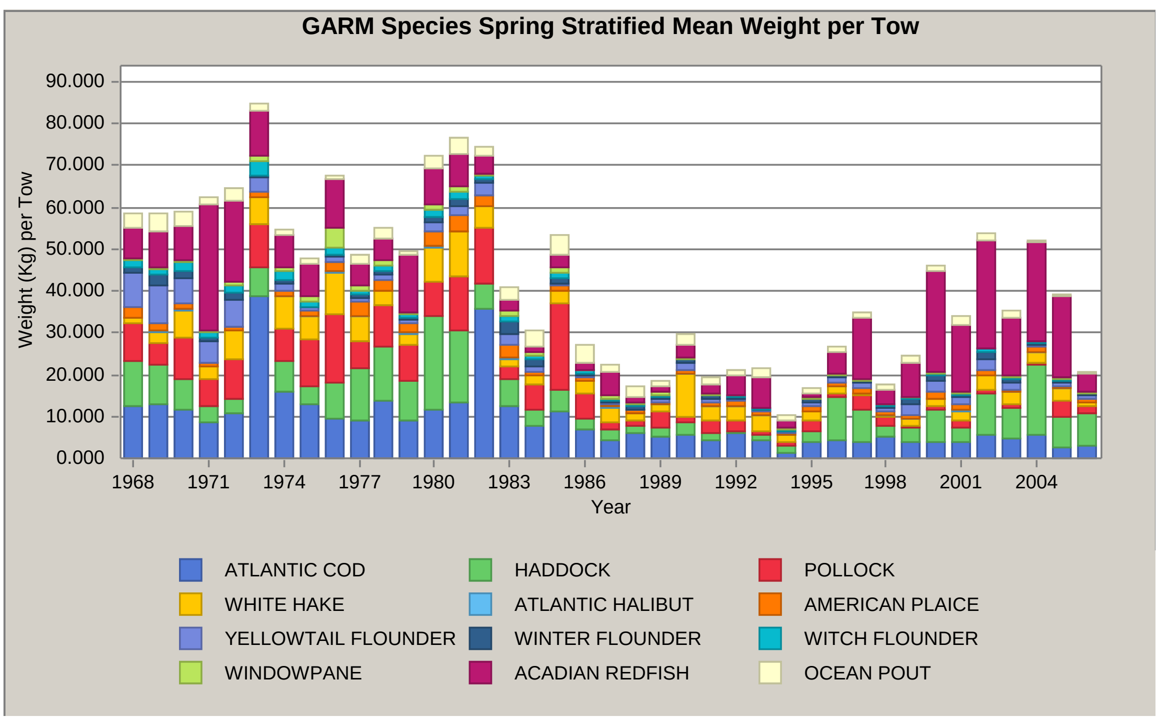

Figure 2. Stocks composition of spring stratified mean weight per tow (kg) for all GARM stocks during 1968-2006.

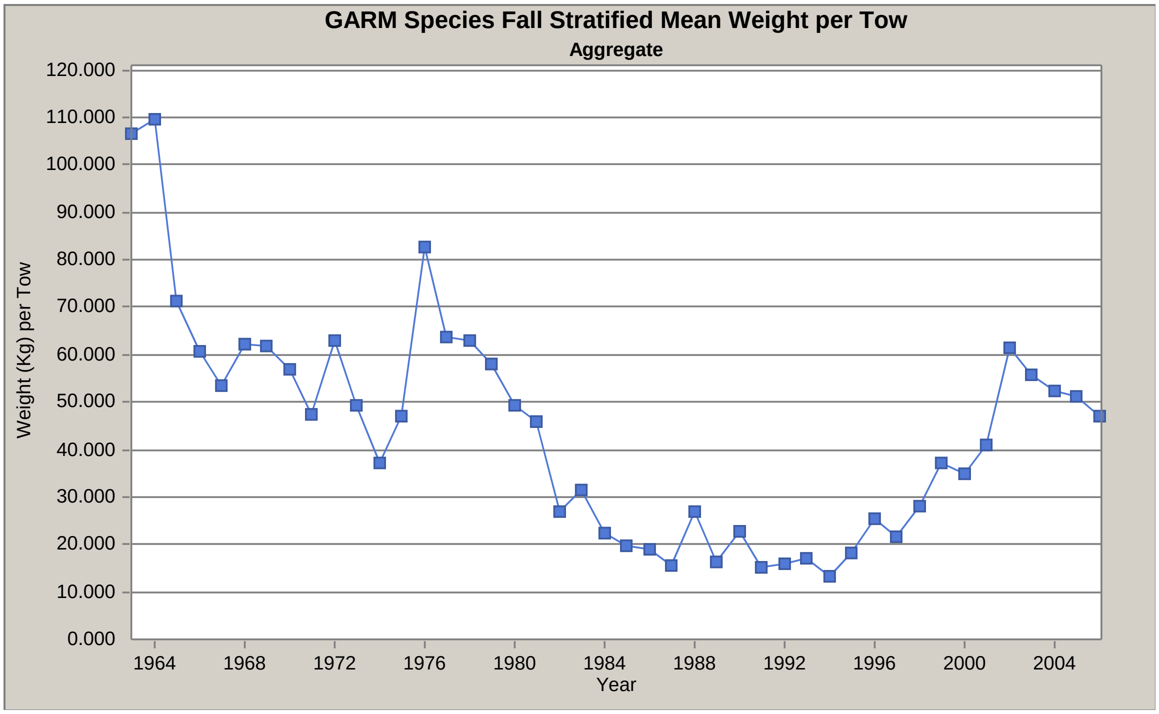

Figure 3. Autumn stratified mean weight per tow (kg) for all GARM stocks during 1963-2006.

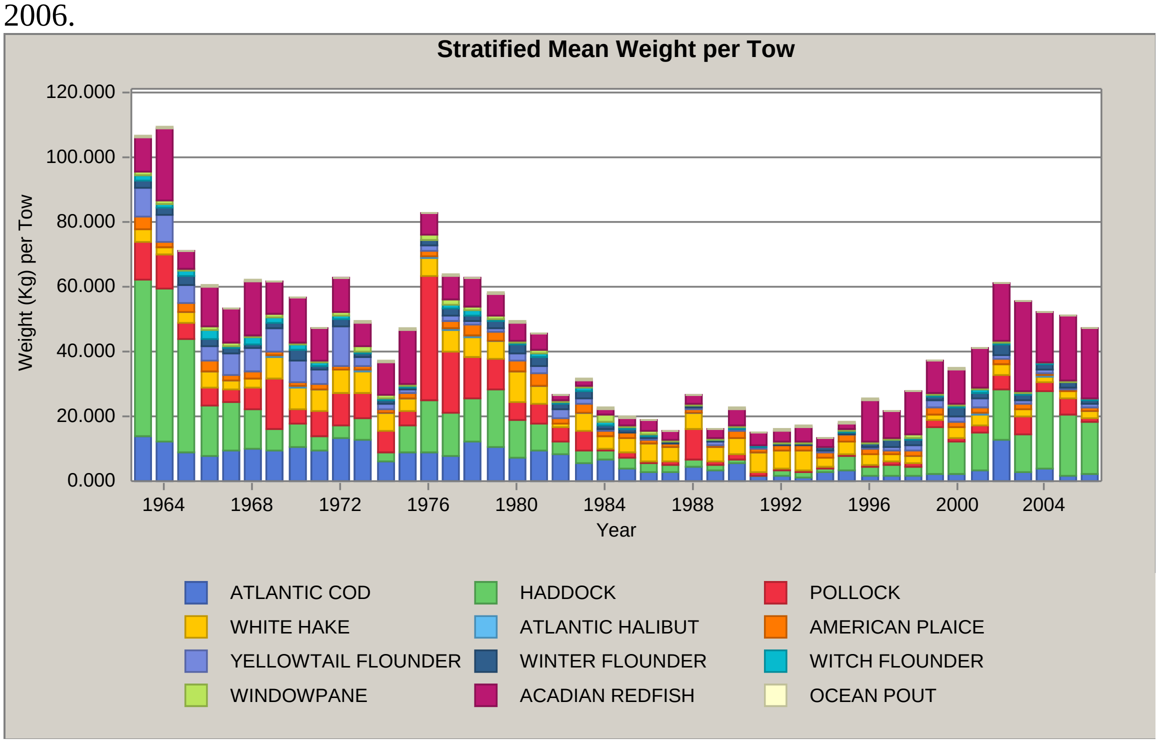

Figure 4. Stocks composition of autumn stratified mean weight per tow (kg) for all GARM stocks during 1968-2006.

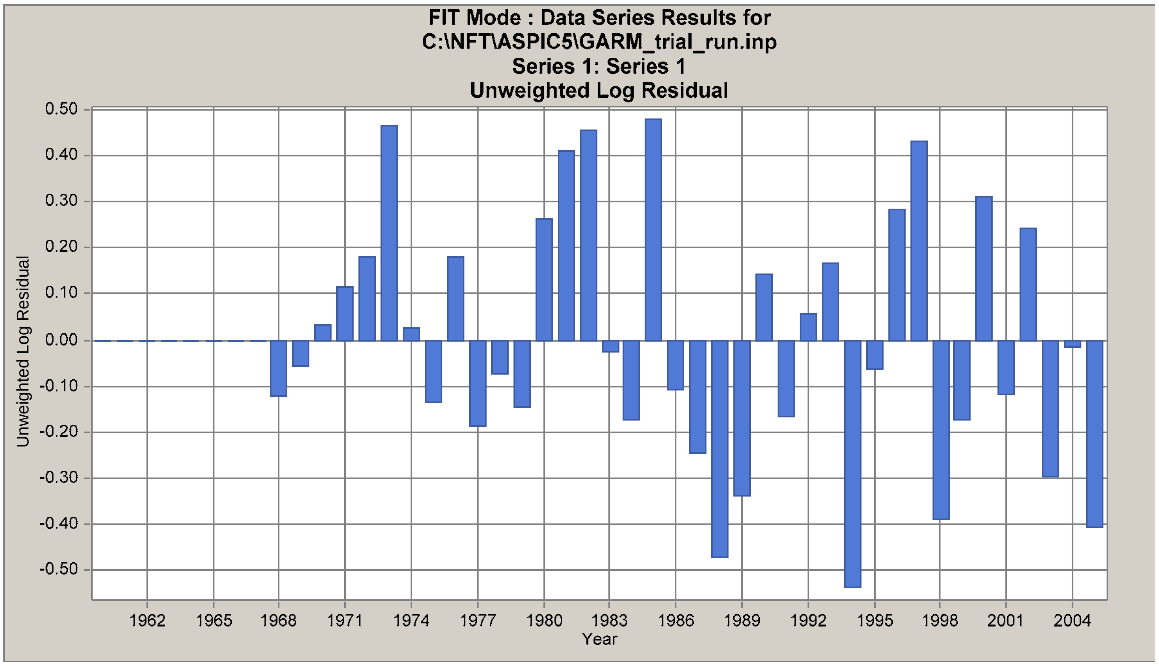

Figure 5. Residual plot from ASPIC model results for spring stratified weight per tow for the GARM stocks during 1968-2005.

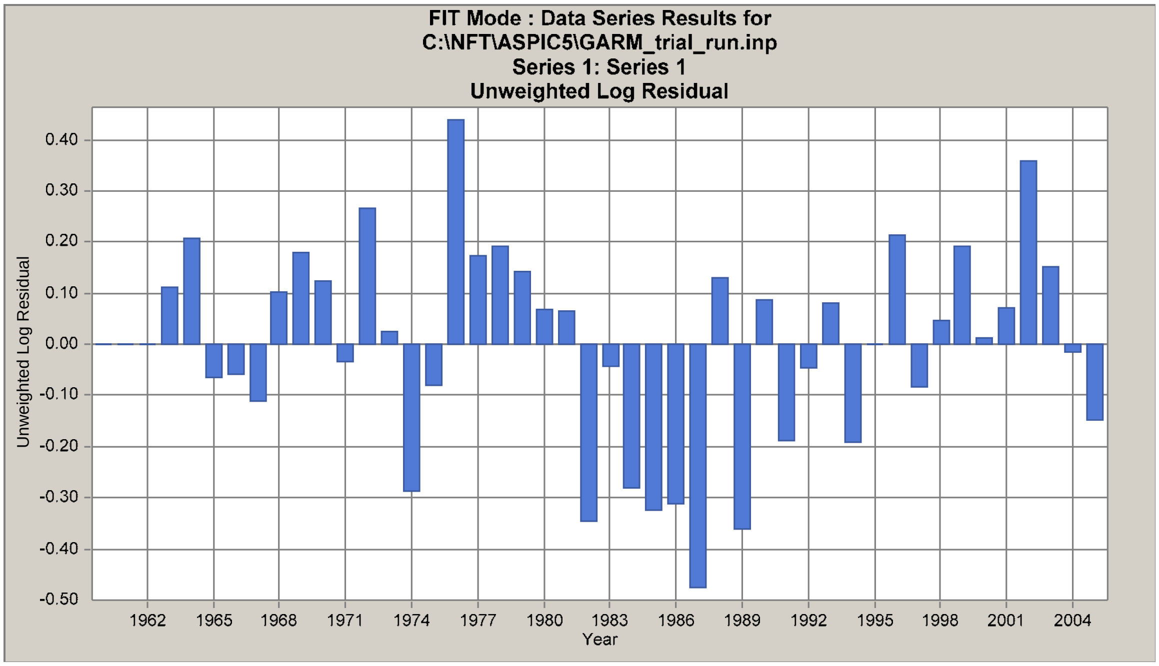

Figure 6. Residual plot from ASPIC model results for autumn stratified weight per tow for the GARM stocks during 1968-2005.

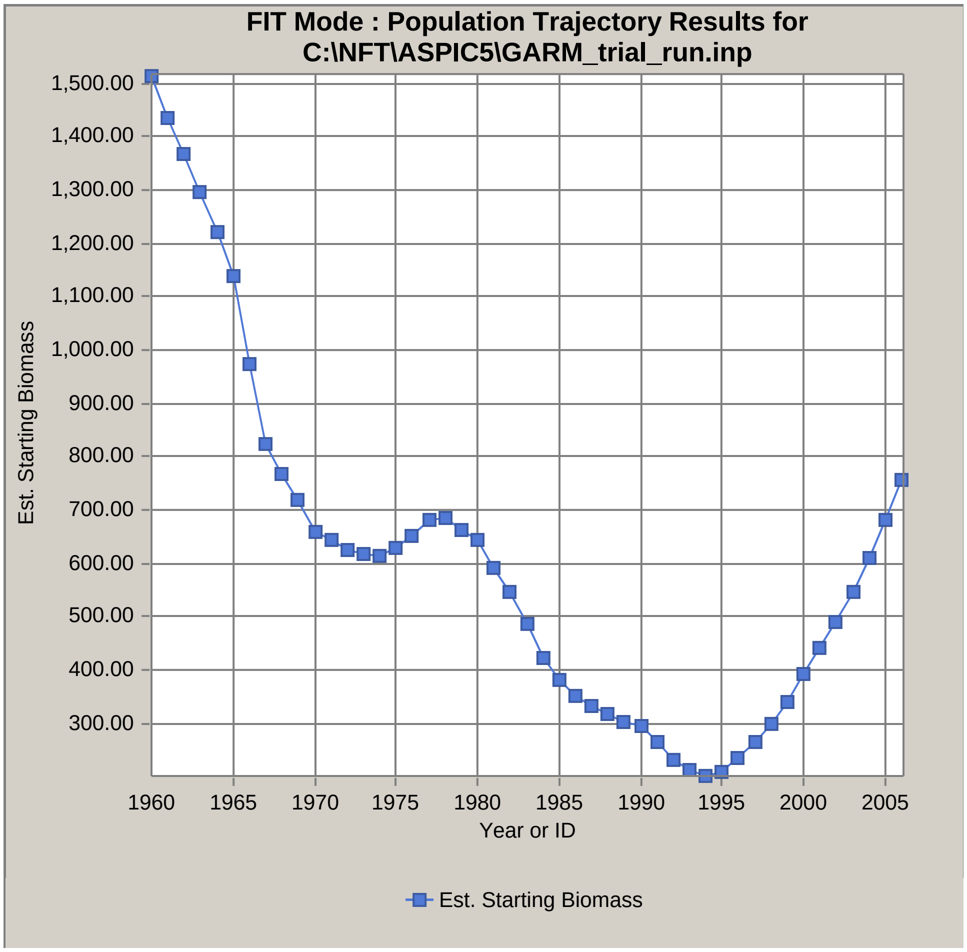

Figure 7. Biomass (000s mt) for GARM stocks from ASPIC model results during 1960-2006.

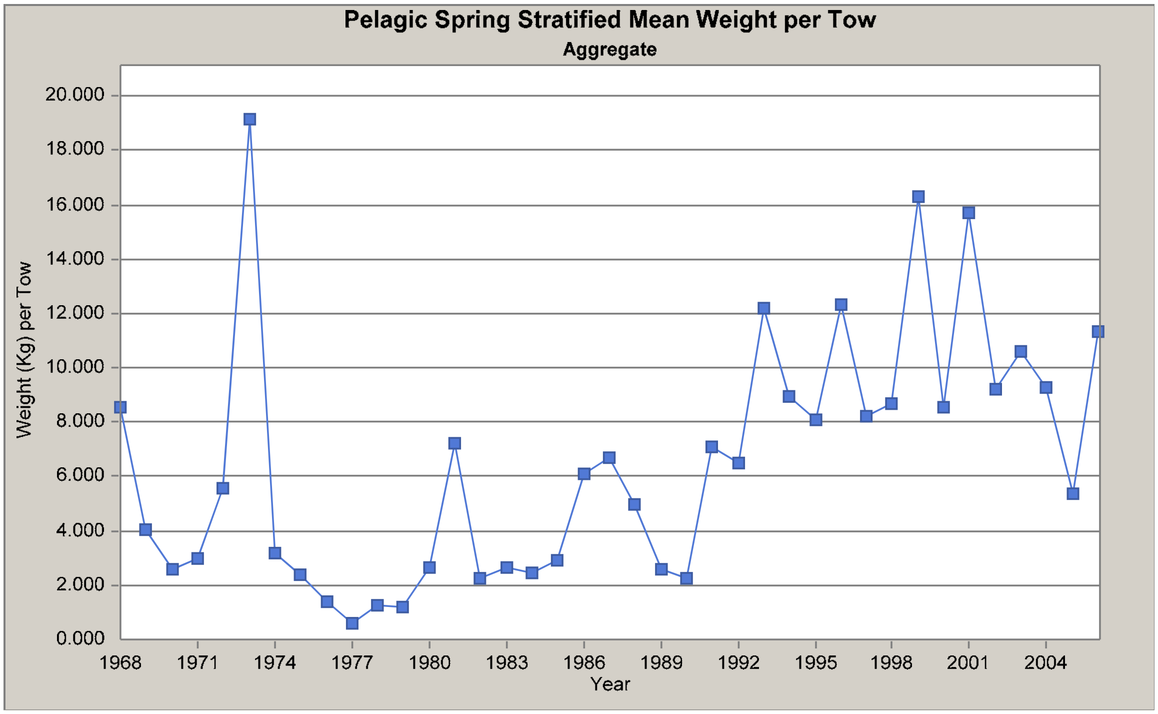

Figure 8. Spring stratified mean weight per tow (kg) for all pelagic stocks during 1968-2006.

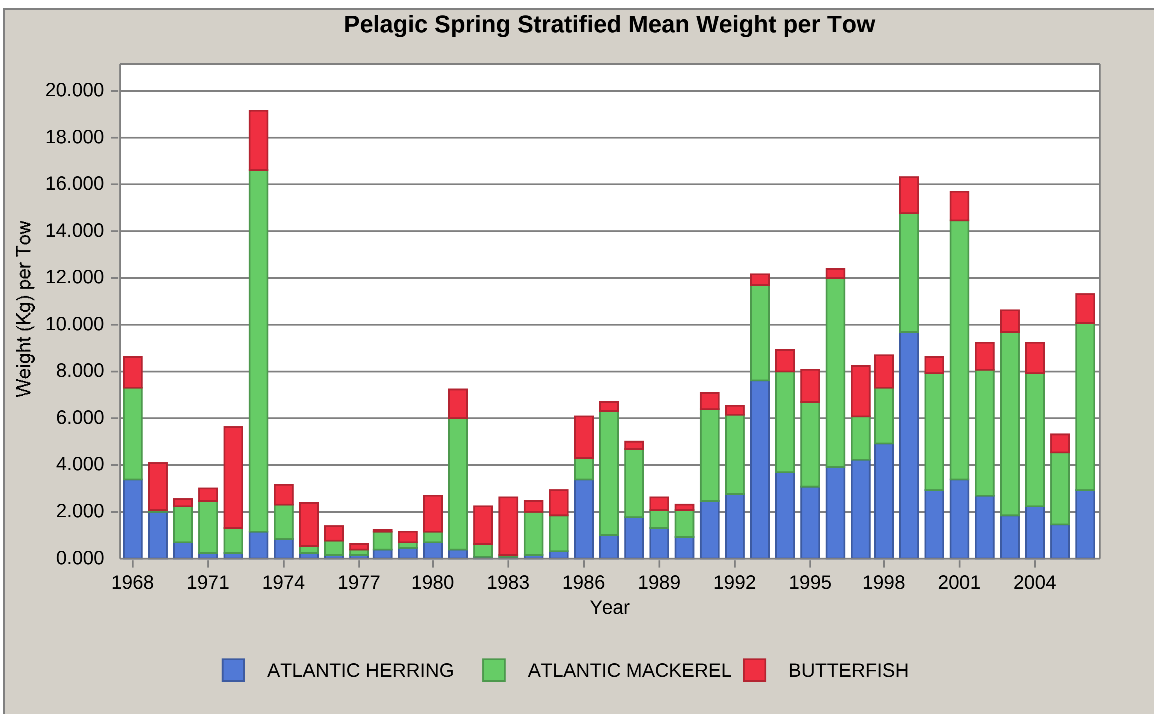

Figure 9. Stocks composition of spring stratified mean weight per tow (kg) for all pelagic stocks during 1968-2006.

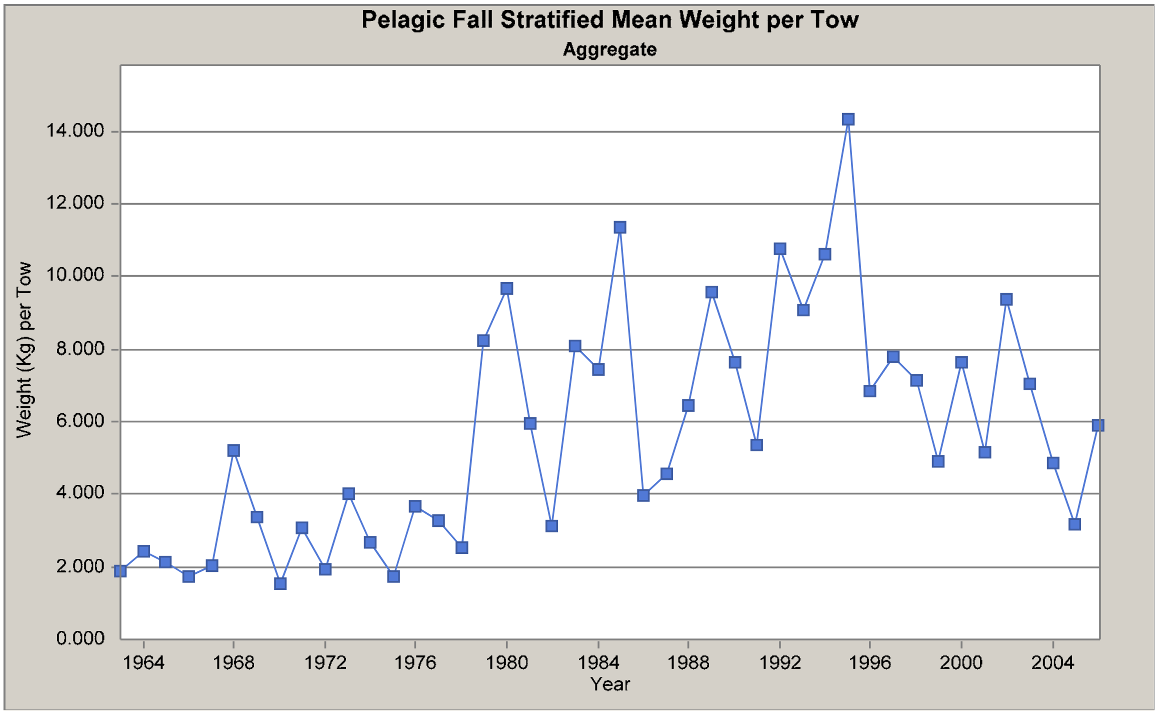

Figure 10. Autumn stratified mean weight per tow (kg) for all pelagic stocks during 1968-2006.

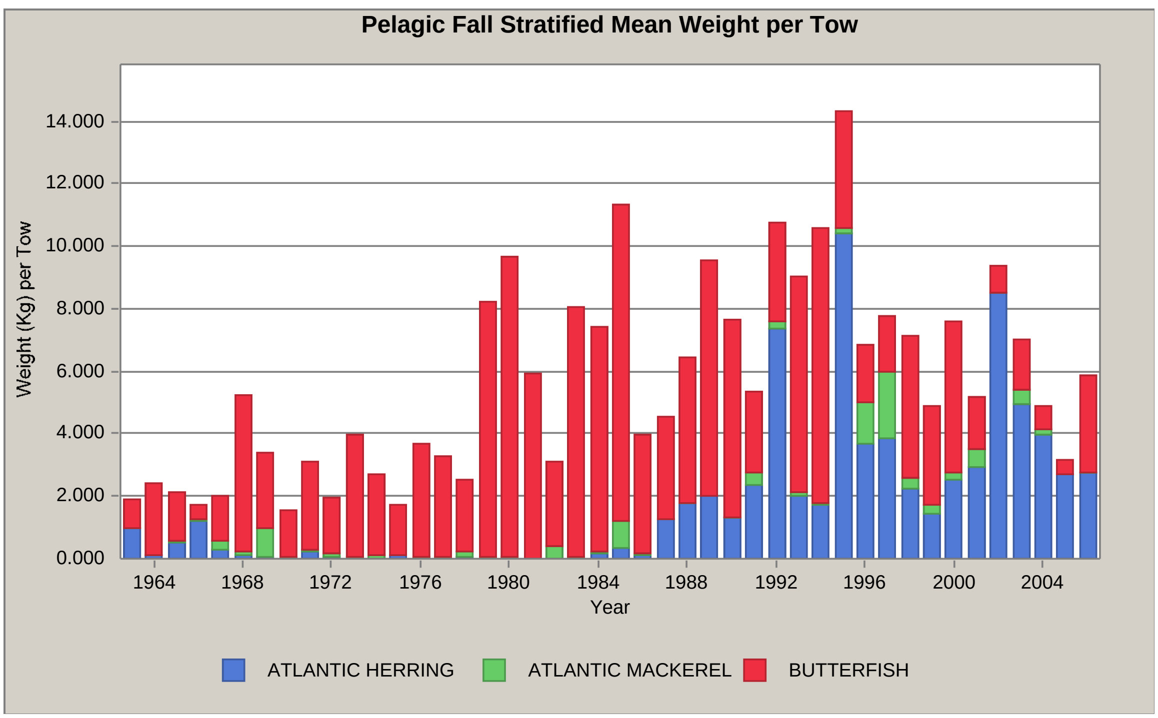

Figure 11. Stocks composition of autumn stratified mean weight per tow (kg) for all pelagic stocks during 1968-2006.

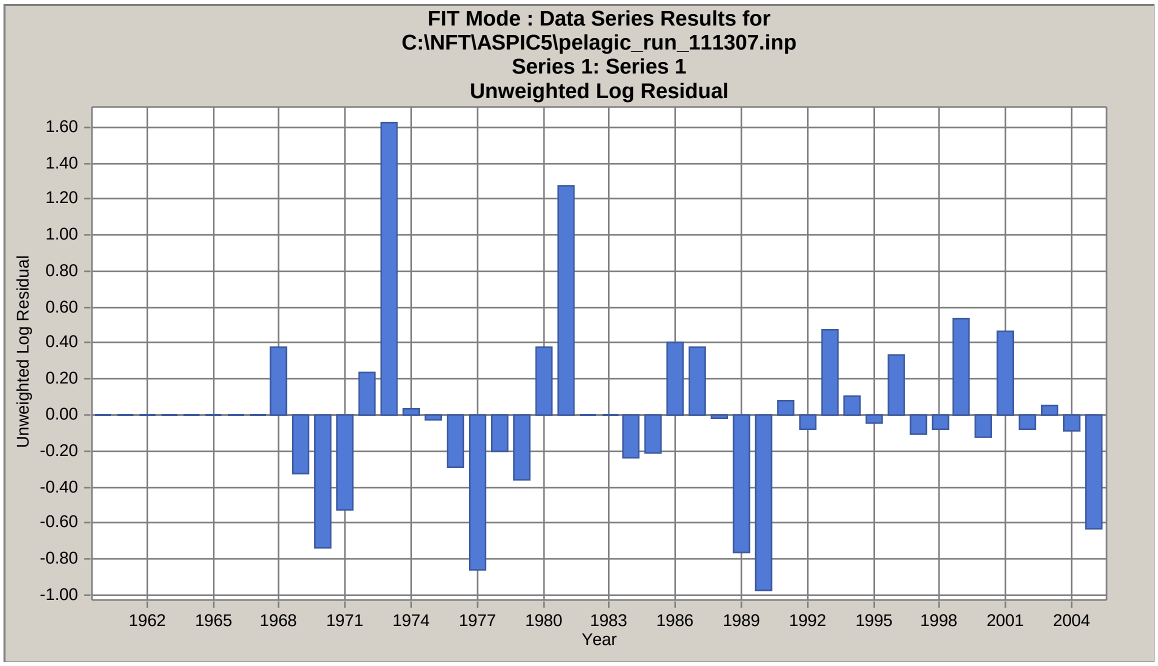

Figure 12 Residual plot from ASPIC model results for spring stratified weight per tow for the pelagic stocks during 1968-2005.

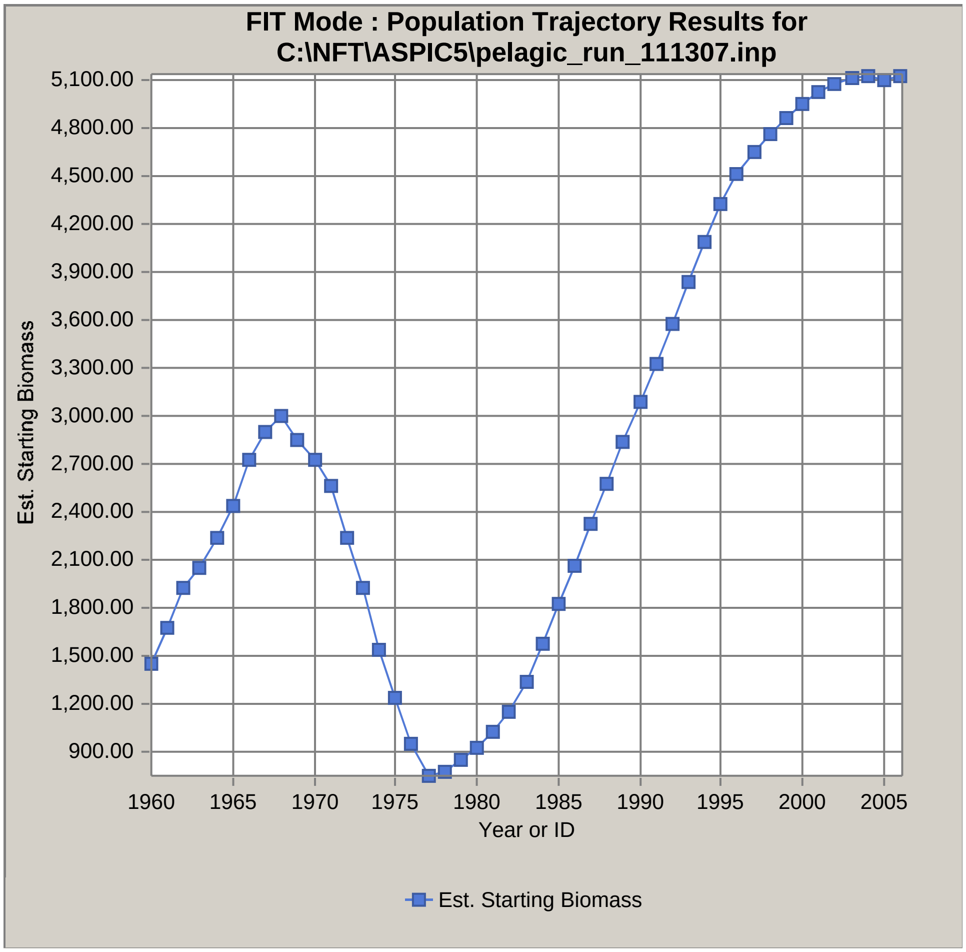

Figure 13. Biomass (000s mt) for pelagic stocks from ASPIC model results during 1960-2006.

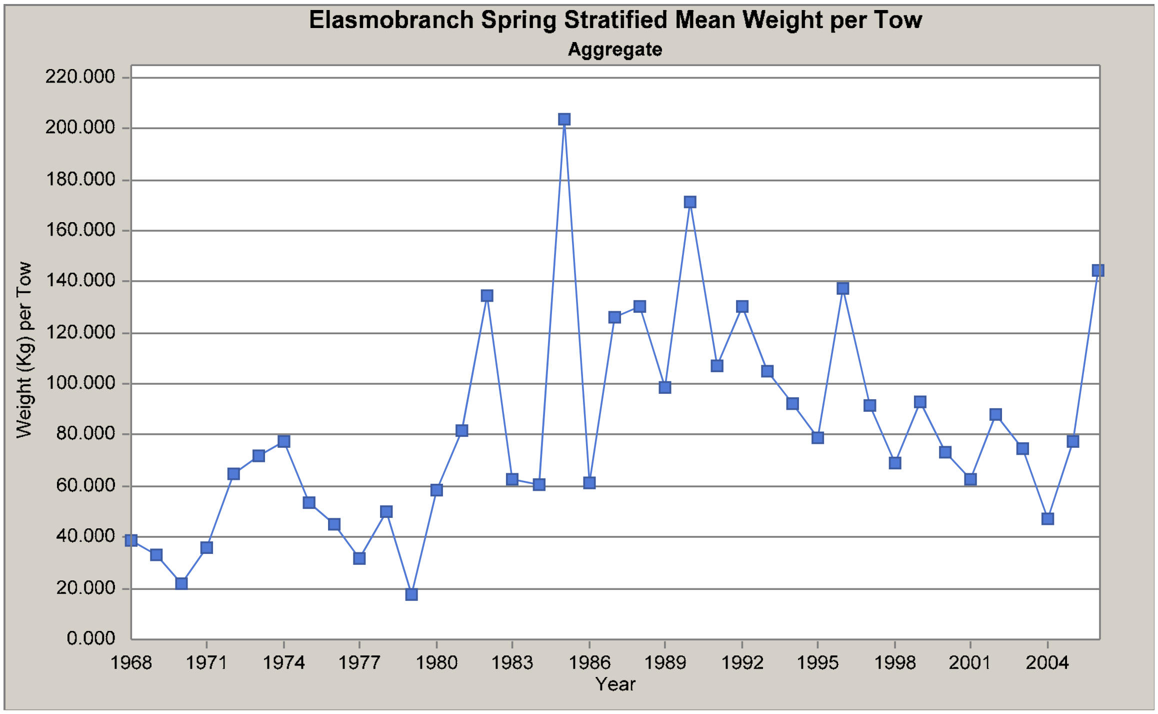

Figure 14. Spring stratified mean weight per tow (kg) for all elasmobranch stocks during 1968-2006.

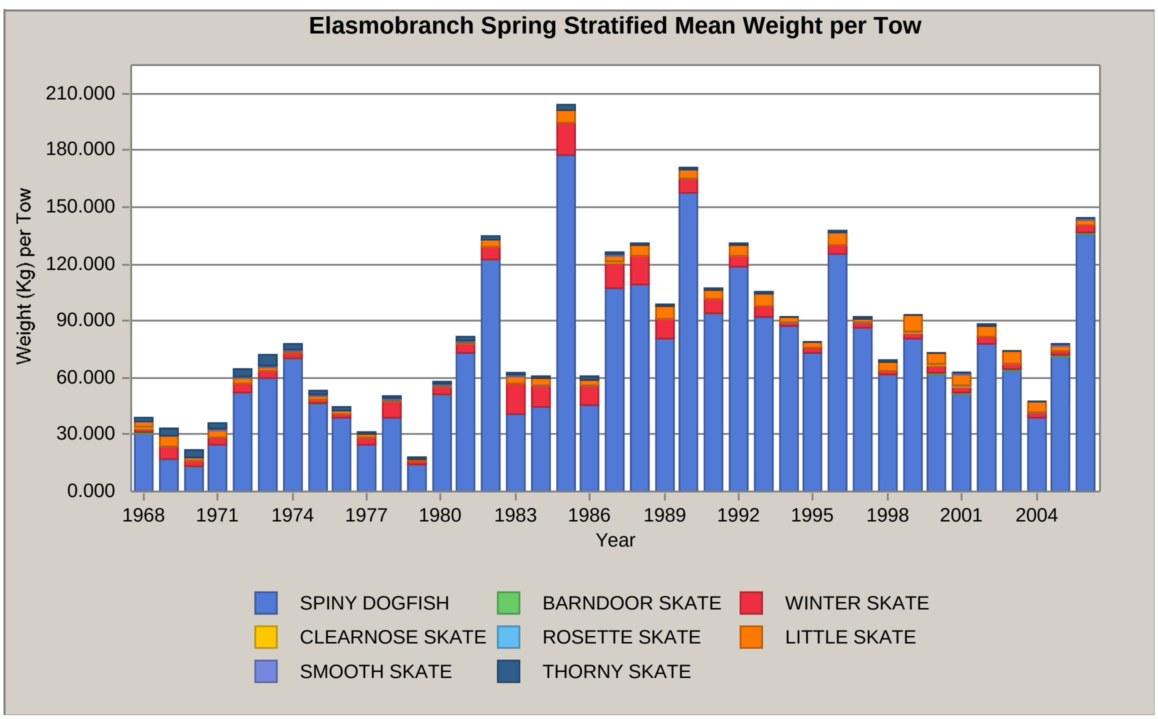

Figure 15. Stocks composition of spring stratified mean weight per tow (kg) for all elasmobranch stocks during 1968-2006

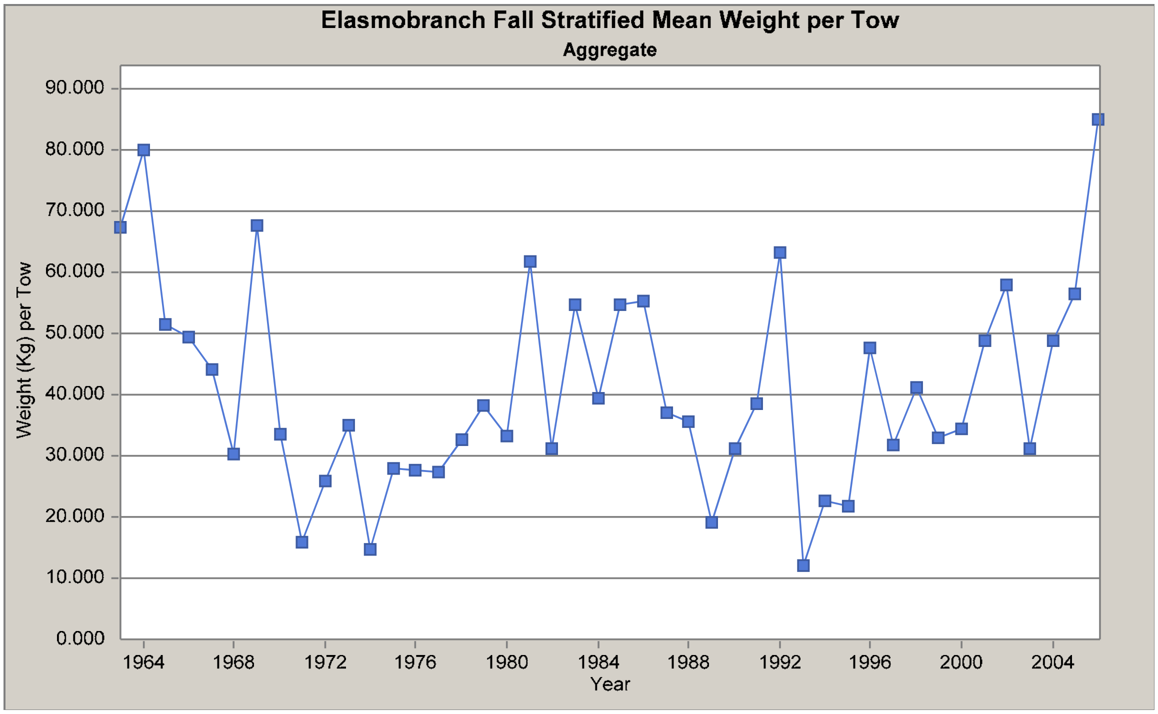

Figure 16. Autumn stratified mean weight per tow (kg) for all elasmobranch stocks during 1963-2006.

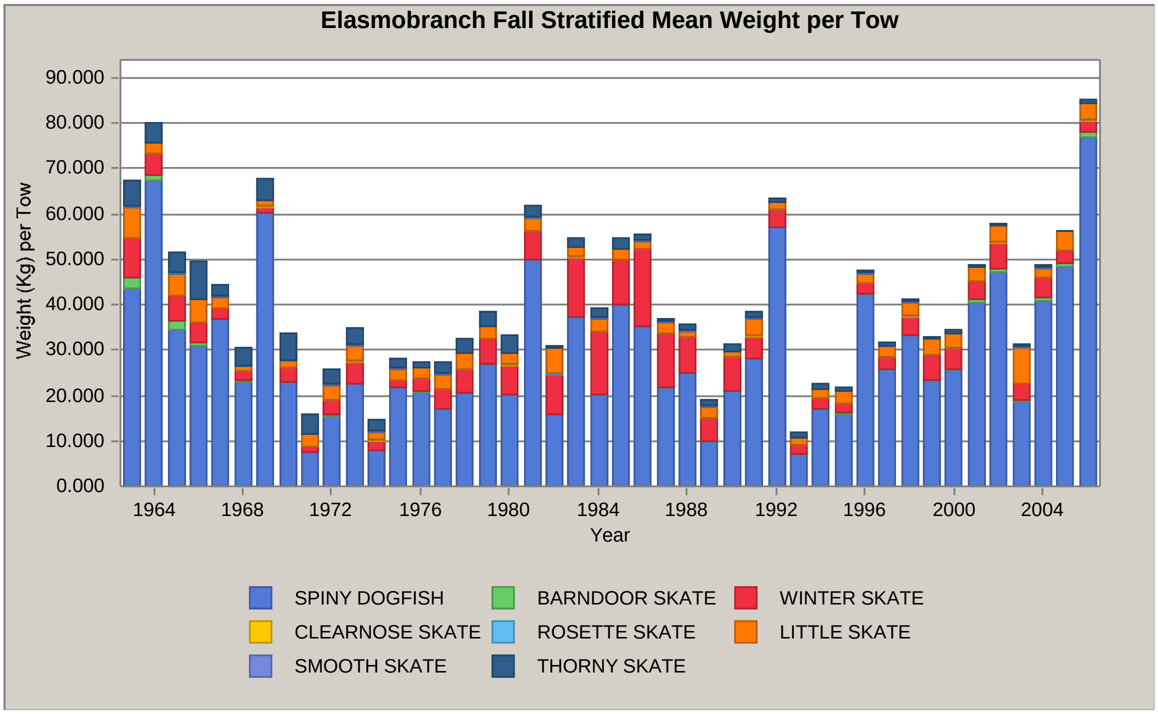

Figure 17. Stocks composition of autumn stratified mean weight per tow (kg) for all elasmobranch stocks during 1963-2006

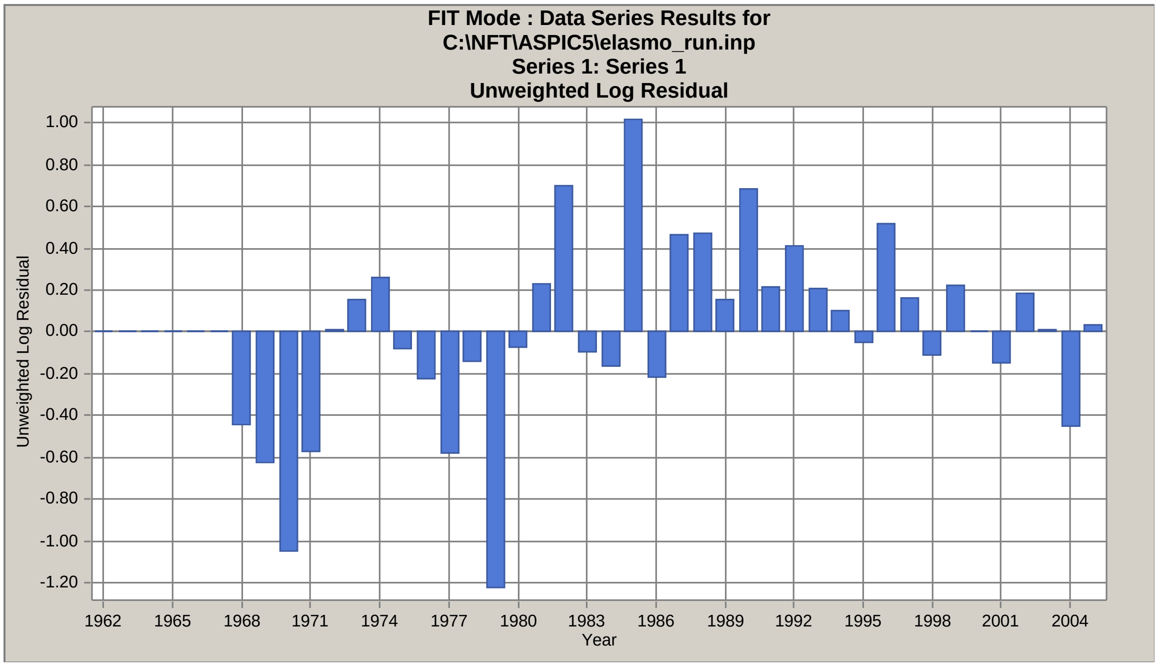

Figure 18. Residual plot from ASPIC model results for spring stratified weight per tow for the elasmobranch stocks during 1968-2005.

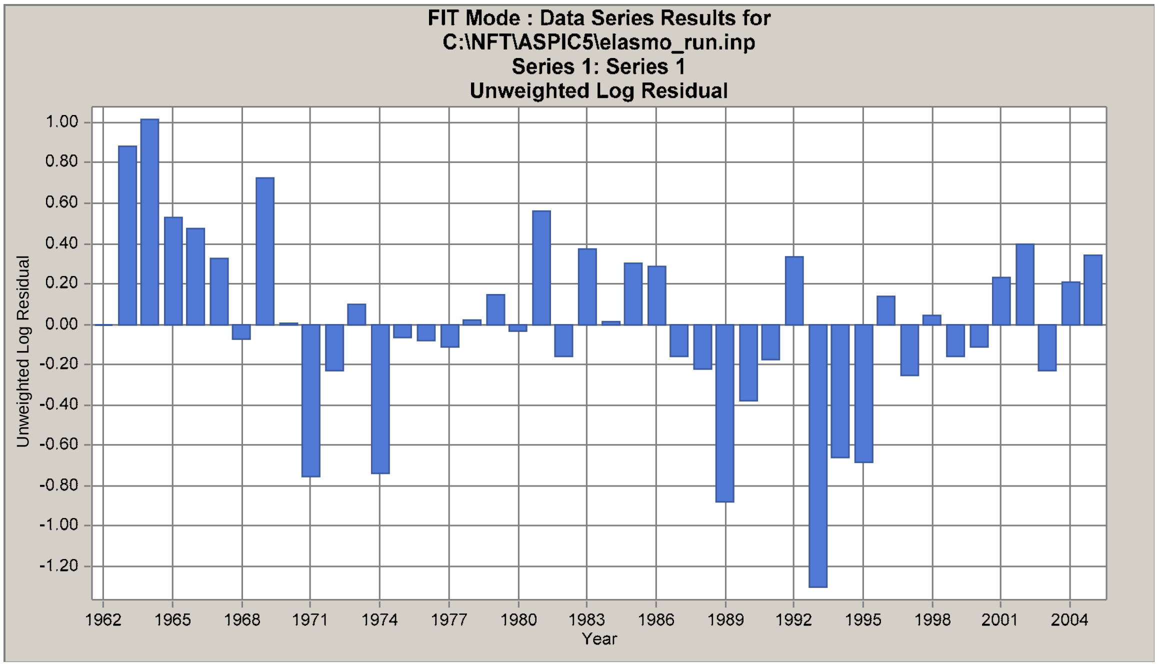

Figure 19. Residual plot from ASPIC model results for autumn stratified weight per tow for the elasmobranch stocks during 1963-2005.

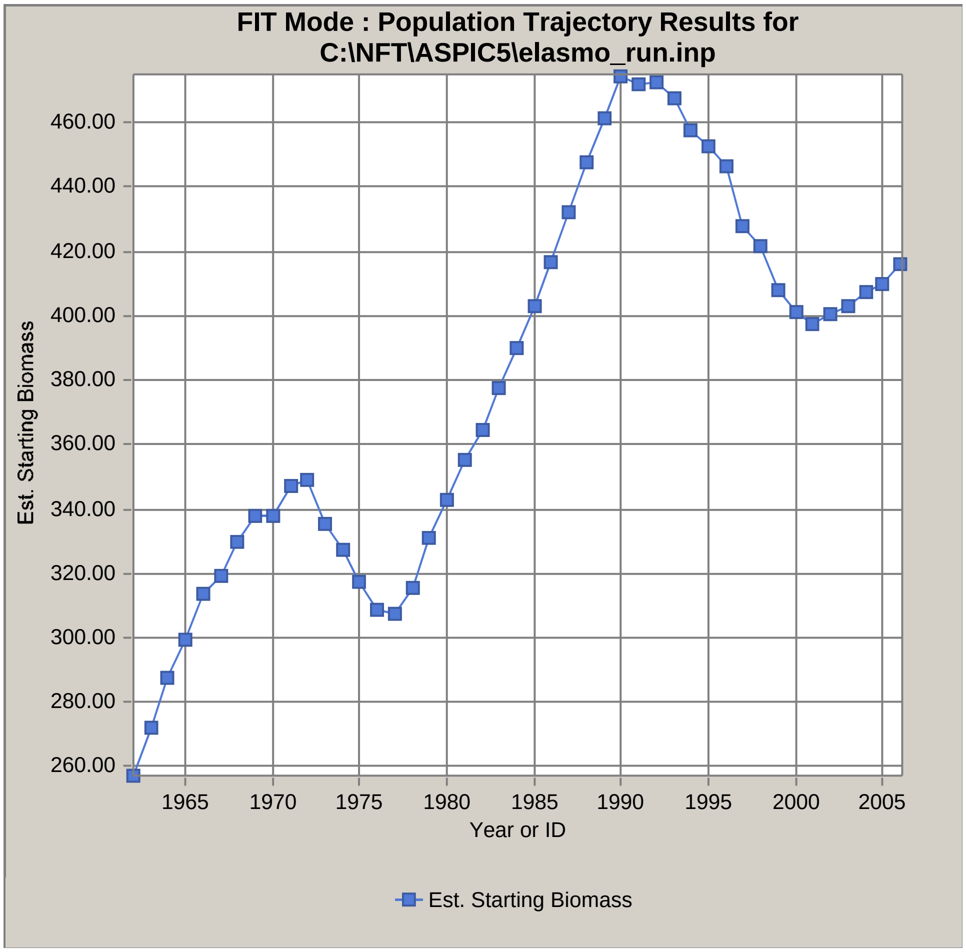

Figure 20. Biomass (000s mt) for elasmobranch stocks from ASPIC model results during 1960-2006.

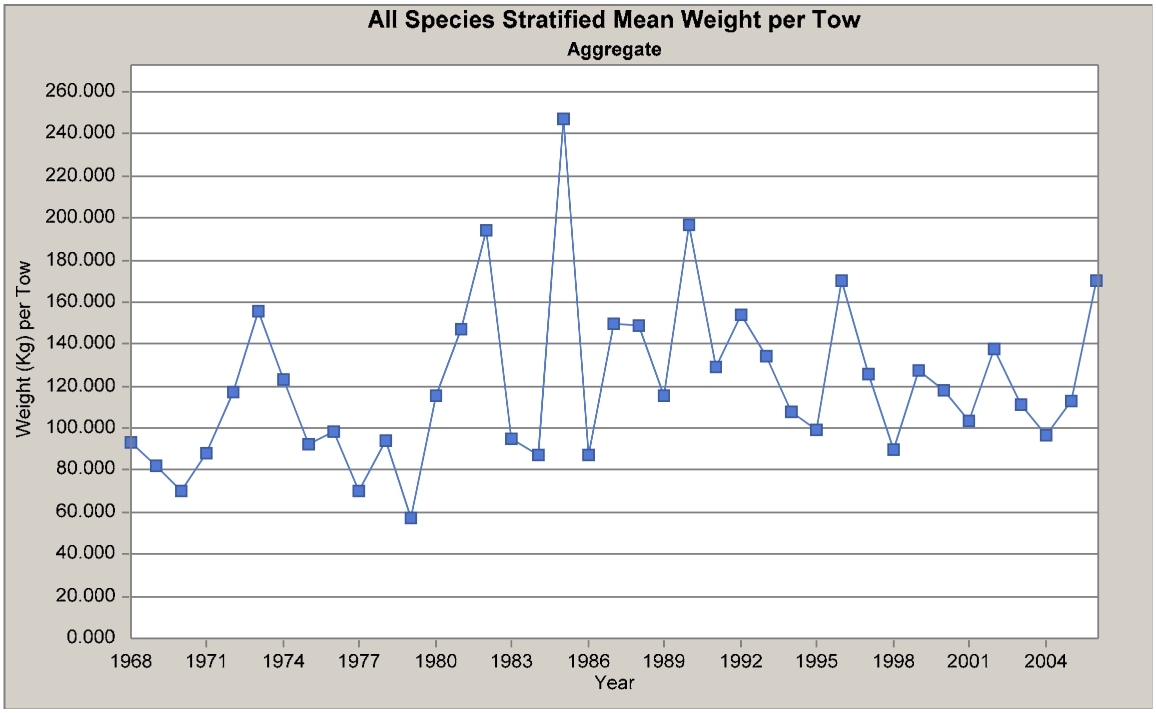

Figure 21. Spring stratified mean weight per tow (kg) for all stocks 1968-2006.

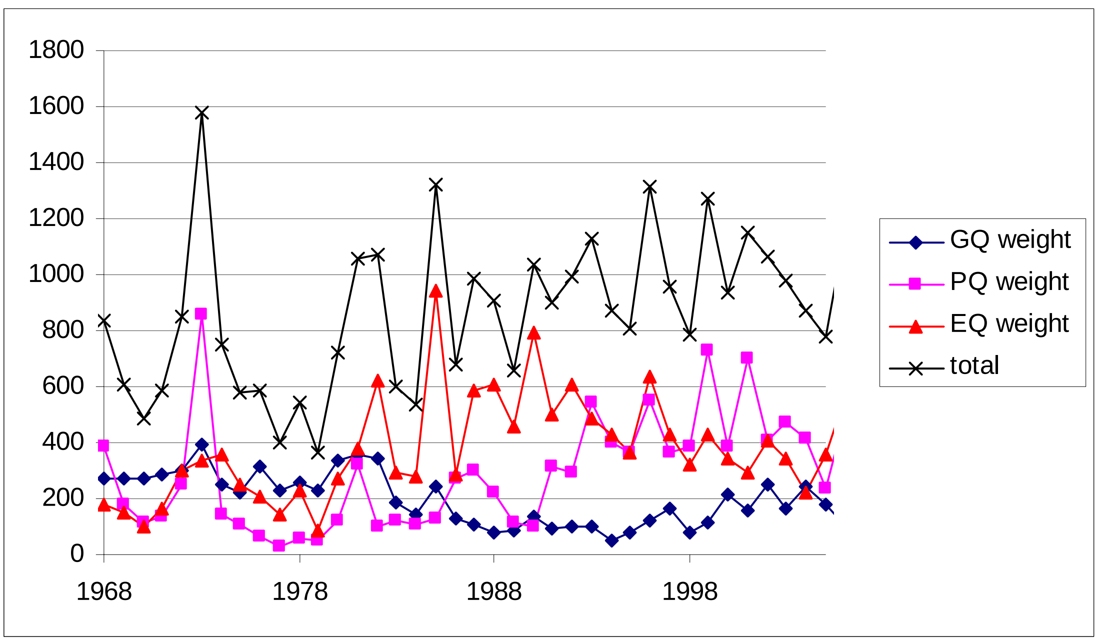

Figure 22. Spring stratified weight per tow (kg) for GARM, pelagic, and elasmobranch stocks scaled by q estimate for swept area biomass and total for combined GARM-Pelagic-Elasmobranch stocks.

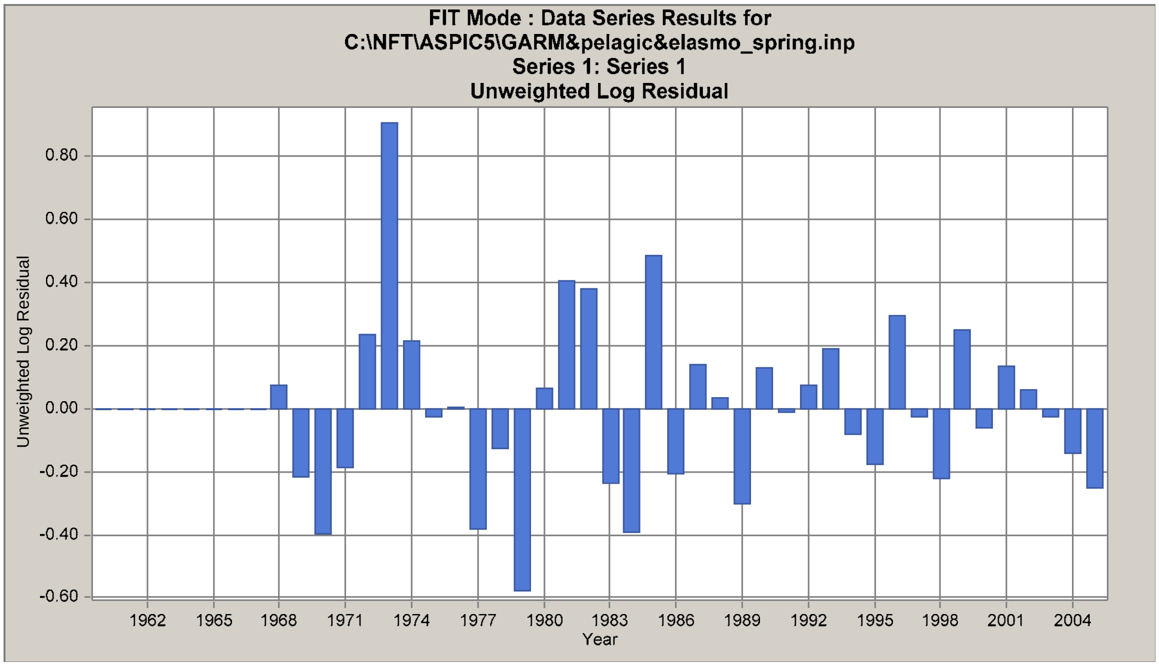

Figure 23. Residual plot from ASPIC model results for spring stratified weight per tow for the combined GARM-Pelagic-Elasmobranch stocks during 1968-2005.

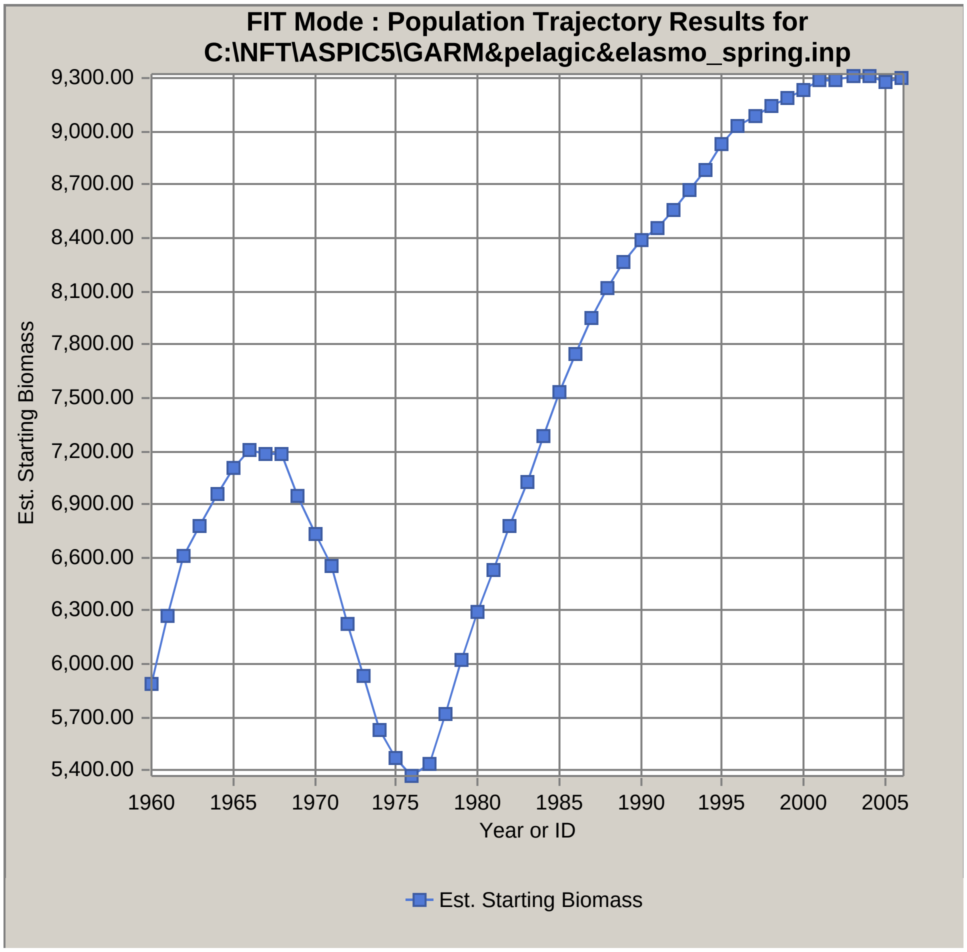

Figure 24. Biomass (000s mt) for combined GARM-Pelagic-Elasmobranch stocks from ASPIC model results during 1960-2006

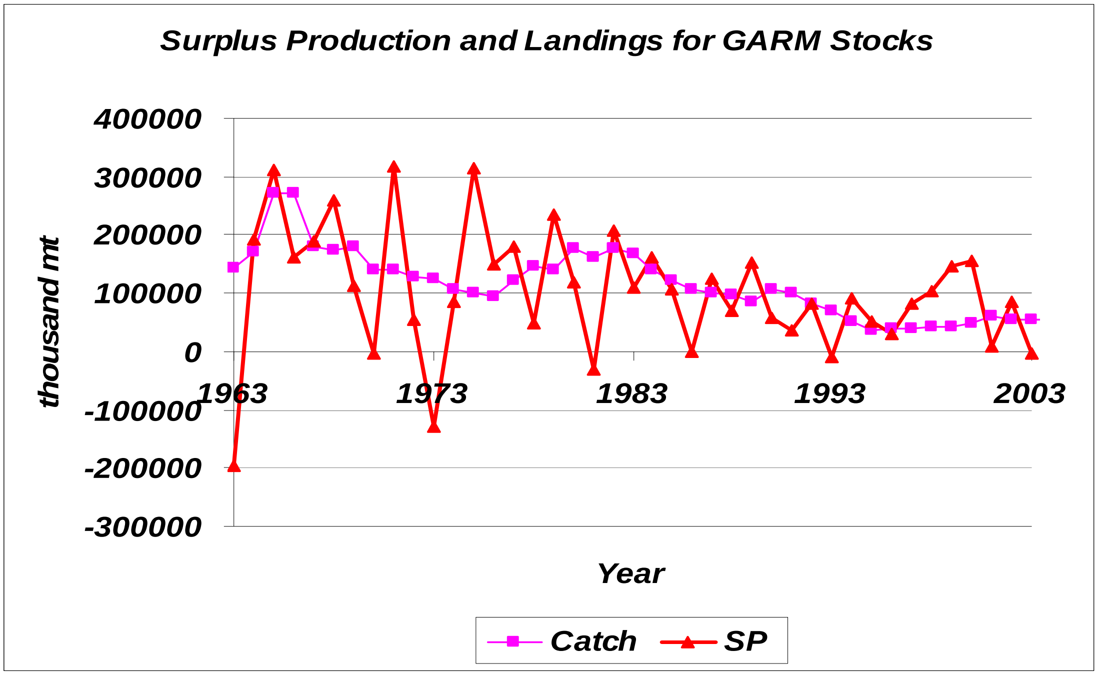

Figure 25. Surplus production and landings for GARM stocks during 1963-2003.

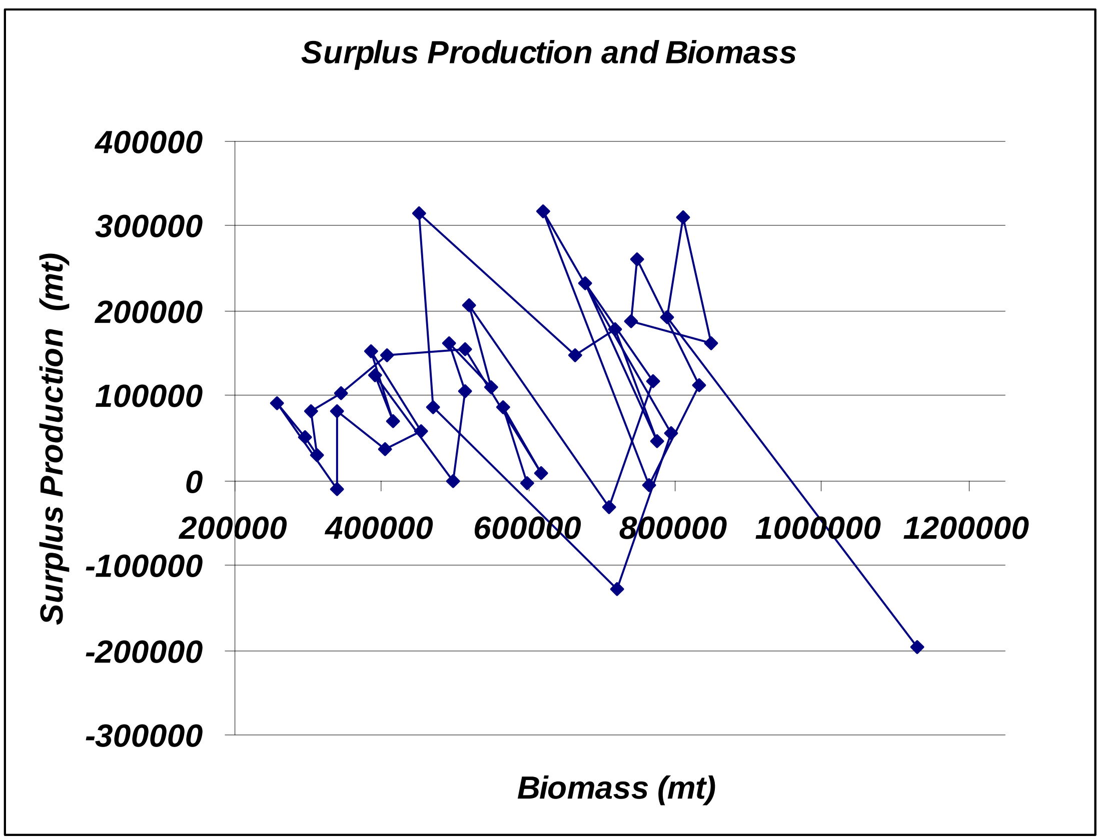

Figure 26. Surplus production and biomass for GARM Stocks during 1963-2003.

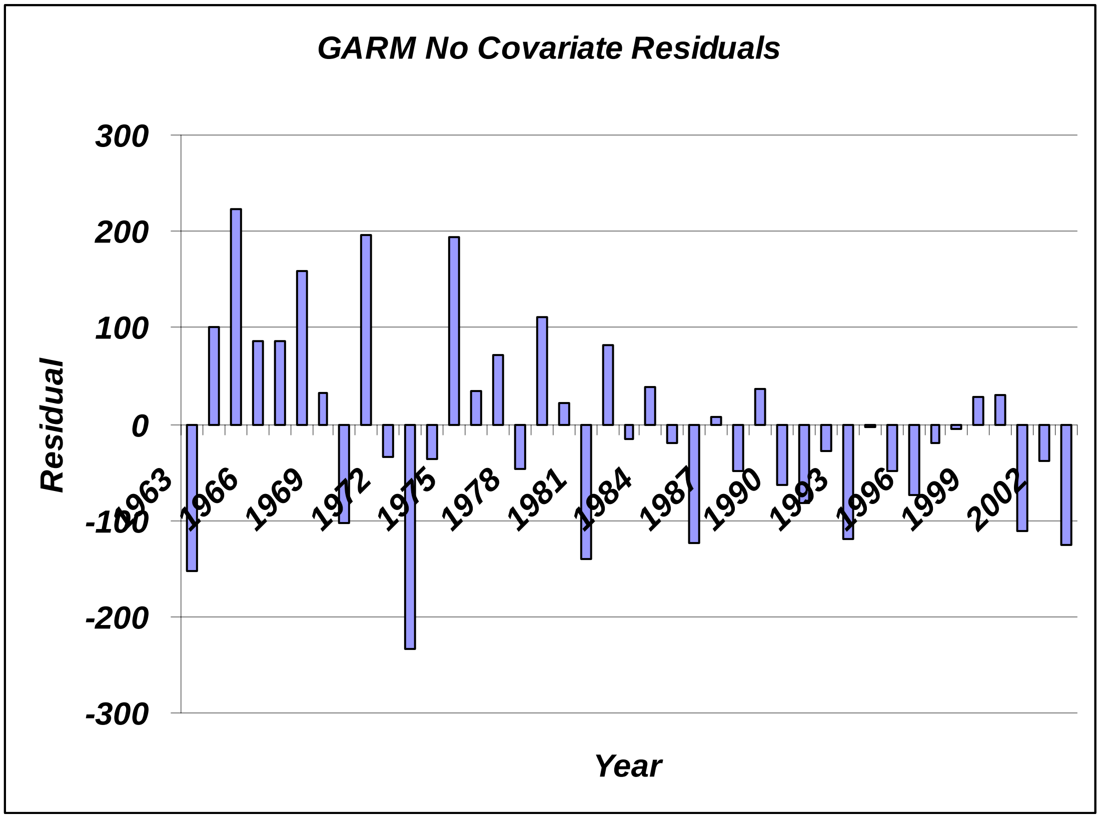

Figure 27. Residuals from surplus production model (no-covariates) for GARM stocks during 1963-2003.