A State-Space, Age-Structured Production Model for Sandbar Shark

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SUMMARY:
Two forms of an age-structured production model were employed to assess sandbar shark. The first was the continuity model used in the 2002 assessment. The second model (2006 base model) does not use catch, and all calculations are made relative to the unexploited stock. Both the continuity model and the 2006 base model (catch-free) reached the same conclusion that the stock is overfished and undergoing overfishing. Despite the differences in the way fishing mortality is estimated, and the fact that one model used catch and the other did not, both models agreed remarkably well on the estimates of biomass relative to MSY (continuity: 0.21-0.47; catch-free: 0.35-0.51) and on the level of current depletion (continuity: 0.15-0.26; catch-free: 0.19-0.26). One major input difference between the continuity model and the 2006 base model was the maturity ogive. Conclusions about status did not appear sensitive to this model input.

Continuity Model Description – Age-structured production model

The model used in the 2002 Large Coastal Shark was a state space, age structured production model (SSASPM, Porch 2002). Unlike a production model, the SSASPM can incorporate age-specific differences in model parameters such as growth, fecundity, and gear vulnerability (selectivity). In the case of long-lived, late-maturing fish or when there are multiple fisheries that exploit different age classes, having the flexibility to incorporate age-specific information could lead to a better fit to observed data. Age-specific vectors for fecundity, maturity, and selectivity are specified by the user, and length and weight at age are calculated within the model based on user-specified growth functions. Natural mortality at age and a stock recruitment function are additional model parameters. The stock recruit function is parameterized in terms of virgin recruitment (R0) and pup survival. To derive the initial age structure for the first year that data is available, the model estimates a level of historic fishing (F_{hist}) and calculates the corresponding equilibrium population age structure. A historic selectivity vector is specified by the user, which is multiplied by F_{hist} to arrive at the historic age-specific fishing mortality rate. A historic selectivity vector of 1 for all ages was assumed.

Continuity Model Inputs

Data

Data inputted to the model included maturity at age, fecundity at age (pups per mature female), spawning season, catches, indices, and selectivity functions (Tables 1-4; Figures 1-4). Catches were made by the commercial sector, the recreational sector, and the Mexican fishery. In addition, unreported commercial catches were estimated, as were menhaden discards. Because of similar selectivity functions, the commercial and unreported catches were combined, and recreational catches were combined with Mexican catches, yielding a model with 3 distinct “fleets”. A total of 13 indices were made available after the data workshop. The “DEL age 0” index was not used, as this model began with age class 1, which means that the stock recruitment relationship governed the number of one year olds to survive from the initial number of pups produced in a given year.

Catch data begin in 1981, while the earliest data for the indices is 1975 (VA-LL). The missing catch for years 1975-1980 was treated several ways: the model estimated the missing catch; the missing catch was filled in with either the series-specific average, or series-specific assumptions were made (Table 1).

Parameters

Estimated model parameters were pup survival, natural mortality (ages 1+), virgin recruitment (R0), catchabilities associated with catches and indices, and fleet-specific effort. In some models, a level of historic fishing (F_{hist}) was estimated, while other models fixed this parameter at 0 (assumes virgin conditions in 1975).

Description of Continuity Model Runs
Model C-BASE was the base continuity run, while the CS configurations were sensitivity runs.

C-BASE – F_{hist} was estimated, 1975-1980 catches were estimated, all indices were used and given equal weighting
CS-2 – F_{hist} was fixed at 0, 1975-1980 catches were estimated, all indices were used and given equal weighting
CS-3 – F_{hist} was fixed at 0, 1975-1980 catches were fixed at series-specific averages, all indices were used and given equal weighting
CS-4 – F_{hist} was fixed at 0, 1975-1980 catches were fixed (commercial fixed at 1981 value; recreational+Mexican fixed to linearly decrease from 1981 value to 0; menhaden fixed at series average), all indices were used and given equal weighting
CS-5 – F_{hist} was fixed at 0, 1975-1980 catches were estimated, recreational catch in 1983 was treated as missing, all indices were used and given equal weighting

Results of Continuity Model Runs
Only models C-BASE, CS-2, and CS-4 reached a solution, although no Hessian was obtained. All models found that the stock was overfished and that overfishing was occurring (Table 5, Fig. 6). The base model estimated a stock which is at the lower limit of steepness (0.21), indicating low resiliency, while CS-4 estimated a somewhat more robust stock (steepness=0.55). As a result of these differences in estimated stock resiliency, estimates of MSY vary from approximately 50,000 to 1,000,000 kg (Fig. 7). Likewise, the estimate of F_{MSY} varied by an order of magnitude, from 0.003 to 0.05. Estimates of fleet-specific F showed very low values prior to the 1980s, a large spike in the recreational+Mexican fleet (F in range of 0.4-0.8), corresponding to the large estimated catch in that year, and an F ranging from about 0.05-0.25 for the commercial and recreational fleets from the late 1980s to the current year, 2004 (Fig. 8). In age-specific terms, immature sharks experience non-negligible fishing mortality from about age 2 or 3, until they are fully selected at age 7 (Fig. 9). Estimates of stock depletion (B/B0) range from 15-26% of the unexploited stock (Table 5, Fig. 10).

2006 Assessment
Base Model Description – Catchfree Age-structured production model
In the 2002 assessment, the parameter F_{hist} was difficult to estimate, and that parameter was again problematic this time. For this reason, and given several comments from the CIE reviewers of the 2002 assessment regarding great uncertainty in MSY as a result of uncertain catches, a catch-free age-structured production model (Porch 2004) was used as the base model for the 2006 asssessment rather than the continuity model previously described. Without accurate knowledge of the magnitude of total catches and discards, it is not possible to estimate absolute abundance levels for the population. An alternative modeling methodology appropriate to these situations is to re-scale the model population dynamics as proportional to virgin (unexploited) conditions. If estimates of effort are available for the time series of exploitation, this information can be incorporated to guide model estimates of annual fishing mortality. Information about population declines

relative to virgin can also be incorporated if there is expert opinion or data to suggest possible estimates of depletion. If catch and effort information are available from sampled trips or observer programs, then standardized catch rates can be developed and incorporated into the model.

A first step in applying the catch-free methodology is to determine a year in which the population can be considered to be at virgin conditions. From that year forward, information on fleet-specific effort and/or prior information about possible levels of depletion allow the model to estimate the relative number at age for the year that data (e.g., catch rates) are first available. The period from virgin conditions just prior to availability of fishery data is referred to as the *historic* period. The time period spanning the first year with fishery data through the most recent observation is referred to as the *modern* period.

A discussion was held at the data workshop, and it was agreed that 1960 would represent a year when the stock could be considered unexploited. The first data point is from the VA-LL index in 1975. Therefore, the *historic* period spans 1960-1974, while the *modern* period spans 1975-2004.

Relative effort series for the same three fleets as in the continuity model (Commercial +Unreported, Recreational+Mexican, Menhaden) were developed as follows. A series of relative hooks per line was developed from the ICCAT database for the US Pelagic longline fleet (ICCAT 2005). For the recreational fleet, the catch series was divided by the 1981 value to create a relative series from 1981-2004, and then the value in 1981 (which is now 1, after standardization) was linearly interpolated back to 1975. Recreational effort from 1960-1974 was assumed to be zero, as it is widely held that the recreational fishery for sharks started and rapidly developed after the release of the movie JAWS in 1975. The number of boats operating in the menhaden fishery were available from 1964-2004. The average number of boats for 1964-1968 was used for the number of boats in the years 1960-1963. In order to express the Menhaden relative effort on a scale that would be relative to the other fleets, its annual fraction of total catch was multiplied by its relative effort for 1981-2004, and the average fraction for (1981-1983) was used to scale the relative effort for the years 1960-1980. The resulting relative effort series are given in Table 6 and shown in Figure 11.

Fleet specific annual fishing mortality is estimated from the annual effort series, and the overall population dynamics are fit to the indices in the model. If anecdotal information or expert opinion can provide guidance as to historical levels of depletion for a given time period, this information can also be included into the model. For example, if one had a sense that the stock was only lightly exploited by the year 1975, that information could be incorporated into a relative index of population depletion. This would be similar to the simple production models, which sometimes put priors on the starting biomass in the first year of the model (B1/K). For this stock assessment, a relative biomass index was included with two data points: a value of 1 in 1960 (virgin conditions), and a value of 0.95 in 1975, suggesting only very low depletion at the start of the *modern* period when data become available. The selectivity associated with this relative biomass index was a value of 1 for all age classes. This choice for selectivity allows for direct comparison with estimates of B1/K in the simple production models.

Base Model Inputs

Data

Data inputted to the model included maturity at age, fecundity at age (pups per mature female), spawning season, indices, and selectivity functions (Tables 2-4; Figures 2-4). Note that there are several differences between the continuity data inputs and those decided by the data workshop this time. Specifically, the data workshop decided to use fixed age-specific mortality rather than an estimated age-constant value; the maturity ogive is shifted to older ages; and only a subset of the available indices were identified as suitable for the base model (Figures 2b, 4-5).

Parameters

Estimated model parameters were pup survival, catchabilities associated with indices, and scalars of fleet-specific effort, as well as annual deviations in fleet-specific fishing mortality in the *modern* period.

Description of Base Model Runs

BASE – Historic fishing estimated, Base indices used, equal weighting of indices
BS-1 – Historic fishing estimated, Base indices used, CV weighting of indices
BS-2 – Historic fishing estimated, ALL indices used, equal weighting of indices
BS-3 – Historic fishing estimated, Base indices used, equal weighting of indices, old maturity ogive used
BS-4 – Historic fishing fixed=0, Base indices used, equal weighting of indices
BS-5 – Historic fishing fixed=0, Base indices used, equal weighting of indices

Results of 2006 Base Model Runs

Only model BS-2, where all indices were used, did not converge. All of the converged models indicate that the stock is overfished with about 30-50% of the level that would produce MSY, and that overfishing is occurring, with anywhere from 2-20 times the F that would produce MSY (Table 7, Fig. 12). Estimates of fleet-specific F showed very low values prior to the 1980s, typically 0.02 or less. As in the continuity models, there is a large spike in the recreational+Mexican F in 1983, although it is more stable across all models. In the *modern* period, commercial and recreational F ranges from about 0.02-0.14 (Fig. 13). Fits to the relative biomass index generally show that the stock was about 88% of unexploited levels at the start of the *modern* period (Fig. 14). Estimates of steepness were fairly similar, ranging from 0.21-0.32, all of which suggest that the stock is not very resilient and therefore not able to support much exploitation. This is further supported by the estimates of SPR_{MSY}, which range from 0.74-0.97. Despite the difference noted in the maturity ogive for this assessment, the conclusion about stock status did not depend on which maturity ogive was used. Model runs BS-3 and BS-5, which used the maturity ogive from the 2002 assessment, produce the higher steepness estimates, however these were not the most optimistic outcomes.

Discussion/Conclusions

Both the continuity model and the 2006 base model (catch-free) reached the same conclusion that the stock is overfished and undergoing overfishing. Despite the differences in the way fishing mortality is estimated, and the fact that one model used catch and the other did not, both models agreed remarkably well on the estimates of biomass relative to MSY (continuity: 0.21-0.47; catch-free: 0.35-0.51) and on the level of current depletion (continuity: 0.15-0.26; catch-free: 0.19-0.26; see Tables 6 and 7). One major input difference between the continuity model and the 2006 base model was the maturity ogive. Conclusions about status did not appear sensitive to this model input. Regardless of the maturity ogive used, it is clear from Figures 3 and 9 that sharks are experiencing fishing mortality long before they reach maturity.

No projections were done at this point.

References

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Table 1. Catches of Sandbar shark, including two scenarios for missing catch in the period 1975-1980 (bold italics). For Scenario-1, missing catches were filled in with the series specific average. For Scenario-2 missing catches, the commercial+unreported was fixed to the 1981 value, the recreational+Mexican was fixed with a linear decrease from the 1981 value, and the menhaden catches were fixed at the series average. In some runs, the recreational+Mexican catch in 1983 (bold red) was downweighted or treated as missing.

	Scenario-1			Scenario-2		
Year	**Commercial +Unreported**	**Recreational + Mexican**	**Menhaden**	**Commercial +Unreported**	**Recreational + Mexican**	**Menhaden**
1975	***61587***	***65961***	***531***	***6640***	***19880***	***531***
1976	***61587***	***65961***	***531***	***6640***	***39760***	***531***
1977	***61587***	***65961***	***531***	***6640***	***59640***	***531***
1978	***61587***	***65961***	***531***	***6640***	***79520***	***531***
1979	***61587***	***65961***	***531***	***6640***	***99400***	***531***
1980	***61587***	***65961***	***531***	***6640***	***119280***	***531***
1981	6640	139160	696	6640	139160	696
1982	6640	45402	713	6640	45402	713
1983	7173	**428112**	705	7173	**-1**	705
1984	9797	69503	705	9797	69503	705
1985	9100	88083	635	9100	88083	635
1986	25826	134938	626	25826	134938	626
1987	73983	39625	653	73983	39625	653
1988	124680	76875	635	124680	76875	635
1989	160712	36950	670	160712	36950	670
1990	122440	69559	653	122440	69559	653
1991	96680	45857	505	96680	45857	505
1992	100592	46081	444	100592	46081	444
1993	71977	35870	452	71977	35870	452
1994	126454	23738	486	126454	23738	486
1995	84371	36188	445	84371	36188	445
1996	65515	47403	444	65515	47403	444
1997	41415	50264	452	41415	50264	452
1998	62776	42200	435	62776	42200	435
1999	53248	28060	479	53248	28060	479
2000	37330	17909	409	37330	17909	409
2001	50138	43145	383	50138	43145	383
2002	56342	15278	374	56342	15278	374
2003	45190	12202	365	45190	12202	365
2004	39068	10669	374	39068	10669	374

Table 2. Indices available for use in the 2005/2006 large coastal shark assessment. Sensitivity indices in green (last 3 columns).

YEAR	LPS	BLLOP	VA-LL	NMFS LLSE	DEL Bay LL	DEL Bay age 0	DEL Bay Juvs	BLL Logs	NMFS-NE	Pelagic Logs	PC gillnet	SC LL recent	MRFSS
1975	-1	-1	1.900	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
1976	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
1977	-1	-1	2.077	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
1978	-1	-1	1.085	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
1979	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
1980	-1	-1	1.995	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
1981	-1	-1	1.925	-1	-1	-1	-1	-1	-1	-1	-1	-1	2.011
1982	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2.195
1983	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2.766
1984	-1	-1	0.647	-1	-1	-1	-1	-1	-1	-1	-1	-1	2.408
1985	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	2.094
1986	3.557	-1	0.665	-1	-1	-1	-1	-1	-1	-1	-1	-1	2.119
1987	0.859	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1.167
1988	2.326	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0.789
1989	3.204	-1	0.911	-1	-1	-1	-1	-1	-1	-1	-1	-1	0.714
1990	1.008	-1	0.746	-1	-1	-1	-1	-1	-1	-1	-1	-1	0.634
1991	2.327	-1	0.788	-1	-1	-1	-1	-1	-1	-1	-1	-1	0.431
1992	1.382	-1	1.331	-1	-1	-1	-1	-1	-1	-1	-1	-1	0.874
1993	0.739	-1	0.915	-1	-1	-1	-1	-1	-1	-1	-1	-1	0.402
1994	0.378	0.799	-1	-1	-1	-1	-1	-1	-1	0.083	-1	-1	0.243
1995	0.302	0.882	0.860	1.293	-1	-1	-1	-1	-1	0.854	-1	0.458	0.492
1996	0.369	1.000	0.770	0.831	-1	-1	-1	0.789	0.321	2.050	1.00	0.964	0.612
1997	0.530	0.956	0.721	1.301	-1	-1	-1	1.002	-1	0.770	2.25	0.643	0.504
1998	0.124	1.292	0.826	-1	-1	-1	-1	0.919	2.045	0.883	1.22	0.750	0.917
1999	0.202	0.849	0.528	0.390	-1	-1	-1	1.150	-1	1.024	0.53	2.547	0.524
2000	0.213	0.744	0.865	0.971	-1	-1	-1	1.171	-1	1.167	0.69	0.666	0.525
2001	0.986	1.650	0.754	1.041	0.950	0.645	1.162	1.115	1.004	1.032	1.25	0.972	0.503
2002	0.236	0.865	0.626	1.072	0.386	0.518	0.325	0.887	-1	0.707	0.61	-1	0.49
2003	0.181	1.007	0.547	0.880	1.409	1.776	1.163	1.170	-1	0.872	0.97	-1	0.386
2004	0.076	0.955	0.519	1.221	1.070	0.877	1.164	0.798	0.629	1.557	0.47	-1	0.201
Ages Vulnerable													
	all	all	all	all	"juveniles"	0	"juveniles"	all	all	all	all	"juveniles"	"2-7"
Selectivity function (Figure 3)													
	Commercial	Commercial	Commercial	Commercial	"juveniles"		"juveniles"	Commercial	Commercial	Commercial	Commercial	"juveniles"	"2-7"

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Table 3. Biological inputs, classified as continuity (C*) or 2006 base case values (B*). Note that age 0 M is actually a survival rate for pups, not a natural mortality rate. In the continuity case, M was estimated, while in the base case, M at age values were fixed.

Age	M C*	M B*	Female Maturity C*	Female Maturity B*	Pups
0	0.6*	0.6*	0	0	0
1	0.18	0.26	0	0	12
2	0.18	0.23	0	0	12
3	0.18	0.20	0	0	12
4	0.18	0.19	0	0	12
5	0.18	0.17	0	0	12
6	0.18	0.16	0	0	12
7	0.18	0.15	0	0	12
8	0.18	0.15	0	0	12
9	0.18	0.14	0	0	12
10	0.18	0.13	0.01	0	12
11	0.18	0.13	0.04	0	12
12	0.18	0.13	0.15	0	12
13	0.18	0.12	0.43	0.01	12
14	0.18	0.12	0.76	0.05	12
15	0.18	0.12	0.93	0.125	12
16	0.18	0.11	0.98	0.2	12
17	0.18	0.11	1	0.3	12
18	0.18	0.11	1	0.425	12
19	0.18	0.11	1	0.55	12
20	0.18	0.11	1	0.675	12
21	0.18	0.11	1	0.775	12
22	0.18	0.11	1	0.85	12
23	0.18	0.11	1	0.9	12
24	0.18	0.10	1	0.93	12
25	0.18	0.10	1	0.95	12
26	0.18	0.10	1	0.96	12
27	0.18	0.10	1	0.96	12
28	0.18	0.10	1	0.97	12
29	0.18	0.10	1	0.98	12
30	0.18	0.10	1	0.99	12
31	0.18	0.10	1	1	12

Table 4. Additional parameter specifications.

Parameter	Value	Prior
L_∞	164	*constant*
K	0.089	*constant*
t0	-3.8	*constant*
a	1.09E-5	*constant*
b	3.012	*constant*
Pup Survival	0.6	~N with CV=0.15
For Continuity Model		
Virgin Recruitment (R0)	1.0E+6	~U on [1.0E+4, 1.0E+13]
M C*	0.18	~LN with CV=0.25
F_{hist}	0.001	~LN with CV=0.4, or Fixed=0 or Fixed=0.001
Historic Selectivity	1 for all ages	*constant*

Table 5. Results from the continuity base case (C-BASE) and sensitivity runs (CS-2 and CS-4).

	Model Run		
	C-Base	**CS-2**	**CS-4**
Parameter	**Est**	**Est**	**Est**
R0	1.30E+06	6.06E+05	3.91E+05
MSY	4.93E+04	6.74E+05	9.81E+05
B2004/B0	0.17	0.26	0.15
SSF2004/SSF0	0.16	0.20	0.08
SSFMSY	5.04E+05	9.13E+05	8.85E+05
SSF2004/SSFMSY	0.38	0.47	0.21
SPRMSY	0.95	0.63	0.46
F2004	0.20	0.11	0.24
FMSY	0.0030	0.0340	0.0550
F2004/FMSY	65.65	3.34	4.36
Pup-survival	0.66	0.61	0.67
alpha	1.07	2.46	4.81
steepness	0.21	0.38	0.55
M	0.22	0.17	0.14

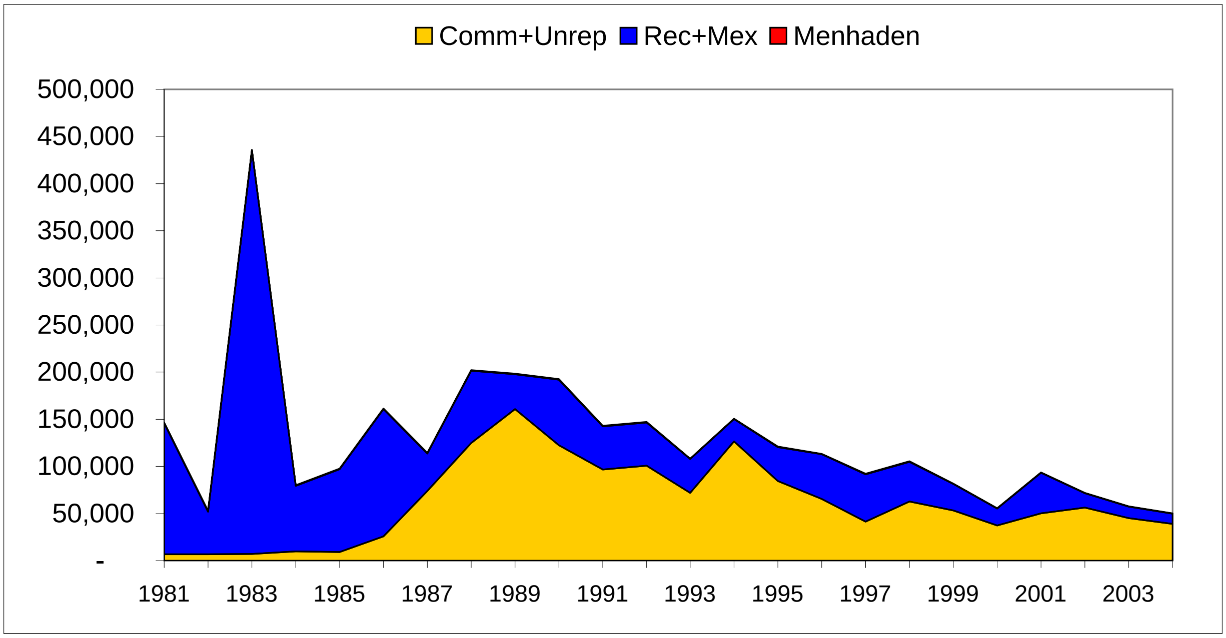
Table 6. Derived relative effort series by fleet.

Year	Comm+Unrep	REC+Mex	Menhaden
1960	0.056	0	0.094
1961	0.052	0	0.094
1962	0.119	0	0.094
1963	0.138	0	0.094
1964	0.234	0	0.088
1965	0.237	0	0.098
1966	0.107	0	0.103
1967	0.081	0	0.096
1968	0.111	0	0.088
1969	0.124	0	0.084
1970	0.154	0	0.085
1971	0.263	0	0.096
1972	0.178	0	0.084
1973	0.209	0	0.074
1974	0.302	0	0.080
1975	0.338	0.143	0.088
1976	0.349	0.286	0.092
1977	0.312	0.429	0.090
1978	0.252	0.571	0.090
1979	0.212	0.714	0.088
1980	0.245	0.857	0.089
1981	0.335	1.0	0.091
1982	0.359	0.326	0.096
1983	0.272	0.413	0.087
1984	0.707	0.499	0.063
1985	0.505	0.633	0.055
1986	0.811	0.970	0.019
1987	0.531	0.285	0.007
1988	0.639	0.552	0.004
1989	0.669	0.266	0.003
1990	0.760	0.500	0.004
1991	0.845	0.330	0.003
1992	0.899	0.331	0.002
1993	0.919	0.258	0.004
1994	1.0	0.171	0.002
1995	0.959	0.260	0.003
1996	0.985	0.341	0.004
1997	0.726	0.361	0.006
1998	0.910	0.303	0.004
1999	0.910	0.202	0.005
2000	0.910	0.129	0.006
2001	0.910	0.310	0.004
2002	0.910	0.110	0.003
2003	0.910	0.088	0.004
2004	0.910	0.077	0.004

Table 7. Results of the 2006 base case (BASE) and sensitivity runs (BS-1 – BS-5) with the catchfree model. CVs are given in parentheses below each model estimate. Model BS-2 did not converge

	Model Run					
	BASE	**BS-1**	**BS-2**	**BS-3**	**BS-4**	**BS-5**
Parameter	Est	Est	Est	Est	Est	Est
B2004/B0	0.19 (0.37)	0.26 (0.14)		0.19 (0.41)	0.22 (0.37)	0.2 (0.42)
SSF2004/SSF0	0.17 (0.38)	0.24 (0.17)		0.14 (0.44)	0.2 (0.39)	0.16 (0.45)
SSFMSY	0.49 (4.63)	0.48 (1.37)		0.43 (0.38)	0.49 (4.76)	0.44 (0.38)
SSF2004/SSFMSY	0.35 (4.77)	0.51 (1.47)		0.32 (0.65)	0.4 (4.91)	0.36 (0.67)
Rel. B1975	0.87 (0.02)	0.87 (0.01)		0.88 (0.01)	1 (0)	1 (0)
SPRMSY	0.97 (0)	0.92 (0)		0.74 (0)	0.97 (0)	0.74 (0)
F2004	0.05 (0.69)	0.02 (0.27)		0.09 (0.56)	0.05 (0.67)	0.09 (0.55)
FMSY	0.0028 (0)	0.0091 (0)		0.0362 (0)	0.0027 (0)	0.0361 (0)
F2004/FMSY	19.03 (0.69)	2.12 (0.27)		2.39 (0.56)	19.43 (0.67)	2.37 (0.55)
Pup-survival	0.61 (0.25)	0.68 (0.23)		0.62 (0.25)	0.61 (0.25)	0.62 (0.25)
alpha	1.05 (0.25)	1.18 (0.23)		1.85 (0.25)	1.05 (0.25)	1.84 (0.25)
steepness	0.21 (0)	0.23 (0)		0.32 (0)	0.21 (0)	0.32 (0)

a



b

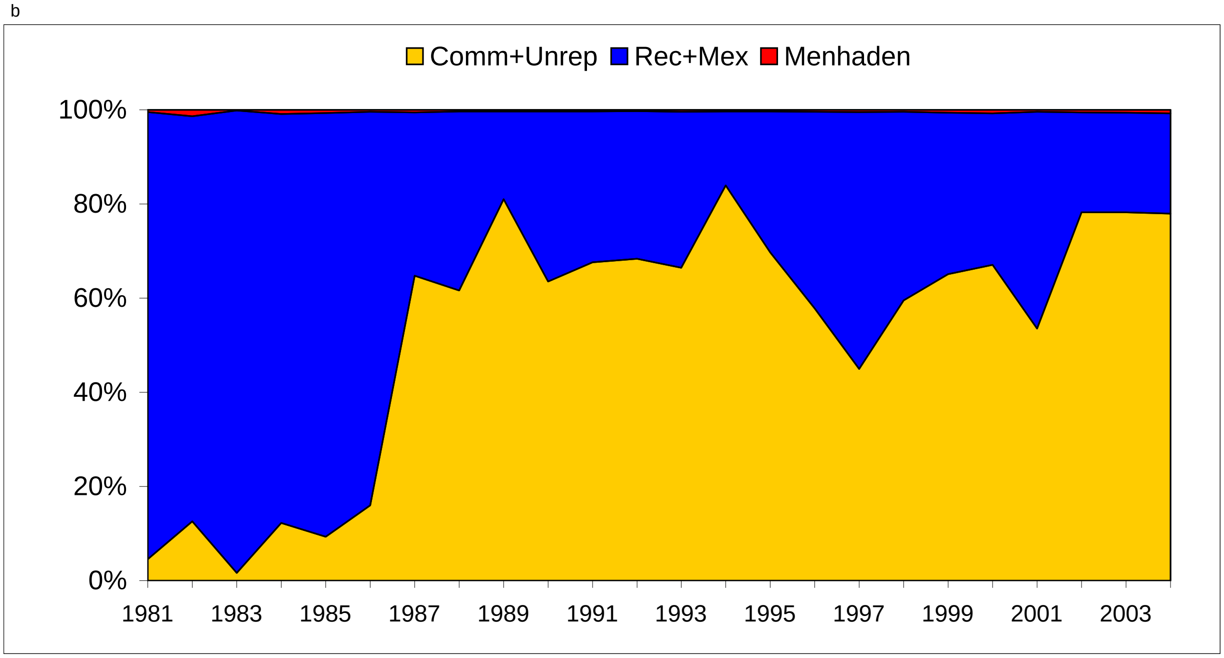


Figure 1. Catch in number by fleet (a) and proportional catch by fleet (b).

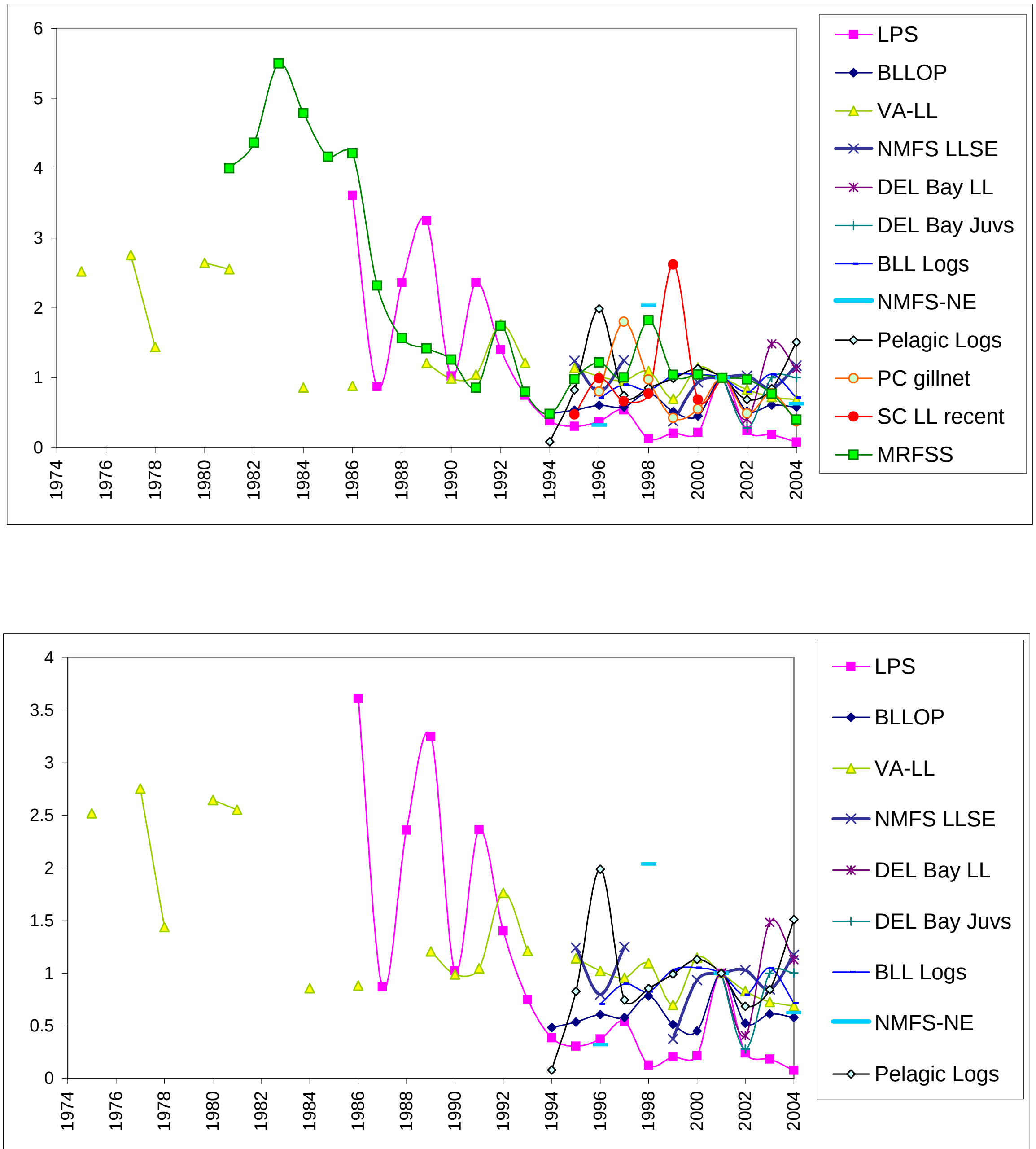


Figure 2. All indices for sandbar (a) and indices designated for the 2006 base model by the data workshop (b).

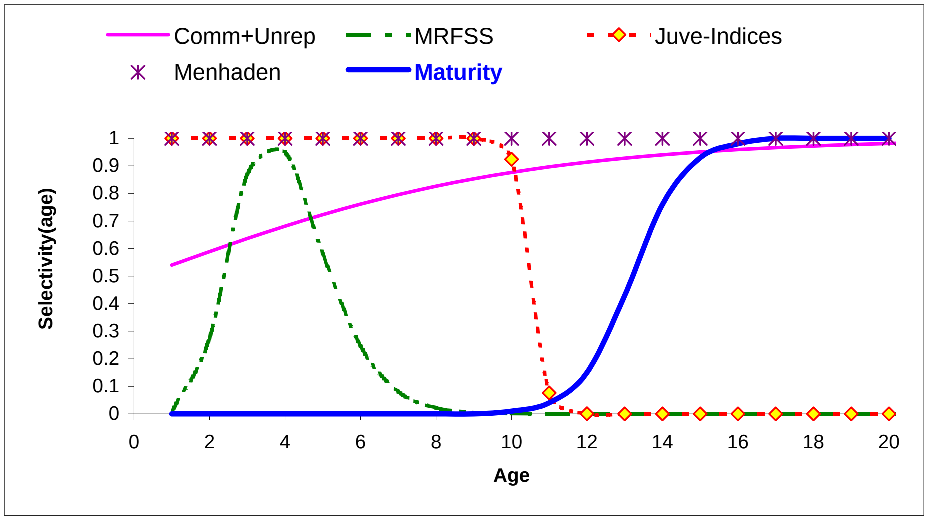


Figure 3. Selectivities for the fleets and the ogive applied to indices that are believed to catch "juveniles".

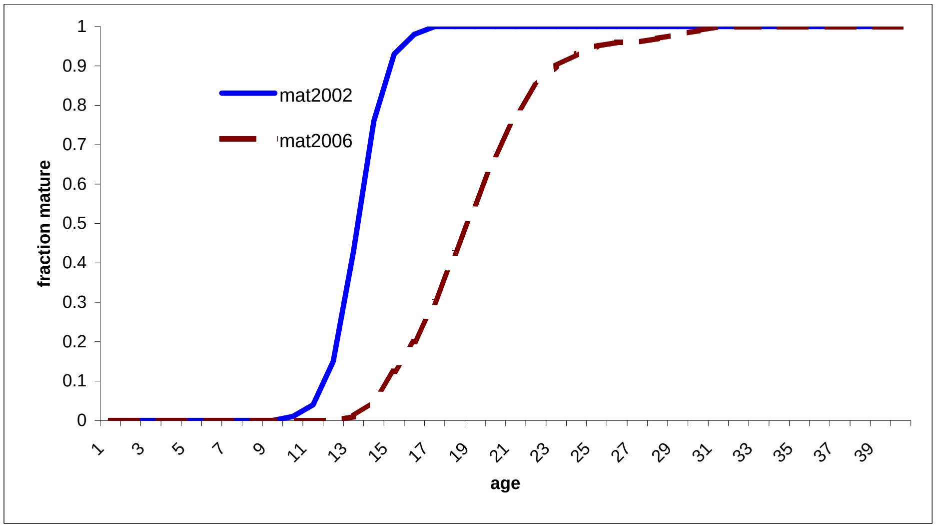


Figure 4. Maturity ogives for the continuity model (mat2002) and the maturity ogive accepted by the data workshop for the 2006 base model (mat2006).

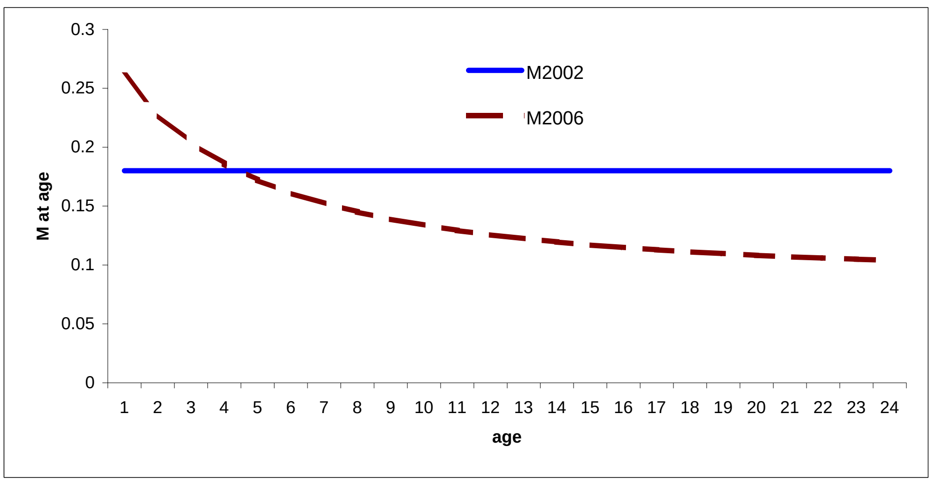


Figure 5. Natural mortality (M) at age for the 2002 continuity model (M2002) and the maturity vector accepted by th dataworkshop for the 2006 base model (M2006).

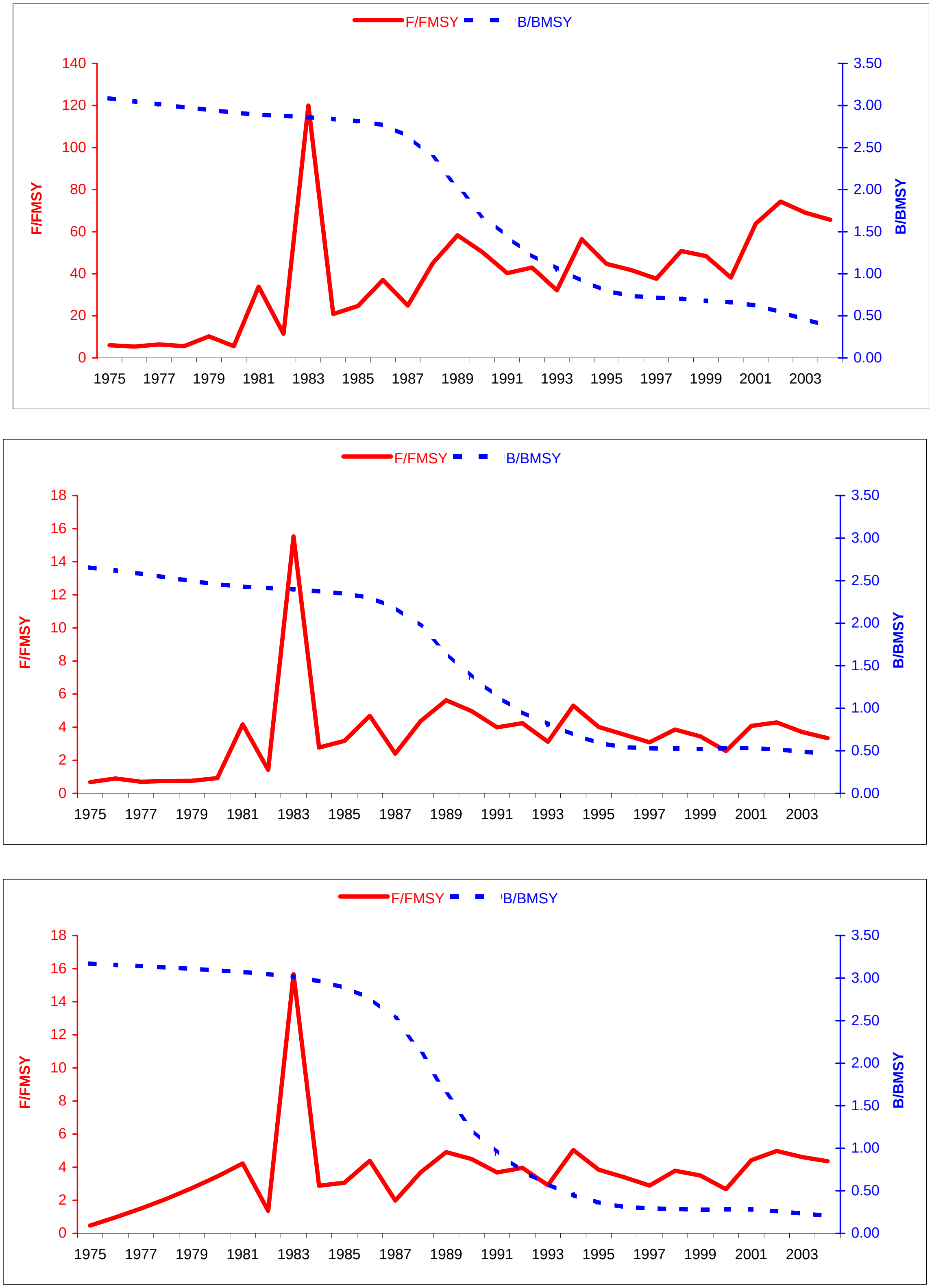


Figure 6. Model estimates of B/Bmsy (dashed) and F/Fmsy (solid).

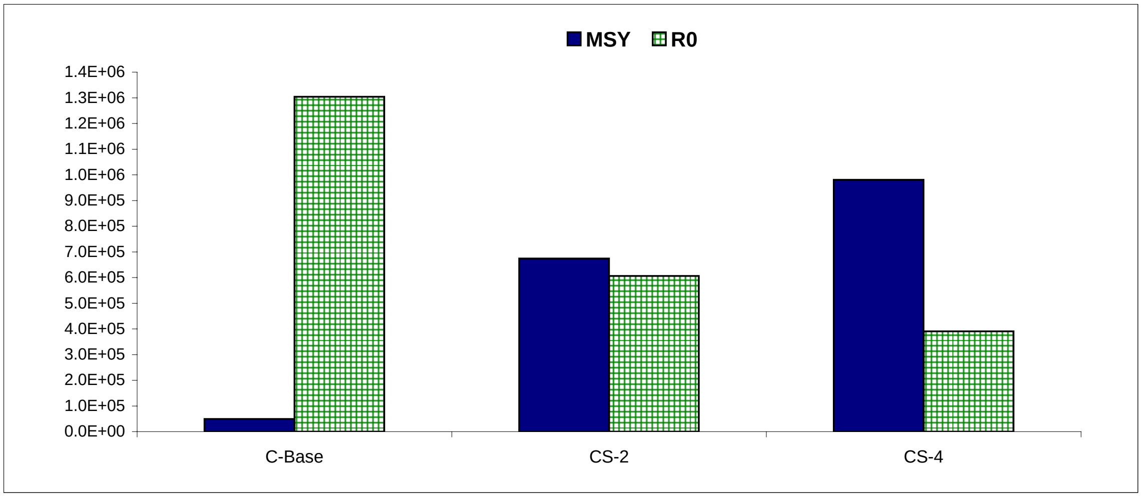


Figure 7. Model estimates of MSY (in kg; solid bars) and virgin recruitment (R0, in numbers; cross-hatched bars).

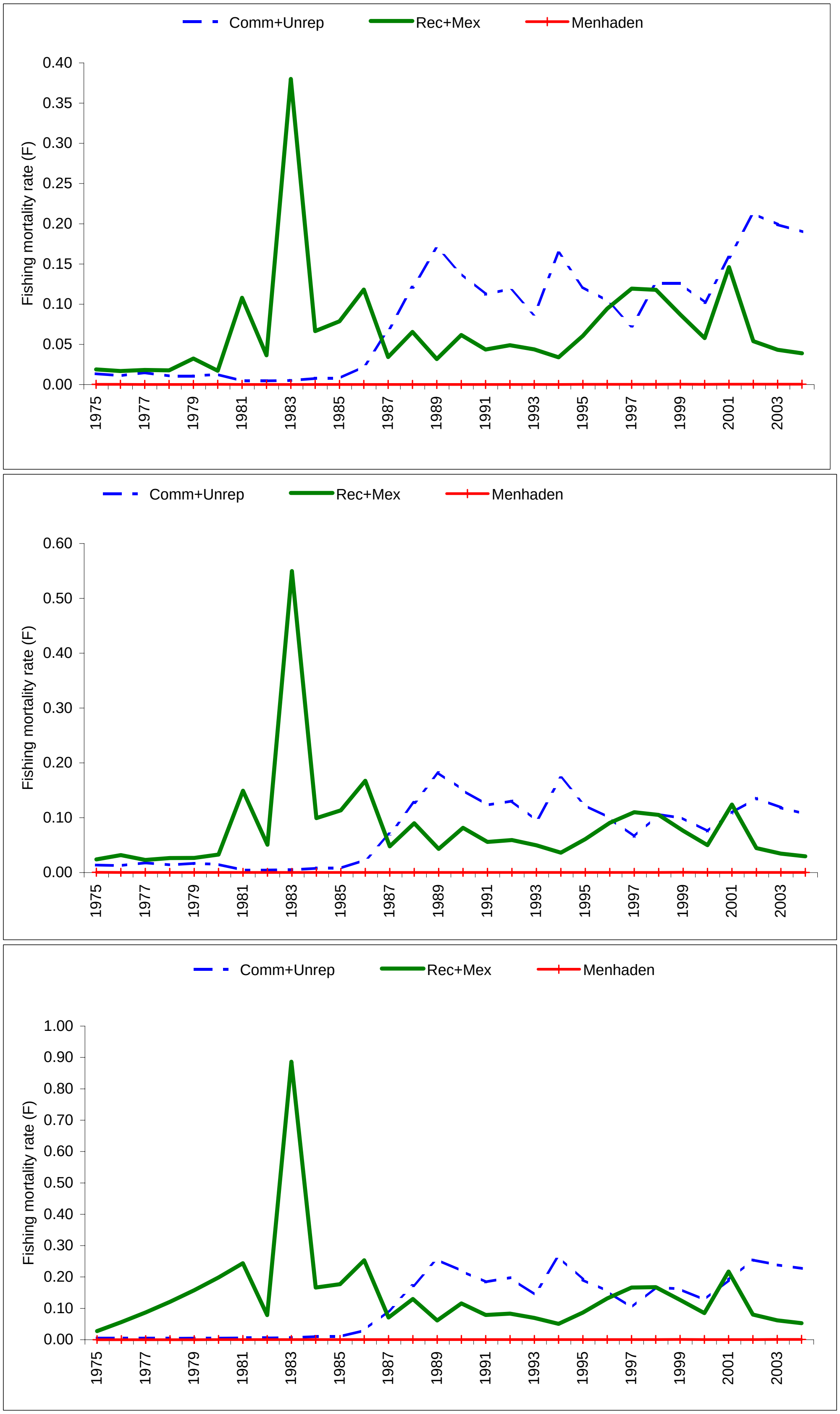


Figure 8. Fleet-specific fishing mortality for the continuity base model (C-BASE, top), CS-2 (middle), and CS-4 (bottom).

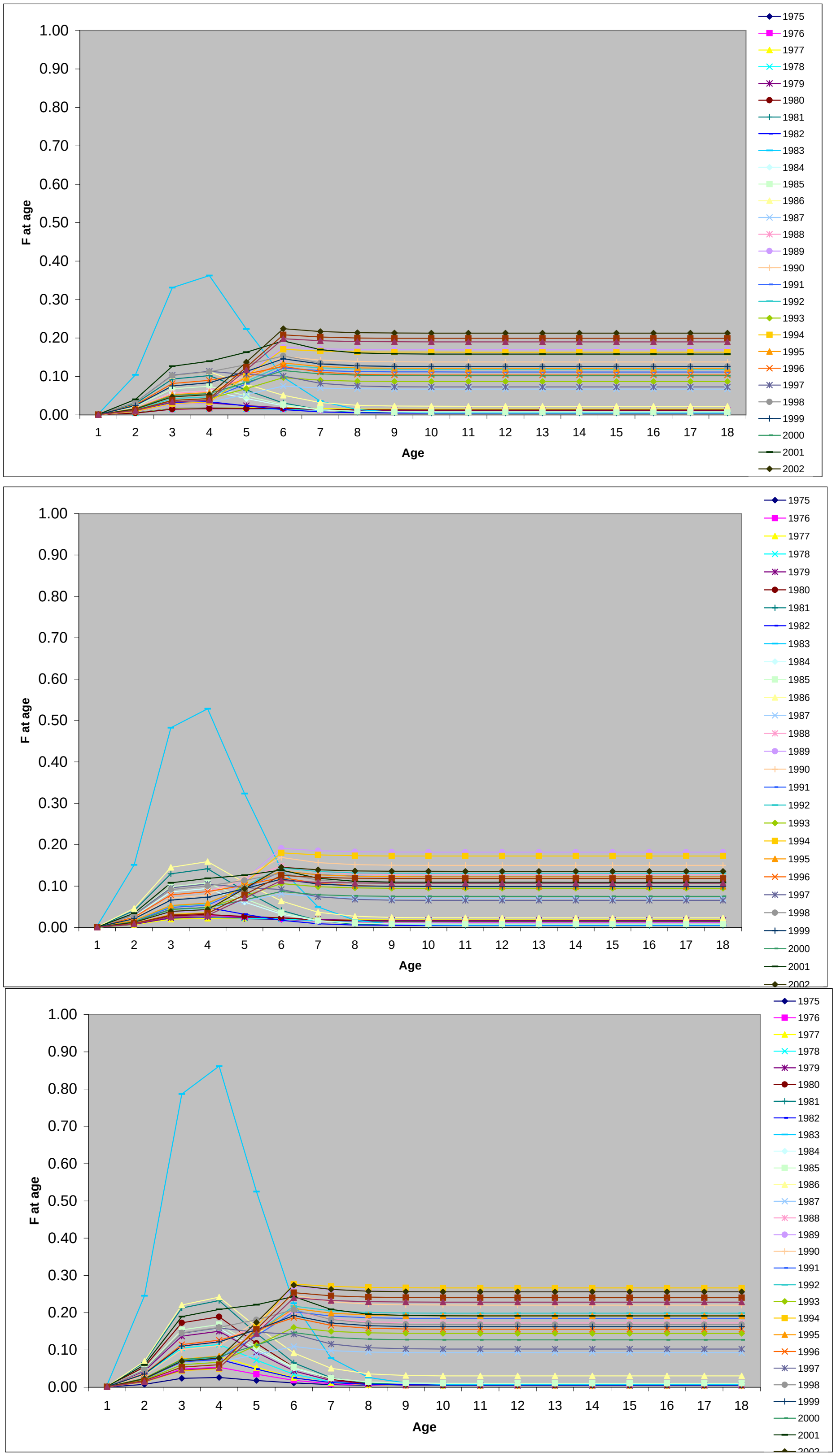


Figure 9. Fleet specific F for the continuity base model (C-BASE, top), CS-2 (middle) and CS-4 (bottom).

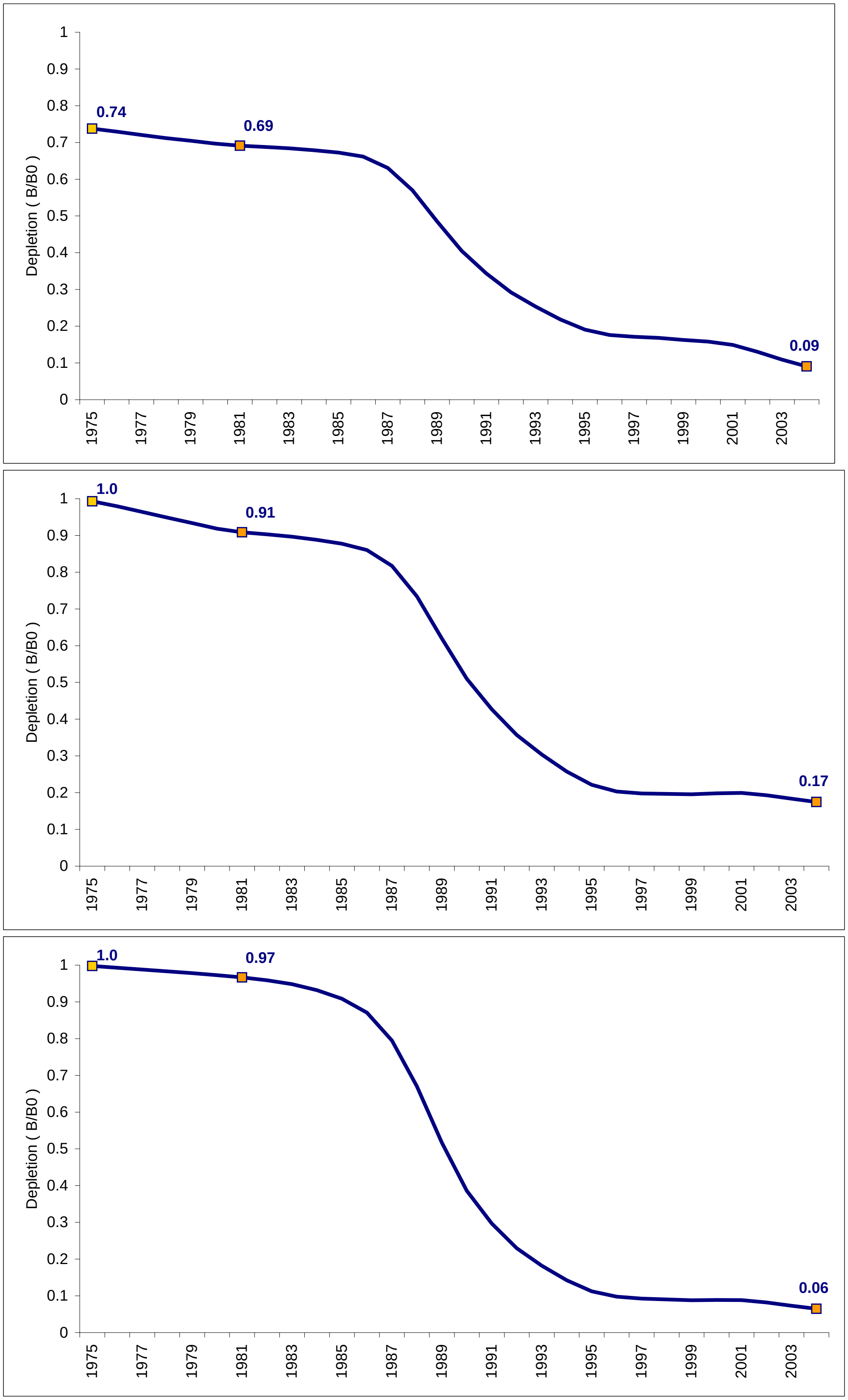


Figure 10. Continuity model estimates of depletion (C-BASE, top; CS-2, middle; CS-4, bottom).

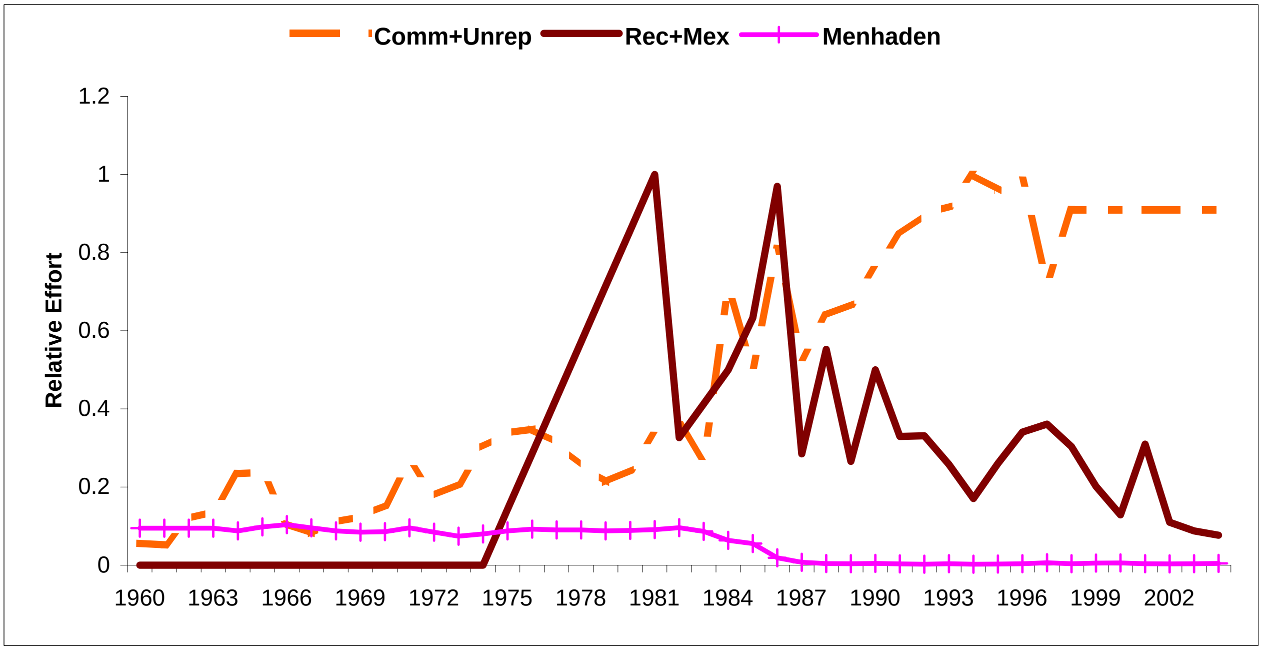


Figure 11. Derived relative effort series by fleet.

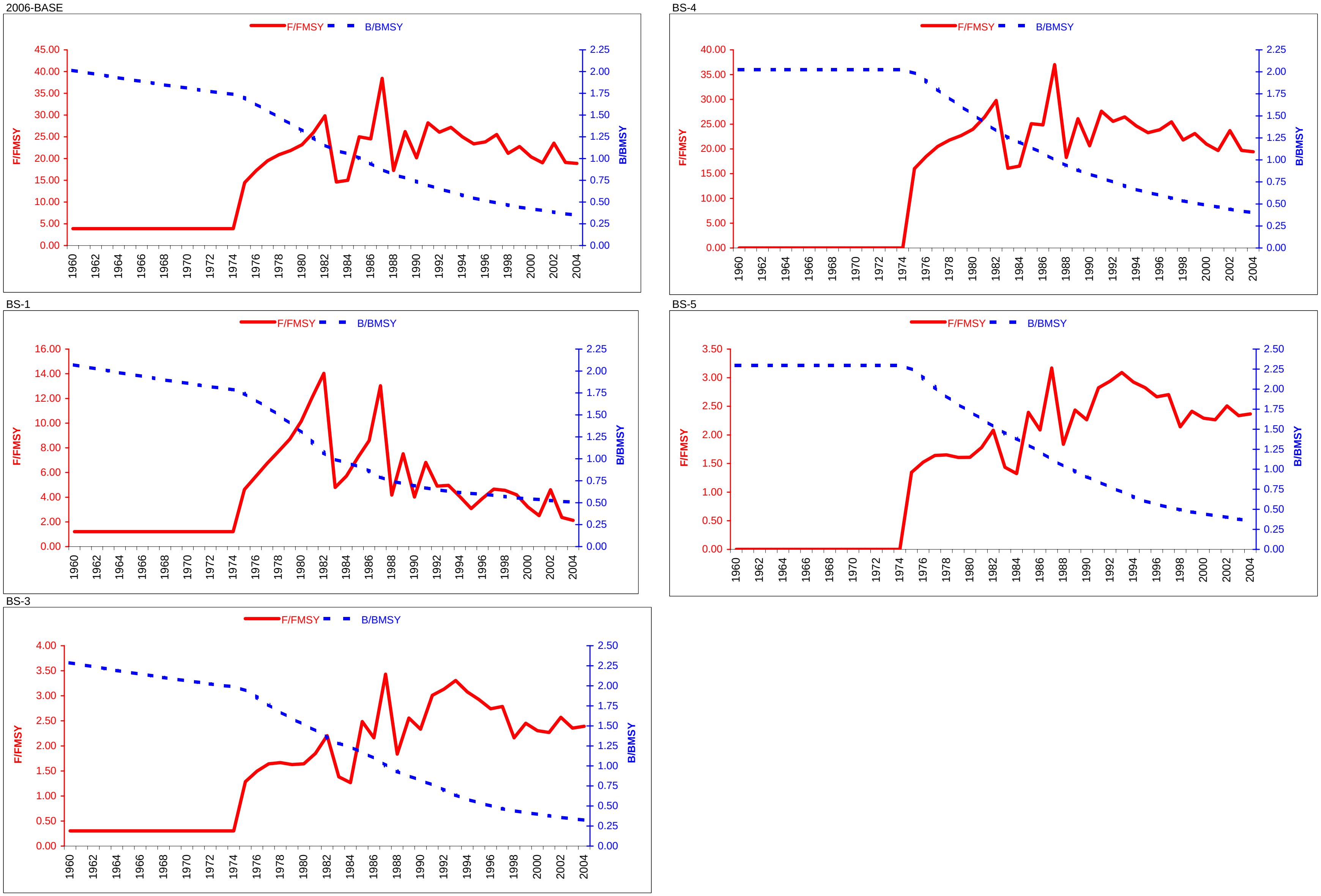


Figure 12. 2006 Base model estimates of B/Bmsy (dashed) and F/Fmsy (solid).

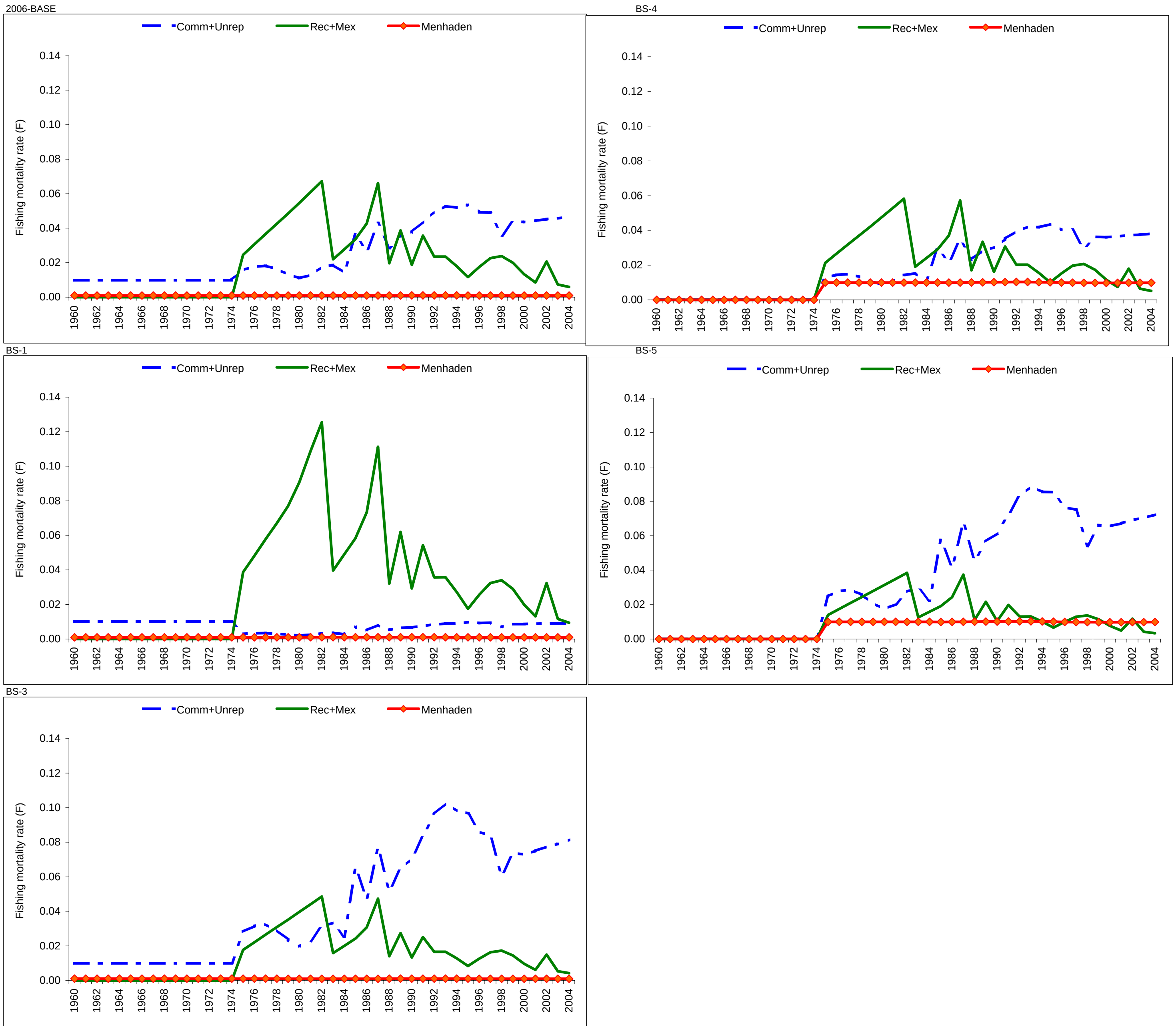


Figure 13. 2006 Base model estimates of fleet specific fishing mortality (F).

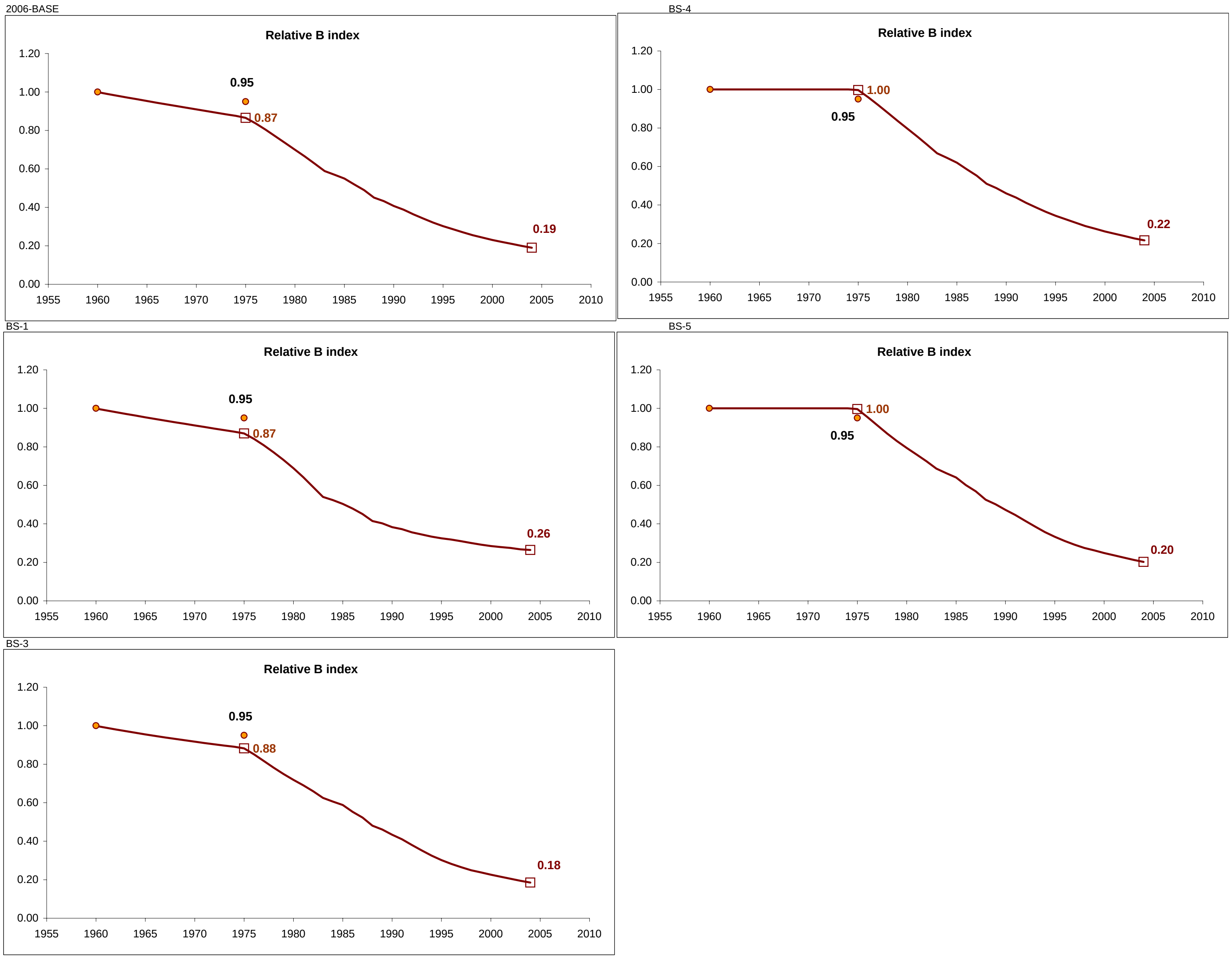


Figure 14. 2006 base model fits to the relative biomass index. Note that BS-4 and BS-5 fixed historic fishing at 0 until 1975, hence the model estimates no depletion in 1975.

Appendix 1: Sensitivity and Retrospective Analyses for the Age-Structured Production Model of Sandbar Shark

As a follow-up to the analyses presented in SEDAR11-AW-03, the group recommended several sensitivity analyses. All of the runs below used the 2006 data workshop biological parameters (S1-S4) or the 2002 inputs (R1-R6). The following scenarios were run using the catch-free methodology:

S1 – dropping the PLL index, using equal weighting of remaining indices
S2 – dropping the PLL index, using inverse CV weighting of remaining indices
S3 – dropping the PLL and VIMS indices, using equal weighting of remaining indices
S4 – dropping the PLL index, using equal weighting of remaining indices, increasing the mode on the prior for pup survival from 0.85 to 0.95

The results of these four cases arrived at the same conclusion regarding stock status: overfished with overfishing (Table A1).

It was noted that the conclusion regarding stock status from the continuity and base models (an overfished stock with overfishing) in this 2006 assessment contradicted the base model conclusion from the 2002 assessment. A first step in searching for possible causes for this result was to compare the catches and indices for the 2002 and 2006 models. In Figure A1, the 2002 and 2006 catches are plotted, and for the years of overlap, there is no discernable difference; the new observations for years 2002-2004 show a slightly declining trend from 2001. Next, the indices were compared (Fig. A2). Several of these indices were directly compared to see more clearly the recent trend. It was noted that several indices had an upward swing in 2001, which was the terminal year for input in the 2002 assessment. Several of those indices, when updated to 2004, showed a consistent decline from the upswing in 2001.

The direct comparisons between indices used in 2002 versus those used in 2006 is confounded somewhat by several issues. First, a number of the indices in 2002 were not available in 2006. In some cases, indices which were not standardized in 2002 were standardized in 2006; in other cases, indices which were not standardized and which were split into two separate nominal indices in 2002 were combined and standardized to one index in 2006 (MRFSS, e.g.). Also, the VIMS data were split into four age-specific indices and one biomass index in 2002, while in 2006 only one VIMS index in numbers for all ages was available. Despite these issues, the overlay of indices from similar data sources shows very similar trends for the years of overlap.

Given the differences between indices noted above, several retrospective analyses were examined to try to determine what was driving the new results. These analyses were:

R1 – Using updated data through 2004, the updated PLL index, equal weighting, and using the imputed catches from 1975-1980 (Catch Scenario 2 in SEDAR11-AW-03)
R2 – Using updated data through 2001, the updated PLL index, equal weighting, and using the imputed catches from 1975-1980 (Catch Scenario 2 in SEDAR11-AW-03)

R3 – Using updated data through 2001, the updated PLL index, equal weighting, and model started in 1981 (did not use imputed historical catches)
R4 – Using updated data through 2001, the updated PLL index, equal weighting, and model started in 1981 (did not use imputed historical catches), added the VIMS age 0-1 index from the last assessment
R5 – Using updated data through 2001, the updated PLL index, equal weighting, and model started in 1981 (did not use imputed historical catches), added the VIMS age 13-max index from the last assessment
R6 – Using updated data through 2001, the updated PLL index, equal weighting, and model started in 1981 (did not use imputed historical catches), added all of the VIMS indices from the last assessment

Model runs R4 and R5 did not converge. All of the remaining retrospective model runs estimated that the stock was overfished with overfishing occurring (Table A1), and it was not possible (with this set of runs) to arrive at the 2002 assessment conclusion. It should be noted that using the data input files from 2002 reproduced exactly the output from 2002, which demonstrates that there were no changes to the model code that affected the estimation procedure.

Table A1. Results of sensitivity and retrospective/continuity model runs. Sensitivity runs (S1-S4) were done with the catch-free model, while retrospective runs (R1-R6) were done with the continuity age structured production model from the 2002 assessment. The reference year for B/B_{MSY} and F/F_{MSY} depend on the terminal year for data in the model. In model runs S1-S4 and R1, the terminal year is 2004; model runs R2-R6 used 2001 as the terminal year.

Model Run	B/B_{MSY}	F/F_{MSY}
S1	0.37	153
S2	0.64	58
S3	0.48	160
S4	0.35	8.64
R1	0.15	235
R2	0.15	82.3
R3	0.18	124
R4	--	--
R5	--	--
R6	0.48	3.45

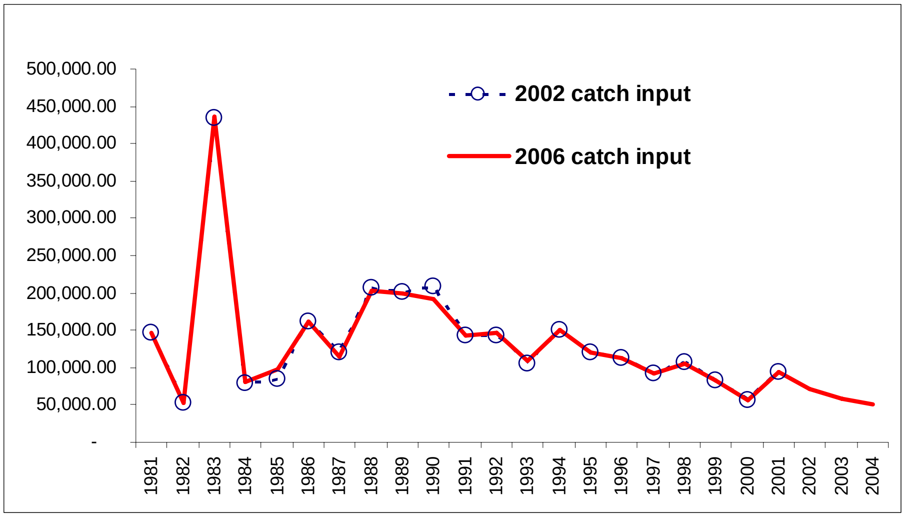
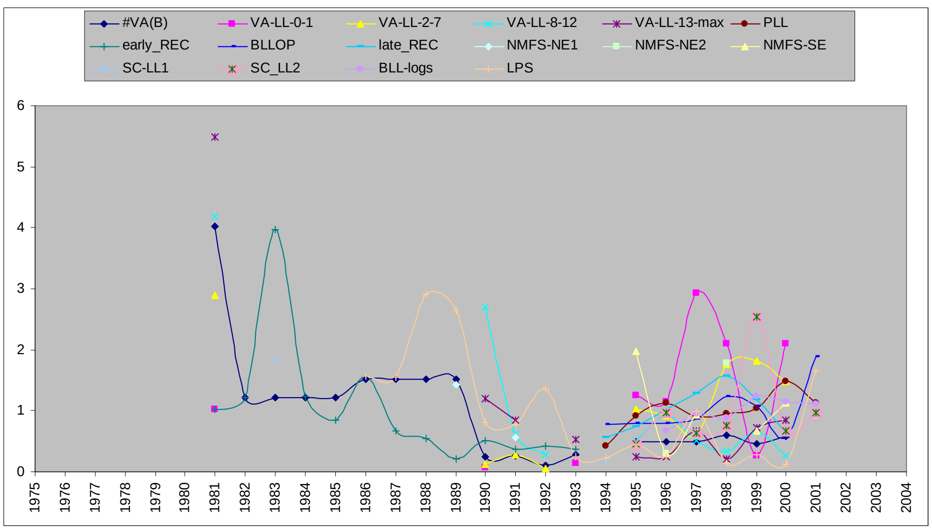


Figure A1. Comparison of 2002 versus 2006 total catch.



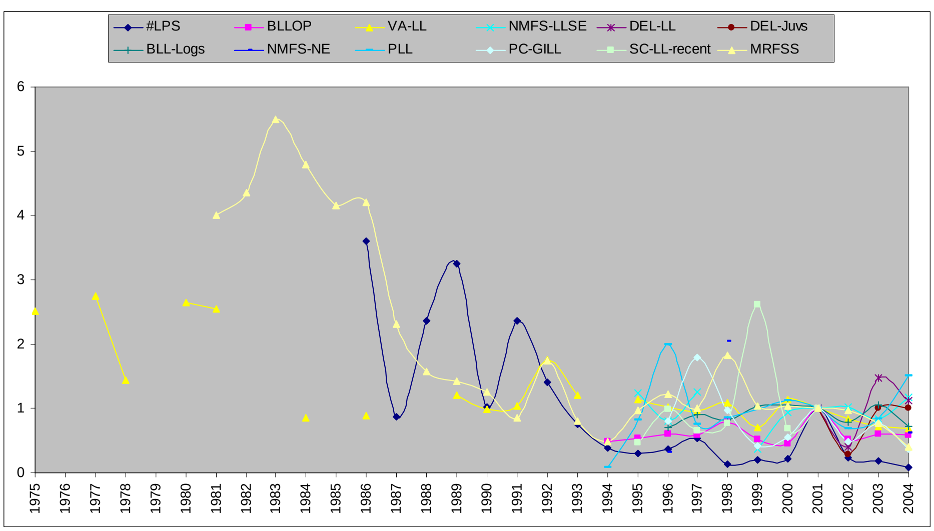


Figure A2. All indices available for the 2002 (top) and 2006 (bottom) assessment. Note that the 2002 indices are not relative to each other as there is no year of overlap.

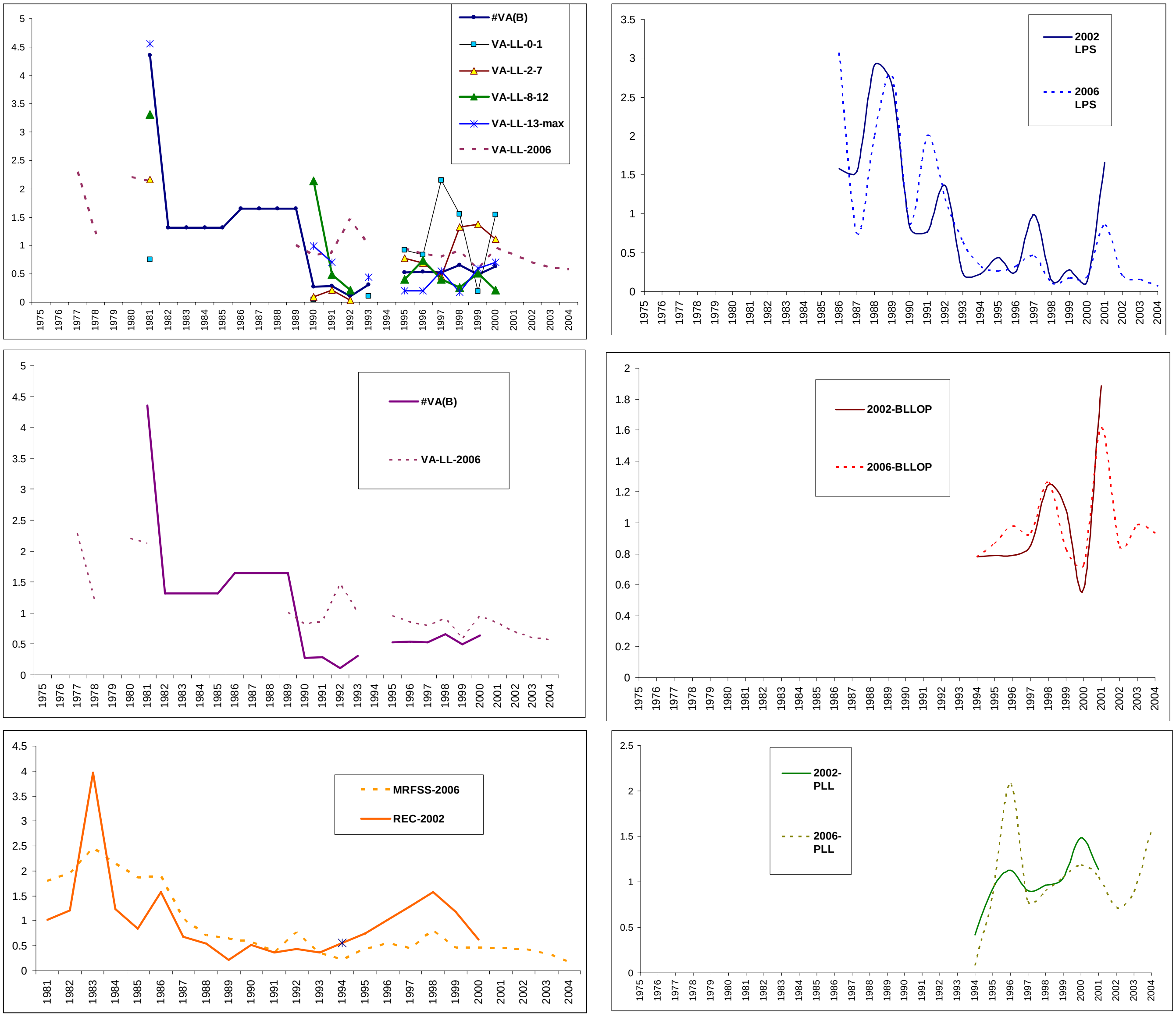


Figure A3. Overlaying indices from 2002 (solid lines) versus those indices in 2006 (dashed lines). Note that in 2002, five indices were available from the VIMS data (top left); the 2006 VIMS index is plotted against the VIMS biomass index (middle left) since it refers to the same age classes, even though the units are not the same. In 2002, the MRFSS index was split into two nominal indices, REC-early and REC-late, with the division in year 1994 (indicated by blue asterisk on bottom left plot) whereas in 2006 there was a single MRFSS index that was standardized for the entire time interval.