THREE DIFFERENT STRATEGIES FOR MODELING THE TERMINAL-YEAR FISHING MORTALITY RATES IN VIRTUAL POPULATION ANALYSES OF WESTERN BLUEFIN TUNA: RETROSPECTIVE PATTERNS AND CONSEQUENCES FOR PROJECTIONS

By

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SUMMARY

Virtual population analysis requires estimation or assumptions regarding terminal year fishing mortality. Previous Western Atlantic Bluefin tuna assessments have assumed a fixed vulnerability schedule that links adjacent years. Terminal year fishing mortality can also be freely estimated or estimated with a penalty that restricts the amount of change within a given age from one year to the next. We explore the implications of these three methods of estimating vulnerability through retrospective analyses of the 2006 Western Atlantic Assessment data and through a series of deterministic simulations. It appears that the current status quo method creates erratic retrospective patterns and may have led to overly optimistic projections of SSB. The method of constraining changes in vulnerabilities appears to mute erratic retrospective patterns in abundance at age and result in projections of SSB that are less prone to initial leaps.

KEYWORDS

Bluefin tuna, Virtual Population Analysis, VPA-2box, terminal year vulnerabilities, retrospective patterns

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1. Introduction

Virtual population analyses (VPA) require the estimation or assumption of terminal year fishing mortality rates (F). Estimation for all age classes is not generally possible unless auxiliary information (such as indices of abundance) is available for every age class. Western Atlantic Bluefin tuna assessments, for example, have reduced the number of terminal year Fs that need to be estimated by linking adjacent age classes through the use of a prespecified partial recruitment (relative vulnerability) vector (ANON., 2006). Assessments conducted since 1994 have all assumed the following relative vulnerability schedule:

$$F_{age\ 1} = 0.318{*}F_{age\ 2};\ F_{age\ 3} = F_{age\ 2};\ F_{age\ 5} = F_{age\ 4};\ F_{age\ 7} = F_{age\ 6};\ F_{age\ 9} = F_{age\ 8} \qquad (1)$$

where $F_{age\ i}$ is the fishing mortality rate at a given age and only F_{age2}, F_{age4}, F_{age6} and F_{age8} are estimated. The oldest age class represents a plus group (ages 10 and older) and the corresponding terminal fishing mortality rate is specified as the product of $F_{age\ 9}$ and an estimated 'F-ratio' parameter that represents the ratio of $F_{age\ 10}$ to $F_{age\ 9}$ (assumed to be the same since 1981).

Assuming a fixed ratio of terminal fishing mortalities for successive ages can potentially introduce biases when vulnerability actually varies with age (NRC 1998) and there are several alternative methods to estimate these vulnerabilities within the VPA. These include estimating all age-specific terminal Fs either as free parameters (recognizing that they will not all be well-determined) or subject to constraints that restricts the amount of change in the vulnerability pattern from one year (or multiple years) to the next. The latter approach was recommended by the SCRS Methods group in 1996 (SCRS/1996/014) and is available in the VPA-2BOX program (Porch 2003), but has not yet been explored in Western Atlantic Bluefin Assessments.

This objectives of this paper are 1) to explore the consequences of the status quo method of estimating vulnerabilities in previous assessments, 2) to perform retrospective analyses using the 2006 assessment data to examine the effects of allowing vulnerabilities to vary freely or with a restriction and 3) to perform a deterministic simulation using constructed data to determine which method performs better given an underlying assumption of relative vulnerability patterns.

2. Materials and Methods

Retrospective analysis

We used the same VPA-2BOX data input and control files for the 2006 Western Atlantic Bluefin tuna assessment (SCRS /2006/013) to perform retrospective analyses going back five years using three methods of estimating vulnerabilities:

1) Status quo, terminal-year Fs for ages 2, 4, 6, and 8 estimated as free parameters and the remaining terminal Fs determined from the relative vulnerability schedule specified by equation (1).
2) terminal-year Fs for all ages (1-9) estimated as free parameters with no penalty
3) terminal-year Fs for all ages (1-9) estimated subject to a penalty that constrains the amount of annual change in the relative vulnerability of each age class (Porch, VPA-2BOX manual). In this case we have linked the vulnerabilities for ages 1-9 over 3 years with a standard deviation of 0.5.

No changes in either the configuration or the parameter files were made for the status quo retrospective runs. To estimate all terminal Fs with no penalty we changed the method of estimation specified in the parameter file for all ages to '1' corresponding to estimation in the frequentist sense. We also replaced the 'best estimate' column with the number corresponding to the 2004 catch at age and placed upper bounds of 5,000,000 for ages 1-4, 100,000 for ages 5-7 and 10,000 for ages 8-9. Note that that the configuration file parameter estimation option was set to '2', use numbers as terminal year parameters. To apply the vulnerability penalty we changed the configuration file constraint on vulnerability method to '3' (impose constraint over last 3 years), with a standard deviation of 0.5, linked to the first 1 through 9 ages.

Deterministic simulations

We performed simple deterministic simulations to evaluate the performance of each method of estimating terminal Fs using created datasets with the following assumptions about the fishing mortality rates in the last year:

1) relative vulnerabilities in the last year exactly conform to the ratios in equation (1) above.
2) relative vulnerabilities in the last three years held constant (but absolute magnitudes of F varying)
3) terminal Fs at age arbitrarily set to the geometric average of 1990-1992.

Each simulated dataset consisted of 1) a catch at age matrix created according to one of the three vulnerability schedule assumptions above, 2) a set of 6 simulated relative abundance indices (for ages 1,3,5,7,9 and 10) created by dividing the simulated abundance at the given age for each year by the mean for that age over all years. The specification file (Table 2) for the indices used a lognormal pdf, applied each index to the numbers of fish, a fixed vulnerability applied to ages 1,3,5,7,9 and 10 respectively and an index CV of 1.

To create a vulnerability schedule that exactly conformed to the ratios in equation (1) we used the 2006 assessment fishing mortality at age matrix and number at age matrix to obtain a catch at age matrix which was input in the data file (Table 3). For the constant relative vulnerability schedule we calculated the geometric mean fishing mortality at age for years 2002-2004 and multiplied these mean values by the original apical F values (the maximum F over all ages) to give fishing mortality schedules for 2002-2004 that had different absolute values (due to different apical F values) but constant relative rates (Table 3). To obtain an arbitrary relative vulnerability schedule for 2004 we used the geometric average of 1990-1992, scaled to the apical geometric mean F and multiplied by the apical F in 2004 (Table 3). The combination of three different methods of estimating vulnerabilities and three different simulated vulnerability schedules gave a total of 9 scenarios.

3. Results and Discussion

Retrospective analysis

ADAPT VPA estimates of age-specific fishing mortality rates were obtained from five previous assessments (1996, 1998, 2000, 2002 and 2006) and compared against the status quo linkage assumptions. Figure 1 compares the assumed terminal F ratios of equation (1) with the ratios of the actual Fs estimated for all years by the 2000, 2002 and 2006 assessments. There is a systematic underestimation of the ratio of F_{age1}/F_{age2}, i.e., F_{age1} was generally estimated to be less than the assumed value of 0.318. In contrast, F_{age3}/F_{age2} appeared to often be higher than the assumed value of 1, though the ratios of the other years appeared to be symmetrically distributed around the assumed value of 1.

Another way to examine the possible misspecification of the terminal F ratios is to take advantage of the fact that estimates of F at age in VPA tend to be increasingly accurate as one goes back in time, implying that the estimates of F at age for a given year (say 1998) should be better determined in the latest assessment (2006) than they were during previous assessments. Inasmuch as the same assumption about the terminal F's (equation 1) was made for the last several assessments, an idea of the degree to which that assumption was satisfied can be obtained from the ratios estimated by the 2006 assessment for the years corresponding to the terminal years of each previous assessment. This is done in Figure 2, where it is apparent that the ratio of F_{age3}/F_{age2} was usually estimated to be higher than the assumed value, indicating that F_{age3} was estimated to be higher than F_{age2}. The pattern of under or overestimation for ratios of older ages was less clear but indicated that this ratio was often subsequently estimated to be much different than assumed.

Analysis of the retrospective patterns in age 1 recruitment (Figure 3) indicated that both the status quo and the no vulnerability constraint method tended to erratically overestimate age 1 recruitment in the most recent years, including years prior to the last 3. In contrast, the retrospective patterns for the vulnerability constraint appeared more muted except for the last two years. Total population number (Figure 4) also appeared to be affected more by retrospective patterns for the status quo and the no vulnerability constraint than for estimation with the vulnerability constraint. The generally poor estimation of recent recruitments has been handled in past assessments by replacing the recruitments in the last three years by the assumed stock recruitment relationship, including recalculating the abundance and F values for subsequent years to match the corresponding observed catches (Anon 2006). However, recruitments prior to the last three years (corresponding to terminal F values for ages older than 3) also show a strong retrospective pattern in the status-quo and no-penalty cases.

Comparison of the three methods of estimating terminal year fishing mortality indicated that both the status quo and the no-penalty methods produced erratic retrospective patterns for abundances at age (Figure 5). When viewed in detail (Figure 6), abundances at ages 5-7 several years in the past appeared to be overestimated for the status-quo and no-penalty methods, but less so with the vulnerability constraint. In contrast, ages 8-10 (the spawning stock ages) appear to be systematically underestimated in all cases though this is likely more a consequence of the F-ratio specifications).

The potential impact of adopting the vulnerability constraint on management advice was examined by applying it to the 2006 base-case model (rather than equation 1). The results indicated higher estimates of spawning stock biomass in the terminal year (2004) than for the 2006 base-case (status quo method), but somewhat less optimistic projections under the current 2100 MT TAC. The status quo method estimates larger numbers of 5-8 year old fish in the last few years than does the vulnerability penalty method, which results in a conspicuous bump in SSB and SSB/SSB_{MSY} early in the projections not seen when the vulnerability penalty is employed. Similar patterns of a bump in SSB in the early years of the projections can be seen in projections from four previous assessments (Anon 1999, Figures 25, 26; Anon 2000, Figures 13, 14; Anon 2002, Figures 40-42; Anon 2006, Figures 39).

Deterministic simulations

The deterministic simulations verify that the method that exactly followed the relative vulnerability assumption of the created dataset produced the best estimates (Figures 8-10). It is clear from the Figures 1 and 2, that the assumption of a constant fixed ratio was often not met in subsequent estimates so that the question becomes which method performs best when the vulnerability schedule differs from the assumptions. In the situation where relative vulnerability exactly matched the status quo assumption, the constrained estimation method underestimated ages 3-7 but overestimated ages 8-10 in the latest years and total numbers were slightly lower as a result. When relative vulnerability was constant in the last three years the status quo assumption overestimated ages 1-7 in either the most recent year or several years in the past, leading to overestimates of total abundance in the latter 3 years. When an arbitrary vector of relative vulnerabilities was used for 2004, it was unclear which method was preferable as the status quo method overestimated and the vulnerability constraint underestimated total abundance. Note that we have not plotted the lines for estimation allowing vulnerability to vary freely as they exactly match known values (the created datasets have no process or observation error).

4. Conclusions

The problem of how to estimate terminal year fishing mortalities is an important issue for assessments of bluefin tuna conducted using VPAs. Gavaris et al (2008) pointed out that projected SSB trajectories from the various assessments that were made by SCRS all feature a "bump" in the SSB values that appears early in the projected time horizon and leads to overly optimistic appraisals of future abundance. Our analyses show that the status quo method of linking relative vulnerabilities to adjacent ages creates this false spike in SSB. This is likely due to linking the relative vulnerabilities of ages 3, 5, 7, and 9 to the next younger age class when vulnerability of the older age is actually higher. This artificially lowers the relative fishing mortality rate on the older ages, resulting in an overestimation of abundance of that age. In particular it is the overestimation of ages 5-7 in years prior to the terminal year that creates these anomalous spikes in projected SSB. Our results suggest that imposing a constraint on how much the vulnerability at age can change from one year to the next appears to mute the wildly varying estimates of numbers at age. It may provide an adequate solution to the problem of overestimating future SSB caused by the status quo assumption that vulnerabilities follow a fixed linkage schedule. Fully stochastic simulations could provide further guidance as to which method of estimation is optimal given various hypotheses regarding the vulnerability schedule, though we will not know which method is best for Western Atlantic Bluefin tuna. Rather there is a tradeoff between the assumption that the terminal year vulnerability schedule follows equation (1) or whether it is relatively constant from one year to the next within an age. This is likely a safer assumption, given the effect that the status quo method has upon projected SSB.

In the particular case of the 2006 assessment the different SSB/SSB_{MSY} values (Figure 7) for the two methods would probably not have led to different management advice. However, this may not have been true for earlier assessments such as in 2002 where unusually strong year classes were estimated for 1997 and 1999. Given the above results, we recommend changing the method of estimating all terminal year vulnerabilities by using a constraint on interannual changes in vulnerability rather than the fixed vulnerability schedule in the terminal year.

5. Literature Cited

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Table 1. Parameter file Terminal F specifications for estimation of fishing mortalities for all ages. Note that for the last age is estimated by an F-ratio parameter, so the number of entries is one fewer than the number of ages

Age	Lower bound	Best estimate	Upper bound	Method of estimation	Reference age
1	0	9869	5000000	1	2
2	0.01	31233	5000000	1	0.1
3	0	70437	5000000	1	2
4	0.01	17391	5000000	1	0.1
5	0	14446	1000000	1	4
6	0.01	27115	1000000	1	0.1
7	0	22619	1000000	1	6
8	0.01	6716	100000	1	0.1
9	0	23940	100000	1	8

Table 2. Data file abundance index specifications for the simulations.

Index	PDF (1=lognormal)	Units (1=numbers)	Vulnerability (1=fixed)	Timing (0 months elapsed)	First age	Last Age
1	1	1	1	0	1	1
2	1	1	1	0	3	3
3	1	1	1	0	5	5
4	1	1	1	0	7	7
5	1	1	1	0	9	9
6	1	1	1	0	10	10

Table 3. Fishing mortality at age matrix for each simulation. A. Fishing mortality at age used for the status quo simulation where vulnerability at age follows the ratios in equation 1. B. Replacement values for 2002-2004 for constant relative vulnerability in last three years. C. Replacement values for 2004 for an arbitrarily different vector of relative vulnerability.

	F at age									
A. Fishing mortality for status quo assumption										
year	1	2	3	4	5	6	7	8	9	10
1970	0.228	0.721	0.918	0.227	0.082	0.024	0.014	0.004	0.020	0.020
1971	0.290	1.170	0.588	0.980	0.009	0.046	0.075	0.129	0.033	0.033
1972	0.230	0.921	0.832	0.094	0.176	0.002	0.021	0.025	0.031	0.031
1973	0.035	0.662	0.773	0.383	0.067	0.087	0.020	0.069	0.028	0.028
1974	0.129	0.178	0.367	0.339	0.272	0.026	0.078	0.023	0.059	0.085
1975	0.374	0.538	0.098	0.342	0.061	0.064	0.016	0.070	0.049	0.071
1976	0.042	0.271	0.513	0.042	0.121	0.031	0.033	0.071	0.072	0.104
1977	0.015	0.226	0.194	0.419	0.088	0.205	0.119	0.101	0.084	0.121
1978	0.102	0.164	0.302	0.174	0.219	0.091	0.055	0.074	0.085	0.122
1979	0.034	0.291	0.366	0.359	0.127	0.098	0.082	0.061	0.110	0.158
1980	0.046	0.268	0.522	0.324	0.101	0.145	0.238	0.140	0.138	0.199
1981	0.101	0.181	0.447	0.467	0.355	0.172	0.218	0.193	0.146	0.210
1982	0.059	0.078	0.040	0.020	0.046	0.063	0.032	0.051	0.070	0.057
1983	0.037	0.050	0.084	0.026	0.041	0.157	0.173	0.106	0.118	0.096
1984	0.012	0.094	0.045	0.067	0.073	0.097	0.154	0.124	0.115	0.093
1985	0.007	0.094	0.204	0.085	0.182	0.183	0.084	0.219	0.150	0.122
1986	0.006	0.086	0.158	0.076	0.042	0.096	0.062	0.053	0.169	0.137
1987	0.018	0.166	0.173	0.162	0.123	0.110	0.132	0.106	0.143	0.116
1988	0.050	0.138	0.203	0.104	0.156	0.158	0.157	0.165	0.180	0.146
1989	0.013	0.168	0.032	0.088	0.055	0.114	0.151	0.167	0.217	0.176
1990	0.022	0.088	0.347	0.048	0.074	0.068	0.133	0.179	0.189	0.153
1991	0.035	0.168	0.312	0.087	0.048	0.077	0.131	0.204	0.190	0.154
1992	0.008	0.077	0.032	0.056	0.055	0.039	0.103	0.130	0.196	0.159
1993	0.006	0.022	0.084	0.062	0.103	0.087	0.079	0.165	0.144	0.117
1994	0.042	0.013	0.037	0.051	0.059	0.111	0.130	0.137	0.130	0.105
1995	0.014	0.030	0.086	0.117	0.107	0.067	0.071	0.129	0.138	0.112
1996	0.006	0.150	0.060	0.176	0.091	0.052	0.105	0.104	0.145	0.117
1997	0.005	0.016	0.139	0.048	0.070	0.074	0.102	0.108	0.156	0.126
1998	0.003	0.025	0.079	0.087	0.052	0.055	0.124	0.188	0.171	0.139
1999	0.001	0.007	0.073	0.049	0.058	0.051	0.152	0.187	0.213	0.173
2000	0.002	0.004	0.016	0.074	0.141	0.120	0.141	0.164	0.184	0.149
2001	0.027	0.008	0.045	0.076	0.064	0.077	0.171	0.109	0.231	0.187
2002	0.004	0.138	0.122	0.121	0.083	0.069	0.231	0.288	0.279	0.226
2003	0.004	0.026	0.161	0.160	0.054	0.024	0.177	0.249	0.215	0.174
2004	0.026	0.081	0.081	0.155	0.155	0.086	0.086	0.179	0.179	0.145
B. Replacements for constant relative vulnerability										
2002	0.004	0.138	0.122	0.121	0.083	0.069	0.231	0.288	0.279	0.226
2003	0.004	0.026	0.161	0.160	0.054	0.024	0.177	0.249	0.215	0.174
2004	0.026	0.081	0.081	0.155	0.155	0.086	0.086	0.179	0.179	0.145
C. Replacement for arbitrary relative vulnerability for 2004										
2004	0.017	0.098	0.141	0.058	0.054	0.055	0.114	0.157	0.179	0.145

Figure 1. Ratio of fishing mortality rates estimated in three previous Western Atlantic Bluefin tuna assessments. The dashed line is the fixed ratio used for the terminal years, and the numbers represent the ratio of subsequently estimated fishing mortalities for earlier years. Marginal histograms display the distribution of values around the assumed ratios.

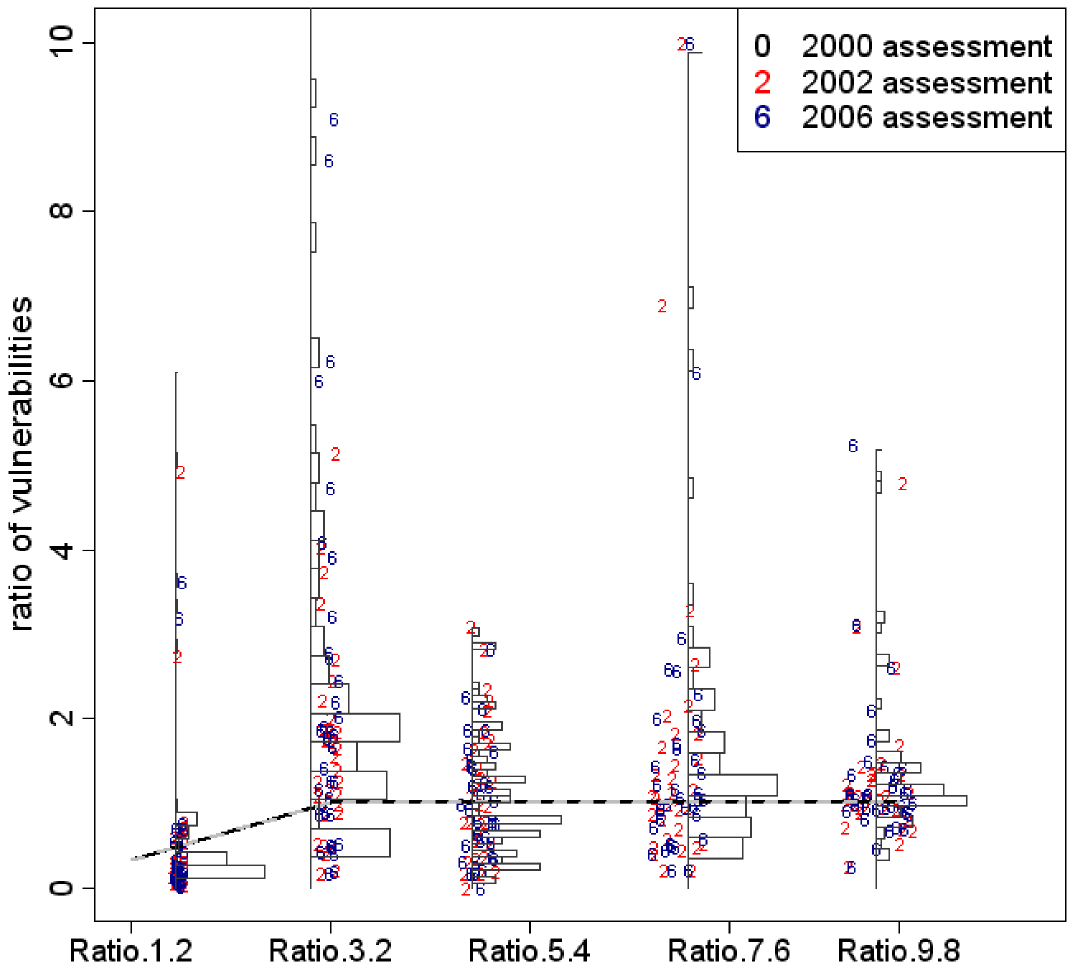


Figure 2. Estimated versus assumed ratios of terminal year fishing mortalities for a) terminal year 1995, assessment year 1996, b) terminal year 1997, assessment year 1998 c) terminal year 1999, assessment year 2000 d) terminal year 2001, assessment year 2002.

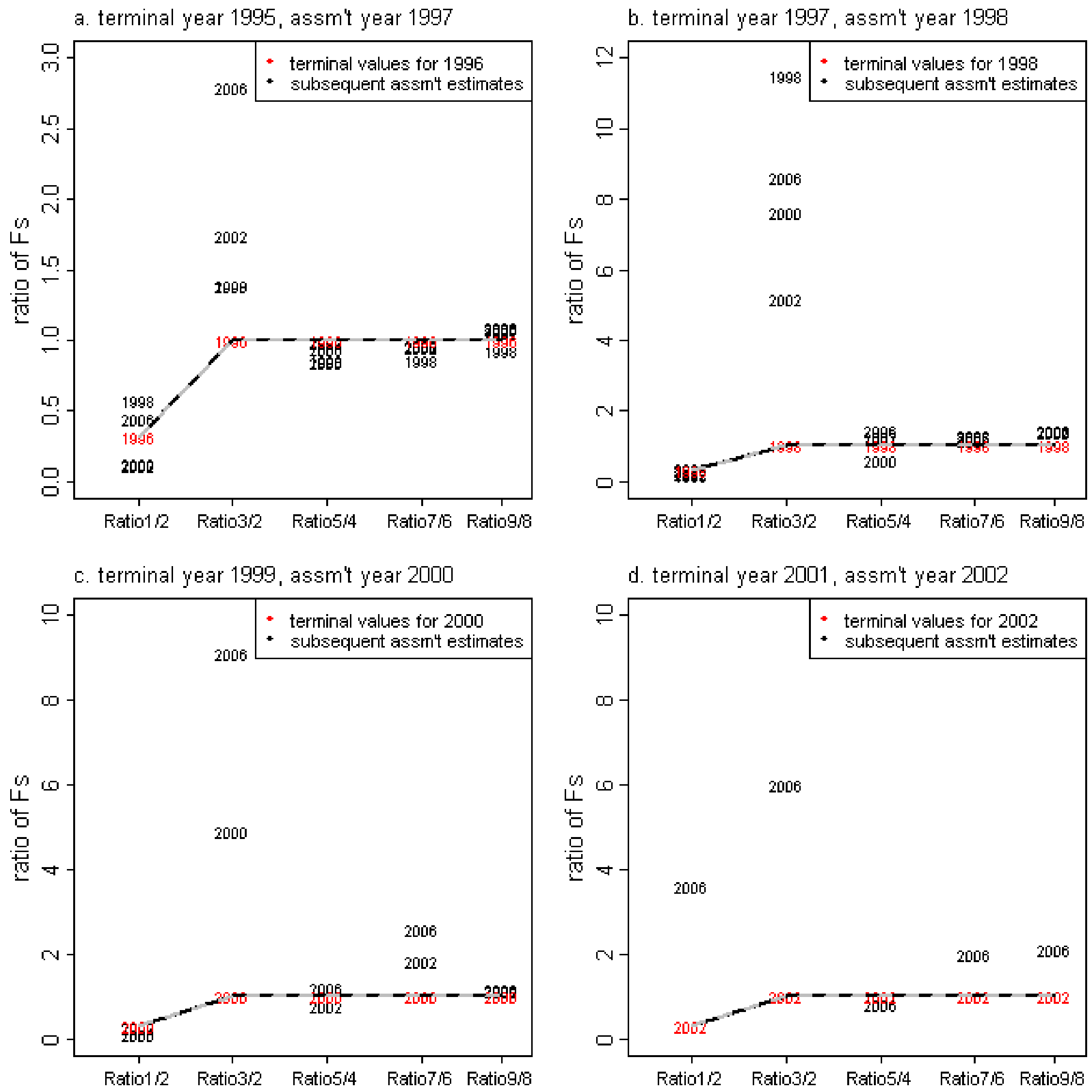


Figure 3. Retrospective analysis of age 1 recruitment for the three vulnerability estimation methods.

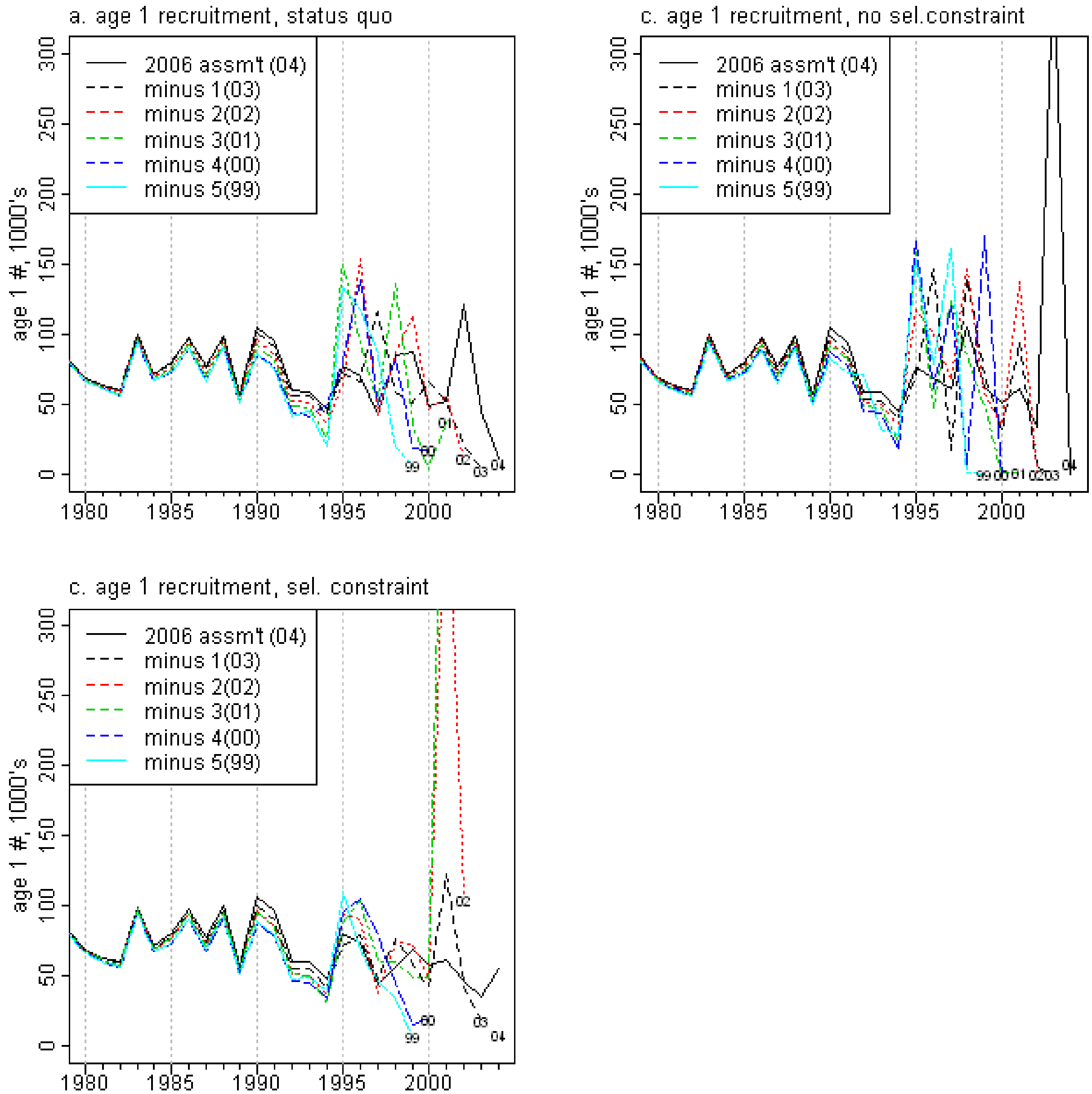


Figure 4. Retrospective analysis of total population size for the three methods of estimating terminal year fishing mortality. a) status quo b) estimate all vulnerabilities with no constraint c) estimate with penalty.

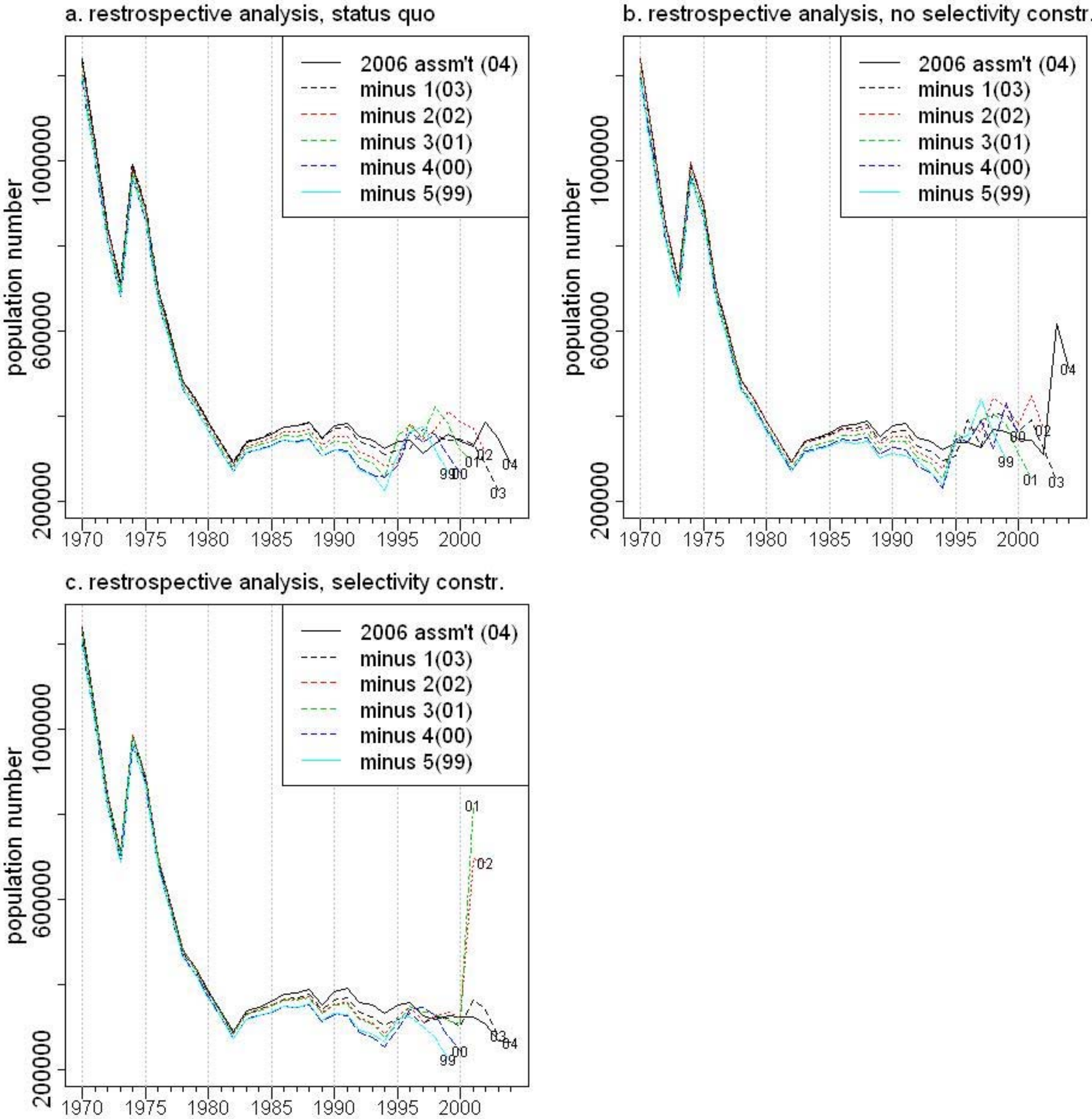


Figure 5. Retrospective analysis of number at age for the three methods of estimating terminal year fishing mortality. a) status quo b) estimate all vulnerabilities with no constraint c) estimate with penalty.

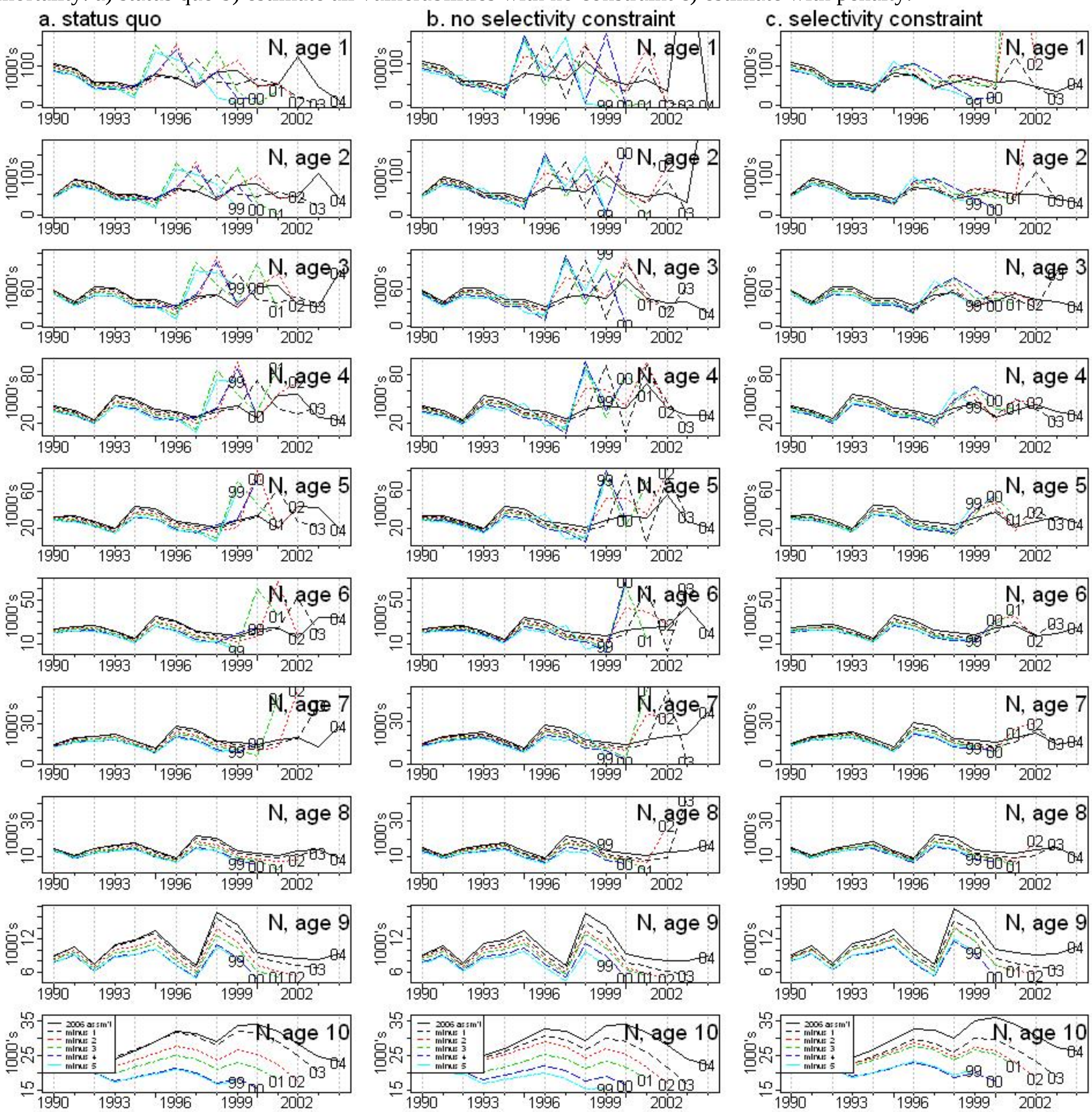


Figure 6. Plot of number at age for ages 5-8 for the three terminal vulnerability methods showing the retrospective patterns for older age classes.

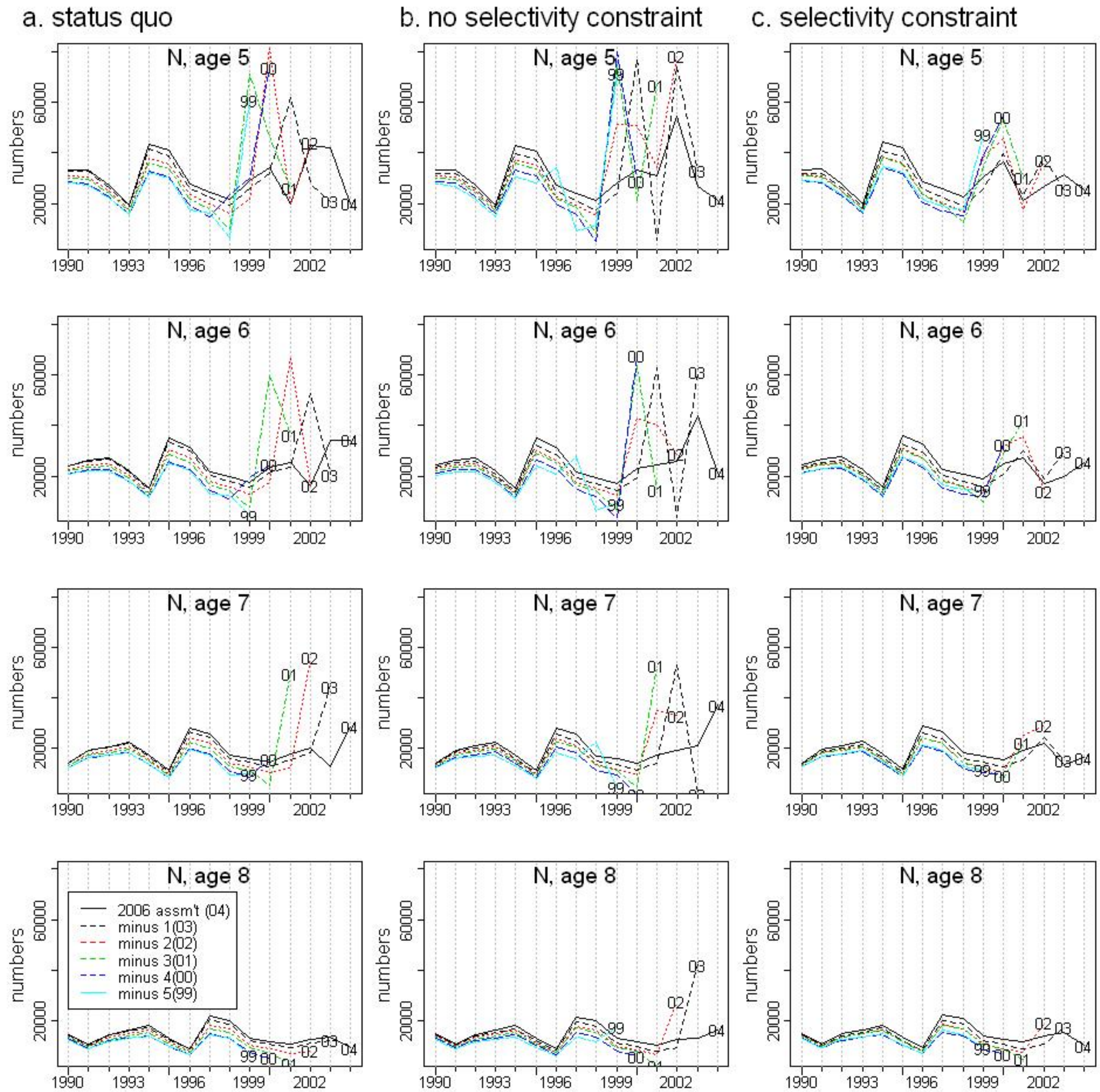
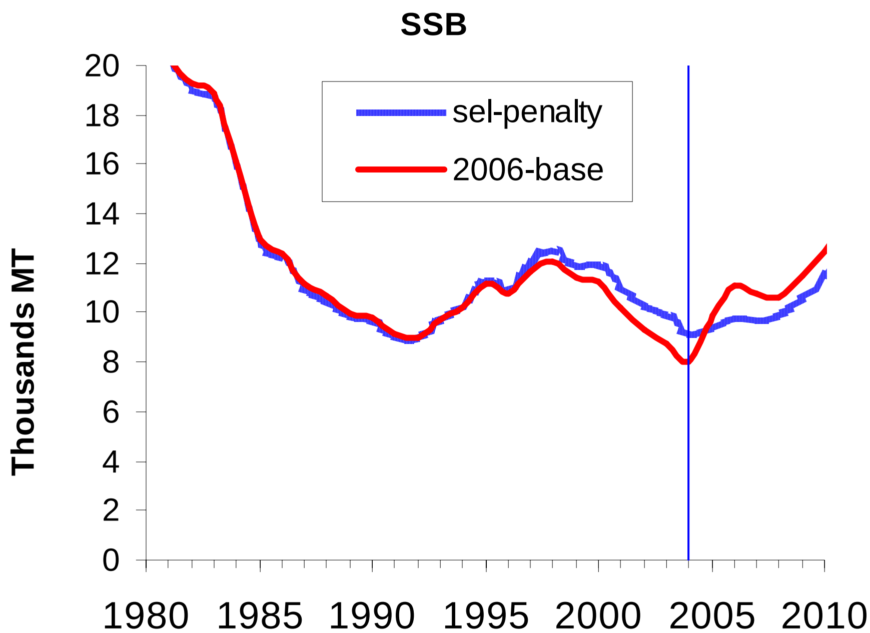


Figure 7. Projections of a) spawning stock biomass and b) SSB/SSB_{MSY} with a constant 2100 mt quota for the 2006 base case assessment with fishing mortalities estimated with the status quo linkage ratios (red) and with a penalty on vulnerability.

a.



b.

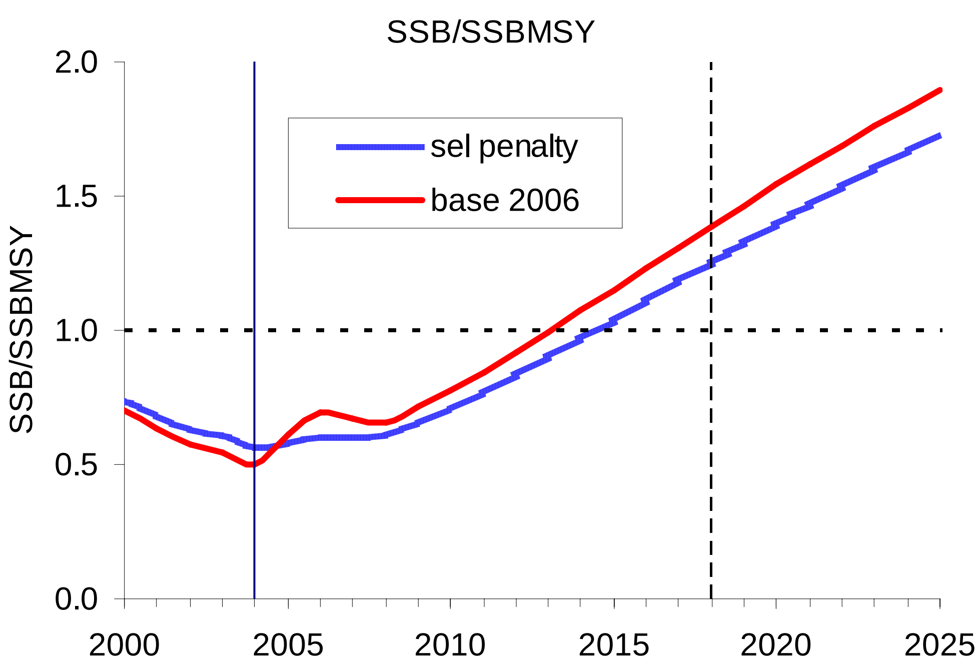


Figure 8. Deterministic simulation results comparing Method 1: status quo and Method 3: constraining vulnerability with a dataset created with vulnerabilities that exactly match the status quo assumption.

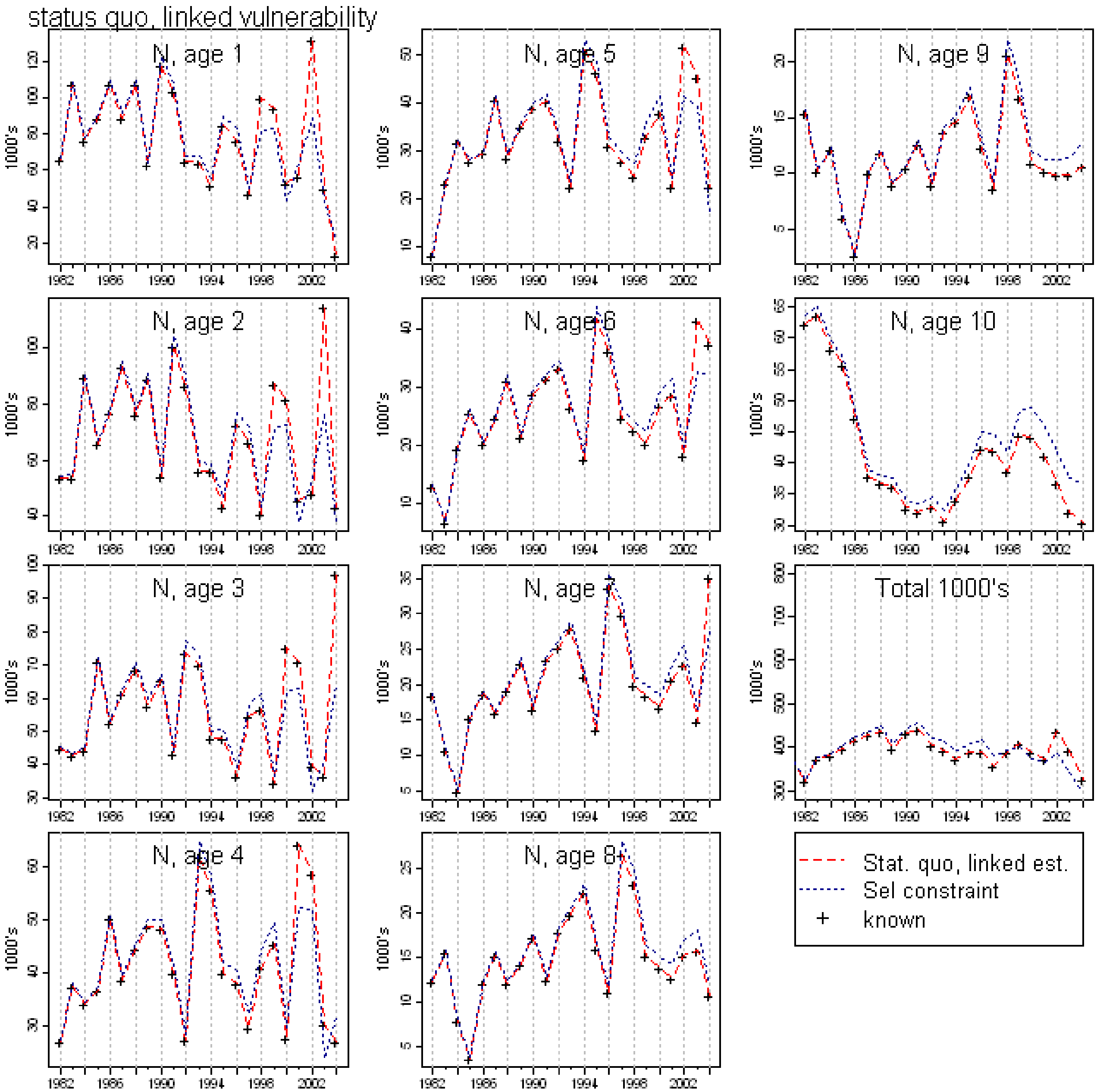


Figure 9. Deterministic simulation results comparing Method 1: status quo and Method 3: constraining vulnerability with a dataset created with constant vulnerability schedule for the last 3 years.

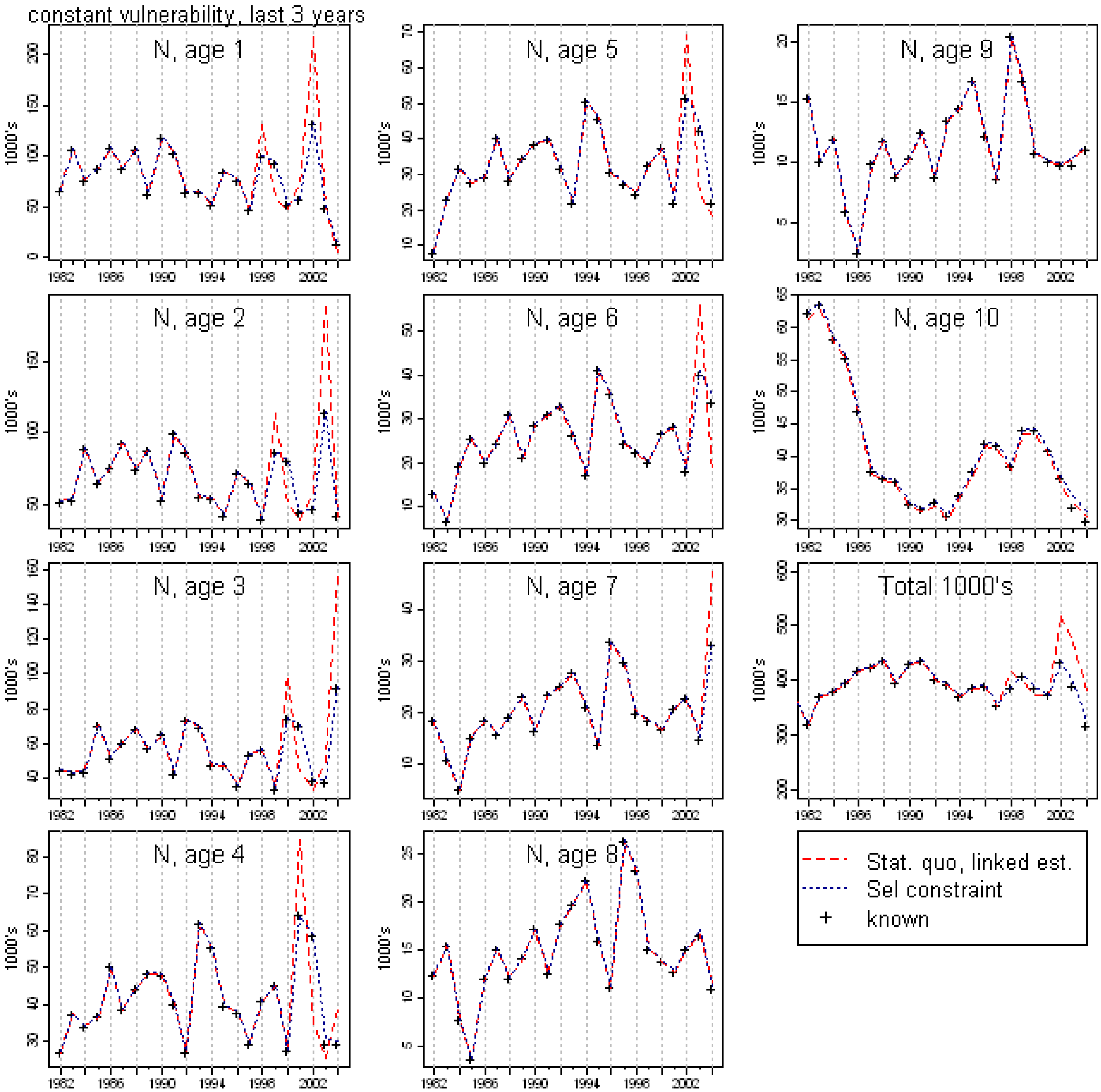


Figure 10. Deterministic simulation results comparing Method 1: status quo and Method 3: constraining vulnerability with a dataset created with vulnerability schedule that of the geometric mean of 1990-1992.