Semi-separable untuned VPA for red drum.

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Summary

Untuned backwards VPA's were applied to catch at age data for the northern and southern regions red drum stocks to provide comparisons with estimates of historic stock size from statistical catch at age (SCCA) assessment models. The final year (2007) abundance of age two fish was determined by specifying their fishing mortality (F), and 2007 abundances at other ages were selected with a combination of constraints on selectivity in 2007 and approximate separability of F during 2003-2007. The constraints on selectivity were similar to those used in the SCCA assessment model, and were consistent with tagging information. Age compositions for the release mortality component of the recreational fishery (i.e. B2 catches) were inferred from the harvested age compositions (i.e. A+B1 catches) and the selectivity of the B2 fishery component relative to the A+B1 component, as inferred from a tagging model.

The results show that average F for ages 1-3 in the **northern region** was about 1.5 during 1982-1990 but declined during 1991-1994 and was relatively stable during 1995-2002 with a mean of 0.9. Total abundance during 1982-1997 fluctuated between 200 000 and 400 000, but increased to 660 000 in 1998 and then declined to 160 000 in 2003, the second lowest value during 1982-2003. Untuned VPA results after 2003 are more speculative because the VPA is not yet converged.

Results for the **southern region** demonstrated that the VPA was not converged in the base setup. This is because of the low levels of F during 1990-2000, and the truncated age-structure of the catches. Cohorts are never "fished-out", and the size of the plus group that survives the larger juvenile fishery is quite uncertain. The basic trend in the VPA is for stock abundance to increase during 1982-1987, and then decline after 1991.

Untuned VPA's using alternative F-constraints were similar to the base setting for the NR, but quite different for the SR, which again demonstrates the lack of convergence in the SR VPA. The alternative VPA for the SR stock, which utilized specific selectivity information obtained from tagging studies for the NR stock, seemed more reliable in that some degree of convergence was achieved. However, the scale and trends in the base and alternative VPA for the SR stock were quite different, suggesting that the assessment of this stock will be more uncertain than the NR stock.

Methods

Semi-separable VPA

The VPA was based on Pope's approximation,

$$N_{a,y} = N_{a-1,y-1}\exp(-M_{a-1,y-1}) - C_{a-1,y-1}\exp(-M_{a-1,y-1}/2). \tag{1}$$

Fishing mortality is

$$F_{a,y} = -\log\left(\frac{N_{a+1,y+1}}{N_{a,y}}\right) - M_{a,y} = -\log\left(1 - e^{M_{a,y}/2}\frac{C_{a,y}}{N_{a,y}}\right). \tag{2}$$

A plus group was used at age 6, and $F_{6+,2007} = F_{5,2007}$ was assumed for all years y. There were too many zeros in the catches at ages > 6, which cause problems when using F constraints in standard VPA's (see below).

If the values for $N_{a,2007}$ for $a = 1,\ldots 5$ (i.e. the survivors) are known then (1) can be used to reconstruct the population for 1981-2007. Typically, the survivors are estimated using time series of abundance indices; however, in this paper we essentially fix the survivors at reasonable values to illustrate stock trends inferred only from catch data. VPA's usually converge back in time if fishing mortalities are sufficiently high, and an untuned VPA can be used to provide absolute abundance and F estimates in the converged block of the VPA.

We specified values for $N_{2,2007}$ based on $F_{2,2007}$ and equation (2). We set $F_{2,2007} = 0.25, 0.5, 1.0$, and 2.0 to illustrate the VPA. These are arbitrary values, which we speculate cover the range of true values. A value for $N_{1,2007}$ was specified by assuming

$$\frac{F_{1,2007}}{F_{2,2007}} = \frac{F_{1,2006}}{F_{2,2006}}$$

In this equation $F_{2,2007}$, and consequently $F_{1,2006}$, are specified, and $F_{2,2006}$ is derived from an approximate separability condition (see below). Hence, $F_{1,2007}$ can be computed and used to derive $N_{1,2007}$. Values for $N_{4,2007}$, $N_{5,2007}$, and $N_{6+,2007}$, were derived using their F's obtained from the conditions:

$$F_{4,2007} = 0.1 \times F_{3,2007},\ F_{5,y} = 0.05 \times F_{3,y}, \textit{and}\ F_{6+,y} = F_{5,y},\ y = 1981 - 2007.$$

The value for $N_{3,2007}$ was selected to minimize the between year variation in the age patterns in F relative to age2, for 2003-2007; that is, minimize

$$Penalty\,(N_{3,2007}) = \sum_{y=2004}^{2007}\sum_{a=2}^{5}\left(\frac{R_{a,y}}{R_{a,y-1}} - 1\right)^2,\; R_{a,y} = \frac{F_{a,y}}{F_{2,y}}.$$

This is the semi-separable part of the VPA. Usually age patterns in F are expressed as $R_{a,y} = F_{a,y}/max_a\, F_{a,y}$. However, in our VPA formulation we think this caused some non-smoothness in the penalty term (caused by switching ages in which F is maximum) as a function of $N_{3,2007}$ which causes problems for common optimization algorithms, so we decided to fix the reference to age 2.

Some years and ages had zero catches, which cause problems when using F-constraints. For example, ignoring small differences in M at ages 5 and 6, $F_{6+,y} = F_{5,y}$ implies

$$N_{6+,y} = \frac{C_{6+,y}}{C_{5,y}} N_{5,y}.$$

If a catch at age 5 is zero then this leads to a division by zero error. As an ad hoc solution to this problem, we added one to these problem catches.

For the northern region stock, zeros were replaced with one’s in the catch at age five in 2004-2007. However, there were substantially larger catches at age 4 in these cohorts. The constraint $F_{5,y} = 0.05F_{3,y}$ led to unrealistically high F’s at age 4, sometimes exceeding 3 in value. Essentially, the inferred F_5 from the constraint generated a small stock size from a catch of one, and this implied that the much larger catch at the previous age in the cohort had a very high F. As a quick fix to this problem we assumed $F_{5,y} = 0.001\, F_{3,y}$ for $y = 2004,\ldots,2007$. Numbers at older ages were derived from the assumption $F_{6+,y} = F_{5,y}$.

The value of relative selectivity for age 5 compared to age 2 (i.e. 0.05) is consistent with tagging selectivity estimates for the NR give in Bacheler et al. (2008) (also see Cadigan and Paramore (2009 AW WP). The tagging estimates are $F_{5,y} = 0.08\, F_{3,y}$ for $y = 1983,\ldots,1991$, $F_{5,y} = 0.16\, F_{3,y}$ for $y = 1992,\ldots,1998$, and $F_{5,y} = 0.01\, F_{3,y}$ for $y = 1999,\ldots,2007$. As a sensitivity analysis, we also computed the semi-separable untuned NR VPA using these F constraints. For the SR we used similar constraints, except that took $F_{5,y} = 0.08\, F_{3,y}$ for $y = 1999,\ldots,2007$. The catch at age for the SR does not indicate the same degree of “dome” in the fishery selectivity for the 2000’s compared the NR.

B2 age compositions

A significant component of the total deaths due to fishing come from the mortality of caught and released fish (i.e. B2 catch). These fish are difficult to sample for ages, and consequently there is poor age sampling information for them. Fortunately Bacheler et al. (2008) provided estimates of fishing selectivity patterns (S_a) for the B2 and A+B1 catches in North Carolina (NC) recreational and commercial fisheries based on recaptures from tagging experiments conducted during 1983-2006. These fisheries comprise the majority of the landings for the northern region stock, and we can reasonably assume that the selectivity estimates in Bacheler et al. (2008) are indicative of the entire northern region fishery.

We used the selectivity estimates of the B2 fishery compared to A+B1 fisheries to infer the age composition of the B2 catches from the estimated age composition of the A+B1 landings. The selectivity (S) estimated by Bacheler et al. (2008) was the age component of fishing mortality, $S_{a,y} = F_{a,y} / F_{max,y}$. Let C^r_{ay} and C^h_{ay} denote the B2 (i.e. r) and A+B1 (i.e. h) catches. Define S^r_{ay} and S^h_{ay} similarly. The Baranov catch equation can be used to show

$$\frac{C^r_{a,y}}{C^h_{a,y}} = \frac{F^r_{a,y}}{F^h_{a,y}} = \frac{F^r_{\max,y}}{F^h_{\max,y}} \frac{S^r_{a,y}}{S^h_{a,y}} \Rightarrow C^r_{a,y} = \frac{F^r_{\max,y}}{F^h_{\max,y}} \frac{S^r_{a,y}}{S^h_{a,y}} C^h_{a,y}. \quad (3)$$

Let p^r_{ay} denote the proportion at age in the release mortality component, and let p^h_{ay} denote the proportion in the harvest component. The estimate of p^r_{ay} we propose is based on (3),

$$p^r_{a,y} = \frac{C^r_{a,y}}{\sum_a C^r_{a,y}} = \frac{S^r_{a,y} C^h_{a,y} / S^h_{a,y}}{\sum_a S^r_{a,y} C^h_{a,y} / S^h_{a,y}} = \frac{S^r_{a,y} p^h_{a,y} / S^h_{a,y}}{\sum_a S^r_{a,y} p^h_{a,y} / S^h_{a,y}}. \quad (4)$$

We estimate p^h_{ay} by plugging in estimates of S^r_{ay}, S^h_{ay} and C^h_{ay} into (4). It is intuitively reasonable that if $S^r_{ay} = S^h_{ay}$ then $p^r_{ay} = p^h_{ay}$.

The estimate of C^r_{ay} that we use in the VPA is $C^r_{ay} = 0.05 \times p^r_{ay} \times C^{rt}_y$ where C^{rt}_y is the estimated total number of releases and 0.05 is the assumed release mortality. These catch estimates were added to estimates of recreational harvest catch at age (A+B1) and the commercial catch at age to produce estimates of the total deaths-at-age due to fishing.

We also used the relative selectivity (S^r_{ay}/S^h_{ay}) estimates from the northern region to infer the age composition of the B2 catches in the southern region. While there are reasons to suspect that the selectivity of the B2 catches are different in both regions, the relative selectivity may be more similar between regions. However, this is speculative and requires careful consideration by experts for these fisheries.

Results

Catch at age (Table 1), annual trends in the age compositions, and relative sizes of catches for the northern region are shown in Figure 1 and Table 1. The anomalous zero catches at ages 5 and 6 in 2004-2007 (replaced by one’s) are evident in the bottom panels of Figure 1.

Similar information is shown in Table 4 and Figures 2 for the southern region.

Estimates of F's averaged for ages 1-4 and 4-7, recruitment, and total (ages 1-6+) abundance are shown in Figure 3 for the northern region for each of the four choices for $F_{2,2007}$ used to scale the untuned VPA. Estimated F's for $F_{2,2007} = 0.5$ for are given in Table 2. Population abundance-at-age estimates are given in Table 3 and Figure 4.

Results for the southern region are given in Tables 5 and 6, and Figures 5 and 6.

Sensitivity analysis results were conducted based alternative $F_{5,y}$ constraints described in the **Methods**. Average F's and abundance estimates are presented in Figures 7 and 8 for the northern and southern regions, respectively. They are substantially different in both scale and trend for the SR stock compared to Figure 5.

Discussion additional to the Summary

The declining trend in stock size after 1995 in most of the SR untuned VPA's is not consistent with survey information.

F's selectivity patterns had considerable between age and year variability in 2004-2007 for the northern region. This does not seem realistic unless management regulations have changed substantially during this period. The age composition of the catch is quite variable in this period. This was less of a problem for the southern region stock. Nonetheless, both the northern and southern red drum stocks seem to have non-negligible errors in catch age compositions, and an assessment model approach such as VPA that (typically) treats catch at age as known without error may give misleading results. The estimates for the "converged" part of the VPA should be interpreted only broadly in terms of scale. Short-term variations in stock size estimates may be the consequence of measurement errors in catch that are not accounted for in the VPA.

References

Bacheler, N.M., Hightower, J.E., Paramore, L.M., Buckel, J.A., Pollock, K.H., 2008. Age-dependent tag return model to estimate mortality and selectivity of an estuarine-dependent fish with high rates of catch and release. Trans. Am. Fish. Soc. 137, 1422-1432.

Tables

Table 1. Northern region red drum catch at age used in the VPA.

	Age					
Year	1	2	3	4	5	6+
1982	21197	10822	1426	304	11	1119
1983	177724	64791	5875	1962	54	3891
1984	112991	73885	14143	2226	6	2900
1985	41813	26088	3011	261	31	1664
1986	92946	43620	2417	191	52	5704
1987	136711	59090	4221	2963	30	882
1988	166674	50072	6573	534	118	6930
1989	65880	77142	7016	163	8	4937
1990	71743	24042	2626	97	29	2410
1991	93306	25483	725	1167	65	940
1992	3899	68503	4184	251	71	316
1993	9860	77303	30413	64	46	1081
1994	4852	27964	21251	3206	125	4413
1995	18481	113217	15253	1118	936	221
1996	17489	31396	10974	1166	467	586
1997	24214	11861	4178	816	313	656
1998	12952	220010	5604	794	604	1210
1999	23579	126686	34250	1228	4	268
2000	4544	76030	69642	7432	39	104
2001	3363	20363	35871	11005	574	1776
2002	63987	107826	4512	11014	1212	5264
2003	1099	47569	18385	1951	95	1
2004	15602	16555	21468	2783	1	2
2005	4453	96437	2431	32	1	7
2006	17280	84301	29292	11908	1	1
2007	8997	145357	61921	3738	1	22

Table 2. Northern region red drum F. $F_{2,2007}$ was set at 0.5.

	Age					
Year	1	2	3	4	5	6+
1982	0.193	0.744	0.492	0.247	0.025	0.025
1983	1.078	1.456	1.113	3.2	0.056	0.056
1984	1.333	2.955	1.628	1.89	0.081	0.081
1985	0.544	1.422	1.777	0.086	0.089	0.089
1986	0.77	2.173	0.395	0.418	0.02	0.02
1987	1.049	2.019	1.854	1.052	0.093	0.093
1988	0.986	1.608	1.681	1.375	0.084	0.084
1989	1.133	2.465	0.986	0.127	0.049	0.049
1990	1.011	2.346	0.528	0.026	0.026	0.026
1991	0.486	1.311	0.384	0.414	0.019	0.019
1992	0.027	0.778	0.69	0.196	0.035	0.035
1993	0.15	0.988	0.879	0.017	0.044	0.044
1994	0.029	0.779	0.732	0.178	0.037	0.037
1995	0.353	1.652	1.274	0.064	0.064	0.064
1996	0.54	1.864	0.612	0.243	0.031	0.031
1997	0.071	0.848	1.672	0.071	0.084	0.084
1998	0.043	1.538	1.225	2.307	0.061	0.061
1999	0.141	0.696	1.016	0.862	0.051	0.051
2000	0.127	0.854	0.967	0.543	0.048	0.048
2001	0.02	1.25	1.247	0.332	0.062	0.062
2002	0.539	1.448	0.964	1.802	0.048	0.048
2003	0.025	0.981	0.972	1.462	0.049	0.049
2004	0.058	0.603	1.848	0.318	0.002	0.002
2005	0.014	0.565	0.146	0.009	<0.001	<0.001
2006	0.039	0.391	0.299	1.869	<0.001	<0.001
2007	0.05	0.5	0.5	0.05	0.001	0.001

Table 3. Northern region red drum population numbers at age. $F_{2,2007}$ was set at 0.5.

	Age						
Year	1	2	3	4	5	6+	1+
1982	132983	22001	3852	1448	471	47577	208332
1983	297073	90149	9188	2135	1038	74295	473877
1984	169194	83152	18478	2737	80	38338	311978
1985	109957	36684	3805	3288	379	20230	174344
1986	190870	52515	7779	584	2768	301551	556066
1987	231959	72690	5255	4752	353	10296	325305
1988	293144	66793	8481	746	1523	88849	459537
1989	107132	89942	11753	1431	173	106116	316549
1990	124360	28365	6719	3977	1158	95555	260134
1991	267291	37217	2388	3592	3557	51095	365141
1992	164042	135216	8815	1475	2179	9632	321359
1993	77919	131381	54598	4009	1113	25978	294999
1994	187040	55143	42979	20549	3618	126875	436205
1995	68578	149431	22240	18738	15789	3703	278479
1996	46199	39642	25174	5643	16127	20099	152884
1997	390110	22136	5402	12379	4062	8456	442545
1998	341924	298888	8332	920	10579	21050	681694
1999	197752	269470	56393	2219	84	5596	531515
2000	42025	141259	118024	18523	860	2279	322970
2001	186550	30443	52852	40709	9881	30365	350799
2002	169291	150379	7661	13768	26820	115697	483615
2003	48647	81204	31060	2651	2085	22	165669
2004	306937	39013	26762	10659	564	1120	385055
2005	342936	238292	18761	3825	7116	49478	660409
2006	498235	278011	118983	14698	3480	3457	916864
2007	203857	394105	165259	80003	2082	45496	890802

Table 4. Southern region red drum catch at age used in the VPA.

	Age					
Year	1	2	3	4	5	6+
1982	308982	85611	5029	3710	3452	9299
1983	414304	97776	16817	4435	370	534
1984	759652	151664	30478	6628	1576	13738
1985	787542	177824	37155	5653	246	1108
1986	235357	164195	37806	4294	758	4239
1987	566585	168684	23798	6484	742	1804
1988	264950	182114	19918	2388	100	1315
1989	113226	90234	20741	4920	374	579
1990	120143	98806	20890	6239	710	4461
1991	267080	106957	32695	24567	3304	1779
1992	155194	123185	28921	15946	2014	3403
1993	140615	135325	39843	16105	2140	2363
1994	183825	161593	56572	27038	1718	7719
1995	262938	150519	47285	21572	2926	2402
1996	147215	153488	46335	24673	2911	1302
1997	182303	52056	26178	19515	2506	3456
1998	45121	102250	44280	18638	2287	1437
1999	85680	126147	57165	9221	2915	198
2000	80651	158760	98286	29728	6490	0
2001	117471	127720	79490	58156	9970	6485
2002	101512	127683	48909	18331	5934	3046
2003	130079	262764	97849	35542	7712	7
2004	118292	252278	91901	49869	1667	8
2005	134636	285438	95417	32252	2229	0
2006	95519	160256	80508	48103	2418	408
2007	119546	208673	105439	35852	2618	0

Table 5. Southern region red drum F. $F_{2,2007}$ was set at 0.5.

	Age					
Year	1	2	3	4	5	6+
1982	0.253	0.024	0.006	0.002	0	0
1983	0.016	0.121	0.006	0.006	0	0
1984	0.33	0.007	0.049	0.003	0.002	0.002
1985	0.025	0.121	0.002	0.011	0	0
1986	0.018	0.007	0.033	0	0.002	0.002
1987	0.009	0.017	0.001	0.007	0	0
1988	0.019	0.004	0.002	0	0	0
1989	0.005	0.008	0	0.001	0	0
1990	0.016	0.005	0.002	0	0	0
1991	0.015	0.018	0.002	0.003	0	0
1992	0.016	0.009	0.006	0.001	0	0
1993	0.013	0.018	0.003	0.004	0	0
1994	0.031	0.019	0.009	0.003	0	0
1995	0.059	0.033	0.007	0.004	0	0
1996	0.035	0.046	0.012	0.004	0.001	0.001
1997	0.056	0.016	0.009	0.006	0	0
1998	0.018	0.041	0.016	0.008	0.001	0.001
1999	0.073	0.065	0.028	0.004	0.001	0.001
2000	0.09	0.193	0.064	0.017	0.003	0.003
2001	0.176	0.207	0.134	0.046	0.007	0.007
2002	0.063	0.303	0.11	0.039	0.006	0.006
2003	0.161	0.236	0.387	0.103	0.019	0.019
2004	0.066	0.55	0.116	0.326	0.006	0.006
2005	0.203	0.231	0.397	0.051	0.02	0.02
2006	0.135	0.409	0.091	0.334	0.005	0.005
2007	0.164	0.5	0.5	0.05	0.025	0.025

Table 6. Southern region red drum population numbers at age. $F_{2,2007}$ was set at 0.5.

	Age						
Year	1	2	3	4	5	6+	1+
1982	1578606	4031537	937217	1634222	12681482	33748725	54611789
1983	29811050	941719	3275782	800441	1420891	2025920	38275803
1984	3085600	22534515	694243	2798425	693508	5972288	35778579
1985	36443859	1704258	18608305	568131	2432864	10825408	70582824
1986	14772981	27302010	1255593	15950753	489894	2706564	62477795
1987	75002068	11140732	22562991	1043559	13898348	33382409	157030108
1988	16295815	57111892	9114206	19360348	903492	11737396	114523149
1989	28051223	12284473	47345718	7810963	16871862	25804286	138168524
1990	8896825	21446674	10137246	40652418	6803286	42229356	130165805
1991	20043117	6728282	17751533	8688890	35426007	18844299	107482128
1992	11050875	15160877	5499755	15218890	7550127	12603135	67083659
1993	12330020	8352070	12500094	4697678	13249592	14453543	65582998
1994	6818255	9347347	6824723	10701094	4079367	18107250	55878035
1995	5213396	5075938	7628743	5810244	9301616	7543606	40573543
1996	4881491	3773924	4085425	6509533	5043953	2228752	26523078
1997	3827108	3620411	2999562	3466579	5650544	7698477	27262681
1998	2919209	2779797	2964368	2552466	3003182	1864207	16083229
1999	1391830	2202675	2219273	2505456	2207278	148117	10674630
2000	1066143	993962	1717365	1853451	2175097	331	7806349
2001	831377	748212	682082	1384181	1587677	1020232	6253761
2002	1902262	535621	505951	512257	1152131	584260	5192483
2003	999853	1372145	329129	389299	429360	385	3520171
2004	2112858	653976	901834	192043	306124	1451	4168286
2005	834851	1519196	313948	689529	120824	54	3478402
2006	866005	523246	1003486	181256	570870	95162	3240024
2007	899937	581457	289124	787412	113071	43	2671044

Figures

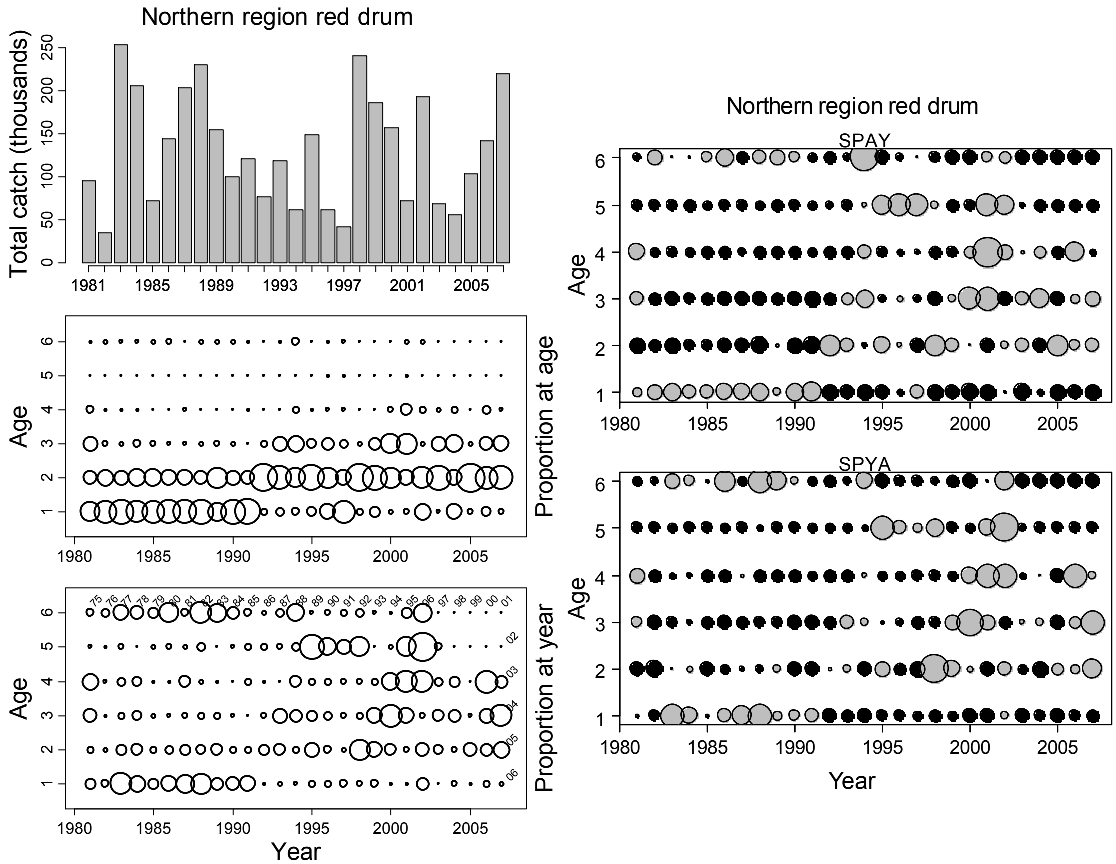

Figure 1. Commercial catch for the northern region red drum stock. Top left panel: Total annual catch. Age 6 is a plus group. Middle left panel: annual proportion at age. Bottom left panel: proportion at year for each age. Cohorts are indicated along the margins of the bottom panel. Top right panel: standardized proportion at age (*SPAY*). Age 6 is a plus group. Bottom right panel: standardized proportion at year (*SPYA*). Black denotes negative values, and grey denotes positive. Bubble areas are proportional to absolute values. A small bubble means the proportion is near average in size for that age in the time series.

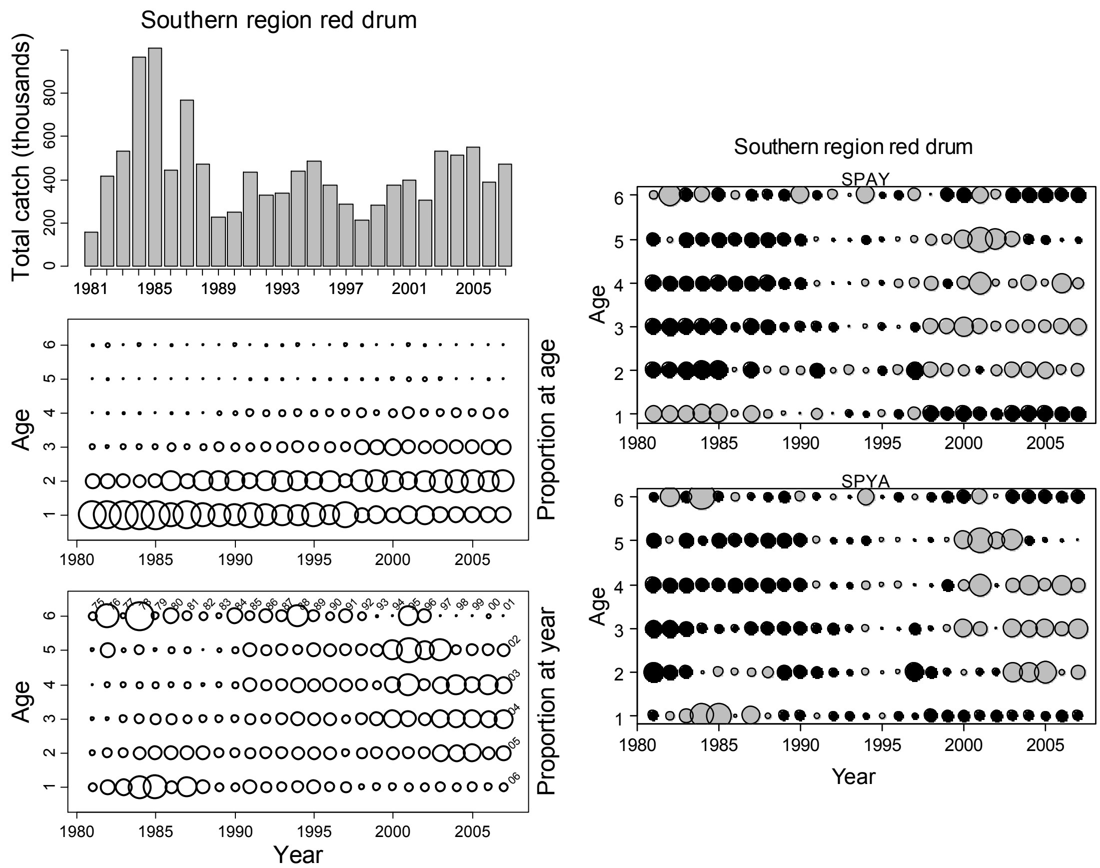

Figure 2. Commercial catch for the southern region red drum stock. Top left panel: Total annual catch. Age 6 is a plus group. Middle left panel: annual proportion at age. Bottom left panel: proportion at year for each age. Cohorts are indicated along the margins of the bottom panel. Top right panel: standardized proportion at age (*SPAY*). Age 6 is a plus group. Bottom right panel: standardized proportion at year (*SPYA*). Black denotes negative values, and grey denotes positive. Bubble areas are proportional to absolute values. A small bubble means the proportion is near average in size for that age in the time series.

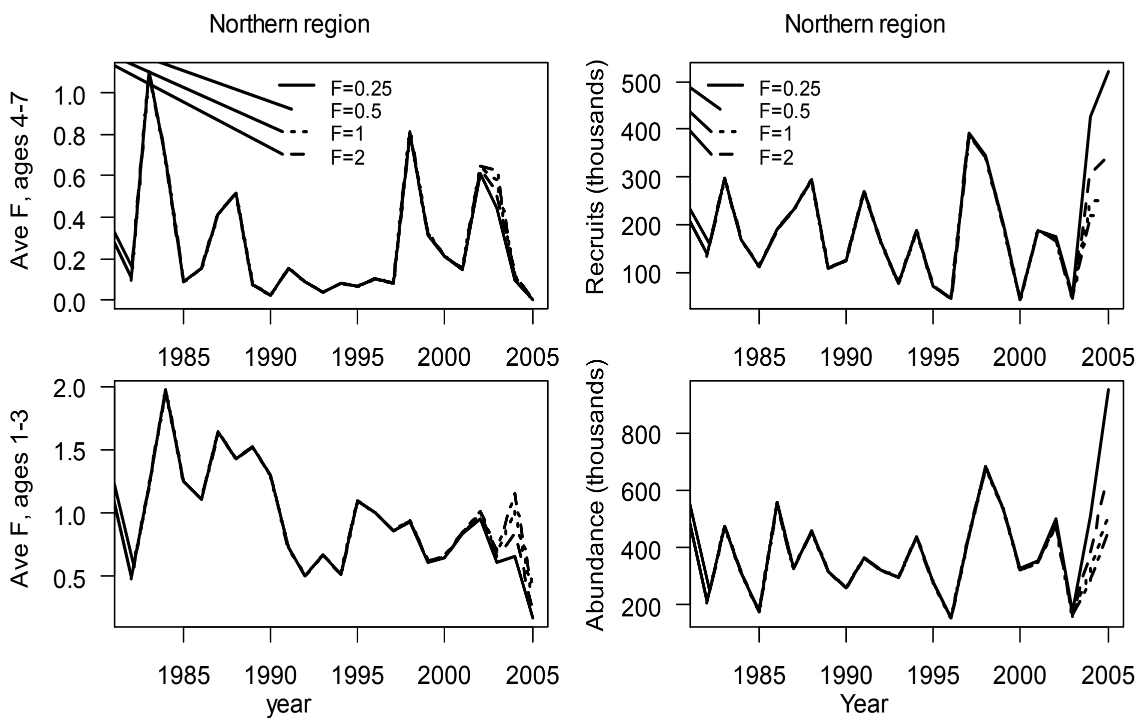

Figure 3. Estimates of average F (left panels) and abundance (right panels; recruitment and total for ages 1-6+) for the northern region red drum stock. Estimates are derived from an untuned VPA and four assigned values of F at age two in 2007 (denoted as F in the legend).

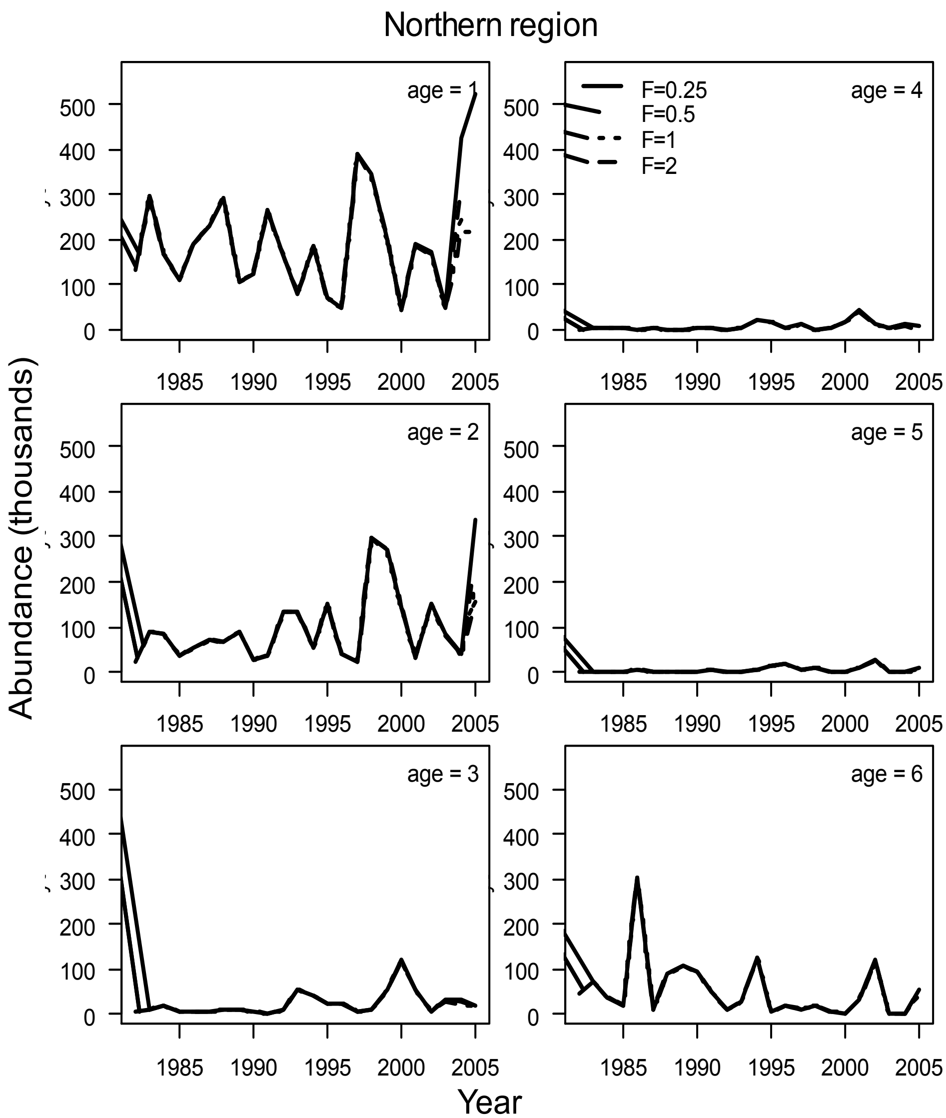

Figure 4. Estimates of abundance at age for the northern region red drum stock. Estimates are derived from an untuned VPA and four assigned values of F at age two in 2007 (denoted as F in the legend).

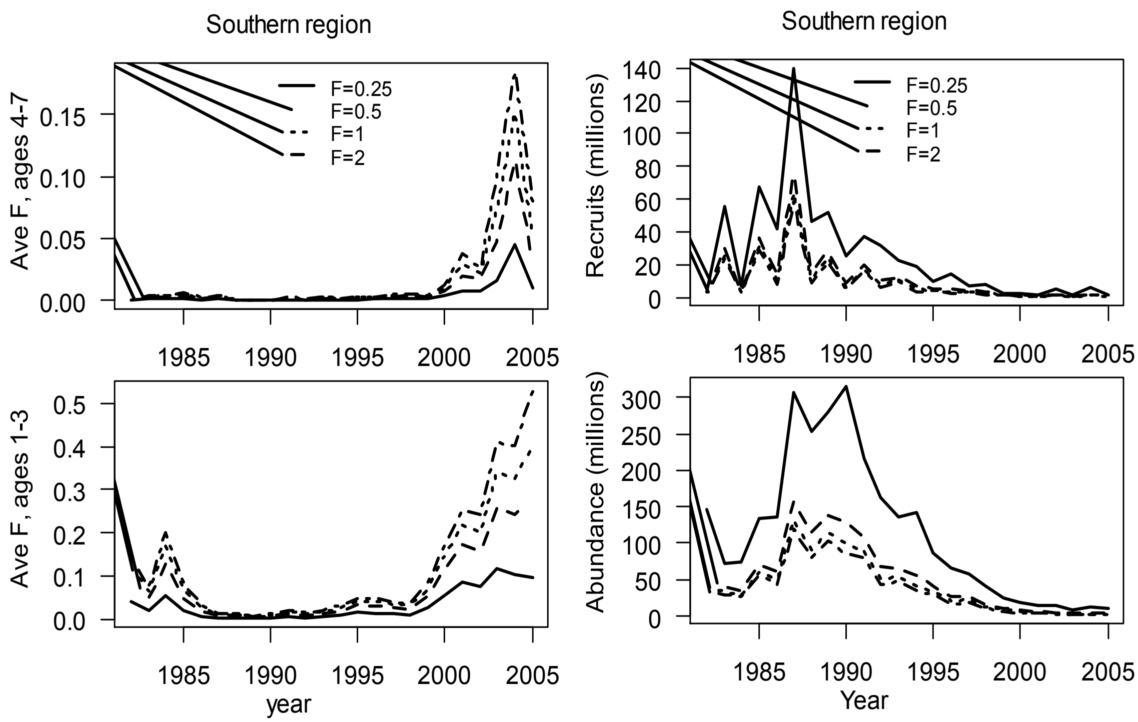

Figure 5. Estimates of average F (left panels) and abundance (right panels; recruitment and total for ages 1-6+) for the southern region red drum stock. Estimates are derived from an untuned VPA and four assigned values of F at age two in 2007 (denoted as F in the legend).

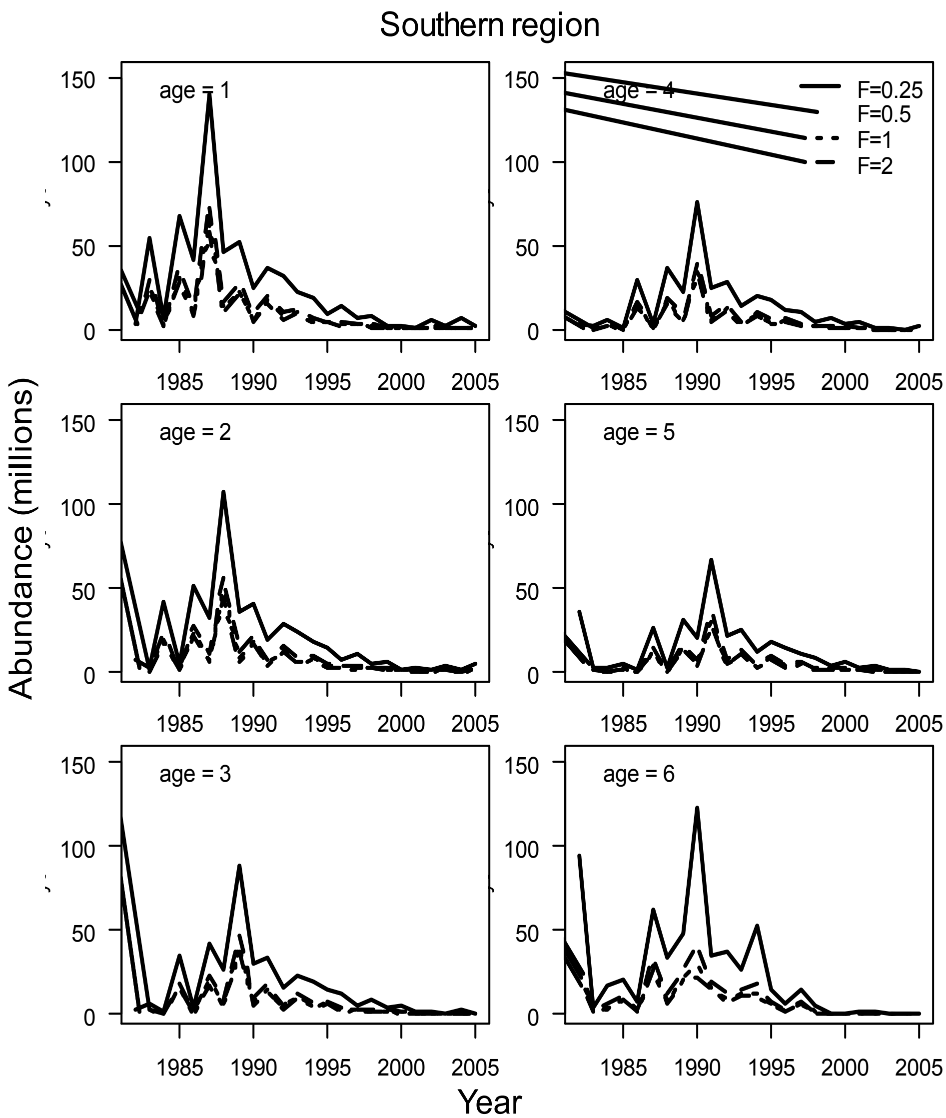

Figure 6. Estimates of abundance at age for the southern region red drum stock. Estimates are derived from an untuned VPA and four assigned values of F at age two in 2007 (denoted as F in the legend).

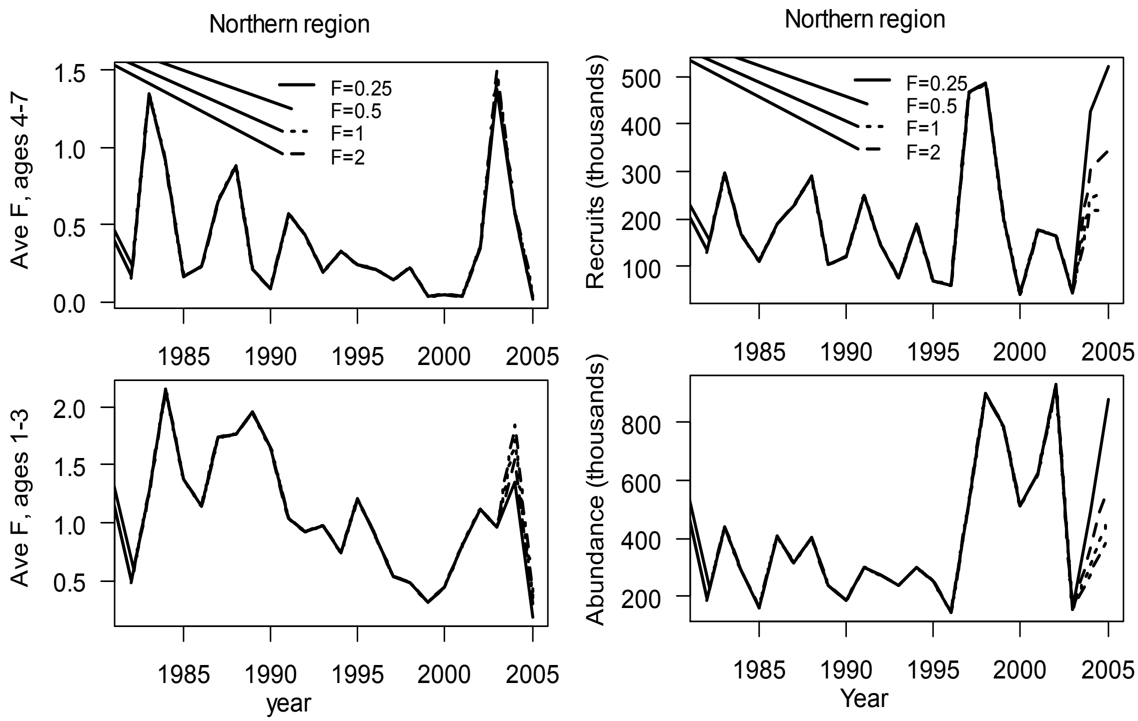

Figure 7. Sensitivity analysis ($F_5 = 0.03F_2$) estimates of average F (left panels) and abundance (right panels; recruitment and total for ages 1-6+) abundance (right panels) for the northern region red drum stock. Estimates are derived from an untuned VPA and four assigned values of F at age two in 2007 (denoted as F in the legend).

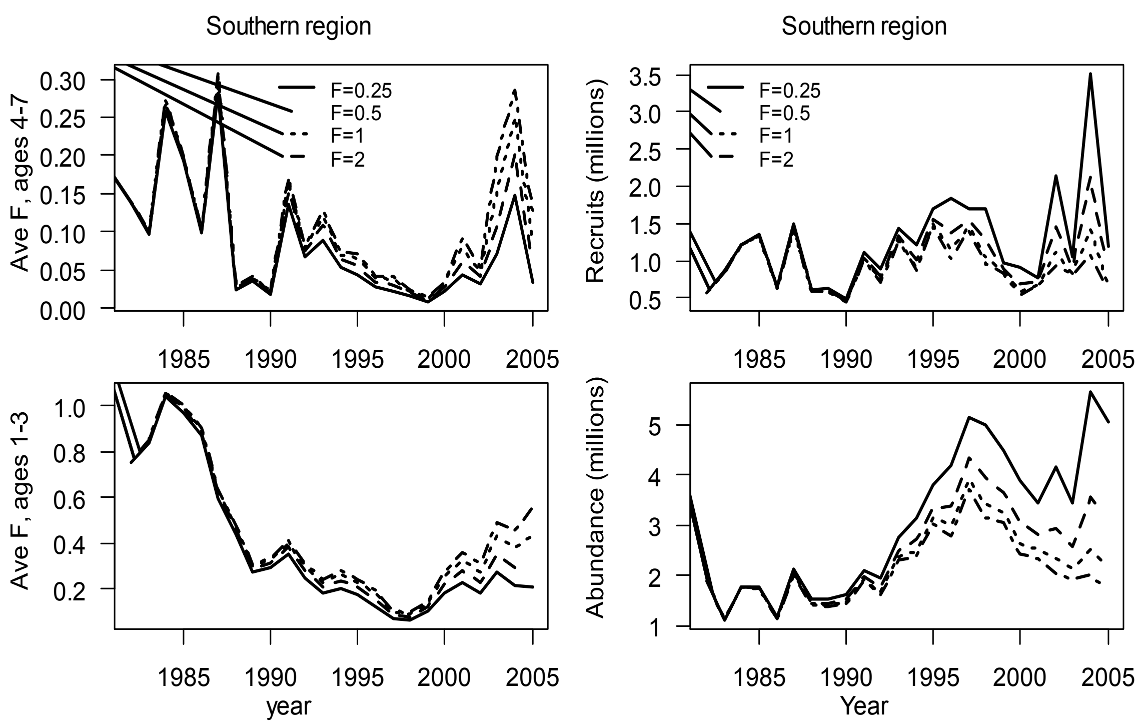

Figure 8. Sensitivity analysis ($F_5 = 0.03F_2$) estimates of average F (left panels) and abundance (right panels; recruitment and total for ages 1-6+) for the southern region red drum stock. Estimates are derived from an untuned VPA and four assigned values of F at age two in 2007 (denoted as F in the legend).