# Stock Assessment of Sprat and Whiting in the Western Black Sea in Relation to Global and Local Anthropogenic Factors

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## ABSTRACT

Historical stock assessments of the Black Sea sprat (1957-1992) and whiting (1976-1992) have been performed using Virtual Population Analysis. Relationships between fish stock parameters (recruitment, spawning biomass, mortality rates) and environmental variables (wind speed and duration, sea temperature, light, phyto- and zooplankton biomasses) have been analyzed using multiple regression models. Strong correlation has been found between sprat recruitment and western winds during November-December and January-March. The western winds force the upwelling of deep waters and their progress shorewards. As the upwelled waters are rich in nutrients and organic matter, they contribute to the intense productivity in the Black Sea. The role of the other variables appears to be less significant. The need for including more reliable data on plankton and ctenophore *Mnemiopsis maccradii* in the analysis is pointed out.

# Résumé

L'évaluation à long terme du stock du sprat *Sprattus sprattus* L. pour la période 1957-1992 et du merlan *Merlangius merlangus euxinus* de 1976 à 1992 en mer Noire a été effectuée par l'analyse des cohortes (VPA, analyse virtuelle des populations). Les relations entre les paramètres des stocks de poisson (recrutement, biomasse féconde et taux de mortalité) et des variables environnementales (vitesse du vent et durée des événements de vent d'ouest, température de la mer, activité solaire, biomasses du phyto- et du zooplancton) ont été analysées avec des modèles de régression. Une corrélation importante a été trouvée entre le recrutement du sprat et les données du vent d'ouest pour novembre-décembre et janvier-mars. Le vent d'ouest est responsable d'un upwelling côtier qui apparaît à certains endroits en fonction de la topographie. La remontée d'eau enrichie en éléments nutritifs et en matière organique, qui contribue aux taux de production, augmente dans ces régions. La contribution des autres variables est moins significative. L'importance d'analyser des données de meilleure qualité sur le plancton et sur le cténophore *Mnemiopsis maccradii* est soulignée.


# Introduction

During the last 30-35 years, the Black Sea ecosystem has been subjected to dramatic changes due to the increased pollution of the basin and the overexploitation of the main commercial fish species. The period of eutrophication dating back to the early 1970s is characterized by structural and functional alterations in the ecosystem as a result of the intensification and spreading of both local and regional phytoplankton blooms. These blooms over the last decade attain their maximum intensity in late spring-summer, a period abnormal for the Black sea, where peak production normally occurred in early spring and autumn. Changes have also been registered in the taxonomic composition of bloom-producing phytoplankton species with succession shifted towards the predominance of Dinophyta and since 1989 — towards an increasing importance of *Chrysophyta* species — *Emiliania huxleyi* and *Phaeocystis pouchettii* (Moncheva, 1991, 1992). Recently some new phyto- and zooplankton species for the Black Sea ecosystem have invaded the basin resulting in dramatic alterations in the food web (Moncheva *et al.*, 1995). During the period under consideration, the abundance of the most common carnivores has sharply decreased: bonito (*Sarda sarda* Bloch), bluefish (*Pomatomus saltator*) and mackerel (*Scomber scombrus*) have almost become extinct in the Black Sea since 1986. This has been the period of rapid intensification of fishing particularly of sprat, horse mackerel (*Trachurus mediterraneus ponticus*) and anchovy (*Engraulis encrasicolus ponticus*) catches of which have been extended from 3.1, 4.9 and 193.3 $10^3$ t (1970) up to 105.2 (1989), 147.7 (1985) and 502.6 (1984) thousand t, respectively. Shljakhov *et al.* (1990) claim that the rapid decline of sprat stock is related both to the deteriorated environmental conditions and to overfishing. In 1982, the ctenophore *Mnemiopsis leidyi* invaded the Black Sea (Zaitsev, 1994; Konsulov and Konsulova, 1993) with a biomass attaining its maximum in 1990-1991 and decreasing thereafter. In 1991 and 1992, the ctenophore biomass was 40.9 and 18.6 million t, respectively. This has resulted in a reduction in the biomass of zooplankton consumed by fish, and of copepod species in particular (Vinogradov *et al.*, 1989; Zaika and Sergeeva, 1991). Taking into account the fact that *M. leidyi* feeds on eggs and larvae of spawning fish, although at less significant rate (Eremeev and Chudinovsky, 1990) it is reasonable to assert that the sharp reduction in sprat, anchovy and horse mackerel stocks is due mainly to the complex impact of the four above mentioned factors: pollution, eutrophication, structural alterations in the ecosystem and intensification of exploitation. All four factors are of local origin and should be distinguished from factors such as global climatic changes, and their impact on the hydrology and hydrochemistry of the basin (Brjantzev, 1989). An example of such global effects is that of sunlight on phytoplankton (Petrova-Karadjova, 1993; Petrova-Karadjova and Apostolov, 1988).

The results of virtual population analyses (VPA) are reported; they aimed at the assessment of sprat abundance and biomass dynamics over the period 1957-1992. Based on these results, an attempt is made to highlight the impact of some abiotic and biotic factors related to global and local anthropogenic causes.

# 1. MATERIAL AND METHODS

The sprat data for VPA to be applied over the period 1957-1992 were collected and analyzed in conformity with the research program of the international project Environmental management of Black Sea fish resources and their rational exploitation, funded by the Central European University Foundation. Experts from Bulgaria, Romania, Ukraine and Turkey participate in this project, which facilitated the integration of available data, including that of fishery statistics. Thus, it became possible for the first time to perform a retrospective assessment of sprat stock in the western part of Black Sea, where most of the catch originates.

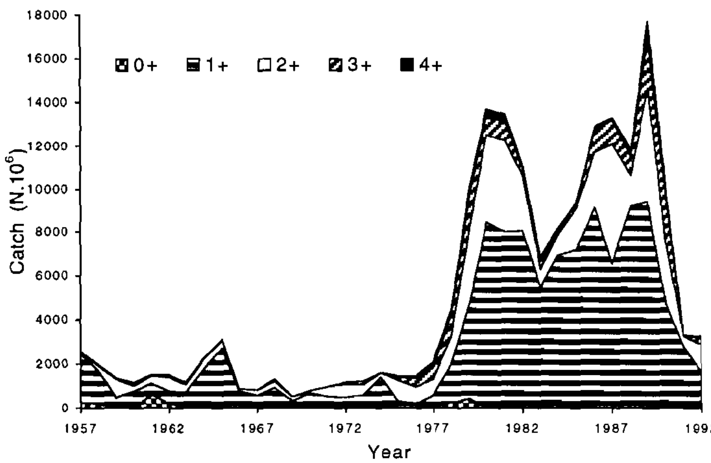
The age composition of sprat catches in the abovementioned regions are presented in Table 1 and Figure 1. Until 1974, the fishery was carried out mostly by coastal fishing gear (trap nets), while thereafter, it was carried out mainly from ships. Thus, after 1974, the catch by coastal fishing gear does not exceed 5% of total catch. That is why the calculated fishing effort for the 1975-1992 period is based on the catch/effort of the fishing fleet and those for the preceding period, on the number of trap nets in the Black Sea countries. Another peculiarity that was considered is the space distribution of the different age groups, as the 3, 4 and 5 years old fishes normally line further offshore, which is why trap net catches are dominated by 1- and 2-year old individuals. With the beginning of the fishing fleet operation deeper waters became exploited, from 20-25 down to 80-110m which resulted in considerable changes in the age composition of the catch (Table 1, Fig. 1). Still, the 1- and 2-year old fishes dominate over the 3-year old individuals, and especially on the 4- and 5-year old fishes (integrated in the age group 4+). The explanation lies in the fact that trawl sprat fishing is of highest intensity in spring-summer months (April-July and in some years in August) at 20-40m depth, when the young-age groups (1- and 2-years), move towards the coastal zone for feeding. During this period the thermocline is located at 15-30m. That is why the older age groups, which prefer colder waters, may be found in deeper waters, although food availability there is

| Years | 0+ | 1+ | 2+ | 3+ | 4+ | 5+ | Total | Catch in weight (C) |
|---|---|---|---|---|---|---|---|---|
| 1957 | 281.63 | 2216.94 | 91.52 | 7.91 | 0.00 | 0.00 | 2598.00 | 6534 |
| 1958 | 214.06 | 1459.66 | 257.17 | 4.99 | 0.00 | 0.00 | 1935.88 | 5793 |
| 1959 | 74.70 | 410.25 | 822.50 | 75.98 | 0.00 | 0.00 | 1383.43 | 5917 |
| 1960 | 0.00 | 781.81 | 254.61 | 127.75 | 0.00 | 0.00 | 1164.17 | 4541 |
| 1961 | 612.95 | 493.98 | 372.50 | 36.56 | 0.00 | 0.00 | 1515.95 | 4228 |
| 1962 | 246.46 | 557.74 | 605.77 | 89.53 | 4.72 | 0.00 | 1504.22 | 5342 |
| 1963 | 0.00 | 749.36 | 334.88 | 93.91 | 4.41 | 0.00 | 1182.56 | 4418 |
| 1964 | 42.44 | 1772.23 | 442.88 | 55.84 | 7.58 | 0.00 | 2320.97 | 7640 |
| 1965 | 0.00 | 2739.56 | 335.34 | 35.15 | 6.51 | 0.00 | 3116.56 | 9480 |
| 1966 | 0.00 | 783.46 | 94.20 | 0.00 | 0.00 | 0.00 | 877.66 | 2704 |
| 1967 | 89.85 | 507.88 | 210.08 | 21.78 | 1.77 | 0.00 | 831.36 | 2669 |
| 1968 | 84.65 | 848.15 | 313.46 | 64.98 | 6.91 | 0.00 | 1318.50 | 4597 |
| 1969 | 27.67 | 316.19 | 179.44 | 27.74 | 1.89 | 0.00 | 552.93 | 2560 |
| 1970 | 37.60 | 646.78 | 77.26 | 10.43 | 1.07 | 0.00 | 773.14 | 3068 |
| 1971 | 36.98 | 497.49 | 440.44 | 16.74 | 1.40 | 0.01 | 993.06 | 4662 |
| 1972 | 59.62 | 407.22 | 586.71 | 110.33 | 1.49 | 0.00 | 1165.37 | 6142 |
| 1973 | 54.91 | 512.79 | 513.68 | 145.92 | 1.92 | 0.02 | 1292.24 | 6483 |
| 1974 | 32.83 | 1401.73 | 175.90 | 20.68 | 1.04 | 0.00 | 1632.18 | 6253 |
| 1975 | 0.63 | 320.08 | 973.40 | 134.55 | 53.18 | 4.81 | 1486.65 | 7127 |
| 1976 | 1.01 | 209.81 | 758.46 | 399.49 | 110.94 | 7.78 | 1487.49 | 10420 |
| 1977 | 45.92 | 555.45 | 715.81 | 551.63 | 253.33 | 4.58 | 2126.72 | 16917 |
| 1978 | 222.54 | 1771.58 | 1282.85 | 939.46 | 234.73 | 34.87 | 4486.03 | 34893 |
| 1979 | 422.41 | 4309.72 | 3432.60 | 1543.36 | 355.96 | 13.77 | 10077.82 | 73732 |
| 1980 | 15.40 | 8464.69 | 4055.19 | 757.59 | 410.88 | 100.07 | 13803.82 | 84450 |
| 1981 | 39.16 | 7981.03 | 4190.29 | 953.01 | 288.69 | 193.60 | 13644.78 | 96284 |
| 1982 | 19.23 | 8048.58 | 2562.35 | 336.67 | 115.31 | 75.08 | 11157.82 | 75876 |
| 1983 | 13.50 | 5477.16 | 800.38 | 381.61 | 165.07 | 58.09 | 6895.81 | 40913 |
| 1984 | 19.67 | 6926.63 | 915.52 | 195.22 | 87.14 | 9.17 | 8153.35 | 42515 |
| 1985 | 27.78 | 7179.45 | 1872.86 | 240.56 | 31.11 | 0.00 | 9351.76 | 51271 |
| 1986 | 18.18 | 9112.10 | 2540.13 | 1044.34 | 185.99 | 0.00 | 12900.74 | 63610 |
| 1987 | 22.04 | 6550.62 | 5487.69 | 1149.77 | 92.71 | 0.00 | 13302.83 | 79591 |
| 1988 | 1.48 | 9181.94 | 1433.27 | 885.91 | 262.81 | 0.00 | 11765.41 | 66819 |
| 1989 | 22.29 | 9349.17 | 5268.56 | 2176.05 | 902.64 | 0.00 | 17718.71 | 105170 |
| 1990 | 64.97 | 4613.33 | 2734.95 | 2060.84 | 319.30 | 0.00 | 9793.39 | 53896 |
| 1991 | 28.26 | 2761.78 | 470.08 | 36.08 | 20.29 | 0.00 | 3316.49 | 18405 |
| 1992 | 10.06 | 1602.65 | 1274.40 | 320.37 | 58.32 | 4.43 | 3270.23 | 19431 |

Table 1: Age composition ($N.10^6$) of sprat catches in the western part of Black Sea, 1957-1992.

lower. The two periods (1957-1973 and 1974-1992) differ by their predator abundances, which dropped sharply after 1971-1972, with favorable effect on their prey: sprat, anchovy and horse mackerel. Stoyanov (1966) estimated a total mortality rate of 1.14 year$^{-1}$ in 1959 for 1- and 2-year old sprats. The same author, however noted that this figure may be an underestimate, due to the underestimation of 1- year old fish abundance. The analysis of sprat catch suggests that, in that particular year, total mortality was almost equal to natural mortality, e.g. in the range 1.15-1.20 year$^{-1}$. Our estimation of sprat natural mortality for the period 1957-1973, based on indirect estimates of the biomass of their predators (mackerel, bonito, bluefish), are presented in Table 2.

Fig. 1: Bulgarian sprat catches by age groups (N $10^6$) from 1957 to 1992.




| Year | M | Year | M | Year | M | Year | M |
|---|---|---|---|---|---|---|---|
| 1957 | 1.27 | 1961 | 1.32 | 1965 | 1.22 | 1969 | 1.31 |
| 1958 | 1.17 | 1962 | 1.29 | 1966 | 1.27 | 1970 | 1.25 |
| 1959 | 1.18 | 1963 | 1.25 | 1967 | 1.36 | 1971 | 1.13 |
| 1960 | 1.32 | 1964 | 1.15 | 1968 | 1.34 | 1972 | 1.06 |
| — | — | — | — | — | — | 1973 | 0.98 |

Table 2: Estimates of natural mortality coefficient for sprats (M . $year^{-1}$).

After 1973, a constant M of 0.95 $year^{-1}$ value was assumed (Domashenko and Ijurev, 1978). The relationship between spawning biomass ($B_{1\text{-}4+}$) and recruitment abundance (R) is determined by the equations of Ricker (1975) and Ivanov (1977):

$$R = aB\, e^{-bB} \qquad (1)$$

$$R = aB - bB^2 \qquad (2)$$

The influence of environmental factors on sprat recruitment was evaluated by applying linear and nonlinear relationships as well as multiple linear regression.

The correlation coefficients (r) for the corresponding equations were calculated from:

$$r = [1-\Sigma(R_{Ti} - R_{Fi})^2/(R_{Fi})^2]^{1/2} \qquad (3)$$

where : $R_{Ti}$ = theoretical value of $R_i$; $R_{Fi}$ = the observed value of $R_i$; $R_F$ = mean value of $R_i$.

The coefficient of determination (D%) as a measure of the extent of the variability in $R_i$ value related to the variability of the examined factors is defined by:

$$D\,\% = 100\, r^2 \qquad (4)$$

The coefficient of indetermination (S%) is a measure of the extent of the variability in $R_i$ due to random factors, and is defined by:

$$S\,\% = 100\,(1-r^2) \qquad (5)$$

Equation (3) is applicable both in linear and nonlinear correlations.

## 2. RESULTS AND DISCUSSION

The changes sprat in spawning standing stock biomass ($B_{1-4+}$) from 1957-1992 in the western part of Black Sea are depicted on Figure 2. During the 1967-1992 period, sprat biomass was determined by trawling, and hydroacoustics. The results of these surveys can be compared with the VPA estimates( Table 3).

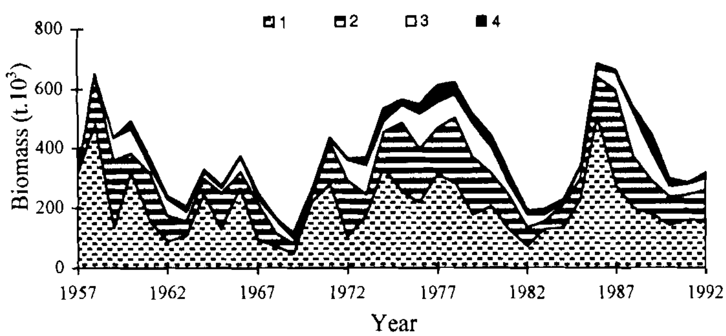



Fig. 2: Sprat spawning biomass (by age groups) in the western part of the Black Sea during 1957-1992.

| Year | Surveys | VPA | Year | Surveys | VPA |
|---|---|---|---|---|---|
| 1967 | 145.0 | 253.2 | 1980 | 1327.5 | 447.5 |
| 1968 | 187.0 | 166.7 | 1981 | 540.5 | 322.8 |
| 1969 | 210.0 | 114.8 | 1982 | — | 190.6 |
| 1970 | 152.0 | 271.0 | 1983 | 104.4 | 195.1 |
| 1971 | 218.0 | 436.0 | 1984 | 187.4 | 226.5 |
| 1972 | 134.0 | 326.8 | 1985 | 20.9 | 336.0 |
| 1973 | 157.0 | 370.7 | 1986 | 300.0 | 684.4 |
| 1974 | 370.0 | 534.3 | 1987 | 480.0 | 663.6 |
| 1975 | 490.0 | 566.0 | 1988 | 108.9 | 540.3 |
| 1976 | 400.0 | 546.6 | 1989 | 109.0 | 448.0 |
| 1977 | 240.0 | 613.4 | 1990 | 78.0 | 295.9 |
| 1978 | 633.9 | 623.1 | 1991 | 95.0 | 286.5 |
| 1979 | 792.5 | 515.9 | 1992 | 475.0 | 316.4 |

Table 3: Sprat biomass ($10^3$ t) in the western part of the Black Sea during 1967-1992, as estimated by hydroacoustic surveys and by VPA.

The biomass estimated by hydroacoustics refer to the entire Black Sea. As obvious in some specific years the differences between the two estimates are considerable, particularly in 1980 and 1986 (880 and 384 t.$10^3$, respectively). Similar differences occur between the VPA estimates of recruitment and the fingerling abundances estimated by ichthyoplankton surveys conducted in May-June (Table 4).

| Year | Surveys | VPA | Year | Surveys | VPA |
|---|---|---|---|---|---|
| 1967 | 30.9 | 75.9 | 1980 | 51.3 | 103.0 |
| 1968 | 51.3 | 45.0 | 1981 | 68.7 | 56.8 |
| 1969 | 22.0 | 199.0 | 1982 | 368.3 | 104.0 |
| 1970 | 74.2 | 229.0 | 1983 | 86.9 | 108.0 |
| 1971 | 6.1 | 82.8 | 1984 | 276.6 | 179.0 |
| 1972 | 163.1 | 137.0 | 1985 | 215.3 | 400.0 |
| 1973 | 31.5 | 263.0 | 1986 | 22.1 | 215.0 |
| 1974 | 32.0 | 201.0 | 1987 | 92.1 | 160.0 |
| 1975 | 52.0 | 173.0 | 1988 | 23.9 | 141.0 |
| 1976 | 28.9 | 247.0 | 1989 | 38.1 | 112.0 |
| 1977 | 30.5 | 225.0 | 1990 | 440.9 | 128.0 |
| 1978 | 60.1 | 140.0 | 1991 | 93.4 | 121.0 |
| 1979 | 48.6 | 163.0 | 1992 | 193.1 | Ñ |

Table 4: Estimated (N.$10^9$ of sprat fingerlings (0+) during 1967-1992, from ichthyoplankton surveys and VPA.

The sources for the differences in the survey and VPA estimates in Table 3 and 4 are not obvious, and, pending detailed study assumed to be due to the heterogeneity of the data we used.

The estimates of the parameters of equation (1) and (2) and their corresponding values for $B_{opt}$ and $R_{max}$ are presented in Table 5.

| Equations | a | b | r | D% | S% | $B_{opt}$ | $R_{max}$ |
|---|---|---|---|---|---|---|---|
| 1 | 0.85262 | 0.00185 | 0.535 | 28.62 | 71.38 | 540.1 | 169.4 |
| 2 | 0.89169 | 0.00124 | 0.543 | 29.48 | 70.52 | 400.6 | 198.6 |

Table 5: Parameters estimates of equations (1) and (2), and the corresponding values for $B_{opt}$ (t.$10^3$) and $R_{max}$ (N.$10^{-9}$).

The multiple regression model used to investigate the impact of various factors on sprat recruitment (R) has the form

$$R = a\,B + b\,Z + c\,X_1 + d\,X_2 + e\,X_3 + f\,X_4 + g\,X_5 + h\,X_6 \qquad (6a)$$

Where:

B is the parental biomass;
Z the total mortality;
$X_1$ the phytoplankton standing stock;
$X_2$ the zooplankton standing stock;
$X_3$ the sea surface temperature;
$X_4$ the amount of sunlight;
$X_5$ the intensity of cosmic rays; and
$X_6$ an index of the Earth's geomagnetism.

These variables were introduced one at a time, starting with R=f(B) and ending with the full model in (6a). Table 6 summarises the results thus obtained.

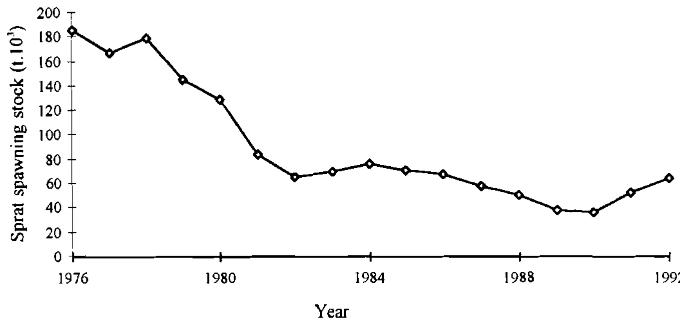
Sprat biomass along the Bulgarian Black Sea coast from 1952 to 1992 is illustrated in Figure 3. The overall trend has a maximum in the period 1974-1979, and decreases to about $35.10^6$ t after some fluctuations in 1990, after which biomass again increases. The variability in sprat biomass seems mainly dependent on the number of its predators. Their sharp decrease after 1968-1971 resulted in an increase in sprat standing stock, which coincided with a period (1975-1978) of sprat fishery intensification. In 1981 the Bulgarian catches reached the figure $19.10^9$ t, where after a decline occurred, especially during 1990-1991. The latter period coincides with the invasion of the new ctenophore whose biomass attained its peak in this particular period. The present trend of sprat biomass recovery may be related to the decrease in ctenophore abundance and a decrease of fishing effort.

During 1984-1990 regular hydroacoustic assessment of sprat biomass have been conducted in Bulgarian waters, in June-September, excepting the last three years, when the surveys were conducted in June. The results of these investigations together with the VPA estimates are presented in Table 7.

| R = | f(B... | + Z | + $X_1$ | + $X_2$ | + $X_3$ | + $X_4$ | + $X_5$ | + $X_6$ |
|---|---|---|---|---|---|---|---|---|
| a | 139.4 | 144.1 | 170.3 | 754.2 | 775.1 | 947.0 | 1494.6 | 1746.7 |
| b | 0.068 | 0.072 | 0.050 | 0.067 | -0.064 | -0.083 | -0.034 | -0.111 |
| c | | -0.0073 | -0.0045 | -0.0043 | 0.0443 | 0.0491 | 0.0528 | 0.0310 |
| d | | | -0.2217 | -0.3274 | -0.3007 | -0.4464 | -0.4536 | -0.2797 |
| e | | | | -32.65 | -24.00 | -28.51 | -27.00 | -25.32 |
| f | | | | | -1.30 | -1.22 | -1.67 | -1.36 |
| g | | | | | | -3.67 | -5.60 | -5.67 |
| h | | | | | | | -0.12 | -0.14 |
| r | 0.13 | 0.14 | 0.20 | 0.32 | 0.66 | 0.68 | 0.68 | 0.71 |
| D% | 1.9 | 2.1 | 4.3 | 10.4 | 44.5 | 46.6 | 47.2 | 50.7 |
| S% | 98.1 | 97.9 | 95.7 | 89.6 | 55.5 | 53.4 | 52.8 | 49.3 |

Table 6: Parameters values in equation (6), reflecting the relationships between the abundance of sprat recruits in the western part of Black Sea and environmental factors added one at a time.

Fig. 3: Sprat spawning stock (age 1-4+) along the Bulgarian Black Sea coast from 1976 to 1992.




| Year | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | Mean |
|---|---|---|---|---|---|---|---|---|
| Surveys | 24.0 | 69.0 | 77.0 | 16-28 | 74.0 | 25.0 | 70.0 | 51.6 |
| VPA | 76.2 | 71.3 | 67.8 | 57.6 | 50.1 | 37.9 | 35.6 | 56.6 |

Table 7: Hydroacoustic and VPA estimates of sprat biomass ($t.10^3$) along the Bulgarian Black Sea coast from 1984 to 1990.

From 1957 to 1992, the sprat biomass along the Bulgarian Black Sea coast comprised about 23% of total sprat biomass in the western Black Sea, but in 1989 and 1990, it represented only 8.5 and 12.0% respectively.

The values of the parameter of equation (1) and (2) concerning the relationship between sprat biomass and recruitment off the Bulgarian coast are presented on Table 8.

| Equations | a | b | r | D% | S% | $B_{opt}$ | $R_{max}$ |
|---|---|---|---|---|---|---|---|
| 1 | 0.98834 | 0.00607 | 0.390 | 15.2 | 84.8 | 164.8 | 59.9 |
| 2 | 0.49872 | 0.00093 | 0.565 | 31.9 | 68.1 | 268.4 | 66.9 |

Table 8 : Parameter estimates for equations (1) and (2).

The impact of fishing mortality rate during 1973-1989 is estimated by the equations:

$$R = aB - bB^2 + cBF \qquad (7)$$

$$R = aB - bB^2 + cBF + dB^2F \qquad (8)$$

The estimated parameters of these equations are presented on Table 9. This shows that fishing mortality exerts a strong impact on the stock-recruitment relationships.

| Equations | a | b | c | d | r | D% | S% |
|---|---|---|---|---|---|---|---|
| 7 | 1.1356 | 0.0041 | 1.4732 | — | 0.771 | 59.5 | 40.5 |
| 8 | 1.1082 | 0.0035 | 0.9109 | 0.0092 | 0.796 | 63.4 | 36.6 |

Table 9: Parameters estimates for equations (7) and (8).

The second multiple regression model used to investigate the impact of various factors on sprat recruitment (R) has the form:

$$R= aB + bF + cX_1 + dX_2 + eX_3 + fX_4 + gX_5 + hX_6 \qquad (6b)$$

where

B is the parental biomass;
F the fishing mortality;
$X_1$ the duration of the western wind component in November-December;
$X_2$ the mean speed of the western wind component in November-December;
$X_3$ the duration of the western wind component in January-March;
$X_4$ the mean speed of the western wind component in January-March;
$X_5$ the intensity of cosmic rays; and
$X_6$ the amount of sunlight.

As for equation (6), these variables were introduced one at a time, starting with R=f(B) and ending with the full model in (6b).

It is known that the western winds generate an upwelling of deep waters and their shoreward progression. As these waters are rich in nutrients they contribute to phytoplankton bloom in summer. Because of their low temperature and low $O_2$ content they may also be responsible, however, for regional zoobenthic mortality, including of fish species (Rozhdestvenski, 1969; Kolarov, 1970; Dimitrov and Yaneva, 1992).

During the winter similar upwelling of deep waters occurs, but unlike in summer, their temperature is higher than at the surface. For species that reproduce in winter, such as sprat, the upwelling of the deep waters towards the shelf is very dangerous such that this tends to lower the survival of the eggs and larvae.

That is why the wind factor is represented by four variables: $X_1$ (western wind duration in November-December with a speed above 5m/sec - in hours); $X_2$ ( average wind speed in November-December) with $X_3$ and $X_4$ as the corresponding values for January-March.

As is apparent from the results (Table 10), the influence of wind speed is higher than that of wind duration. Wind velocity has a favorable effect while wind duration has a negative one. The joint impact of these variables on recruitment survival is considerable with $r = 0.843$ (D% =73.0%; S% = 27.0%).

The stock-recruitment relationship of sprat, depends both on the predator abundance and on the number of the days with water temperature below 6°C during the reproduction period (November-March). The same author points to the fact that the influence of water temperature is indirect and occurs via the food web. Similar conclusions are drawn by Feldman (1986) who has reported a strong correlation between water temperature and the recruitment of sprat and cod (*Gadus morbua*) in the Baltic Sea. During severe winters sprat recruitment is less abundant while that of cod, increases. In warmer

| R = | f(B... | + Z | + $X_1$ | + $X_2$ | + $X_3$ | + $X_4$ | + $X_5$ | + $X_6$ |
|---|---|---|---|---|---|---|---|---|
| a | 41.9 | -73.0 | -55.8 | -192.6 | -187.0 | -152.4 | -153.7 | 75.6 |
| b | -0.00 | -0.068 | -0.06 | -0.021 | -0.018 | -0.020 | -0.020 | -0.017 |
| c | | 16.29 | 15.52 | 8.77 | 8.01 | 7.913 | 7.90 | 4.16 |
| d | | | -0.023 | -0.065 | -0.05 | -0.052 | -0.052 | -0.062 |
| e | | | | 21.31 | 20.16 | 17.95 | 17.91 | 21.68 |
| f | | | | | 0.048 | -0.007 | -0.008 | 0.093 |
| g | | | | | | -39.26 | -39.13 | -14.48 |
| h | | | | | | | 0.00 | -0.052 |
| r | 0.25 | 0.54 | 0.55 | 0.84 | 0.84 | 0.85 | 0.85 | 0.86 |
| D% | 6.2 | 29.4 | 31.1 | 71.0 | 71.4 | 73.0 | 73.0 | 75.4 |
| S% | 93.7 | 70.5 | 68.8 | 28.9 | 28.5 | 26.9 | 26.9 | 24.5 |

Table 10: The parameter values in equations (6), reflecting the relationships between the abundance of sprat fingerlings along Bulgarian Black Sea coast and the investigated factors.

winters this relationship is inversed. The same author claims that low temperatures in February-March restrict zooplankton reproduction rate in the North and Baltic Sea.

Gapishko and Malyshev (1990) documented that small sprat (2.5-3.0 cm of length) feeds principally on *Calanus* and *Pseudocalanus nauplii*. According to these authors the number of individuals with empty stomach depends on the stability of the ratio between nauplii, copepodites and adult forms, as well as on the availability of other nutritive and non-nutritive zooplankton.

Prodanov and Konsulov (1987) established that sprat recruitment along the Bulgarian coast is strongly influenced by status of the food web and by whiting biomass, whose reproduction occurs during the same months and at the same depths for sprat reproduction. During its reproductive period, whiting still actively feeds on sprat and large decapod crustaceans. Small whiting has almost the same food spectrum as small sprat, which implies a high food competition. Since 1985, the recruitment of both species declined resulting in a reduction in their standing stocks.

Table 11 presents the numbers and total biomasses of sprat and whiting for the period 1976-1991, and estimates of whiting recruits (0+) in the Western Black Sea. As might be seen, the sprat abundance decreased by a factor of two from the beginning to the end of the series, while that of whiting declined by 1.4. In this particular case the critical factor seems to be the expansion of ctenophores, which, after their introduction in 1982, sharply expanded in biomass. The estimates of sprat biomass from 1957 to 1992 show great fluctuations, as it has already been stated this may be due to a variety of reasons. Until 1971-1972, environmental conditions and predators play a decisive role. During 1978-1989 the key factors are the intensification of the fishery and environmental alterations, especially the invasion by ctenophores. After 1989 a lowering of pollution of the basin occurred as a result of the economical recession in the former USSR, Romania and Bulgaria followed by a reduction of their industrial production: the chemical industry in particular is operating at present at only 30% of its total capacity. As a consequence during the last 1-2 years, a decline in the phytoplankton blooms occurred, along with a decline of their adverse effects: toxicity, $O_2$ deficiency, asphyxia, etc. (Moncheva *et al.*, 1995). Since 1991, the ctenophores also exhibit a decreasing trend. As a consequence a recovery in sprat stock has occurred. The reduction in fishing effort after 1990 is also thought to here contribute positively to this recovery.

| Year | Sprat biomass | Sprat recruits | Whiting biomass | Whiting recruits | Whiting recruits* |
|---|---|---|---|---|---|
| 1976 | 186.1 | 52.7 | 27.3 | 1.55 | 40.0 |
| 1977 | 167.7 | 75.9 | 25.3 | 1.00 | 10.0 |
| 1978 | 179.0 | 38.1 | 25.2 | 1.45 | 3.0 |
| 1979 | 145.2 | 47.0 | 25.1 | 0.73 | 12.0 |
| 1980 | 129.2 | 18.3 | 21.6 | 1.03 | 23.0 |
| 1981 | 84.6 | 29.6 | 17.9 | 0.74 | - |
| 1982 | 65.6 | 33.1 | 15.7 | 0.97 | 19.4 |
| 1983 | 69.7 | 34.5 | 13.5 | 0.85 | 10.5 |
| 1984 | 76.2 | 29.4 | 14.7 | 0.87 | 3.1 |
| 1985 | 71.3 | 30.2 | 14.6 | 0.66 | 4.5 |
| 1986 | 67.8 | 20.7 | 14.0 | 0.60 | 3.8 |
| 1987 | 57.6 | 20.9 | 12.8 | 0.45 | 0.3 |
| 1988 | 50.1 | 11.0 | 10.9 | 0.90 | 2.7 |
| 1989 | 37.9 | 17.5 | 12.1 | 0.94 | 5.1 |
| 1990 | 35.6 | 26.9 | 14.5 | 0.64 | 20.7 |
| 1991 | 52.4 | 26.3 | 15.4 | 0.51 | 6.0 |
| 1992 | 64.3 | - | - | - | 12.6 |
| Mean | 90.6 | 29.85 | 17.5 | 0.87 | 11.1 |

* abundance of whiting recruits in the entire Black Sea, as estimated from ichthyoplankton surveys.

Table 11: Estimates of sprat and whiting biomass ($t.10^3$) and abundance of 0+ groups (from ichthyoplankton surveys; $10^9$) along Bulgarian Black Sea coast (and entire Black Sea for whithings recruits).

# Conclusion

Fish recruitment abundance depends on numerous natural and anthropogenic factors and its dynamics are difficult to predict. Among the natural variables, the strongest correlation is found between recruitment and the western wind average velocity during November-December and January-March when sprat is actively spawning, at 25-100m depth. The western winds force the upwelling of deep waters and their shorewards progress. As they are rich in nutrients and organic matter, they contribute to the intensive productivity in these regions. The role of the other variables is less important. The comparatively low correlations in equations (6) could be explained to a certain extent by the fact that there is no term in the equation accounting for role of the ctenophore (which is impossible at this stage as there is no long-term data set). The same is valid for phytoplankton bloom data except for the data reported by Moncheva *et al.* (1995). In the case of phytoplankton, the great interannual variability of the species producing blooms restricts the possibility to collect statistically significant long-term data reliable enough to be included in equation (6). Because they were unsure about the relative importance of various factors they considered, Brjantzev (1989) considered the correlations they established as too risky to rely upon for the determination of sprat recruitment. This is similar to the situation with equations (6a, b) which leaves much variance unexplained. The task is now to reduce this unexplained variance and thus to obtain better predictions for the factor that determines biomasses.

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