DRAFT
Please do not cite outside SEDAR process

Application of the age-structured assessment model CATCHEM
to the U.S. Gulf of Mexico red snapper fishery since 1962

Clay E. Porch

March 10, 2005

Southeast Fisheries Science Center
Sustainable Fisheries Division
75 Virginia Beach Drive
Miami, FL 33149-1099

Sustainable Fisheries Division Contribution No. SFD-2005-002

Introduction

Porch (2004) assessed the status of red snapper in the U.S. Gulf of Mexico by use of various configurations of the age-structured statistical model CATCHEM. The results from that assessment consistently indicated that the stock was overfished and that overfishing was still occurring (even when the definition of MSY was conditioned on current levels of offshore shrimp effort). In contrast, applications of the model ASAP (employed during the previous assessment) sometimes indicated that the stock was not overfished and often indicated that overfishing was no longer occurring (Cass-Calay et al. 2005, Cass-Calay and Diaz 2005, Ortiz and Cass-Calay 2005). The outcomes of the ASAP applications were increasingly optimistic with decreases in the steepness parameter from the estimated value, near 1.0, to the centroid of the prior, 0.81. The cases where the stock was estimated not to be overfished usually assumed steepness was 0.81. The outcomes of the CATCHEM applications, however, seemed to be relatively insensitive to such a decrease in steepness.

There are several differences between the CATCHEM and ASAP applications examined during the SEDAR7 process, both in terms of the data used and the underlying structure of the models. One of the more glaring differences was in landings data; the CATCHEM runs in Porch (2004) were based on landings data extending back to 1872 (see Porch and Turner 2004), whereas the ASAP runs were based on data extending back only to 1984 or 1962. Indeed, the impetus behind extending the time series was to gain contrast in the data that might enable the parameters, especially steepness, to be better estimated. Unfortunately, it proved difficult to apply the ASAP model to the longer time series. The purpose of this paper is to apply the CATCHEM model to the shorter time series of landings in order to discern whether the length of the time series might be the primary factor accounting for the difference in stock status estimates from ASAP and CATCHEM.

Methods

The data employed are essentially the same as described in Porch (2004) except that they begin in either 1984 or 1962 rather than 1872. The basic model structure and assumptions are also as described in Porch (2004), with the exception that the population cannot reasonably be assumed to be near virgin levels as it was for the 1872 -2003 runs. This makes it necessary to estimate the effects of fishing on the population age structure at the beginning of the first year of data. In the CATCHEM model this is accomplished by estimating an average ‘prehistoric’ recruitment level for each cohort during the 30 years prior to the first year of data (1 year for each age class) and then adjusting the subsequent abundance of those cohorts to account for the effects of mortality.

As explained in Porch (2004), the fishing mortality rate parameters are decomposed into separable age-dependent and time-dependent effects:

(1) $$F_{iasyh} = q_{iy} v_{ia} f_{iy} \xi_{iay} \delta_{ih} / n\{s\}$$

where q represents the catchability of the most vulnerable age-class, v_a represents the relative vulnerability of the remaining age-classes, f_{iy} is the total effort exerted by fleet i in year y, ξ is the probability that a fish will die once it is caught (landed or released but died), and δ_{ih} equals 1 or 0 depending on whether the fleet does or does not operate in habitat h. Inter-annual variations in f are modeled as

$$(2) \quad f_{iy} = \mu\{f_{iy}\}e^{\varepsilon_{iy}}$$
$$\varepsilon_{iy} = \rho\{f_{iy}\}\varepsilon_{i,y-1} + \eta_{iy}$$

where μ and ρ represent the median and correlation coefficient of the f_{iy}, respectively, and the η_{iy} are normal distributed random variables with mean zero and standard deviation $\sigma\{f_{iy}\}$.

The $\mu\{f_{iy}\}$ are model inputs based on some index of the relative effort expended by each fishery. For σ sufficiently large, the f_{iy} essentially become free parameters and the values of $\mu\{f_{iy}\}$ become arbitrary. However, the absence of data during the 30 year 'prehistoric period' generally precludes the estimation of unconstrained changes in effort. Accordingly, for the prehistoric period σ is set to 0, such that $f_{iy} = \mu\{f_{iy}\}$. The values of $\mu\{f_{iy}\}$ used to tune the initial age structure, summarized in Table 1, are based on several sources of information. The recreational time series is scaled to human census figures (see Scott 2004). The commercial and offshore shrimp trawl series are based on the number vessel operating units in the NMFS statistical bulletins and other information (see Porch et al. 2004 and Porch and Turner 2004). While not necessarily accurate in absolute terms, these effort statistics should provide a reasonable reflection of the relative trends in effort required by the CATCHEM model.

Results

Four models were considered, all of which were set up exactly as described for the base model (model 1) of Porch (2004) except for the following changes:

(a) data from 1962-2003, steepness estimated
(b) data from 1962-2003, steepness fixed to 0.81
(c) data from 1984-2003, steepness estimated
(d) data from 1984-2003, steepness fixed to 0.81

Model a: 1962-2003, steepness estimated

Model fits to data. The model matched the total catch data quite well with the exception of the high shrimp bycatch values during some of the early years, which happen to have high CV's associated with them (Figure 1). The model fit most of the indices of abundance reasonably well (Figure 2), but could not reconcile the increasing trend in the western larval index (representing spawners) with the flat or declining trends indicated by the other western indices. The model fits to the SEAMAP trawl series show a strong residual pattern where the predictions for the early years are considerably lower than the trawl index values, and, in the case of the eastern stock, the predictions for the later years are considerably higher than the trawl index values. The mismatch for the early years can be attributed the very high CV's associated with those data. The mismatch in more recent years reflects the influence of the bycatch data, which, in the context of relatively constant effort, suggests recruitment generally has increased in the east in recent years. The shrimp effort series were fit very well (Figure 3) owing to the rather low observation CV's assigned to those data (10%). The fits to the age composition data, aggregated over all years, appear to be quite good (Figure 4). It should be kept in mind, however, that the fits to individual years are more noisy, particularly where the sample size was small.

Parameter estimates. The estimated vulnerability and apical fishing rates F for the base model are shown in Figure 5 (note that the fishing rate is somewhat greater than the fishing *mortality* rate unless all discarded fish die). In general, the vulnerability of red snapper to the recreational and commercial hand line fleets follows a dome-shaped pattern with a peak at age 1 or 2 for the former and at age 5 for the latter. (It should be reiterated that the vulnerability coefficients reflect the probability of being caught and includes undersized fish; the probability of being caught and landed is the vulnerability coefficient multiplied by the probability that a fish is greater than the size limit.) The vulnerability of red snapper to the commercial long line fleet follows a logistic pattern with older animals (10+) being the most vulnerable. The vulnerability patterns for the closed season "fleets" were between the hand line and longline. As expected, age 1 fish were much more vulnerable to shrimp trawls than age 2 or older.

The estimated trends in apical fishing rates indicate persistent increase for all fleets. Although the recreational fishing rate in the east appears to have declined markedly in recent years, it remains at rather high levels. The highest rates were associated with the western shrimp fishery followed by the eastern recreational and western commercial handline fisheries. Note, however, that the high shrimp bycatch rate applies to a single age group with 100% mortality, whereas the lower apical F's estimated for the handline and recreational fleets apply to multiple age classes where some of the undersized animals that are discarded survive.

There does not appear to be a strong relationship between the number of recruits and the effective number of spawners (S) in the previous years (see Figure 6). The estimates of the maximum potential spawn per recruit (α) were 98 for the east and 143 for the west (not near the limit of 151 imposed by the model), which translates to steepness values of 0.961 and 0.973, respectively.

Estimated population trends. The estimates of historical trends in the effective number of spawners and age 1 recruits are shown in Figure 6. Under pristine conditions, the western population of red snapper in U.S. waters is estimated to have been somewhat larger and about three times as productive as the eastern population. Both populations are estimated to have been heavily overfished by 1962, consistent with the results with the longer time series. The estimates for MSY{current-shrimp} were 7.5 mp for the east and 12.7 mp for the west, much higher than the combined 6.4 mp suggested by the runs with longer time series. The current status of the stock (2003) is estimated to be worse than with the longer time series: the current fishing mortality rate is estimated to be about 3 times F_{MSY} {current-shrimp} and spawning success is estimated to be 13% and 10% of S_{MSY} {current-shrimp} for the east and west, respectively

Model b: 1962-2003, steepness fixed to 0.81

The fits to the data were not quite as good as for model a (i.e., the objective function was larger), but the corresponding graphs are essentially the same and therefore not shown. The vulnerability and fishing mortality rate patterns are similar to model a. The relative condition of the stock in the west appears to be slightly better than estimated by model a (Figure 7): the current fishing mortality rate is estimated to be about 2.7 times F_{MSY} {current-shrimp}, MSY is estimated at 10.5 mp, and spawning is estimated to be 13% of S_{MSY} {current-shrimp}. The relative condition of the stock in the east, however, is estimated to be much worse: spawning is estimated to be only 0.2% of S_{MSY} {current-shrimp} and MSY is unrealistically large at 326 mp.

Model c. 1984-2003, steepness estimated

Model fits to data. The model matched the total catch data quite well with the exception of the high shrimp bycatch values during some of the early years, which happen to have high CV's associated with them (Figure 8). The model fit most of the indices of abundance reasonably well (Figure 9), but, as with the 1962 runs, could not reconcile the increasing trend in the western larval index (representing spawners) with the flat or declining trends indicated by the other western indices. Again, the model fits to the SEAMAP trawl series show a strong residual pattern where the predictions for the early years are considerably lower than the trawl index values, and, in the case of the eastern stock, the predictions for the later years are considerably higher than the trawl index values. The mismatch for the early years can be attributed the very high CV's associated with those data. The mismatch in more recent years reflects the influence of the bycatch data, which, in the context of relatively constant effort, suggests recruitment generally has increased in the east in recent years.

Parameter estimates. The estimated vulnerability and apical fishing rates *F* for the base model were much the same as for the 1962 runs. Again, there was not a strong relationship between the number of recruits and the effective number of spawners (*S*) in the previous years (see Figure 10). The estimates of the maximum potential spawn per recruit (α) were near the limit of 151 imposed by the model, which translates to a steepness value of 0.974.

Estimated population trends. The estimates of historical trends in the effective number of spawners and age 1 recruits are shown in Figure 10. Both populations are estimated to have been heavily overfished by 1984, consistent with the results with the longer time series. The estimates for MSY{current-shrimp} were 9.0 mp for the east and 16.1 mp for the west, slightly higher than the values suggested by the 1962-2003 runs. Stock status is estimated to that estimated by the 1962-2003 model: the current fishing mortality rate is estimated to be about 2.8 times F_{MSY} {current-shrimp} and spawning success is estimated to be 13% and 9% of S_{MSY} {current-shrimp} for the east and west, respectively

Model d. 1984-2003, steepness fixed to 0.81

The fits to the data were not quite as good as for model c (i.e., the objective function was larger), but the corresponding graphs are essentially the same and therefore not shown. The vulnerability and fishing mortality rate patterns are similar to model c. The relative condition of the east and west stocks, however, are much worse (Figure 11): the current fishing mortality rate is estimated to be about 2.7 times F_{MSY}\{current-shrimp\}, spawning is estimated to be less than 0.5% of S_{MSY}\{current-shrimp\}. The values of MSY were unrealistically large at 1,030 and 326 mp for the east and west, respectively.

Discussion

The above results should be viewed in the context of a poorly behaved solution surface, presumably owing to the relative lack of contrast in the shorter time series. The ASAP and CATCHEM models both had some difficulty finding a global minimum. Both found local minima with nearly the same objective function values but very different implications, including solutions with highly unrealistic levels of virgin recruitment and MSY (as was also the case during the previous assessment). This was particularly evident for the runs with steepness fixed at 0.81, which produced rather implausible results.

The estimates of stock status obtained when CATCHEM was applied to the shorter time series suggest the stock is even more overfished than indicated by the 1872-2003 runs. Inasmuch as the ASAP runs suggest just the opposite, the difference between the CATCHEM and ASAP analyses must hinge on some other factors. One obvious candidate is the way the age structure of the population in the first year is estimated. The initial age structure is modeled in ASAP as deviations from the equilibrium age structure expected under virgin conditions:

$$(3) \quad N_a = \begin{cases} R_0 e^{-\sum_{i=0}^{a-1} M_i} e^{-\eta_a} & 0 < a < A \\ R_0 e^{-\sum_{i=0}^{a-1} M_i} \Big/ (1 + e^{-M_A}) & a = A \end{cases}$$

where a denotes age, A is the age of the plus-group (15), R_0 is the estimated virgin recruitment of age 0 fish, M_i is the natural mortality rate at age i, and the η_a are estimates of random normal deviates with a user-defined variance. The recruitment in the first year is computed as a Beverton and Holt function of the effective number of spawners S computed based on the population structure derived by (3). Note that the estimates of η_a and R_0 are clearly correlated with this model structure. If there is little information in the data concerning the initial conditions, the starting age structure will be forced to resemble the virgin condition even if the population has been heavily exploited. On the other hand, if there is some information on the initial age structure in the data, then the structure imposed by (3) will force the model not only to adjust the η_a, but R_0 as well. This is especially problematic for the 1962-2003 ASAP runs, which substitute the age composition data from 1984 in place of the missing values for earlier years and therefore may bias the initial conditions. In the case of CATCHEM, the initial age structure is independent of R_0, but assumes the 'prehistoric' recruitment was relatively constant and requires inputs of effort relative to 1962 (or 1984) levels. If either of these assumptions is grossly in error, the initial conditions will be biased.

Another important difference between the two models is the first age class, which is age 0 in ASAP and age 1 in CATCHEM. Both models assume a Beverton and Holt spawner recruit relationship, therefore starting with age 0 implies all of the density dependent effects occur very early in the life history of the animal and subsequent mortality occurs owing to shrimp bycatch and density independent natural causes ($M0=0.98yr^{-1}$). Starting with age 1, on the other hand, implies that the density dependent processes dominate mortality over the first year of life such that shrimp bycatch of age 0 fish can be ignored (see Powers and Brooks 2004). Stock reduction analyses on similar data suggest that stock appraisals become less optimistic as density dependence extends to older ages, which consistent with the difference between ASAP and CATCHEM (the VPA results, however, suggest the opposite is true). To date these differences have not yet been explored in either CATCHEM or ASAP.

Other differences between ASAP and CATCHEM exist, but are probably less important. They include

(1) the use by ASAP of age composition data derived from length by use of the Goodyear (1997) procedure (see Turner et al. 2004), which is quite different from the observed age composition data discussed by Nowlis (2004).
(2) different indices of abundance
(3) the use by CATCHEM of data on offshore shrimp trawl effort from 1962-2003 (see Porch and Turner 2004)
(4) the use by ASAP of a manufactured (not observed) time series of shrimp bycatches from 1962-1972 (see Porch and Turner 2004)
(5) Discarded fish are modeled internally by CATCHEM, rather than read as inputs in ASAP
(6) CATCHEM models the east and west populations simultaneously, i.e., in a single run. The MSY benchmarks in CATCHEM maximize the Gulf-wide long-term yield and assume that the proportional change in effort will be the same for the eastern and western fleets, which implies that the east and west will be managed as a single unit (as they are presently). In contrast, ASAP models the east and west populations one at a time, i.e., in two separate runs. The MSY benchmarks in ASAP therefore maximize the long-term yields of east and west independently with no linkage between the effort exerted by the respective fleets, which implies that the east and west will be managed separately with their own MSY targets.

Acknowledgments

none yet.

Literature cited

Goodyear, C.P. 1997. Fish age determination from length: an evaluation of three methods using simulated red snapper data. Fish. Bull. 95: 39-46.

Nowlis, J. 2004. Gulf of Mexico Red Snapper Observed Catch at Age. SEDAR7-AW 19.

Porch, C. E. 2004. An age-structured assessment model for red snapper that allows for multiple stocks, fleets and habitats. Sustainable Fisheries Division Contribution No. SFD-2004-027. (SEDAR-AW-6)

Porch, C. E. and Turner, S. C. 2004. Reconstructed time series of shrimp trawl effort in the Gulf of Mexico and the associated bycatch of red snapper from 1948 to 1972. SEDAR7-AW 23.

Porch, C. E., Turner, S. C., and Schirripa, M. J. 2004. On the commercial landings of red snapper in the Gulf of Mexico from 1872 to 1962. Sustainable Fisheries Division Contribution No. SFD-2004-054 (SEDAR7-AW 22)

Powers, J. E. and Brooks, E. N. 2004. Red snapper compensation in the stock-recruitment function and bycatch mortality. SEDAR7-AW 8.

Scott, G. P. 2004. Estimates of Historical Red Snapper Recreational Catch Levels Using US Census Data and Recreational Survey Information. SEDAR7-AW 16

Turner, S. C., Brooks, E. N., Scott, G. P. and Diaz, G. 2004. Modeled age composition of Gulf of Mexico Red Snapper 1984-2003. SEDAR7-AW 18.

Table 1. Relative effort inputs used in the CATCH model formulations.

year	hl e	hl w	ll e	ll w	rec e	rec w	closed e	closed w	bycatch e	bycatch w
1932	0.16	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1933	0.15	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1934	0.14	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1935	0.18	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1936	0.30	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1937	0.27	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1938	0.29	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1939	0.37	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1940	0.26	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1941	0.24	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1942	0.20	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1943	0.15	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1944	0.18	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1945	0.16	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1946	0.26	0.16	0.00	0.00	0.52	0.64	0.00	0.00	0.00	0.00
1947	0.29	0.17	0.00	0.00	0.54	0.66	0.00	0.00	0.00	0.00
1948	0.28	0.17	0.00	0.00	0.56	0.69	0.00	0.00	0.00	0.17
1949	0.33	0.19	0.00	0.00	0.58	0.71	0.00	0.00	0.00	0.28
1950	0.31	0.19	0.00	0.00	0.60	0.73	0.00	0.00	0.25	0.34
1951	0.38	0.14	0.00	0.00	0.64	0.76	0.00	0.00	0.43	0.36
1952	0.30	0.10	0.00	0.00	0.68	0.78	0.00	0.00	0.51	0.42
1953	0.30	0.09	0.00	0.00	0.72	0.81	0.00	0.00	0.57	0.41
1954	0.37	0.21	0.00	0.00	0.76	0.84	0.00	0.00	0.73	0.54
1955	0.47	0.32	0.00	0.00	0.80	0.86	0.00	0.00	0.86	0.45
1956	0.58	0.50	0.00	0.00	0.84	0.89	0.00	0.00	1.08	0.58
1957	0.42	0.69	0.00	0.00	0.88	0.92	0.00	0.00	1.19	0.73
1958	0.67	0.71	0.00	0.00	0.92	0.95	0.00	0.00	1.26	1.12
1959	1.46	1.20	0.00	0.00	0.96	0.97	0.00	0.00	1.36	1.20
1960	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
1961	1.00	1.00	0.00	0.00	1.03	1.02	0.00	0.00	1.20	0.91
1962	1.00	1.00	0.00	0.00	1.06	1.04	0.00	0.00	1.06	0.93

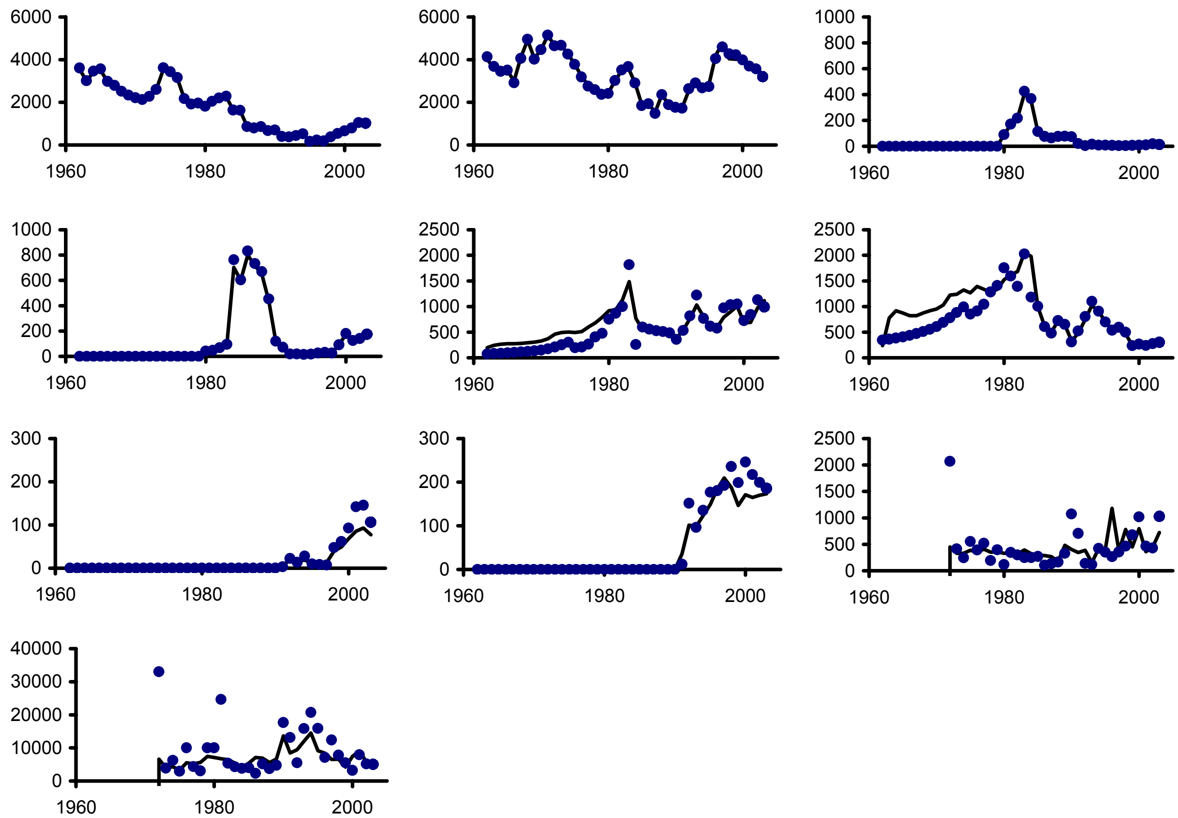


Figure 1. Model a (1962-1963, steepness estimated) fits to the total landings in weight for the handline (HL) and longline (LL) fleets, total number landed for the recreational fleet (REC), and total number killed for the closed season (CS) and shrimp bycatch.

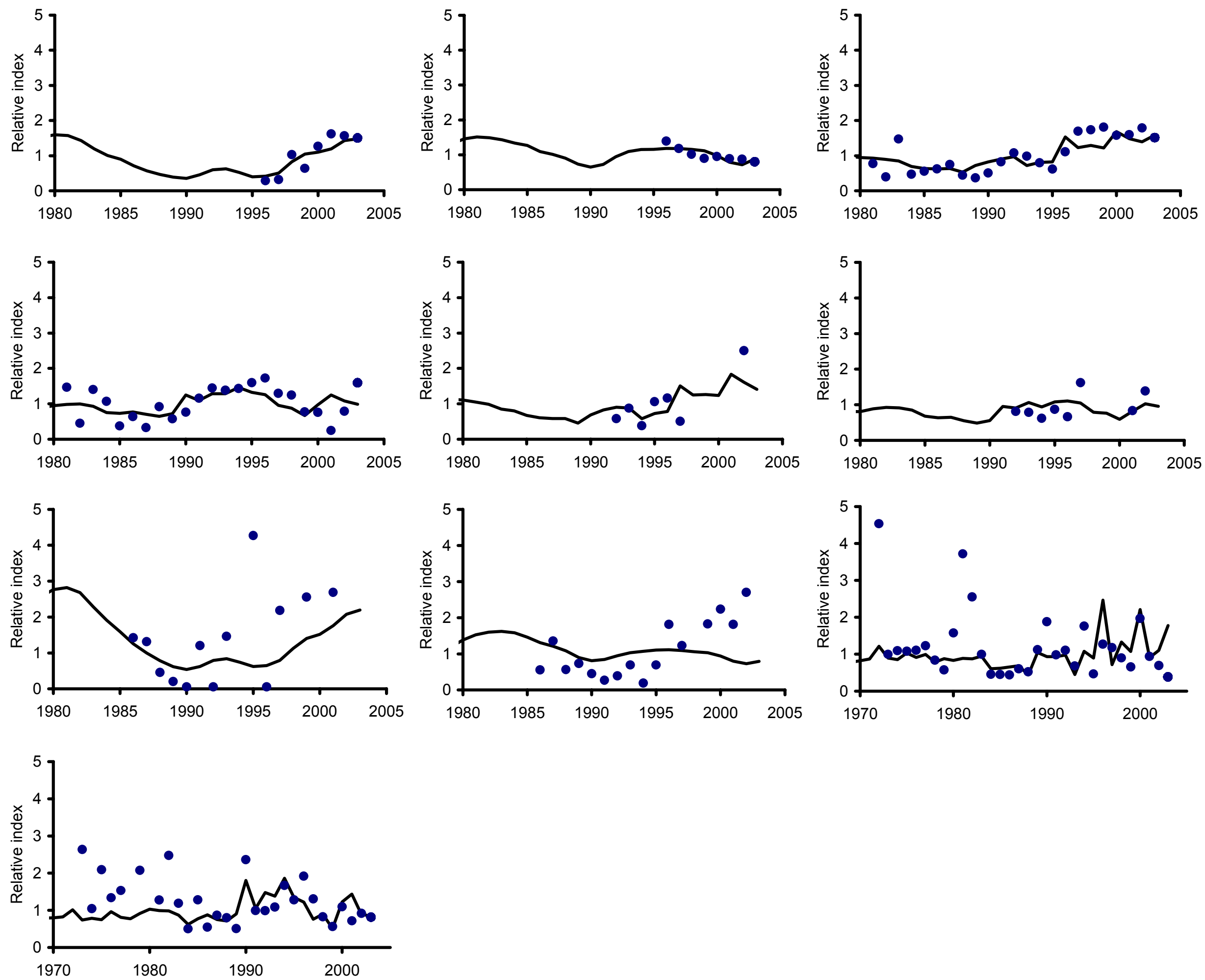


Figure 2. Model a (1962-2003, steepness estimated) fits to indices of abundance (rescaled by the mean of the predicted values).

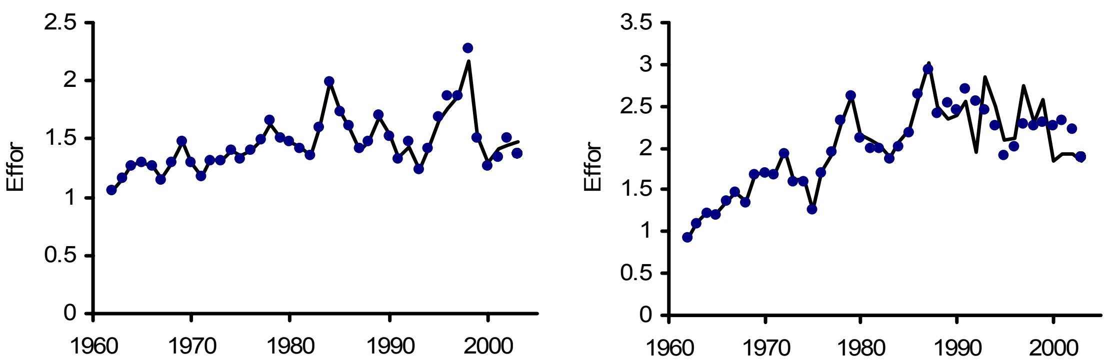


Figure 3. Model a (1962-1963, steepness estimated) fits to the shrimp trawl effort series.

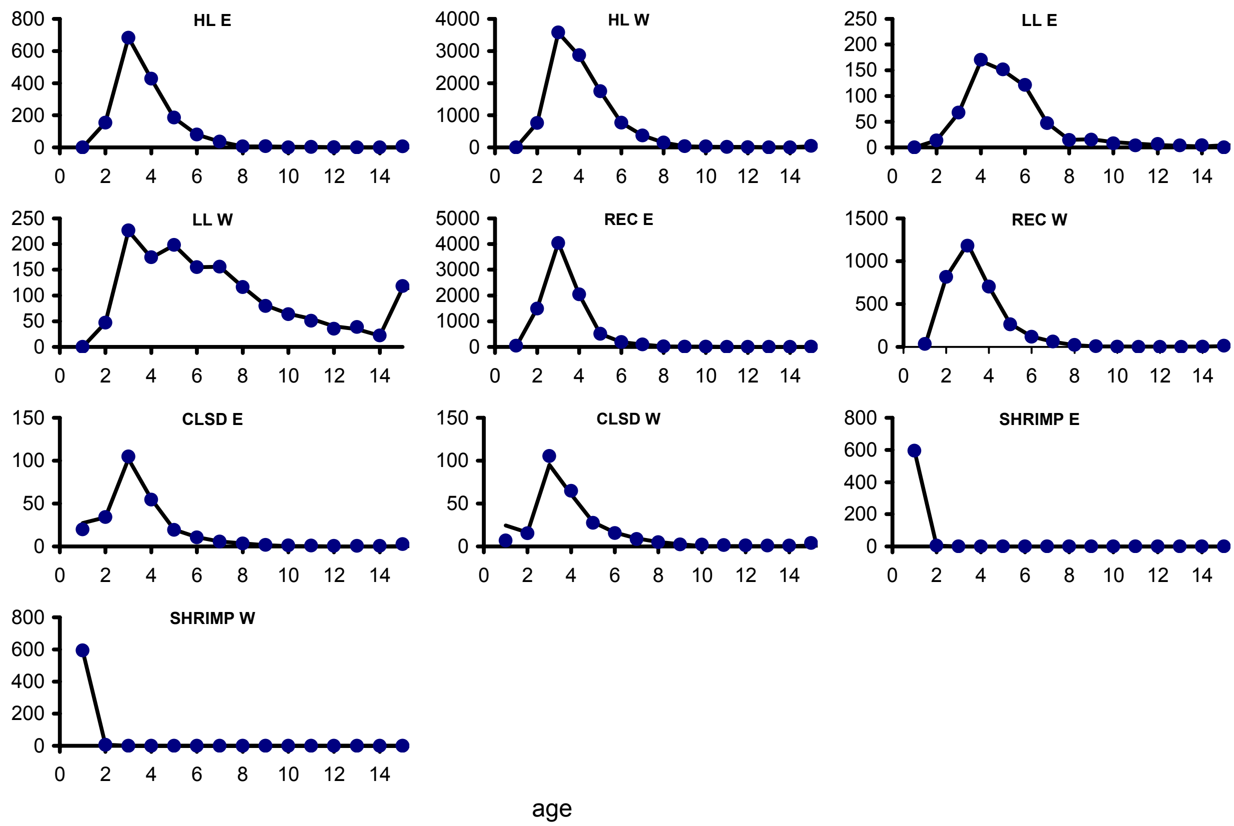
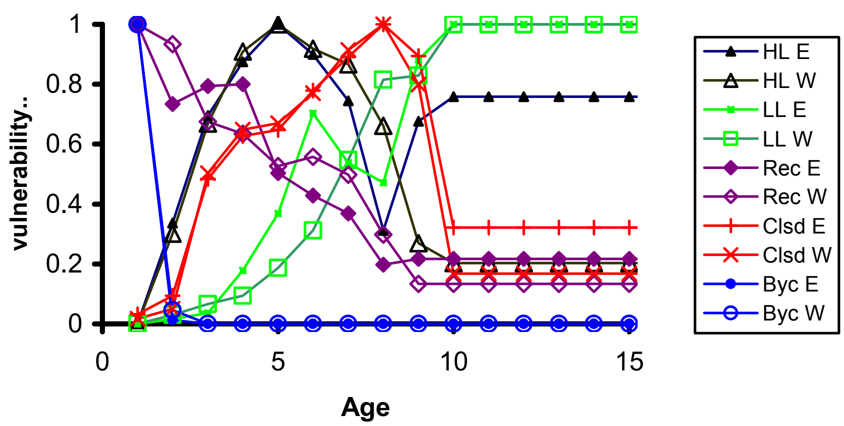


Figure 4. Model a (1962-1963, steepness estimated) fits to the age composition data



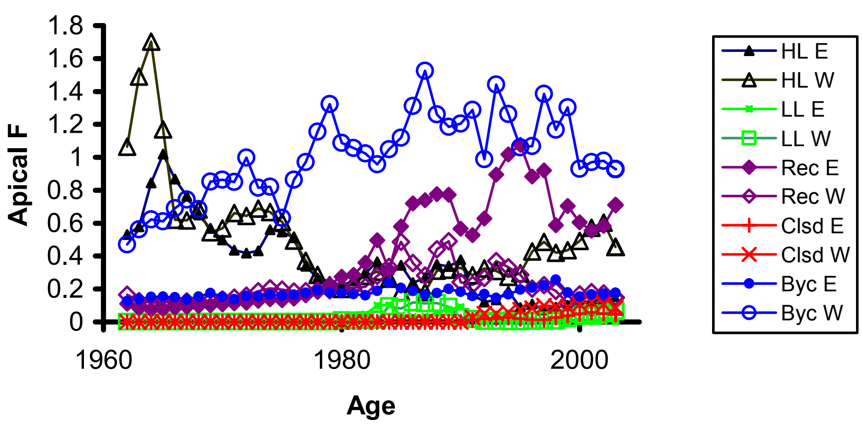
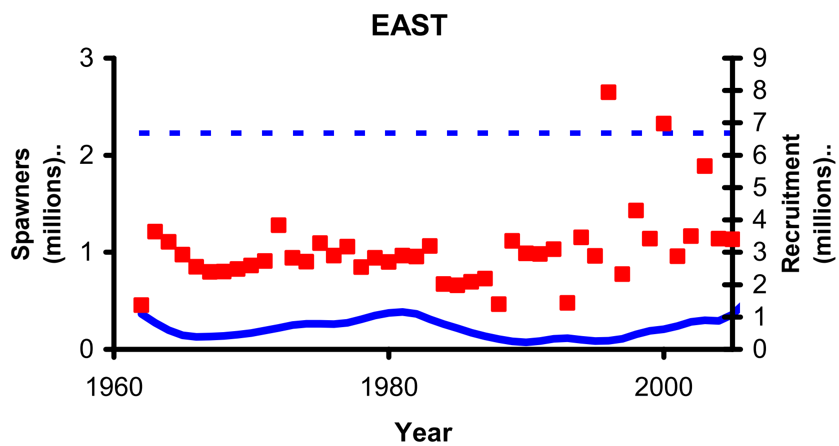


Figure 5. Model a (1962-1963, steepness estimated) estimates of vulnerability and apical fishing mortality rate for each fleet.



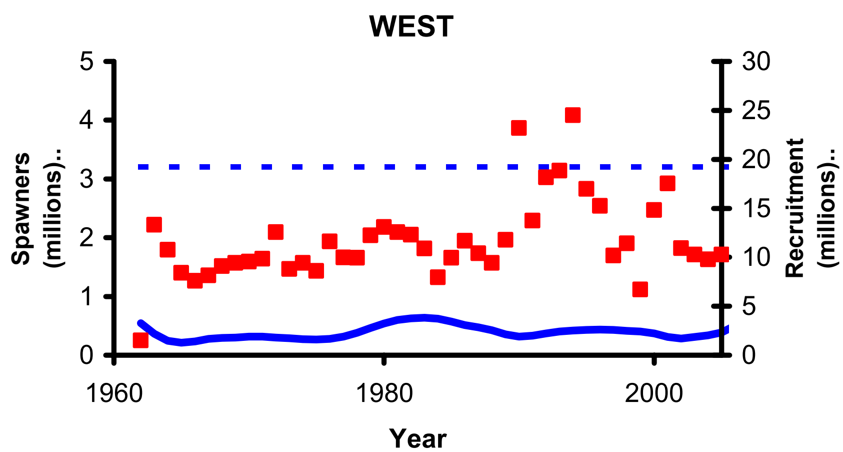


Figure 6. Model a (1962-2003, estimated steepness) estimates of the effective number of spawners (lines) and corresponding number of age 1 recruits (squares). The horizontal line gives the effective number of spawners associated with MSY{current-shrimp}.

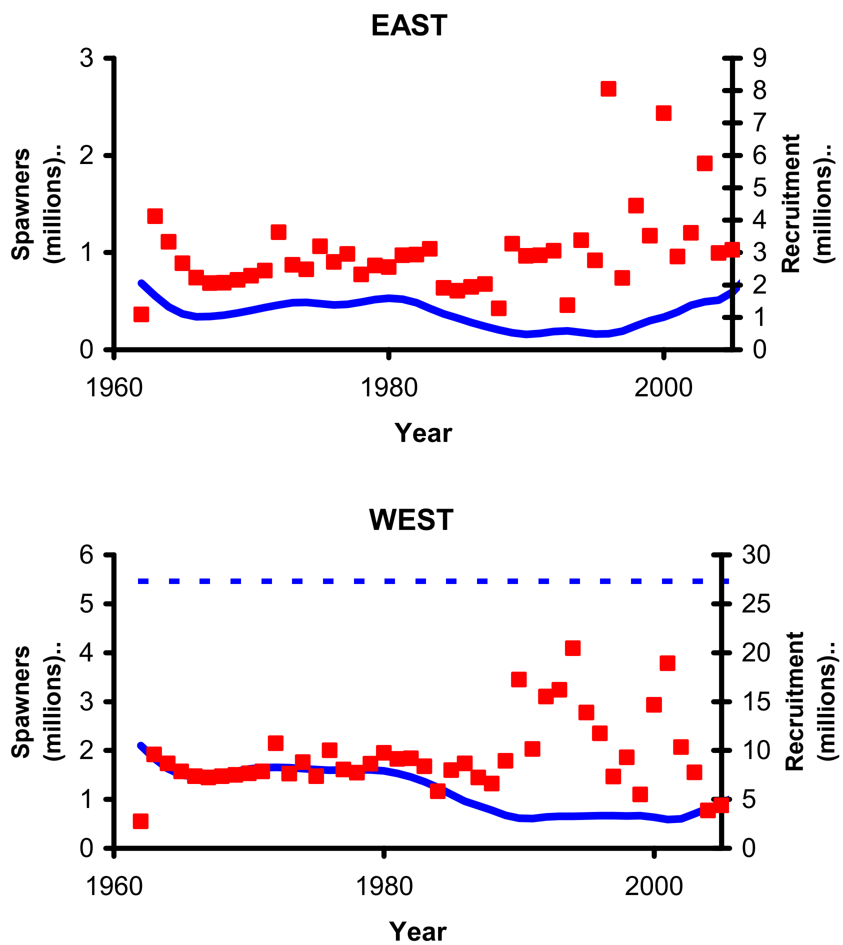


Figure 7. Model b (1962-2003, steepness = 0.81) estimates of the effective number of spawners (lines) and corresponding number of age 1 recruits (squares). The horizontal line gives the effective number of spawners associated with MSY{current-shrimp}, which is off the scale for the east..

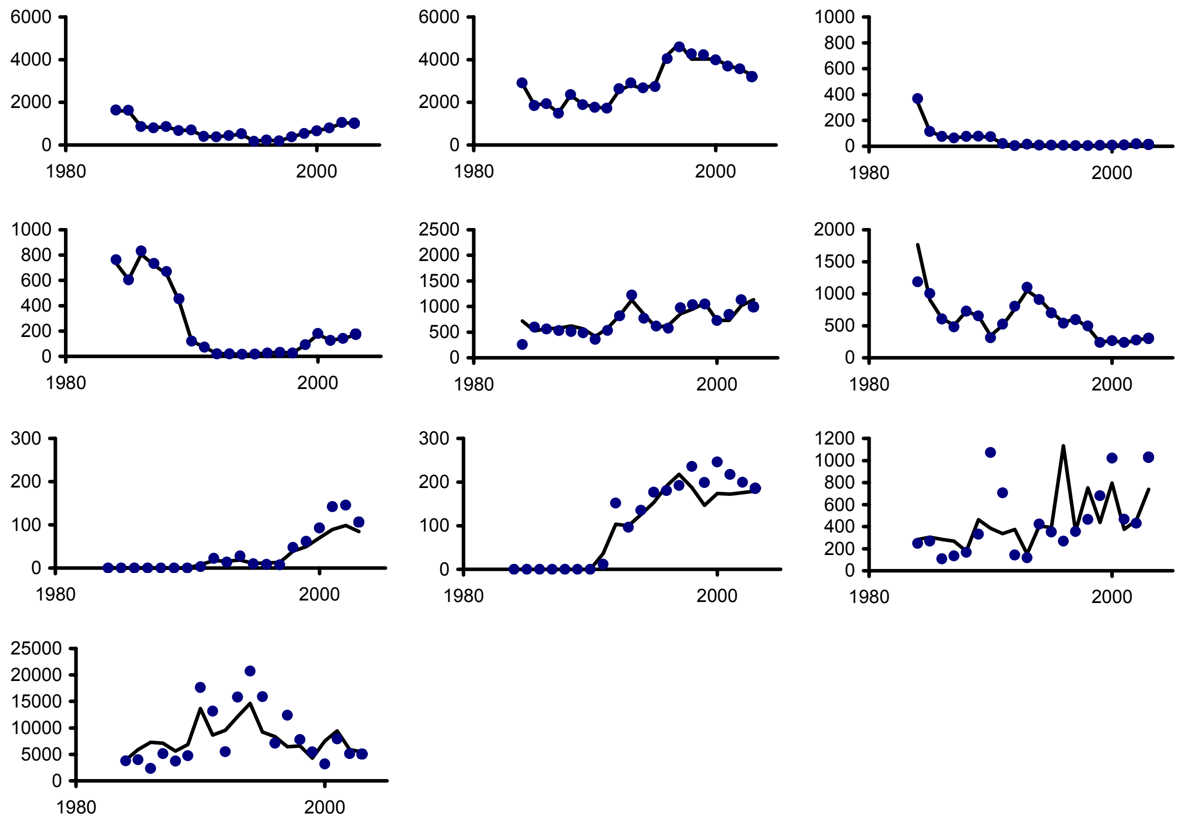


Figure 8. Model c (1984-2003, steepness estimated) fits to the total landings in weight for the handline (HL) and longline (LL) fleets, total number landed for the recreational fleet (REC), and total number killed for the closed season (CS) and shrimp bycatch.

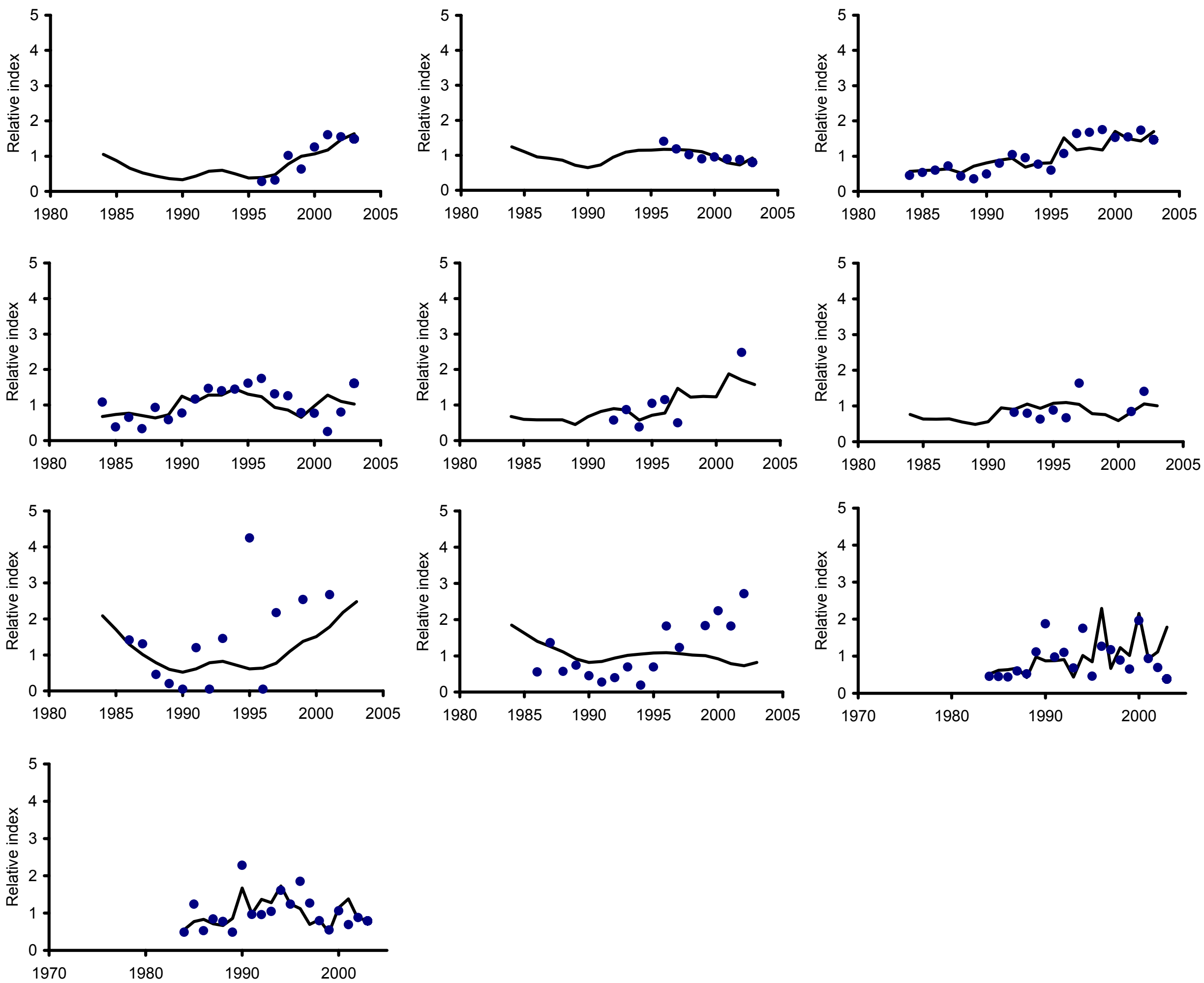


Figure 9. Model c (1984-2003, steepness estimated) fits to indices of abundance (rescaled by the mean of the predicted values).

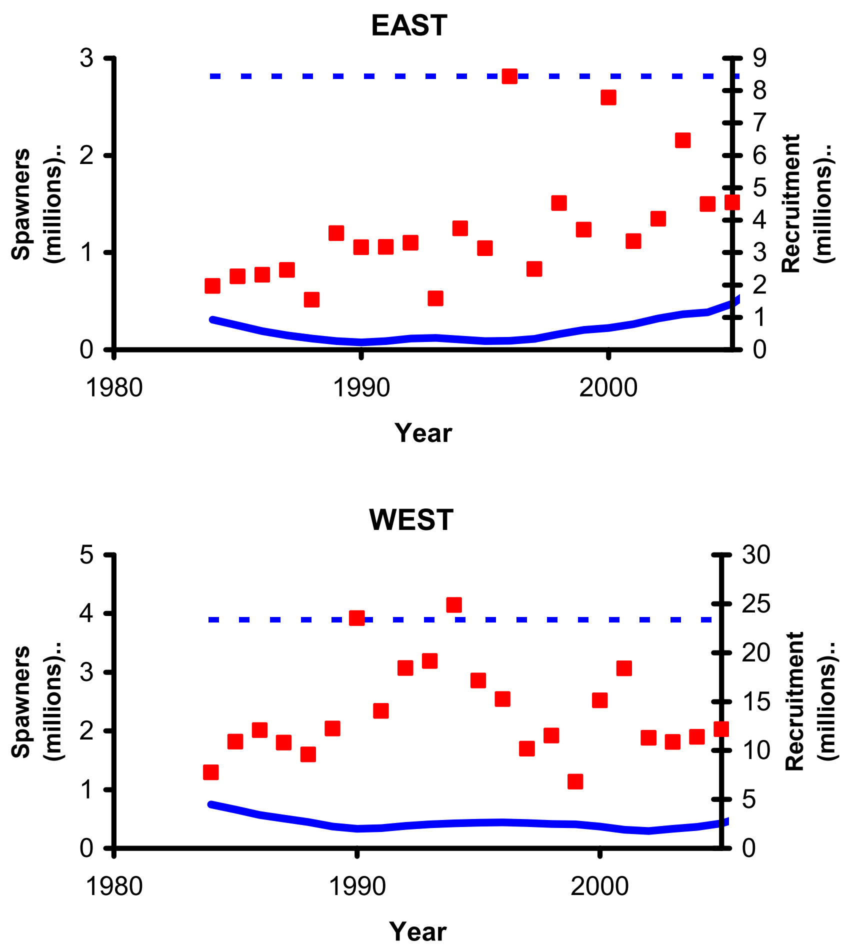


Figure 10. Model c (1984-2003, steepness estimated) estimates of the effective number of spawners (lines) and corresponding number of age 1 recruits (squares). The horizontal line gives the effective number of spawners associated with MSY{current-shrimp}.

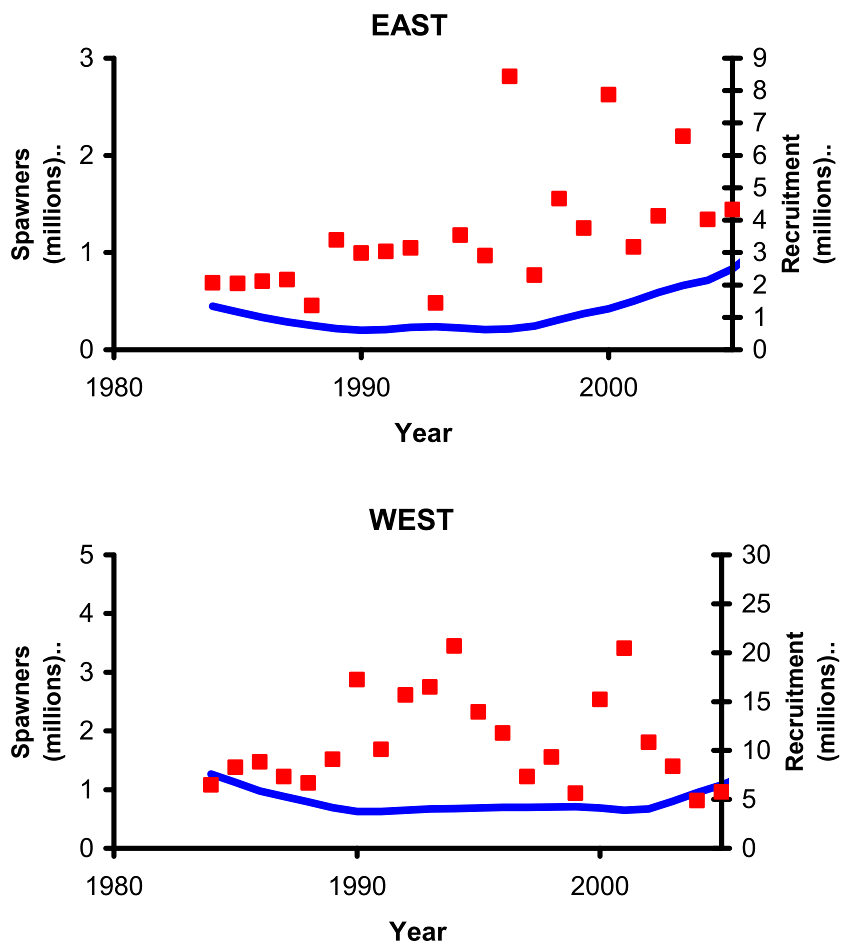


Figure 11. Model d (1984-2003, steepness = 0.81) estimates of the effective number of spawners (lines) and corresponding number of age 1 recruits (squares). The effective number of spawners associated with MSY{current-shrimp} is well off the scale.