Using abundance indices and fishing effort data to tune catch-at-age analyses of sprat Sprattus sprattus L., whiting Merlangius merlangus L. and spiny dogfish Squalus acanthias L. in the Black Sea

Daskalov G.

in

Lleonart J. (ed.).
Dynamique des populations marines

Zaragoza : CIHEAM
Cahiers Options Méditerranéennes; n. 35

1998
pages 215-228

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SUMMARY - Stock assessments based on both fisheries relating data and abundance indices have been carried out on three fishery ecosystem species important for the Black Sea: the sprat, the whiting and the spiny dogfish. Two methods of catch-at-age analysis (CAA) have been applied: the virtual populations analysis (VPA) with *ad hoc* tuning and the extended survivors analysis (XSA). Their relevance to the data on the three stocks has been investigated. The consistency of alternative assessment options has been explored using retrospective analyses. The final assessment results have been discussed in the light of interactions among the three species and the global situation of the Black Sea ecosystem.

Key words: Catch-at-age analysis, tuning, retrospective analyses, *Sprattus sprattus* L., *Merlangius merlangus* L., *Squalus acanthias* L., Black Sea.

RESUME - *"Utilisation des indices d'abondance et des données d'effort de pêche pour la mise au point d'analyses de captures par âge pour le sprat* Sprattus sprattus *L., le merlan* Merlangius merlangus *L., et le chien-piquet* Squalus acanthias *L. dans la mer Noire". L'évaluation des stocks basée sur des données de pêche et des indices d'abondance est faite pour trois espèces importantes de l'écosystème halieutique de la mer Noire : le sprat* Sprattus sprattus *L., le merlan* Merlangius merlangus *L., et le chien-piquet* Squalus acanthias *L. Deux méthodes d'analyse des captures par âge sont utilisées : l'analyse des populations virtuelles (APV) ou analyse des cohortes des analyses rétrospectives. Les résultats d'évaluation des stocks sont discutés avec calibrage* ad hoc *et XSA (eXtended Survivors Analysis) et leurs performances d'estimation sur des jeux des données des trois espèces sont évaluées. La stabilité des options des méthodes d'évaluation possibles est explorée à la lumière des interactions entre les trois espèces et la situation globale de l'écosystème de la mer Noire.*

Mots-clés : *Analyse des cohortes, calibrage, analyses rétrospectives,* Sprattus sprattus *L.,* Merlangius merlangus *L.,* Squalus acanthias *L., la mer Noire.*

Introduction

Assessment methods applied on the Black Sea fish stocks have traditionally been based either on data from the fisheries (VPA, yield-per-recruit, surplus production models) or on research survey estimates of absolute abundance (e.g., Ivanov, 1983; Ivanov and Beverton, 1985; Prodanov and Daskalov, 1992 for the first approach, and Domashenko and Yur'ev, 1978; Effimov *et al.*, 1985, Kirnosova and Shlyakhov, 1988; Kirnosova, 1993, for the second one). Cooperation between the Black Sea scientists in the last years has allowed to summarize the major available data sets regarding the most important fish stocks in the region (Prodanov *et al.*, 1996).

In this study both fishery related data and independent information have been combined in order to arrive at a more precise stock assessment. Commercial catch-per-unit-effort (CPUE) and research survey abundance indices have been used to tune catch-at-age assessment models. Sprat, whiting and spiny dogfish stocks have been considered as examples as they differ much both as biological as well as data characteristics. Comparative assessments of these three species are particularly interesting because they are related by predator-prey interactions.

Materials and methods

Catch-at-age analysis (CAA)

Input data sets for CAA have been derived using information on the total catch and effort by fishing season (or month) and gear type; age and size composition from the former USSR, Bulgaria, Romania and Turkey. Primary data processing and analysis have been carried out within the international project "Environmental management of fish resources in the Black Sea and their rational exploitation" (1992-1995) (Prodanov *et al.,* 1996). The data used come from scientific papers (Stoyanov, 1960, 1965, 1966; Konstantinov, 1964; Grese, 1979; Yur'ev, 1979; Ivanov, 1983; Daskalov, 1993), unpublished reports of the national fishery research institutes and national fishery agencies in Bulgaria, Romania, Ukraine, and Turkey. Landings and abundance indices over the years are shown in Figs 1, 2 and 3. The original data on the three species in the form of catch numbers and stock weights -at-age matrices and multi-fleet tuning data on sprat are presented in Prodanov *et al.* (1996). Only the whiting from the Western part of the Black Sea has been considered because that from the Extern part has different rates of growth and mortality (Fig. 3). Survey data on whiting were kindly provided by V. Shlyakhov (pers. comm.) and those on spiny dogfish come from Kirnosova (1993). Four age-structured CPUE data sets have been used in the assessment of sprat: the former USSR small trawlers <300 h.p. commercial fleet (U SMALL); the former USSR large oceanic trawlers >300 h.p. commercial fleet (U LARGE); the Ukrainian research survey abundance index (SRS - from hydroacoustic and mid-water trawl surveys); and the Ukrainian ichthyoplankton survey fingerling index (SIS) (Fig. 1). The last two indices have been built in the South Research Institute for Fisheries and Oceanography (YugNIRO), Kerch, Ukraine which performs yearly research surveys aiming at a direct assessment of the adult stock and ichthyoplankton absolute abundance. In the assessment of whiting one age-structured exploited stock abundance index (WRS) and one fingerling abundance index (WIS) are available from the YugNIRO surveys (Fig. 2). In the dogfish assessment an age-structured exploited stock abundance index (DRS) from the YugNIRO demersal fish surveys has been used (Fig. 3).

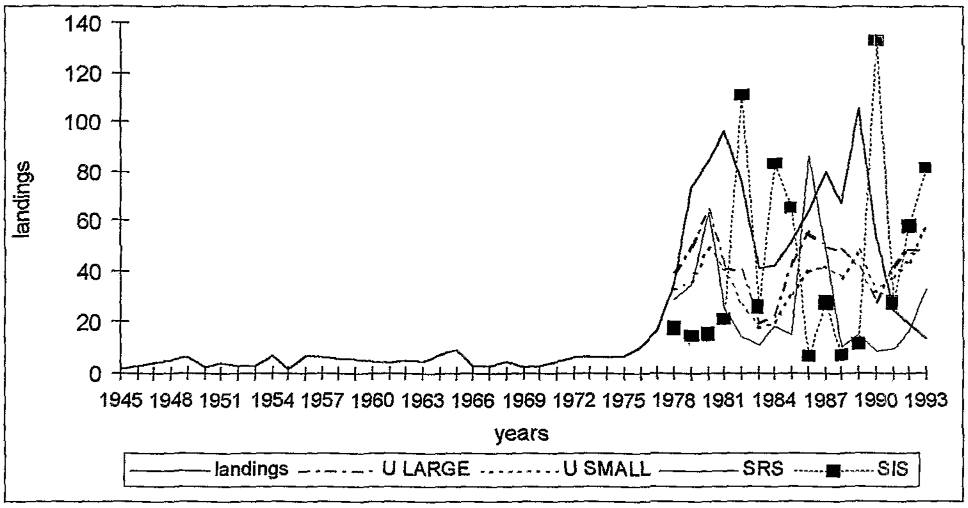

Fig. 1. Sprat landings (thousand tons) in the Black Sea and abundance indices (arbitrary units): U LARGE and U SMALL are comercial CPUE; SRS-research survey stock abundance index, and SIS is ichthyoplankton survey index (see the text).

CAA estimates simultaneously abundance *(N)*-and fishing mortality *(F)*-at-age, and one of the problems with these models is the overparametrization (Hilborn and Walters, 1992). In the case of VPA the terminal fishing mortality rate (a priori unknown) for each cohort has to be supplied to initiate calculations. The methods we have applied: the VPA with *ad hoc* tuning (Pope and Shepherd, 1985) and the Extended Survivors Analysis (XSA) (Shepherd, 1992) generally deal with overparametrization in two ways. One way is to decrease the number of parameters estimated by

CAA e.g., to assume a constant exploitation pattern for the oldest ages (see below), another way is to estimate some parameters (e.g., the last year fishing mortality) using additional information (CPUE, *survey indices*): *a procedure* called tuning. Reviews and comparisons of age-structured models are published by Megrey (1989) and Anon. (1993).

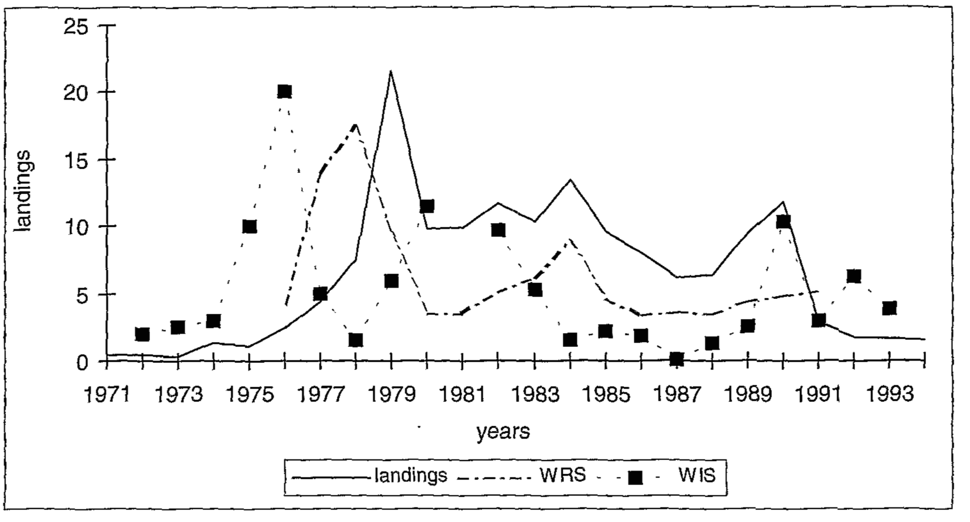

Fig. 2. Whiting landings (thousand tons) in the Western Black Sea and abundance indices (arbitrary units): WRS-bottom trawl survey stock abundance index, WIS-ichthyoplankton survey index.

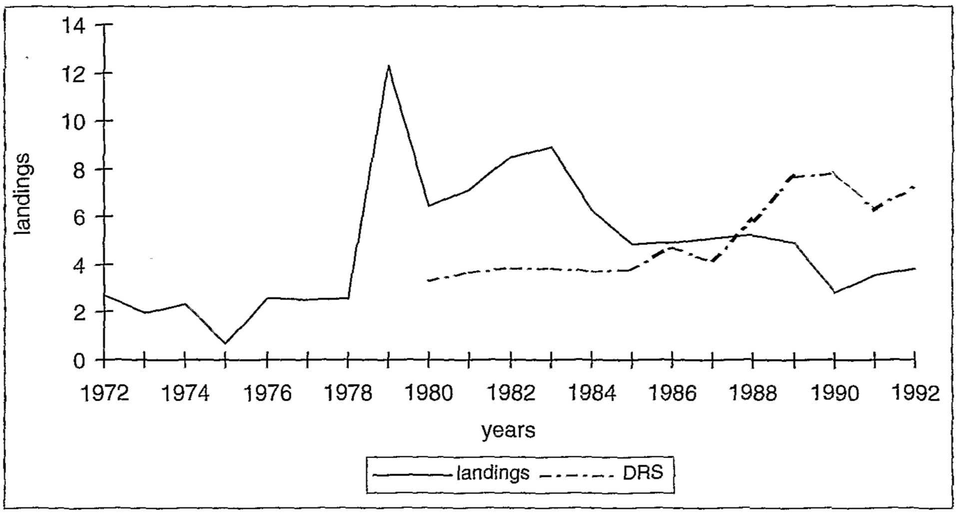

Fig. 3. Spiny dogfish landings (thousand tons) in the Black Sea and bottom trawl *survey stock* abundance index (DRS arbitrary units).

With the VPA *ad hoc* tuning approach, the relationship between fishing effort and fishing mortality is used in order to estimate last year fishing mortalities-at-age. The Laurec and Shepherd (1983) method has been used, that assumes constant fleet catchability-at-age with respect to time with a log-normal error distribution. The last year catchabilities-at-age are thus estimated as geometric means of *previous years* catchabilities. Last year *F's* are then derived as catchabilities multiplied by the effort. The method uses multi-fleet tuning data. The oldest age fishing mortality is constrained to be proportional to the average *F* over some younger ages in the same year (so called backward extension) assuming a constant exploitation pattern for oldest ages. Recruitment abundance (age 0.5) in the last year has been tuned by fitting regressions between ichthyoplankton surveys data and VPA recruitment estimates.

Another method used is the Extended Survivors Analysis (XSA) (Shepherd, 1992). The method fits regressions between abundance-at-age and CPUE for multi-fleet tuning data, assuming power functional relationship for recruitment and a constant catchability with respect to time for fully recruited age groups. XSA is less rigid than VPA about constant exploitation pattern assumption, setting down the catchability to be constant (independent of age) above a certain age. Catchability estimated at a certain age is then used to derive abundance estimates to all subsequent ages including the oldest one. The fleet derived population abundance-at-age is used to estimate survivors at the end of the year for each cohort, which later initiate a modified cohort analysis in each iteration. XSA is considered to be superior than VPA in assuming the error in the catch data and being less sensitive to the last year data quality. In addition it uses an year-class-strength-dependent model to tune recruitment.

The technic called "shrinkage to the mean" could be used in order to stabilize additionally the analysis. It takes into account the mean *F* (or *N)* over the recent years in the calculation of the last year *F's* or *N's,* which means an additional constraint on the last year estimates. In the case of VPA the last year *F's* are shrunk to the arithmetic mean of the previous years *F's* for each age. In XSA two shrinkage options are available: shrinkage to the population mean or *N* shrinkage applied to recruitment and shrinkage to the mean *F* (*F* shrinkage) which is applied to all last year *F's* as well as to the oldest age *F's.* A shrinkage coefficient of variation (CV) has to be supplied by the user in order to weight the *F* shrinkage mean (by the inverse variance). The *N* shrinkage mean is weighted by the inverse of the variance of weighted geometric mean. Within XSA, when the analysis is extended to past years not covered by tuning data, it is necessary in most cases to use *F* shrinkage to the oldest age *F*, that is equivalent to the backward extension constraint used in VPA.

Preliminary assessment runs were performed with the separable VPA (SVPA, Pope and Shepherd, 1982). Its main assumption is the separability of the fishing mortality i.e., the constant exploitation pattern. It can be used to explore the data range for changes in the exploitation pattern. The method is less sensitive to error than the VPA, does not require tuning data and needs only assuming one reference last year *F* and the selectivity for the oldest ages. The selectivities-at-age and reference *F's* over the years are calculated as output.

The above described methods have been applied to the stocks under consideration as implemented in the VPA Lowestoft 3.1 software package (Darby and Flatman, 1994) which provides different weighting, averaging and shrinking options and allows extensive use of diagnostics helping the model specification.

Retrospective analyses

Retrospective analyses have been introduced in the working groups in order to investigate how well methods perform on data and if they produce consistent assessments (Sinclair *et al.*, 1990; Anon., 1993). They are useful to specify the appropriate model options (choosing the input parameter values, setting the appropriate assumptions) and/or to detect anomalous data.

The following procedure is applied. For a given assessment method and data, successive assessment runs are performed, gradually diminishing the time series range by one year, all model options held constant. The results produced with the longest time series covering the most recent data are used as reference. Both trends and bias are examined to assess the consistency of the shorter series of estimates to the reference. Bias is the degree to which the so formulated assessment obviously over- or under-estimate the reference results. Bias and accuracy statistics can be computed and compared, or plotted retrospective series can be examined by eye (Sinclair *et al.*, 1990; Anon., 1993). Time series of stock numbers, biomass, recruitment and average fishing mortality estimates can be analysed for retrospective patterns. In this study the retrospective analysis routine of the VPA Lowestoft 3.1 software (Darby and Flatman, 1994) is used to explore the consistency of our assessments.

Results

Applying the above described methods we have aimed at combining optimally their advantages relevant to the data studied. First the data were analysed with SVPA. This method is sensitive only to the choice of the selectivity at the oldest age for the historic part of the assessment and can give some general idea about the stock dynamics. Residuals have been observed in order to detect data anomalies. SVPA results are used to specify the shape of the exploitation pattern and to chose the selectivity at the oldest age to be used in VPA. Then we apply VPA in order to refine the recent years estimates. Reliability of the tuning data have been examined and the fleets and the years ranges used for tuning-specified. With the XSA more diagnostics and options are available. Retrospective analyses have been used in order to explore different models options (e.g., fleet weighting; shrinkage) and to specify the most appropriate assessments. Retrospective plots (Figs 4, 5 and 6) illustrate the consistency of the assessments performed.

In general XSA produces more consistent assessments than VPA. This is perhaps because XSA is more robust to error in the data and unlike VPA, does not assume the last year data as exact. It uses also the year class strength information to tune recruitment.

In the case with sprat both XSA and VPA perform relatively well without shrinkage. When data are of lower quality (e.g., dogfish and whiting) or the methods assumptions are not sufficiently in agreement with data, patterns of systematic over- or under-estimation may occur (e.g., Figs 5C, 6A and 6C). Considering the spiny dogfish assessment, it has been noted that the research survey index has an increasing trend which is opposite to the trends of the catch and the biomass (Fig. 3). In this case the constant catchability assumption seems to be violated. In fact, examination of residuals tables has shown marked positive trends in catchability for intermediate ages (8 to 12), that inflate VPA biomass estimates (Fig. 6C) Then shrinkage option has to be used in order to stabilize the last years estimates. As it is seen from (Figs 5 and 6) when *F* shrinkage has been applied the bias is more regularly distributed around the reference series.

Final assessments chosen are plotted in Figs 7, 8 and 9. Differences between XSA and VPA in the historical part of the assessment reflect the different formulation of the constraint on the exploitation pattern. For instance in earlier years there may have been a change in the exploitation pattern of whiting (Fig. 8). This change influences more severely VPA, which is more sensitive than XSA to the violation of the constant exploitation pattern assumption. The differences in the recent years results (e.g., the dogfish assessment) are due to the last year's estimates: VPA treats the catch and the tuning data as exact and trends in the tuning data can violate the constant catchability assumption.

According to changes in the exploitation pattern and other features in the stock dynamics, the overall assessment range of the sprat has been divided to shorter periods (blocs) for which constant parameters have been set. Data for 1974-1993 are of better quality because fishing and research activity were intensified during that period. Good tuning data cover 1978-1993. Data prior to 1974 are noisy and their quality decreases back in time. Natural mortality (*M*) has been set at $M = 0.64$ for age 0.5 to 1 (recruitment) for all the years, and for adults (ages 1-5) - $M = 1.19$ for 1945-1973, and $M = 0.96$ for 1974-1993 according to a previous study (Daskalov *et al.*, 1996, in press). Tuning of CAA has been performed for 1978-1993. No time series weighting nor *F* shrinkage has been used for either method. The *F* shrinkage option was rejected after referring to the retrospective plots. Though in some years large residuals have appeared, experimental down weighting has not improved the situation. Prior fleet weighting has slightly improved results and diagnostics with XSA. Data before 1974 are of lower quality and several runs were needed in order to define assessment blocks and parameters. Different time ranges and selectivity patterns were tried. Average results by blocks are given in Table 1.

Prodanov *et al.* (1996) applied *M* variable with age in some of their VPA assessments of whiting and spiny dogfish. As the purpose of this study is to compare the CAA performance on the three stocks, we prefer to keep constant *M* with respect to age and time. $M = 0.7$ (Prodanov *et al.*, 1996) has been assumed for whiting and $M = 0.22$ - for dogfish (Kirnosova, 1990). For this reason our results substantially differ from some of the estimates presented by Prodanov *et al.* (1996). According to the retrospective studies and diagnostics the appropriate choice has been made, regarding the tuning range, the constraint on the exploitation pattern, regressions weight etc. Shrinkage to the mean

F was judged to improve the assessments of whiting and dogfish. Average results are given in Table 2.

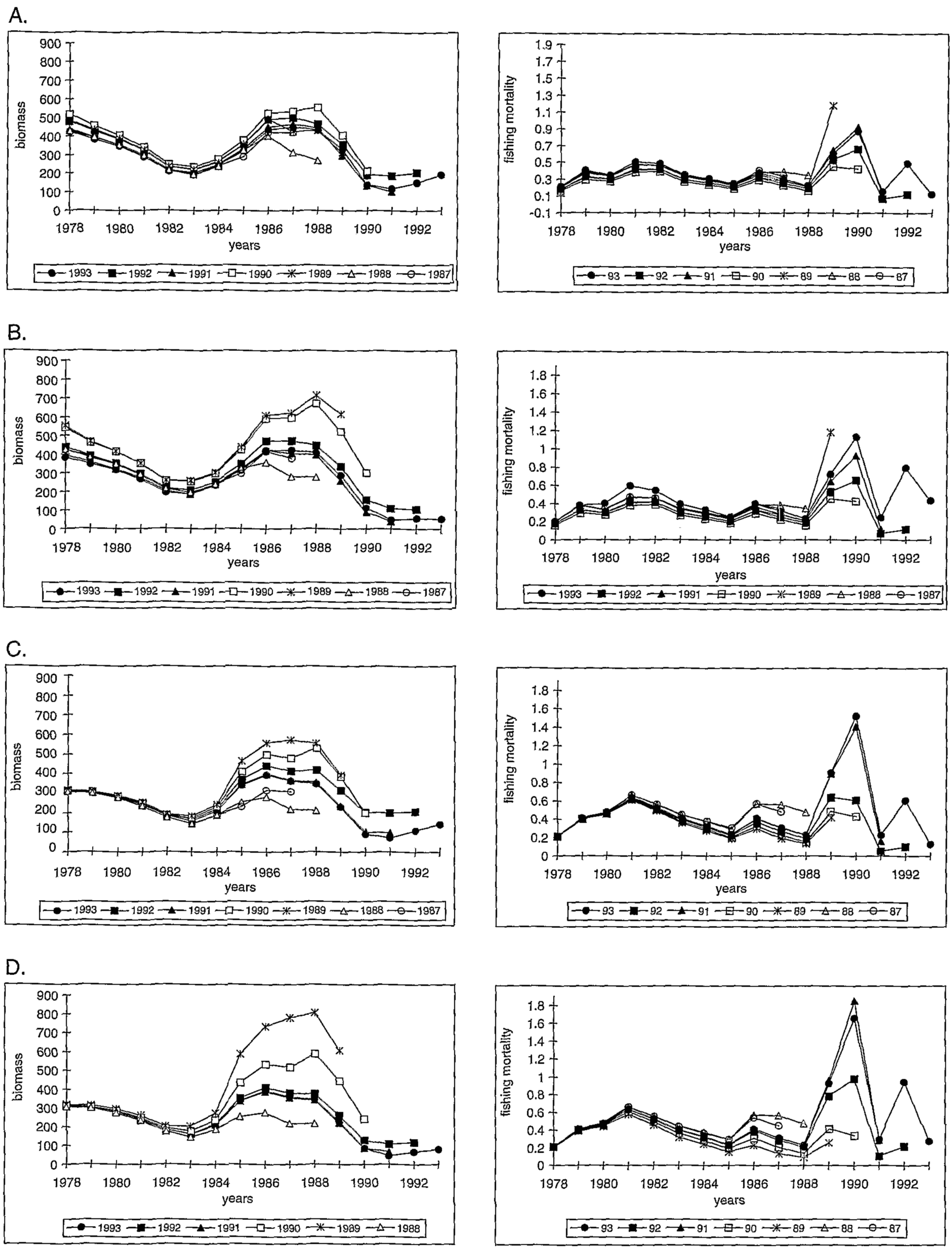

Fig. 4. Retrospective analyses of sprat. (A) XSA without shrinkage; (B) XSA with shrinkage; (C) VPA without shrinkage; (D) VPA with shrinkage.

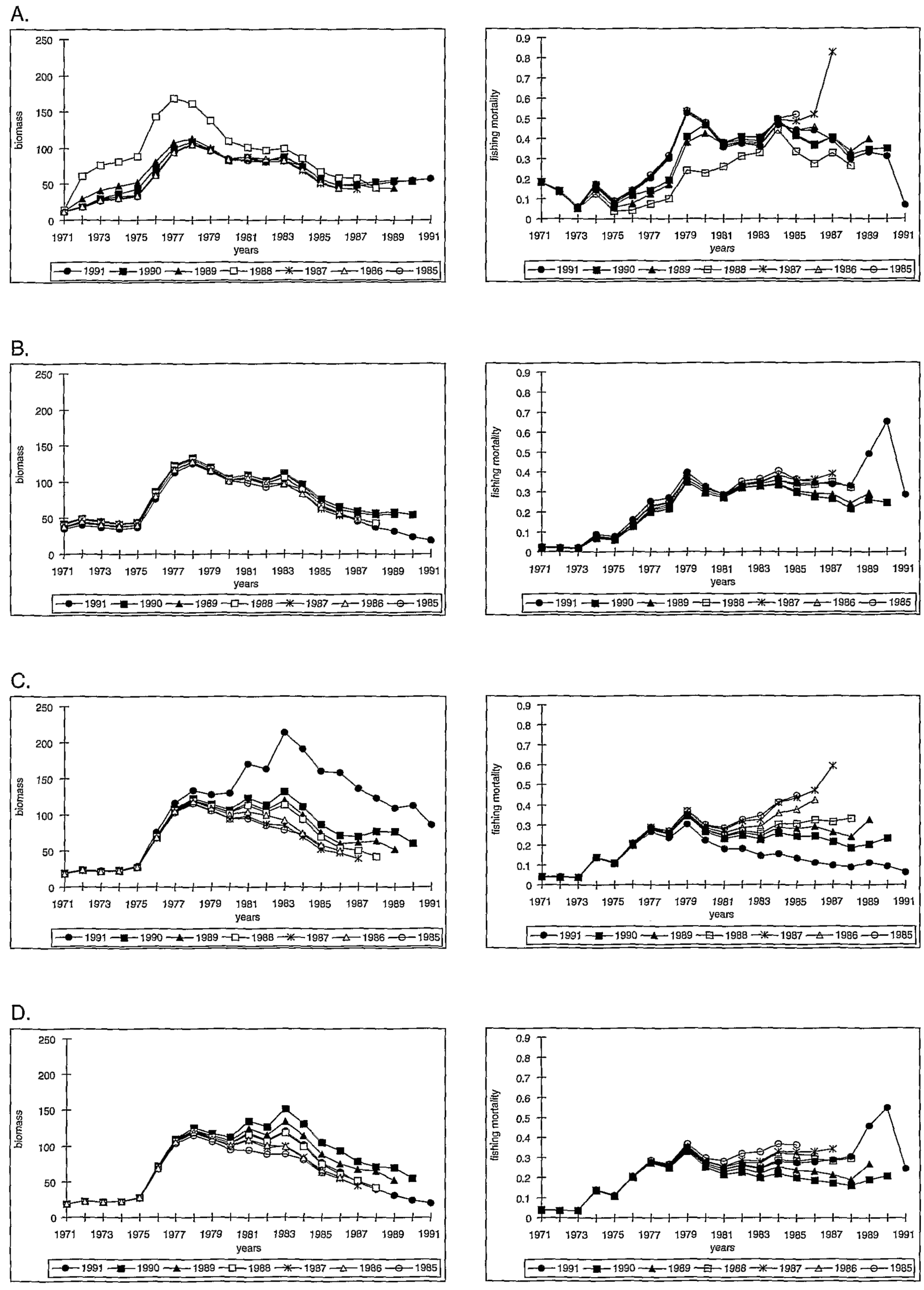

Fig. 5. Retrospective analyses of whiting. (A) XSA without shrinkage; (B) XSA with shrinkage; (C) VPA without shrinkage; (D) VPA with shrinkage.

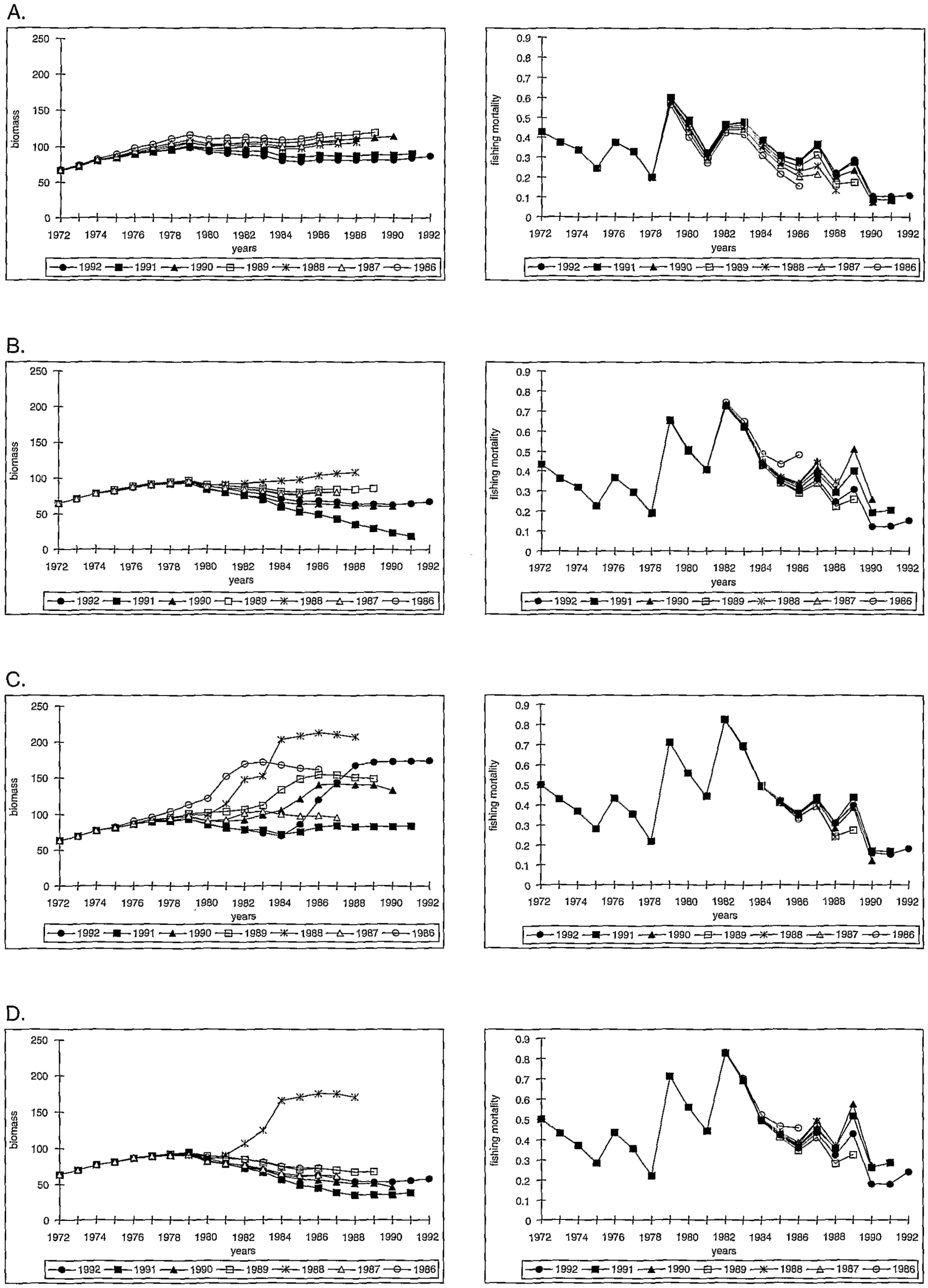

Fig. 6. Retrospective analyses of spiny dogfish. (A) XSA without shrinkage; (B) XSA with shrinkage; (C) VPA without shrinkage; (D) VPA with shrinkage.

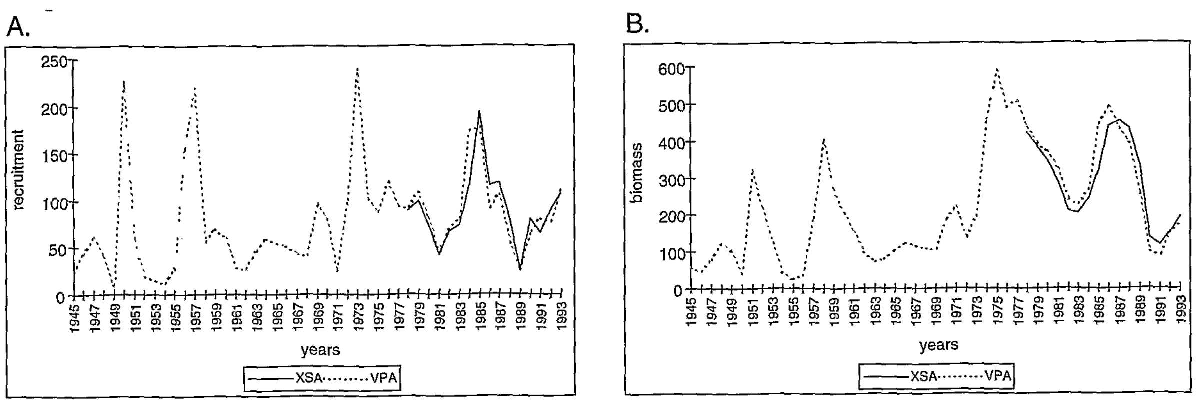

Fig. 7. Sprat recruitment-at-age 0.5, in billion nos (A); and biomass, in thousand tons (B) over the years obtained by Extended Survivor Analysis (XSA) and VPA with *ad hoc* tuning (VPA).

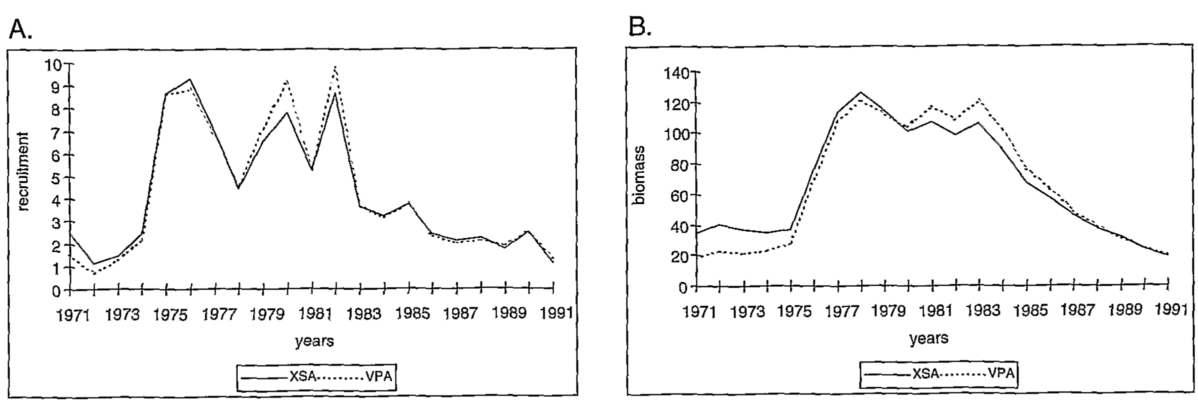

Fig. 8. Whiting recruitment-at-age 0.5, in billion nos (A); and biomass, in thousand tons (B) over the years obtained by Extended Survivor Analysis (XSA) and VPA with *ad hoc* tuning (VPA).

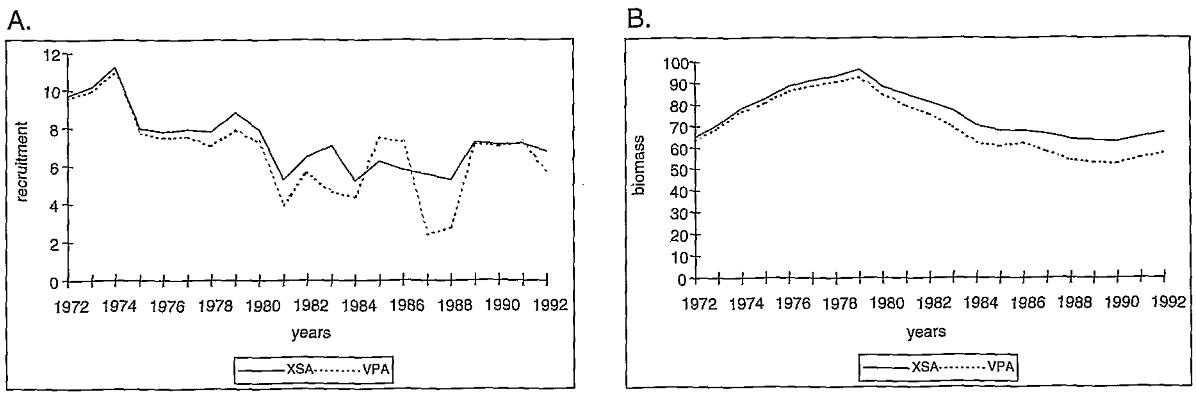

Fig. 9. Spiny dogfish recruitment-at-age 4, in million nos (A); and biomass, in thousand tons (B) over the years obtained by Extended Survivor Analysis (XSA) and VPA with *ad hoc* tuning (VPA).

Table 1. Average fishing mortality (A); (B) selectivity; (C) stock abundance (billion nos); and (D) biomass (thousand tons) of sprat over periods in which exploitation pattern is assumed to be constant

A.

Period	1945-56	1957-73	1974-93
F0.5	0.001	0.004	0.002
F1	0.108	0.053	0.224
F2	0.149	0.080	0.280
F3	0.012	0.037	0.342
F4		0.037	0.230
F5+			0.230

B.

Period	1945-56	1957-73	1974-93
S0.5	0.019	0.061	0.011
S1	0.860	0.713	0.705
S2	1	1	1
S3	0.156	0.480	0.991
S4		0.480	0.717
S5+			0.717

C.

Period	1945-56	1957-73	1974-93
N0.5	56.82	76.10	91.87
N1	24.03	37.50	51.56
N2	6.87	10.18	17.14
N3	2.06	2.88	5.18
N4		0.12	1.55
N5+			0.17

D.

Period	1945-56	1957-73	1974-93
B0.5	108.0	144.6	189.4
B1	61.8	98.2	181.5
B2	27.6	44.9	104.1
B3	11.8	18.4	39.6
B4		1.1	13.7
B5+			1.7

Table 2. Average fishing mortality (*F*), selectivity (*S*), stock abundance (*N*, million nos) and biomass (*B*, thousand tons) of: (A) whiting (1971-1991); and (B) spiny dogfish (1972-1992)

A

Age	*F*	*S*	*N*	*B*
0.5	0.068	0.218	4,053.29	16.2
1	0.157	0.506	1,976.54	22.9
2	0.227	0.735	878.35	18.8
3	0.265	0.855	363.33	12.2
4	0.310	1	140.99	6.8
5	0.291	0.941	52.11	3.3
6	0.299	0.966	19.79	1.6

B

Age	*F*	*S*	*N*	*B*
4	0.000	0.000	6.88	5.5
5	0.001	0.001	5.89	6.5
6	0.002	0.002	4.85	7.3
7	0.004	0.004	3.97	7.7
8	0.005	0.005	3.20	7.7
9	0.022	0.021	2.57	7.2
10	0.022	0.021	2.02	7.2
11	0.034	0.033	1.57	6.8
12	0.080	0.078	1.21	6.3
13	0.231	0.226	0.88	5.4
14	0.320	0.312	0.55	3.9
15	0.686	0.669	0.31	2.5
16	0.887	0.865	0.13	1.1
17	1.025	1	0.05	0.5
18	0.622	0.607	0.02	0.2
19+	0.622	0.607	0.00	0.1

The results of applying CAA combining fisheries data and additional information on the three species have shown, that the stock assessment accuracy depends both on the quality of the data and on the model assumptions relevance to the data. When several not contradictory tuning indices are available (the case with sprat), consistent assessments can be made. In the cases with whiting and spiny dogfish tuning data for the adult stock seem not to contain enough useful information. They are in disagreement with some model assumptions. The survey index for dogfish has been considered not to be representative for the overall stock dynamics. For some ages the model assumptions seems to be in agreement with the data, but for others - they are strongly violated. As it is quasi impossible to ameliorate the data for past periods the only possibility in order to improve the historical assessments is to reformulate the assumptions.

Discussion

The stock and yield dynamics of the three species studied are influenced globally by changes in the Black Sea fisheries ecosystem, and locally by the species interactions. Besides the natural fluctuations of the marine environment, the man- induced eutrophication and the over-fishing are the factors severely impacting the Black Sea during the last 20 years. The sprat as small pelagic planktivorous fish has intermediate position in the food web and depends strongly on both inferior and superior trophic levels. Spiny dogfish is an important predator for whiting and both dogfish and whiting feed on sprat (Shlyakhov, 1985; Kirnosova and Lushnikova, 1990).

Prior to the 70s the three species were exploited by artisanal fisheries and the catches were low. The sprat stock biomass was highly variable and periods of great abundance (1948-52, 1958-61) were followed by weaker ones (1953-57, 1962-1964). The fishing mortality in the first period was relatively low due to the passive way of fishing with traditional gears like trapnets and beach seines. After 1969 the sprat biomass increased and reached its maximum during the mid 70s. Biomass maxima of whiting and dogfish were observed in the late 70s. The industrial trawl fishing for sprat began in the early 70s and reached record levels during the 80s. Generally, whiting in the Western Black Sea appears mainly as by-catch to the sprat catches but dogfish is also an object to special fisheries because of its high commercial value. Between the factors that can be related to the high pelagic fish productivity in the 70s are the extinction of the Black Sea mackerel stock and the strong decline of such top predators as bonito, bluefish and dolphins. At the same time the basin's eutrophication led to an outburst of plankton and an increased carrying capacity of the system.

After reaching their maxima in the 70s the abundance trajectories of the three species go down for the early 80s along with growing up catch rates. In that period the most intensive fishing on the three species took place. The eutrophic plankton hyperproductivity seems to have impacted negatively the ecosystem in the 80s. The plankton unused in the pelagic food web and the detritus conditioned bursts of planktivorous megaloplankton. In the early 80s a dominant species in the pelagic community was the jellyfish *Aurelia aurita*, which has been associated by some researchers (Shul'man *et al.*, 1994) with the decline in the sprat biomass and body condition. In the mid 80s another peak in sprat abundance took place followed by the rise of the landings up to the maximal recorded level of 105 thousand tons in 1989. The whiting and dogfish stocks continued to decline. After 1987 the introduced ctenophore *Mnemeopsis* sp. became dominant in the pelagic system. After 1988 a sharp decline of sprat biomass occurred. It was accompanied by an increase in the fishing mortality in 1989 owing to the high fishing effort in the sprat fishery of the former USSR. During 1989-1991 the *Mnemiopsis* biomass reached maximal values. The ctenophore competes with fish for plankton food and there is also evidence that it feeds on some fish larvae (Grishin, 1994). The ctenophore can be considered as a factor for the recent negative changes in the sprat stock.

The pronounced cycle recurrence in the sprat population dynamics argues for some global determination concerning the stock as well as the whole ecosystem, due primarily to the climatic factor. On the other hand, the anthropogenic impact expressed mainly as eutrophication and bioresources over-exploitation has become very important in the last decades.

Regardless of the high reproductive potential of the sprat population and the existing opinions that the stock is underexploited, the peculiarities of the ecology and behaviour of this species can easily bring to situations with overexploitation and stock depletion. Similarly to other small pelagic fishes the sprat is characterized by a marked variability in the recruitment, as well as by negative dependence of the catchability on the stock size, owing to enhanced availability of the stock to the fishery even in cases of reduced stock. Thus, the cumulative occurrence of certain circumstances like weak recruitment, unfavourable environmental conditions, heavy fishing can result in low survival and stock depletion. Whiting and dogfish as predators strongly depend on the state of the sprat population. The increasing commercial interest toward these species has promoted a development of specialized fishing technics which can bring the fishing rates to unreasonably high levels, which is very dangerous especially for dogfish as a viviparous, slow growing species with a low population turnover.

Another group of factors having negative influence on the fish populations is related to changes due to the eutrophication. The initial positive effect -the so-called eutrophication fishery production was followed by a period with sharp fluctuations of the biota parameters, raised frequency and intensity of plankton blooms, hypoxia and changes in the communities' structure. The hyperproductivity of the plankton eating invertebrates exerts the greatest impact on the pelagic fish and their larvae.

At present the Black Sea ecosystem and fish in particular are subject to the impact, of both the natural environmental factors and the intensive human activities. The cumulative effect of these factors has to be considered in order to find an explanation for the chaotic behaviour of the system during the last decades. Apart from their commercial importance, fish populations are of utmost significance for the ecosystem "health" having an important controlling function in the trophic web. In this way being a target for a direct anthropogenic impact through the fishery, fish stocks are a crucial element in the global ecosystem management strategy.

Acknowledgements

I would like to thank my colleagues I worked with on the project "Environmental management of fish resources in the Black Sea and their rational exploitation" (1992-1995) (Prodanov *et al.,* 1996) and specially Drs Prodanov, Shlyakhov, Maxim and Ozdamar who provided data and performed analyses on the species considered in this study. I would like to acknowledge Dr. Jordi Lleonart and Prof. Giulio Relini who invited me to attend the 2nd DYNPOP Meeting and the CIHEAM of Zaragoza which supported financially my participation. During the work on this paper I was partly supported by a grant from the Open Society Fund., Sofia.

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