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AN IMPLEMENTATION OF THE AGE-STRUCTURED PRODUCTION MODEL WITH APPLICATION TO WEST ATLANTIC BLUEFIN TUNA FISHERIES

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SUMMARY

The age-structured production model (ASPM) of Punt *et al* is implemented with some modifications. A major change is to allow for the composition of fleet-specific fishing mortality rates. The model is applied to historical data for the western Atlantic bluefin tuna management unit. The results suggest that this form of assessment can be quite useful, particularly if earlier time series of relative abundance are included.

RÉSUMÉ

Le modèle de production structuré par âge (ASPM) de Punt et al. a été utilisé avec quelques modifications. Le changement le plus important consiste à permettre le calcul d'un taux de mortalité par pêche spécifique des flottilles. Le modèle a été appliqué aux données historiques dans l'unité de gestion du thon rouge de l'Atlantique Ouest. Les résultats suggèrent que ce type d'évaluation pourrait être très utile, en particulier lorsque les premières séries temporelles de l'abondance relative sont prises en compte.

RESUMEN

Se implementa el modelo de producción estructurado por edad (ASPM) de Punt *et al.*, con algunas modificaciones. Una de las principales, es que tiene en cuenta la computación de la tasas de mortalidad por pesca específicas de la flota. El modelo se aplica a datos históricos para la unidad de ordenación de atún rojo del Atlántico oeste. Los resultados sugieren que esta forma de evaluación puede ser muy útil, sobre todo si se incluyen series temporales anteriores de abundancia relativa.

INTRODUCTION

Production models are frequently used in ICCAT assessments, partly because they make use of relatively simple data, which are often the only kind available for stocks that ICCAT is concerned with: time series of catches, and series of either fishing effort or relative abundance. The most commonly used type of production models are the so-called "lumped biomass" models which can be fitted to yield and effort data assuming equilibrium or making an equilibrium approximation (Fox 1975). A criticism of lumped biomass production models is that, even in nonequilibrium fitting situations (e.g. Prager 1994), they may be unable to account for lags in the rate of population change due to changes in the age structure of the stock. Hilborn (1990) proposed a model that can be used to address this criticism, an age-structured model that estimates a stock-recruitment relationship instead of the age- and year-specific stock sizes that other highly parameterized age-structured models estimate. Punt and colleagues (e.g. Punt et al. 1992, Punt et al. 1995) built upon this idea with some modifications and presented what is known as ASPM (age-structured production model) in ICCAT circles.

There are many possible model formulations for ASPMs to accommodate particular situations. For the most part in ICCAT, ASPMs have been applied to south Atlantic albacore data, although they have also been used with other stocks mainly in trial runs. In

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the case of western Atlantic bluefin tuna, they have been used in two assessments, but their results have been treated as preliminary. However, they generally confirmed the results of other age-structured analyses in terms of overall trends and resource depletion.

The purpose of this note is to introduce a new implementation of ASPM. It contains some modifications from the Punt et al. software previously used for bluefin tuna, which may make it more amenable for actual use. The model is applied to western Atlantic bluefin tuna data for illustrative purposes.

THE MODEL

Population

The basic model equations can be found in the references by Punt et al. and are not repeated here. Briefly, the population model is a forward age-structured projection that includes a plus group, assumed to be composed of ages "plus" up to infinite. Recruitment is deterministic and follows a stock-recruitment relationship (Beverton and Holt- or Ricker- type in this implementation). The stock is assumed to be in equilibrium at the start of the time series. Effort or relative abundance information is not required for the entire time series of catch data being considered.

Parameters

This equilibrium is usually the virgin level, although the current implementation allows for the estimation of an additional "initial biomass ratio" parameter equal to

$$\frac{B_{init}}{B_{virgin}}$$

The three parameters that the software estimates are the initial biomass ratio, the virgin biomass, and the "*steepness*" of the stock recruitment relationship. The latter term was coined by Francis (1992) and represents the fraction of the recruitment at *Bvirgin* that results from a biomass equal to 20% of *Bvirgin*. Estimating *Bvirgin* and *steepness* is equivalent to estimating the two parameters of the stock-recruitment relationship, except that the former two are easier to guess in magnitude. The software also estimates constants of proportionality relating each index of abundance to actual abundance, but does so internally, by Maximum Likelihood.

Yields

Yields (total landings in weight by year) are assumed to be known exactly. This implementation allows for multiple fisheries (currently, up to five) to exploit the stock each year. The software solves for the age and fleet-specific fishing mortality rates each year that would result in the known catch, given population sizes at age, natural mortality, and known selectivity vectors for each fleet. Natural mortality at age and selectivity by age, year and fleet, are required as inputs. A reason for allowing for fleet-specific catches is that it is easier to obtain a fleet- (or gear-) specific selectivity pattern than it is to obtain one for a mixture of fleets with varying efforts.

Indices

Indices of abundance can be treated as they are in implementations of the ADAPT VPA currently used by ICCAT (Powers and Restrepo 1992). That is, the indices can be in biomass or numbers, represent one or more ages, and have partial age-specific selectivities that are input as known constants or are estimated from the partial catches at age (weighted by F). In the objective function, the indices can be treated as being normally or lognormally distributed, and can be weighted equally or their weights can be estimated via Maximum Likelihood. Up to 20 indices can be used in the current implementation.

MSY Outputs

MSY-related statistics (MSY, Fmsy, SSBmsy) are output for each year of data. The reason for this is that changes in the overall selectivity pattern of the fishery can be substantial over time, and such changes can have a profound impact upon yield per recruit as well as the total equilibrium yield that would be expected from a given selection pattern.

Uncertainty

The basic run gives an estimate of the variance-covariance matrix for the estimated parameters. Uncertainty in all other variables of interest is estimated through a parametric bootstrap as detailed in the references by Punt and colleagues.

W. A. BLUEFIN EXAMPLE

Two model runs were performed with basic bluefin data from the western Atlantic. The weights at age were taken from the growth curve currently adopted by the SCRS and maturity was assumed to be knife-edged at age 8. Natural mortality was set to 0.14 per year, and a plus group was defined at age 10+. The indices of abundance were the same seven used in the 1994 assessment (ICCAT 1995), except as noted below. The age-specific selectivity for each index was determined in the same manner as in the assessment.

Four "fleets" were defined based on their targeted age groups and general gear types (S. Turner, NMFS, Miami, Florida, USA, personal communication): Rod and reel small fish, Inshore large fish, Purse seine small fish, and Longline plus others. The yields taken by each fishery over time are shown in Figure 1, starting in 1960. Selectivity patterns were obtained externally for each fishery, based on the VPA base case run from the 1994 assessment: The catch at age for each fleet was multiplied by the VPA-estimated fishing mortality and then divided by the total catch at age, thus yielding a fleet-specific fishing mortality. Each annual fleet-specific F vector was rescaled to one, to give a selectivity. Visual examination of the selectivity patterns in the time period 1970-1993 suggested four time periods in which each fleet's selection pattern remained more or less constant: 1970 to 1975, 1976 to 1982, 1983 to 1988, and 1989 to 1993. Therefore, for these time periods, each fleet's selectivity was fixed equal to the estimated selectivities weighted by the fleet's catch at age. Selectivities prior to 1970 were made equal to those in the 1970-1975 time period. The resulting input selectivity patterns are shown in Figure 1.

A second ASPM run was made including an eighth index of abundance for the 1960s and 1970s, with the objective of finding out whether the fit might improve if an earlier time series of relative abundance data were available. The data are from NMFS (1983) and correspond to longline catch rates of large bluefin in the western Atlantic. It was assumed that the fish ages 8 and up were equally vulnerable to the longline operations.

For both runs, only two parameters were estimated: Steepness and the virgin biomass. In addition, note that yield data prior to 1960 were not included for lack of time. In practice, catch data should extend as far back as possible so that the estimated initial biomass will be as close as possible to a "virgin" state.

RESULTS AND DISCUSSION

The run with 8 indices gave an overall better fit ($R^2 = 0.384$) than the run with 7 indices ($R^2 = 0.200$). The fits to each individual index are shown in Figure 2. For most indices, there are undesirable residual patterns, although none of the fits seem to be extraordinarily poor.

The run with 7 indices estimates a steepness of 0.22, which is close to the lower limit of 0.2 that the software by Punt et al. allow. The run with 8 indices estimates a steepness of 0.52. Steepness controls the curvature of the stock-recruitment relationship. At a value of 0.2, the SRR is essentially linear, without compensation. At smaller values, the relationship becomes concave, as in the lower edge of a depensatory SRR. Plots of recruitment against SSB from previous western bluefin assessments based on VPAs have often shown such a concave curvature, at least for a range of the data. A steepness equal to or lower than 0.2 is difficult to interpret because it does not allow for feasible estimates of MSY-related benchmarks, as it predicts ever-increasing recruitment with increasing parental stock. However, in certain situations, that may be the form of the relationship that the data suggest, for whatever reason, and the analyst is faced with the dilemma of forcing a lower limit on the estimate of steepness, or allowing the model to fit the data as freely as possible. In this example, the fits were not forced to steepness > 0.2, and so it was impossible to estimate MSY-related benchmarks from a number of bootstrap runs.

Figure 3 compares the point estimates of fishing mortality and exploitable biomass for 3 age groupings that resulted form each fit. The trends are quite similar, but the magnitudes differ, as the 8-index fit estimated a lower (initial) virgin biomass.

Figure 4 compares some MSY-related statistics (median and 80% confidence bands) for both fits, based on bootstrap runs. Originally, 250 bootstraps were made for each fit. The 8-index fit resulted in two bootstrap runs giving steepness < 0.2, which were excluded. Similarly, 94 bootstrap runs were omitted from the MSY-related analyses of the 7-index fit. The greater uncertainty present in the 7-index run is evident in all figures: Typical CVs for MSY, F/FMSY and B/BMSY were 0.74, 3.45 and 0.12 for the 7-index fits, compared with 0.20, 0.26 and 0.08 for the 8-index fits. However, it is interesting to note that B/BMSY was estimated rather precisely for the 7-index fit, even when the other benchmarks were not. In addition, it is interesting to note that the trends and magnitude of the B/BMSY estimates, particularly in the latter years, are very similar for both the 7- and 8-index fits. The other benchmarks are similar in trend but differ substantially in magnitude.

Overall, it seems like the ASPM approach may be well suited as an additional form of analyses that could be used in conjunction with VPAs in the assessment of bluefin tuna. However, improvements to the available data sets should be made. In particular, one or more long time series of relative abundance data should be developed, extending as far back in time as possible.

ACKNOWLEDGMENTS

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REFERENCES

Fox. W.W., Jr. 1975. Fitting the generalized stock production model by least-squares and equilibrium approximation. Fish. Bull. 73: 23-36.

Francis. R.I.C.C. 1992. Use of risk analysis to assess fishery management strategies: a case study using orange roughy on the Chatham Rise, New Zealand. Can. J. Fish. Aquat. Sci. 49: 922-930.

Hilborn. R. 1990. Estimating the parameters of full age structured models from catch and abundance data. Bull. Int. N. Pacific Fish. Comm. 50: 207-213.

ICCAT. 1995. Report for biennial period 1994-1995, Part I, Vol. 2.

NMFS (National Marine Fisheries Service - Southeast Fisheries Center). 1983. A review of some Atlantic bluefin tuna fisheries data. Int. Comm. Cons. Atl. Tunas. Coll. Vol. Sci. Pap. 20: 354-373.

Powers. J.E., and V.R. Restrepo. 1992. Additional options for age-sequenced analysis. Int. Comm. Cons. Atl. Tunas, Coll. Vol. Sci. Pap. 39: 346-354.

Prager. M.H. 1994. A suite of extensions to a nonequilibrium surplus-production model. Fish. Bull. 92: 374-389.

Punt. A.E., A.J. Penney, and C.G. Wilke. 1992. Stock assessment of South Atlantic albacore using an age-structured production model. Int. Comm. Cons. Atl. Tunas. Coll. Vol. Sci. Pap. 39: 215-224.

Punt. A.E., D.S. Butterworth, and A.J. Penney. 1995. Stock assessment and risk analysis for the South Atlantic population of albacore *Thunnus alalunga* using an age-structured production model. S. Afr. J. Mar. Sci. 16: 287-310.

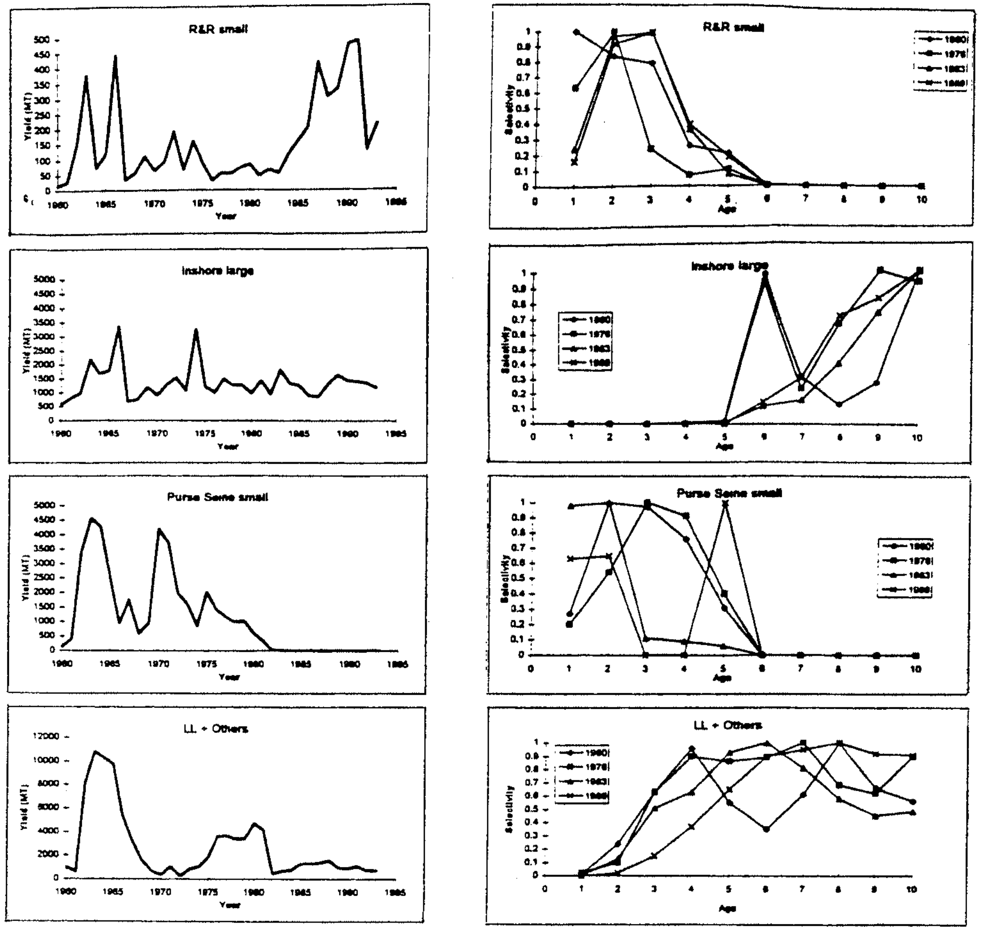


Figure 1. Left column: Time series of yields (metric tons) for the four fisheries considered in the west Atlantic bluefin tuna ASPM analyses. Right column: Assumed input selectivities at age for the four fisheries for the time periods 1960-1975, 1976-1982, 1983-1988, 1989-1993.

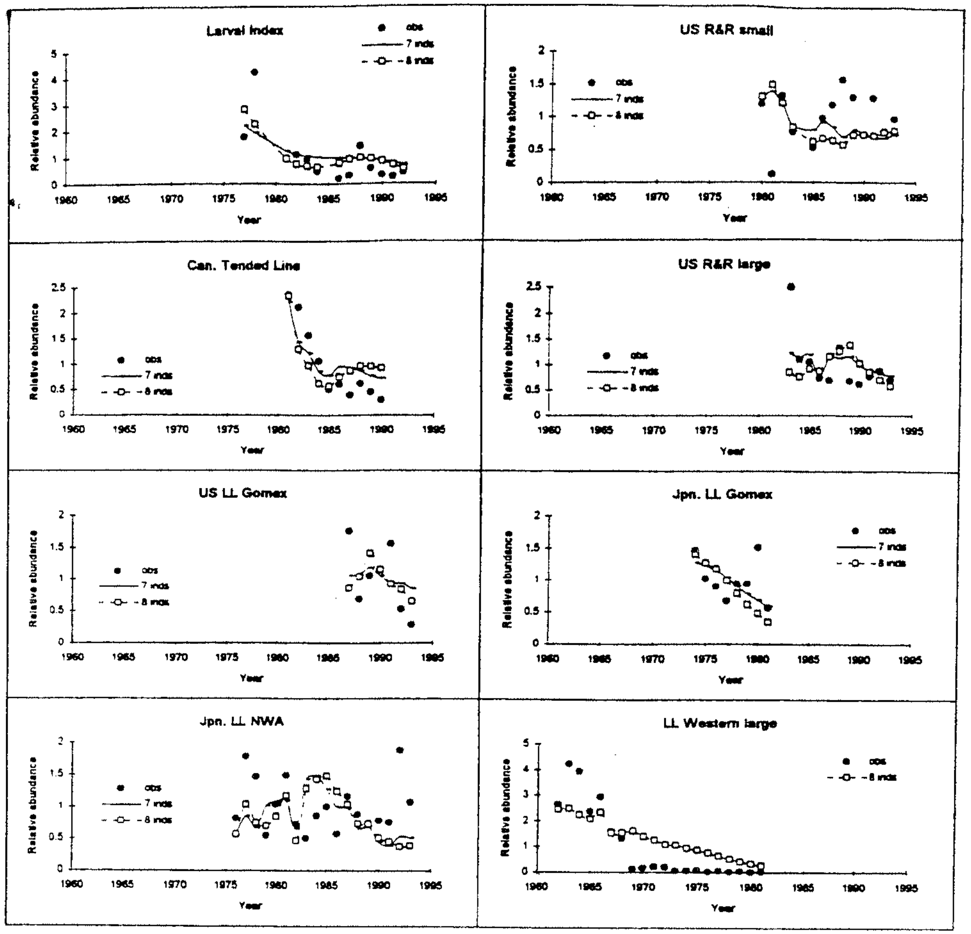


Figure 2. Observed (solid circles) and predicted indices of abundance. The predicted values are from two runs: One using the same indices as in the 1994 assessment (solid line, labelled "7 inds") and the other with an eigth index for the earlier time period (dashed line, labelled "8 inds").

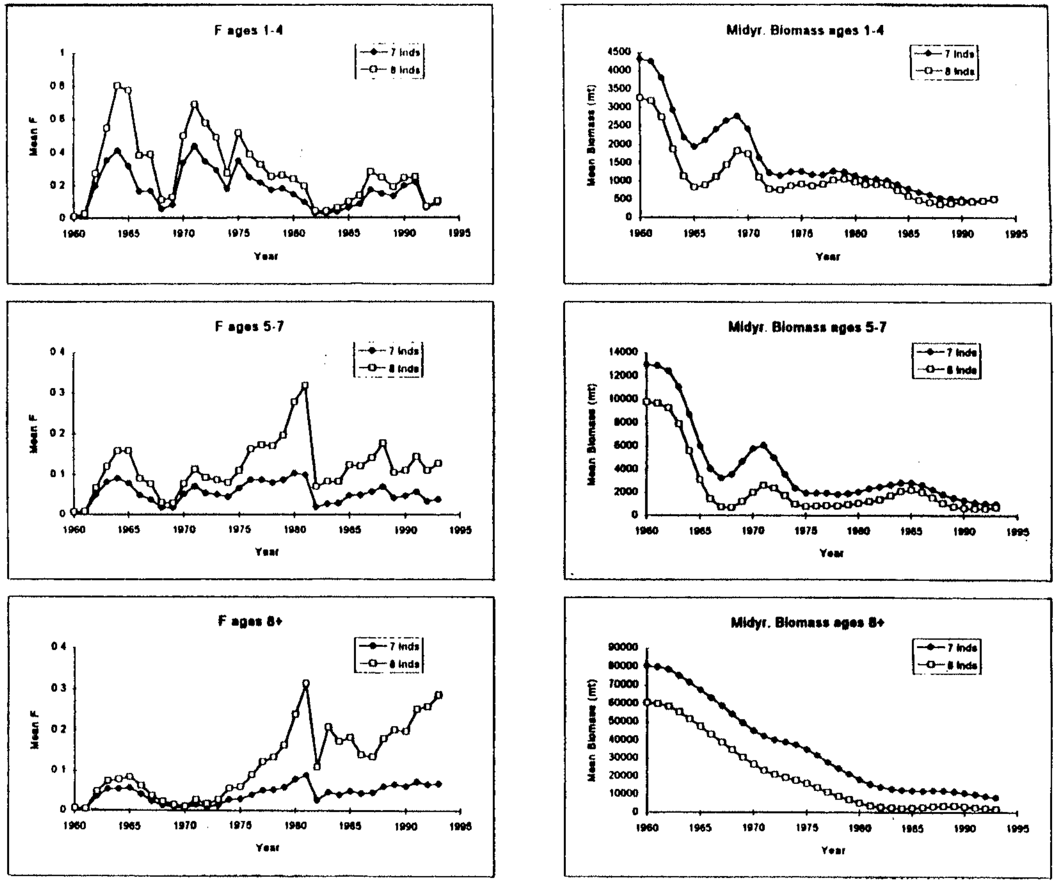


Figure 3. Average fishing mortalities (left column) and mid-year biomasses (right column) estimated for various age groups. Results are presented for the two sets of analyses.

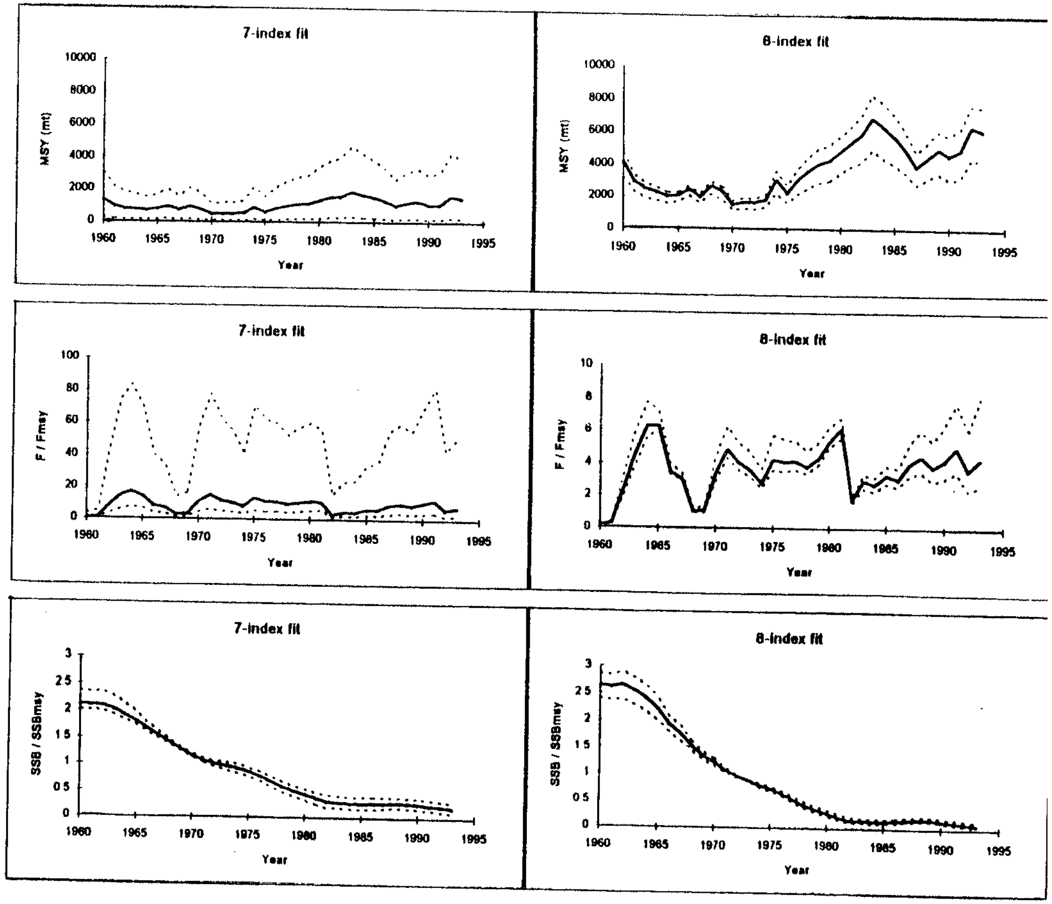
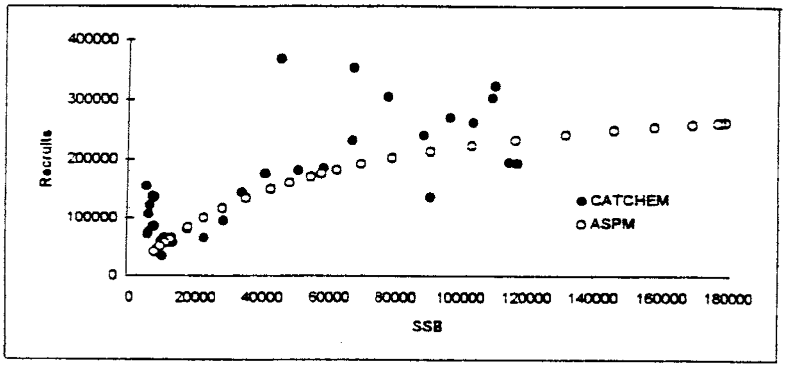
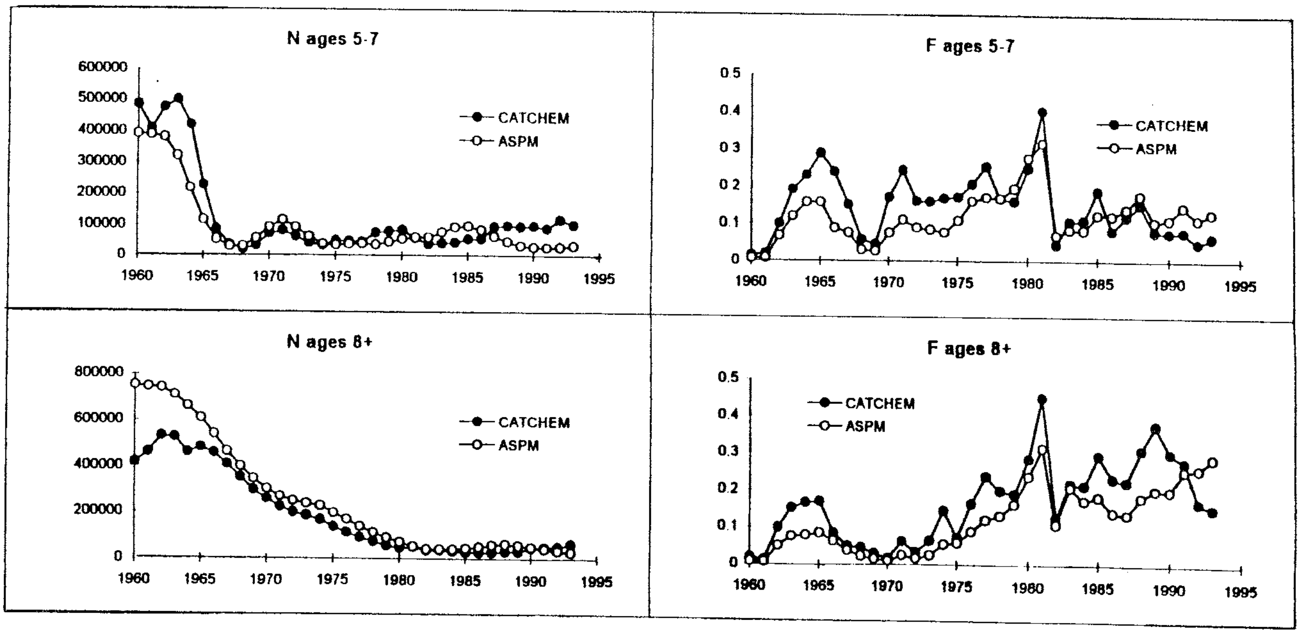


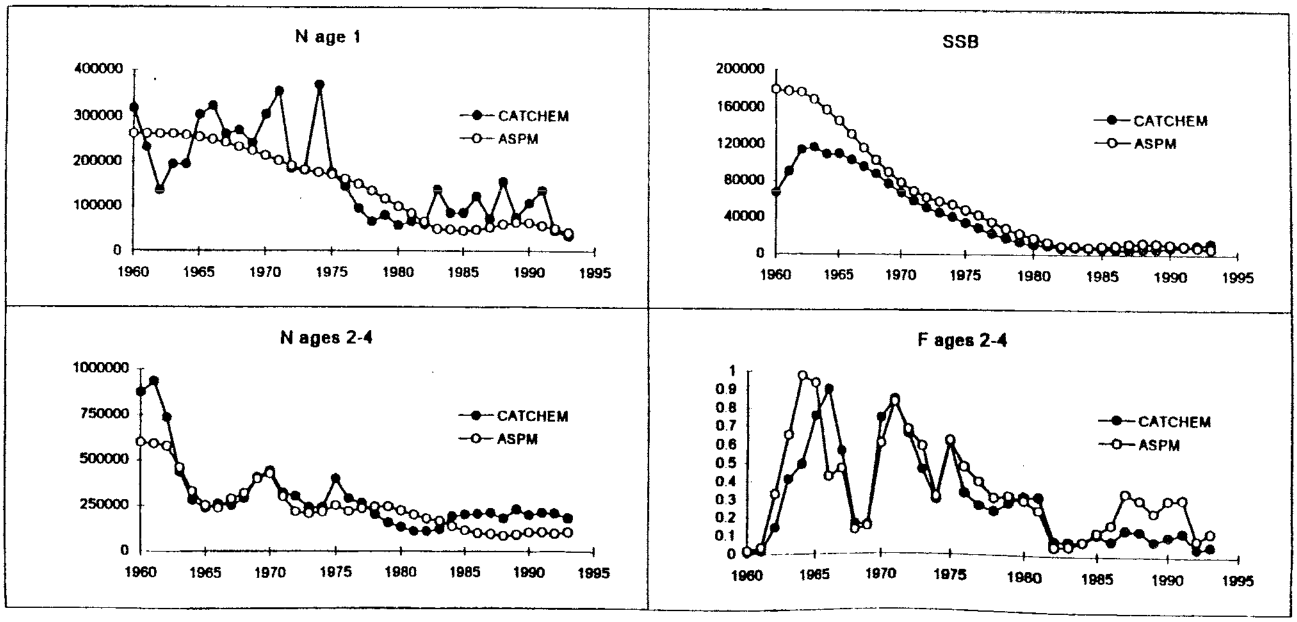
Figure 4. Bootstrap results from the two sets of analyses made, with 7 or 8 indices of abundance. The solid lines are the median result and the dashed lines represent 80% confidence intervals.

ADDENDUM to SCRS/96/130

Porch and Turner (SCRS/96/119) also conducted an analysis of west Atlantic tuna data starting in 1960. They used essentially the same catch and index data as I did, although we worked independently of each other. The figures in this Addendum compare some outputs from their paper to the 8-index run in this paper. The major difference in the two approaches is a tradeoff between estimating many parameters (CATCHEM) or making a big assumption to estimate very few parameters (ASPM).







ADDENDUM 2 to SCRS/96/130

AN IMPLEMENTATION OF THE AGE-STRUCTURED PRODUCTION MODEL WITH APPLICATION TO WEST ATLANTIC SWORDFISH FISHERIES

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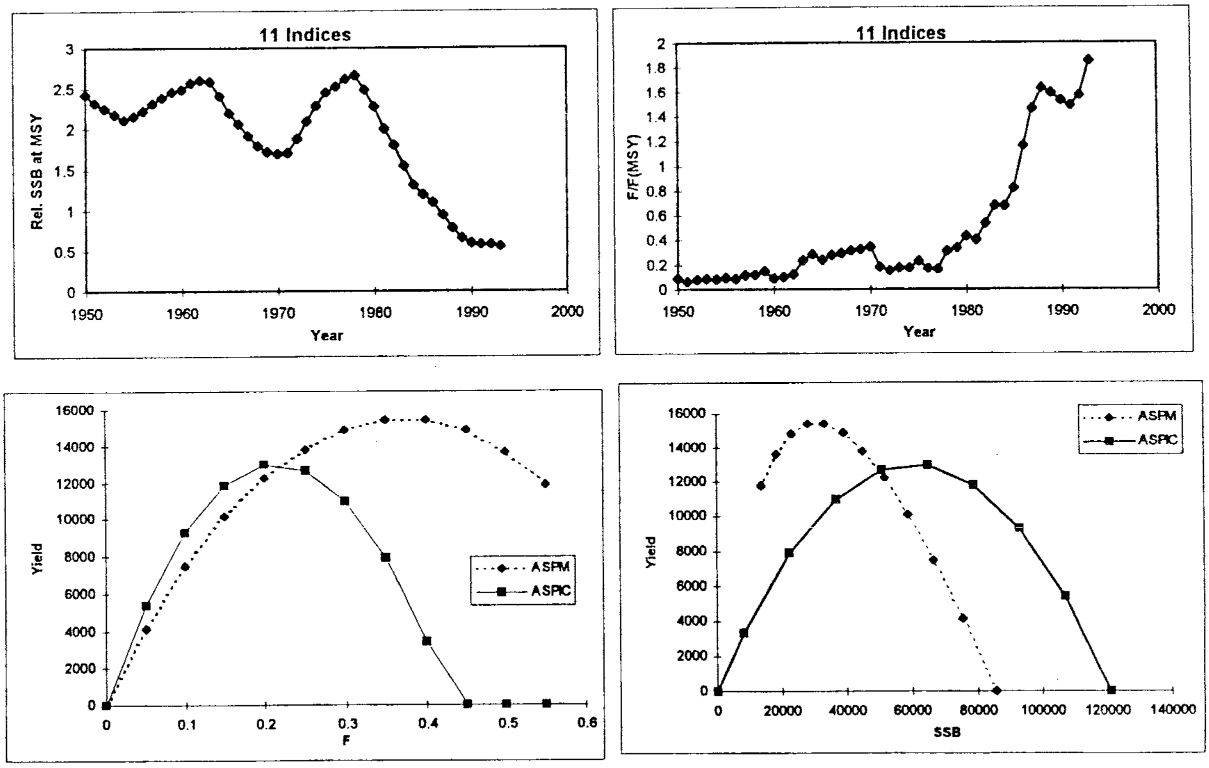
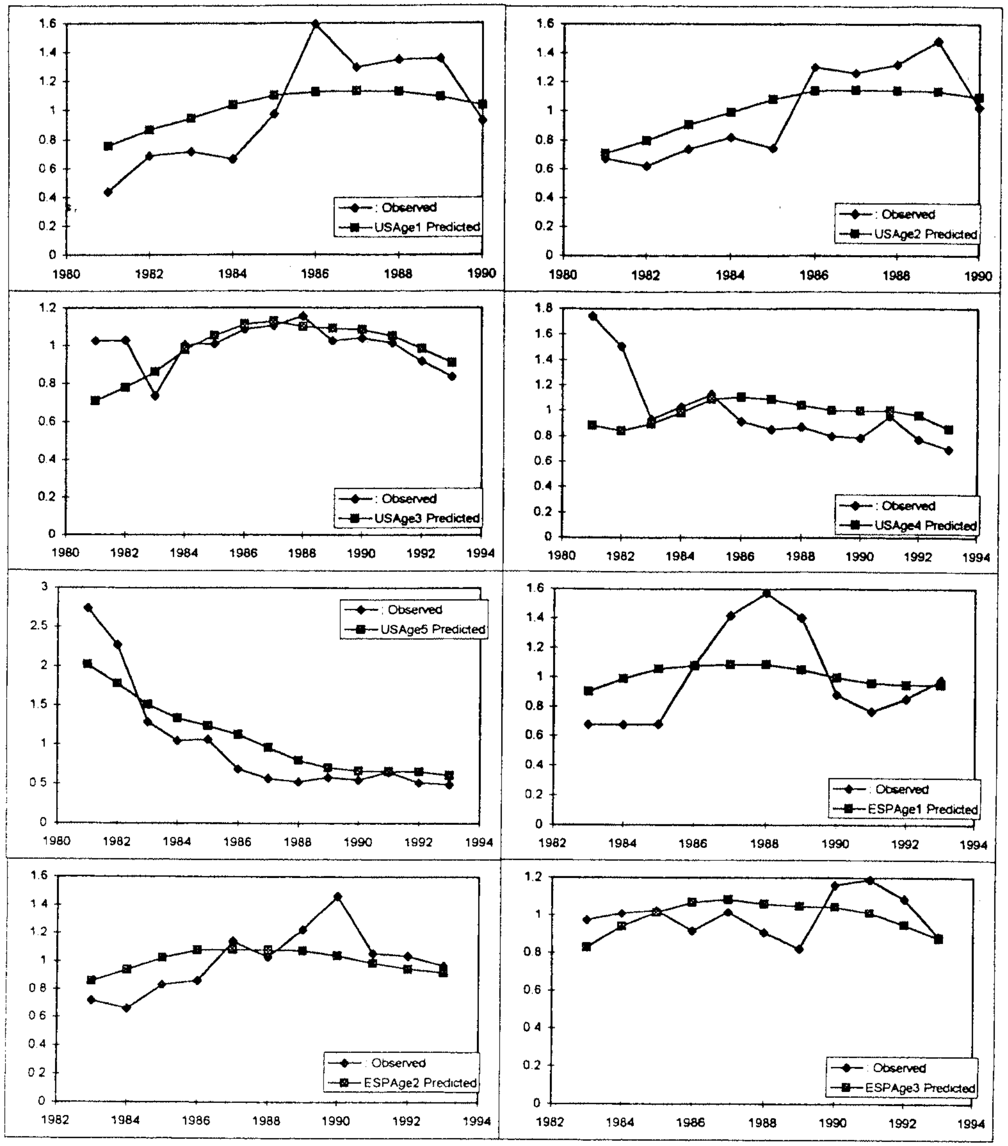
The age-structured production model (ASPM) of Punt et al. is fitted to historical swordfish data for the period 1950-1993. Two approaches are presented. The first uses an 11 index model consisting of U.S. Age 1 through age 5 CPUE data; Spanish age 1 through age 5 CPUE data and Japanese CPUE data. The second approach uses a combined biomass index only. The non-equilibrium production model ASPIC was also fitted to the data used in the second ASPM approach. Relative biomass and fishing mortality trajectories are included, as well as production model yield plots and model fits for each approach.

11 Indices - Trajectories



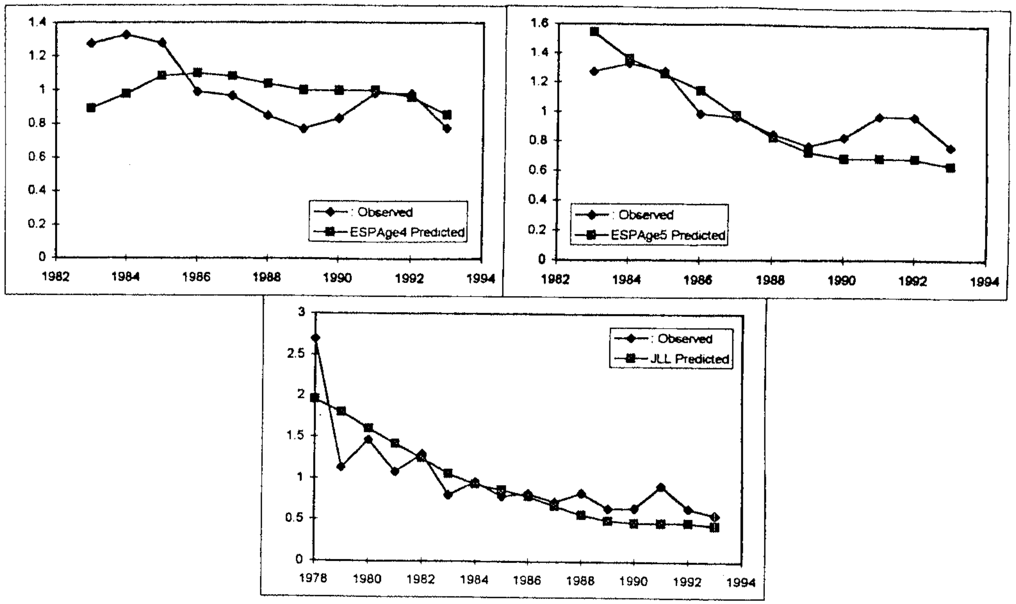
Relative biomass at MSY trajectory, F/FMSY trajectory, and production model yield curves (ASPM and ASPIC) for the 11 CPUE index approach.

11 Indices - CPUE Fits



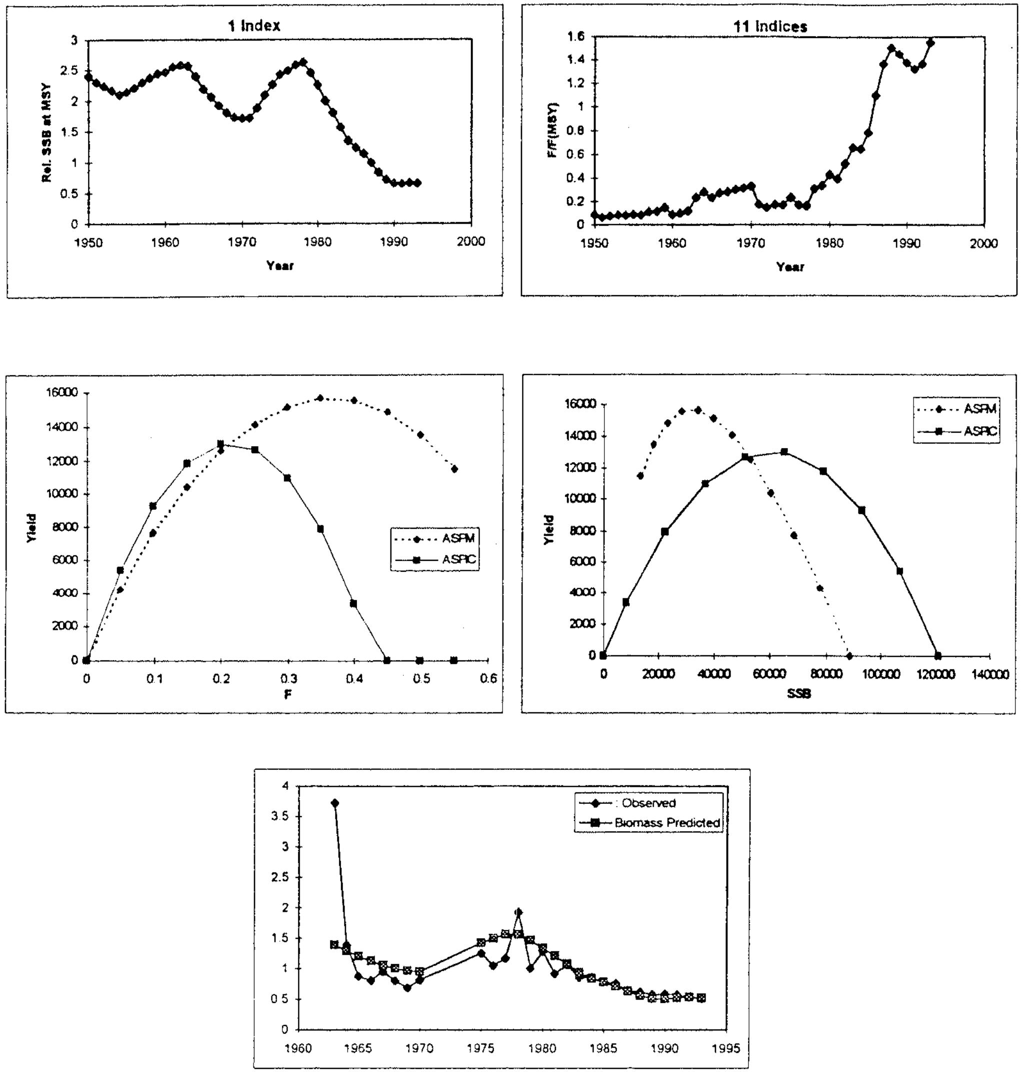
CPUE fits from the ASPM model for the 11 index approach.

11 Indices - CPUE Fits



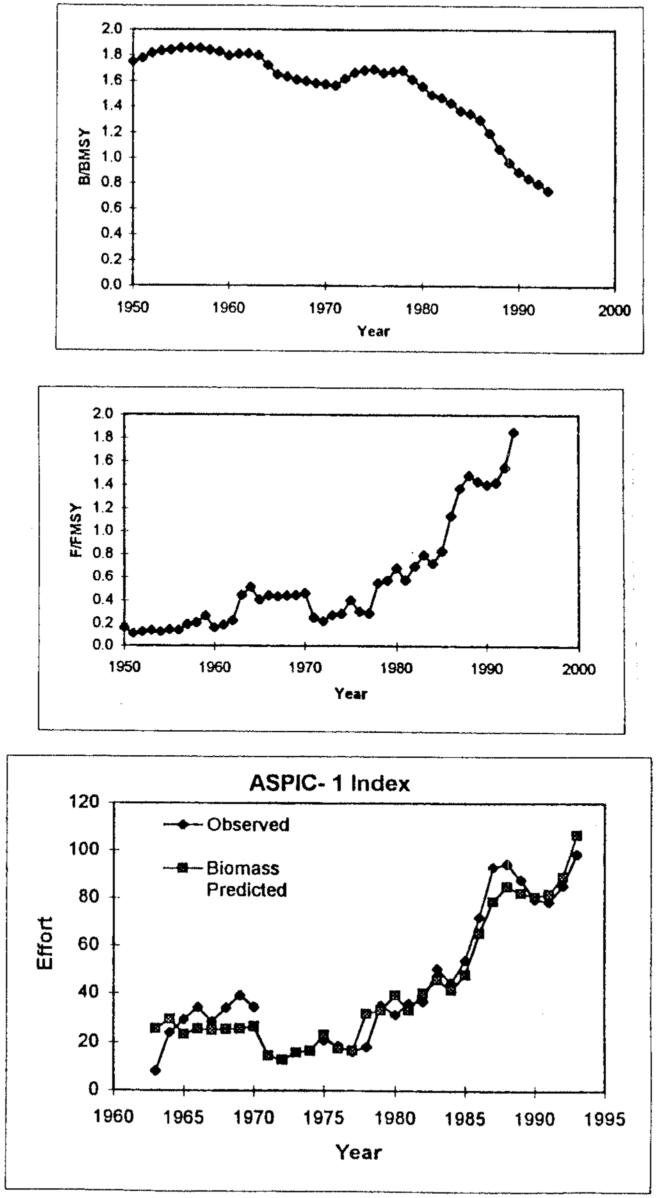
CPUE fits from the ASPM model for the 11 index approach.

1 Index - Trajectories & Fit



Relative biomass at MSY trajectory, F/FMSY trajectory, production model yield curves (ASPM and ASPIC), and CPUE fits from the ASPM model for the 1 index approach.

ASPIC Trajectories



B/BMSY trajectory, F/FMSY trajectory, and CPUE fits from the ASPIC model for the 1 index approach.