BLACK SEA SPRAT, *SPRATTUS SPRATTUS PHALAERICUS* RISSO

During the last 20 years, the sprat has been most abundant and commercially important fish species in the western Black Sea. It is also of great importance for the ecosystem since it represents an important link between the plankton community and its predators. Thus its population level exerts top-down control on the lower components of the foodweb, and bottom-up control on the apical components of the ecosystem.

In the specific environmental conditions of the Black Sea the sprat attains a smaller size and has a shorter life span than the same types in the Atlantic and Mediterranean. In view of a large stock the species is of primary importance for energy transfer through the trophic web: the fish ensures the transition from plankton to predators. Among predators of sprat there are invertebrates, fish and mammals. Dolphins, spiny dogfish, mackerel, whiting, turbot, etc. all feed on adult sprats. The early life stages are components of the diet of horse mackerel and predatory megaplankton. This wide spectrum of predators suggests a high natural mortality that determines the short life span and high individual growth rate.

Climatic change is the other factor conditioning such a growth rate: some authors (Stoyanov, 1965) believed that low winter temperatures and strong off-shore winds are one of the major causes for weak year classes.

The Black Sea sprat possesses great adaptive capacity, such as a short life span, hence high stock turnover, high growth rate, early sexual maturity, batch spawning and protracted spawning period. These biological features are specific response to environmental conditions, and they compensate for the high rate of elimination the population is subjected to.

In **Table 39** are presented sprat catches from 1951-1993. From this table, it is seen that Russian landings after 1978 represented 95% of the total sprat catches in the Black Sea; mostly coming rom the north-western part of the basin.

TABLE 39. Sprat landings in the Black Sea (thousand tonnes)

Year	Bulga-ria	Roma-nia	former USSR	Total	Year	Bulga-ria	Roma-nia	former USSR	Total
1951	1.6	0.6	1.7	3.8	1972	3.0	2.3	0.8	6.1
1952	1.2	1.3	0.7	3.1	1973	3.4	2.2	0.9	6.5
1953	0.6	1.4	0.9	2.9	1974	4.5	1.2	0.5	6.2
1954	0.6	2.0	4.4	7.0	1975	5.6	0.7	0.8	7.1
1955	0.5	0.7	0.5	1.7	1976	7.2	1.6	1.6	10.4
1956	1.9	0.9	4.2	6.9	1977	8.7	1.5	6.7	16.9
1957	2.3	0.9	3.3	6.5	1978	10.6	1.5	22.8	34.9
1958	2.3	1.3	2.2	5.8	1979	13.5	2.3	57.9	73.7
1959	1.8	1.4	2.6	5.9	1980	16.6	1.0	66.9	84.4
1960	1.9	1.4	1.3	4.5	1981	18.9	2.3	75.1	96.3
1961	1.2	2.8	0.3	4.2	1982	16.5	3.0	56.3	75.8
1962	1.4	2.1	1.8	5.3	1983	12.0	3.4	25.5	40.9
1963	1.2	2.2	1.0	4.4	1984	13.9	4.5	24.1	42.5
1964	0.9	3.0	3.7	7.6	1985	15.6	6.8	28.8	51.2
1965	1.1	4.4	4.0	9.5	1986	11.5	9.0	43.1	63.6
1966	0.2	0.5	2.0	2.7	1987	11.0	9.5	59.1	79.6
1967	0.7	0.7	1.3	2.7	1988	6.2	6.5	54.2	66.9
1968	1.1	1.7	1.7	4.6	1989	7.4	8.9	88.9	105.2
1969	1.1	0.9	0.5	2.6	1990	2.7	3.2	48.0	53.9
1970	1.4	1.3	0.3	3.1	1991	1.9	7.3	15.7	24.9
1971	2.5	1.3	0.8	4.7	1992	2.9	2.1	14.6	19.5
					1993	2.4	2.4	9.0*	13.8

The growth analyses were performed on the basis of summarised mean length at ages in Bulgarian catches for cohorts of seasons 1977-1990, as well as on data from Ukrainian trawl surveys carried out in May-June 1980-1990 (**Table 40**). Growth was simulated by means of the von Bertalanffy's function (VBGF), and the software VONBER has been used for this purpose (Sparre, 1987).

TABLE 40. Length at age data (TL in *cm*) and VBGF parameters from YugNIRO TS

Age	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	6.65	6.76	6.54	6.21	6.43	6.98	6.65	6.87	7.64	6.76
1	8.74	9.07	9.29	9.40	9.51	8.63	8.85	9.18	9.18	8.52
2	10.17	10.28	10.06	10.17	10.06	10.28	10.61	10.17	10.28	10.06
3	10.61	10.73	10.61	10.50	10.39	10.95	11.61	10.61	10.95	10.95
4	11.94	11.83	11.94	11.72	11.83	11.94	12.38	11.94	11.94	11.83
L_∞	13.46	12.48	12.24	11.50	11.59	14.11	14.19	12.69	14.27	14.04
k	0.339	0.464	0.516	0.77	0.7	0.287	0.36	0.417	0.244	0.292
phi'	1.788	1.859	1.889	2.008	1.974	1.757	1.860	1.827	1.697	1.760

For the purpose of analysis of annual dynamics the growth performance index was applied (Pauly and Munro, 1984):

(1) $phi' = \log_{10}k + 2 \times \log_{10}Loo$

For determining the theoretical limits of variation of the total and natural mortality coefficient different theoretical and empirical equations described in Veffer (1988) and Sparre (1989) Black Sea parameters derived from the literature were used.

Assessments of mortality coefficients, the optimal level of exploitation, stock-recruitment relationships and the level of total, exploited and spawning biomasses, are presented in the papers of Stoyanov (1966); Ivanov (1983, 1990,1994); Ivanov and Beverton (1985); Efimov *et al.* (1985); Prodanov (1990); Prodanov and Daskalov (1992), Daskalov (1993), Daskalov and Prodanov (1995).

Table 41 shows the results of YugNIRO ichthyoplankton trawl and acoustic surveys for April-June.

TABLE   41. YugNIRO research survey assessments: offspring ($N*10^{-9}$) from ichthyoplankton surveys (IS) in April and parent stock ($tonnes*10^{-3}$) from trawl and acoustic surveys in May-June

Year	1967	1968	1969	1970	1971	1972	1973	1974	1975
offspring	30.9	51.3	22.0	74.2	6.1	163.1	31.5	32.0	52.0
parent stock	145.0	187.0	210.0	152.0	218.0	134.0	157.0	370.0	490.0
Year	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**
offspring	28.9	30.5	60.1	48.6	51.3	68.7	368.3	86.9	276.6
parent stock	400.0	240.0	960.8	1071.6	1609.6	740.0	427.2	288.5	492.8
Year	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**
offspring	215.3	22.1	92.4	23.9	38.1	440.9	93.4	193.1	269.4
parent stock	215.3	22.1	92.4	23.9	38.1	440.9	93.4	193.1	

Age composition data of combined catches (1953-1966) and from trawl surveys (1967-1992) were explored by the linearized catch curve (Sparre, 1989):

(2) $\ln C_t = g - Z * t$

between the obtained values of Z by years and standardised effort (f) for two periods: 1953-1973 with primarily a near shore fishery (with passive gears) and high stocks of pelagic predators, and 1976-1992 with a trawl fishery and reduced predatory impact. Regressions were performed in order to find the mean annual natural mortality coefficient:

(3) $Z = M + q * E$

The fishing effort for the first period was estimated on the basis of data on trapnet numbers per year concerning Bulgaria, Romania and the former USSR, and for the second period from trawl catch data (**Table 42**). Fishing effort was standardised by dividing the total catch by the sum of weighted by corresponding catch relative CPUE by gears (details of the method in Spare, 1989).

A number of researchers, including the results of MSVPA, showed that natural mortality coefficient of recruits is different and often sizeably higher for the parent stock. In order to obtain approximate estimates of M for age 0+ (July-December) the relationship derived by Petersen and Wroblewski (1984) and the theoretical individual weight (w) of 0+ year old fish in the beginning of October: 3.17 g (Ivanov, 1983) were used.

(4) $M(w) = 6.1 * 10^{-8}(s-1) * w^{-0.25}$

To obtain estimates of fishing mortality and number at age during VPA was used. Data are presented in **Table 43.**

TABLE 42. Total catch at age (N x 10^{-6}) and stock weight at age (g) in the beginning of the year matrices used in VPA

Year	Catch	at age	N x 10^{-6}				Wt	at	age,	g		
age	0+	1	2	3	4	5	0+	1	2	3	4	5
1951	0.0	1620.3	8.3	23.1	0.0	0.0	1.9	2.6	3.9	5.3	8.2	10.7
1952	0.0	268.8	492.6	0.0	0.0	0.0	1.9	2.5	4.1	5.9	7.9	10.7
1953	0.0	525.4	218.2	44.1	0.0	0.0	1.9	2.7	3.5	6.0	8.6	10.7
1954	0.0	1615.8	655.7	70.3	0.0	0.0	1.9	2.3	3.6	5.5	8.5	10.7
1955	0.0	512.2	93.7	2.4	0.0	0.0	1.9	2.3	3.7	5.1	8.4	10.7
1956	202.4	2145.2	281.5	0.0	0.0	0.0	1.9	2.0	3.5	5.8	8.2	10.7
1957	227.7	2668.2	113.7	7.0	0.0	0.0	1.9	2.2	3.4	5.1	8.3	10.7
1958	210.7	1613.7	316.3	6.1	0.0	0.0	1.9	2.7	3.7	5.5	7.9	10.7
1959	90.5	431.8	843.8	76.7	0.0	0.0	1.9	2.5	4.4	5.9	8.1	10.7
1960	0.0	891.0	295.7	162.5	0.7	0.0	1.9	3.0	4.3	5.8	8.4	10.7
1961	631.7	491.2	371.4	35.8	1.8	0.0	1.9	2.9	4.4	6.0	8.1	10.7
1962	277.0	576.3	589.2	91.2	5.8	0.0	1.9	2.6	4.5	6.0	8.2	10.7
1963	0.0	751.1	337.5	96.8	5.1	0.0	1.9	2.7	4.2	5.8	8.6	10.7
1964	52.3	1728.1	505.8	62.8	9.8	0.0	1.9	2.3	4.1	6.3	8.2	10.7
1965	0.0	2900.8	372.0	40.7	8.0	0.0	1.9	2.2	4.0	6.2	8.7	10.7
1966	0.0	840.0	122.0	22.2	1.8	0.0	1.9	2.9	4.1	6.2	8.8	10.7
1967	97.1	340.5	142.8	19.7	0.7	0.0	1.9	2.3	4.4	6.9	8.6	10.7
1968	75.5	680.3	269.5	44.0	5.7	0.0	1.9	2.5	4.4	6.4	9.0	10.7
1969	24.5	298.5	171.9	26.4	1.7	0.0	1.9	2.7	4.6	6.8	8.8	10.7
1970	34.8	571.2	87.6	13.2	1.6	0.0	1.9	2.8	4.8	6.9	8.7	10.7
1971	33.5	472.6	367.1	19.7	1.4	0.0	1.9	3.0	5.1	7.5	8.8	10.7
1972	60.3	417.1	495.6	87.9	2.0	0.0	1.9	2.6	5.5	7.8	9.3	10.7
1973	60.7	577.3	429.6	126.6	3.5	0.0	1.9	2.8	4.9	7.3	9.6	10.7
1974	30.6	1150.4	176.2	21.2	1.3	0.0	1.9	3.0	5.1	7.1	8.8	10.7
1975	0.4	303.4	783.0	93.7	33.9	3.0	2.6	4.2	6.6	7.6	8.6	10.8
1976	0.8	332.2	723.1	329.6	86.0	5.2	2.7	4.3	6.6	7.7	8.5	10.4
1977	45.9	555.5	715.8	551.6	253.3	4.6	2.5	4.4	6.6	7.6	8.6	10.3
1978	222.5	1771.6	1282.9	939.5	234.7	34.9	2.6	4.1	6.6	7.7	8.6	10.0
1979	422.4	4309.7	3432.6	1543.4	356.0	13.8	2.4	4.2	6.2	7.4	8.2	10.1
1980	68.9	8430.0	4041.0	755.3	409.0	99.5	2.4	3.8	5.6	7.4	8.3	9.9
1981	165.6	7894.6	4161.6	946.6	285.0	191.3	2.2	3.9	6.2	7.5	9.2	10.8
1982	64.6	8014.0	2553.4	335.8	114.8	74.7	2.3	4.4	7.5	8.8	9.6	10.7
1983	30.9	5464	798.4	380.6	164.1	57.8	2.0	4.2	7.0	8.2	9.2	10.3
1984	35.8	6913.3	913.6	194.7	86.9	9.1	1.7	4.1	6.8	7.7	8.5	10.2
1985	58.9	7153.5	1868.2	240.3	3`1.0	0.0	1.8	3.5	7.1	8.5	9.4	11.0
1986	60.7	9082.3	2535.9	1041.6	185.2	0.0	1.9	2.9	5.7	7.8	9.5	10.5
1987	80.6	6516.3	5467.5	1146.2	92.4	0.0	2.0	3.2	6.2	7.5	8.9	10.7
1988	7.1	9177.4	1432.8	885.5	262.7	0.0	1.9	3.6	6.0	8.1	9.4	10.6
1989	119.9	9299.8	5240.2	2162.3	896.6	0.0	2.6	3.6	5.6	7.7	8.8	10.5
1990	538.0	4401.1	2599.6	1952.2	302.3	0.0	1.5	3.0	5.8	6.9	9.1	10.9
1991	162.1	2650.7	449.5	34.7	18.3	0.0	1.5	2.1	4.4	7.1	9.4	10.8
1992	30.6	1614.8	1276.6	318.8	58.1	4.4	1.7	2.1	4.5	6.8	8.6	10.8
1993	559.3	1417.2	1058.3	203.3	5.7	0.0	1.7	2.5	3.6	6.0	7.7	10.8

The matrix of catches was obtained by summing up the corresponding catches of Bulgaria, Romania and the former USSR.

The basic problem in VPA is the determining of the fishing mortality coefficient for the oldest age group. Different modifications of the method solve this problem in different ways. In the present work the software VPA Lowestoft 3.1 package (Parley and Flatman, 1994) was applied.

The separable VPA (Pope and Shepherd, 1982) suggests that fishing mortality at age for every year ($F_{a,y}$) is a result of the influence of a characteristic annual effect ($F_{o,y}$) on the one hand, and age effect on the other hand, expressed by a specific selectivity pattern by ages (S_a). The separable VPA does not require data for tuning.

(5) $F_{a,y} = F_{o,y} * S_a$

The second approach is the VPA with *ad hoc* tuning of fishing mortality using additional information for fishing mortality (Pope and Shepherd, 1985). This method estimates the fishing mortality for the last year ($F_{at,y}$) as proportional to the mean of some proceeding ages ($avF_{ai,y}$) at permanent exploitation pattern.

(6) $F_{at,y} = avF_{ai,y} * S_o$; $0 \quad S_o \quad 1$

The tuning of fishing mortality for the last year was performed by Laurec and Shepherd's method (1983) which assumes permanent catchability at ages (q_a) and log-normal distribution of deviation from the mean value. The fishing mortality by ages and fleets was obtained as:

(7) $F_{a,y,f_1} = F_{a,y} * C_{a,y,f_1} / C_{a,y,tot}$

where: f_1 is index of fleet; C - catch in number.

The catch ability by fleets was respectively:

(8) $q_{a,y,f_1} = F_{a,y,f_1} / E_{y,f_1}$

where F_{a,y,f_1} is fishing mortality for a given fleet; E_{y,f_1} is fishing effort for a given fleet .

The relationships between growth and biomass level was investigated by Fox's function (Fox, 1974):

(9) $q = a * B^{-b}$

The parameters were estimated by the Solver function in the EXCEL spreadsheet. The relationship between yield and fishing mortality coefficient was investigated in the same manner:

(10) $Y = a * F * exp(-b * F)$

The stock-recruitment relationship was established according to the generalized non-linear model of Shepherd (1982):

(11) $R = a * B / [1 + (B/b)^c]$

In our fishery analysis, four data files of catches and efforts were used (**Table 43).** Data from ichthyoplankton surveys (IS) were used for tuning the recruitment abundance for the last year, by constructing regressions between survey data and that obtained through VPA estimates. For this purpose the software RCT3 (Shepherd and Darby, in press) was used.

TABLE 43. Tuning data by fleet: effort in fishing hours (x 10^{-3} and catch-at-age (TS and IS in $N*10^{-9}$)

Year	Bulgaria, Bourgas, $N*10^{-6}$						USSR, Small vessels, $N*10^{-6}$					
	Effort	0+	1	2	3	4	effort	0+	1	2	3	72.
1978	21.2	5.4	376.3	576.7	292.0	43.0	21.2	8.9	1374.3	726.5	163.5	35.
1979	23.8	49.7	524.7	856.5	340.3	36.9	35.5	112.9	2834.6	1064.	167.4	195
1980	25.8	12.7	1165.2	807.1	140.2	24.8	38.2	31.7	4104.4	1686.	271.5	136
1981	24.1	21.9	519.3	1241.	283.1	41.3	48.1	80.0	4445.0	1477.	331.9	51.
1982	25.4	14.2	1364.7	671.3	125.3	10.5	48.0	25.1	3276.9	851.5	81.7	86.
1983	24.7	10.4	1490.0	290.8	92.4	17.3	44.1	12.1	2158.2	258.7	159.2	52.
1984	27.4	17.6	2507.3	268.3	39.4	3.7	43.3	12.9	2422.4	354.4	93.7	13.
1985	20.1	8.1	1969.5	682.3	57.2	5.2	44.5	28.5	3746.4	687.3	44.9	116
1986	21.2	2.7	1349.1	617.2	105.4	13.6	48.8	30.6	4890.3	941.7	519.5	50.
1987	15.5	18.1	748.5	1071.	85.2	7.9	59.9	51.3	4938.3	2910.	513.2	226
1988	14.1	0.9	868.1	286.5	102.2	5.7	68.2	5.1	6835.2	738.9	596.2	781
1989	13.0	20.6	1076.3	570.9	62.2	3.6	80.4	85.9	6380.1	3669.	1777.	277
1990	7.8	28.6	299.9	106.1	29.5	3.3	76.7	448.9	3464.2	2206.	1774.	15.
1991	7.2	20.2	315.6	31.9	5.3	2.6	21.0	128.4	2073.1	384.6	25.0	39.
1992	7.0	7.5	352.3	141.9	11.0	1.3	14.5	19.4	989.6	819.5	221.9	1.2
1993	4.2	16.3	104.5	96.7	24.7	0.5		515.7	1011.6	430.7	61.4	

Table 43 - continued

Year	USSR, Large vessels, Nos*10^{-6}						YugNIRO TS				IS
	Effort	0+	1	2	3	4	1	2	3	4	0
1978	2.1	1.6	240.9	127.3	28.6	12.7	68.3	36.1	8.1	3.6	60.1
1979	13.2	88.2	2215.4	831.9	130.9	28.0	96.0	36.1	5.7	1.2	48.6
1980	13.5	21.8	2829.6	1162.3	187.2	134.9	167.7	68.9	11.1	8.0	51.3
1981	18.3	46.5	2582.8	858.4	192.9	79.4	70.1	23.3	5.2	2.2	68.7
1982	17.3	20.3	2655.2	689.9	66.2	41.8	45.3	11.8	1.1	0.7	368.3
1983	11.8	5.2	933.6	111.9	68.9	37.2	35.1	4.2	2.6	1.4	86.9
1984	4.8	2.4	451.8	66.1	17.5	9.8	62.1	9.1	2.4	1.4	276.6
1985	1.9	2.6	340.6	62.5	4.1	1.2	50.6	9.3	0.6	0.2	215.3
1986	9.1	11.7	1877.2	361.5	199.4	44.9	260.5	50.2	27.7	6.2	22.1
1987	4.8	7.2	696.9	410.2	72.3	7.1	111.2	65.6	11.6	1.1	92.4
1988	3.8	0.5	740.8	80.1	64.6	24.6	34.6	3.7	3.0	1.1	23.9
1989	8.4	11.8	873.0	502.1	243.3	107.0	30.8	17.7	8.6	3.8	38.1
1990	2.7	20.7	159.5	101.6	81.7	12.8	16.1	10.2	8.2	1.3	440.9
1991	0.5	5.1	82.4	15.3	1.0	0.6	32.5	6.0	0.4	0.2	93.4
1992	0.5	1.1	57.4	47.5	12.9	2.3	30.8	25.5	6.9	1.2	193.1
1993		24.3	47.7	20.3	2.9	0.5	88.0	37.4	5.3	0.1	269.4

The third method used was: Extended Survivors Analysis (XSA). Improved analysis of survival (Shepherd, 1992) combines the approaches of tuning and use in *ad hoc* techniques and in RCT3.

Applying the relationship between CPUE and biomass by ages and fleets, XSA tunes the abundance for the last year (Na,yt), assuming constant catchability in time for fully recruited age groups, and year-class strength dependent catchability for the non recruited ones. XSA has a comparatively complex algorithm, described in Darby and Flatman (1994), permitting different ways of weighing a temporal series and "shrinkage" towards mean Fa,yt or Na,yt. XSA was applied for the first time for the Black Sea sprat on the basis of data for tuning, represented in **Table 43**.

To determine the major characteristics of sprat stock dynamics, such as growth rate, mortality rate and biomass, the age structure of catches was analysed. The obtained series of estimates were investigated, searching for some simple relationships. The results obtained (**Table 44**) show that sprat growth parameters undergo considerable variation between years.

The period 1977-1993 was characterized by a decrease in mean size and an increase in growth rate. Growth was smoothed by averaged data for 4 sub periods (Fig. 12). The highest growth rate was observed in the middle of the period while in the beginning and at the end, the curves show a slower growth rate. For both sets of data, a negative correlation occurs between growth and biomass (**Figures 13 a and b**) which indicates dependence of growth on population density, as a result probably of interspecific competition. Weak negative correlation can be seen also between the condition factor (C_f) and biomass (r = - 0.52). This result disapproves the assumption made by Ivanov and Marinov (1992) of the existence of a positive relationship between C_f and the biomass derived from CPUE data. As one can see later on, CPUE is not a representative index of the stock size, due to the strong variability of the catchability coefficient (q) and its dependence on biomass.

TABLE 44. Growth parameters of sprat in Bulgarian waters

Year	L_{oo}	k	ô'	L_1	L	C_f**
1977	12.62	0.329	1.719	0.89	10.59	-
1978*	30.73*	0.042	1.598	0.89	10.13	0.58
1979	14.30	0.271	1.744	1.31	10.17	0.553
1980	16.85	0.145	1.615	1.04	10.67	0.587
1981	12.41	0.594	1.961	1.79	10.40	0.614
1982	12.80	0.427	1.845	1.48	10.23	0.616
1983	13.21	0.344	1.778	1.37	10.10	0.585
1984	12.02	0.544	1.895	1.44	10.27	0.588
1985	13.50	0.282	1.711	1.27	9.80	0.596
1986	12.65	0.404	1.811	1.49	9.80	0.576
1987*	26.03*	0.069	1.670	1.19	9.27	0.581
1988	19.36	0.129	1.684	1.39	9.57	0.554
1989	15.34	0.230	1.733	1.57	9.06	0.568
1990	12.27	0.399	1.770	1.45	9.10	0.593

 * - Growth of this cohort is linear, so it is not adequately modelled by the VBGF
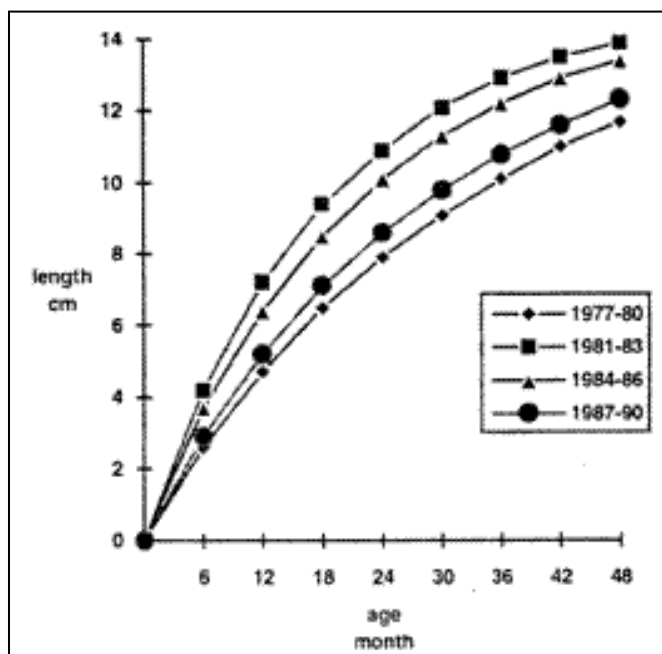** - Data for 1978-1988 are from Ivanov and Marinov (1992)

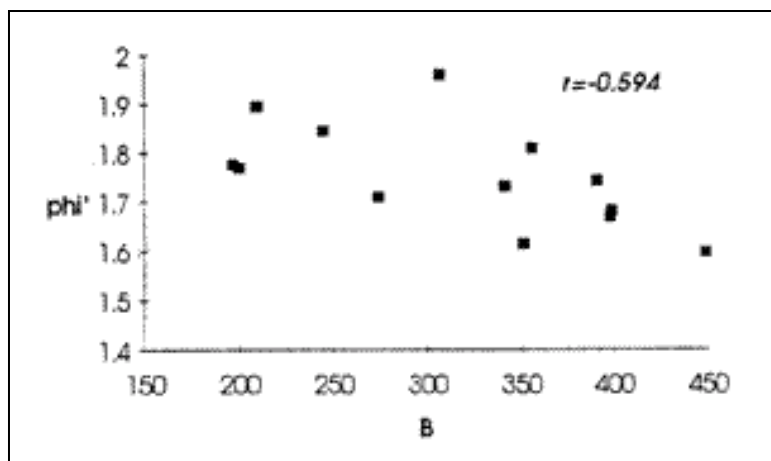**FIGURE 12.** Growth curves for average cohorts 1977-1980; 1981-1983; 1984-1986; 1987-1990

FIGURE 13a. Plot of the growth performance index (phi') from Bulgarian data on the mean biomass (B, in tonnes x 10^{-3})

FIGURE 13b.Plot of the growth performance index (phi') from YugNIRO TS data on the mean biomass for the previous 5 years (B_{i-4}, in tonnes x 10^{-3})

The relationship between sprat growth and various environmental parameters is explored in more detail by Daskalov and Prodanov (1994).

Applying different theoretical and empirical relations (Alagaraya, 1984; Hoenig, 1982; Rikhter and Efanov, 1976; Pauly, 1980 - in Sparre, 1989) place the values of M between 0.85 and 1.3 (a-1); or on average around 1.0. These values are rather close to those reported by Bailey (1980) for the North Sea sprat - 0.8-1.2. The above methods give only superficial idea of the theoretical order of magnitude for the instantaneous coefficient of natural mortality for certain population or species. One may presume that the real values show significant variability, annually and seasonally, as well as between ages.Thus, Ivanov (1983) and Effimov *et al.* (1985) assume variable natural mortality with age and Prodanov *et al.* (1994) variable mean annual values of the coefficient during the period 1957-1973. In the present work two periods are considered separately: prior to and after 1974, that differ as to the state of the fish component of the ecosystem, and the place the sprat occupies in it; (as judged by the interrelations of the landings of different fish species), as well as by the extent and character of sprat exploitation. The analysed data files for the two periods are rather different. Prior to 1974 complete mackerel extinction and strong reduction of bonito and bluefish landings are recorded, while during the 1960s and the early 1970s these were major species for fishery. Stoyanov (1965) paid attention to a probable predator-prey relationship between sprat and mackerel, and between sprat and dolphins. In 1974-1976 the trawl-sprat fishery began and intensified later on.

The calculations obtained by the regression analysis (extreme values were excluded from the analysis) were the following: for 1953-1973 - M = 1.193 (r = 0.534) and for 1976-1992 - M = 0.98 (r = 0.499) (Fig.14 a, b). The value estimated for the second period is quite close to that used so far. For comparison with previous investigations M = 0.95 was used as input value for VPA during 1974-1993. During 1953-1973 a mean annual value of M = 1.19 for the parent stock was adopted.

Applying varying coefficients by age and between years supposes many assumptions, and may lead to a large error. When an appropriate estimate of M is used, a mean value "buffers" the unmeasured interannual variability with age, thus making the results less sensitive to the options of entry parameters. We consider that the problem of age and interannual variability of sprat natural mortality needs additional clarifying for the purpose of this study, we have used constant annual coefficients).

As was already pointed out, the estimation of M for 0+ to 1 year of age is different more due to scarce data and a supposed great fluctuation of mortality in the early ontogenetic stages. The value used up to now of M = 0.56 (Ivanov, Beverton, 1985) has been derived on the basis of the theoretical relationship between survival and age.
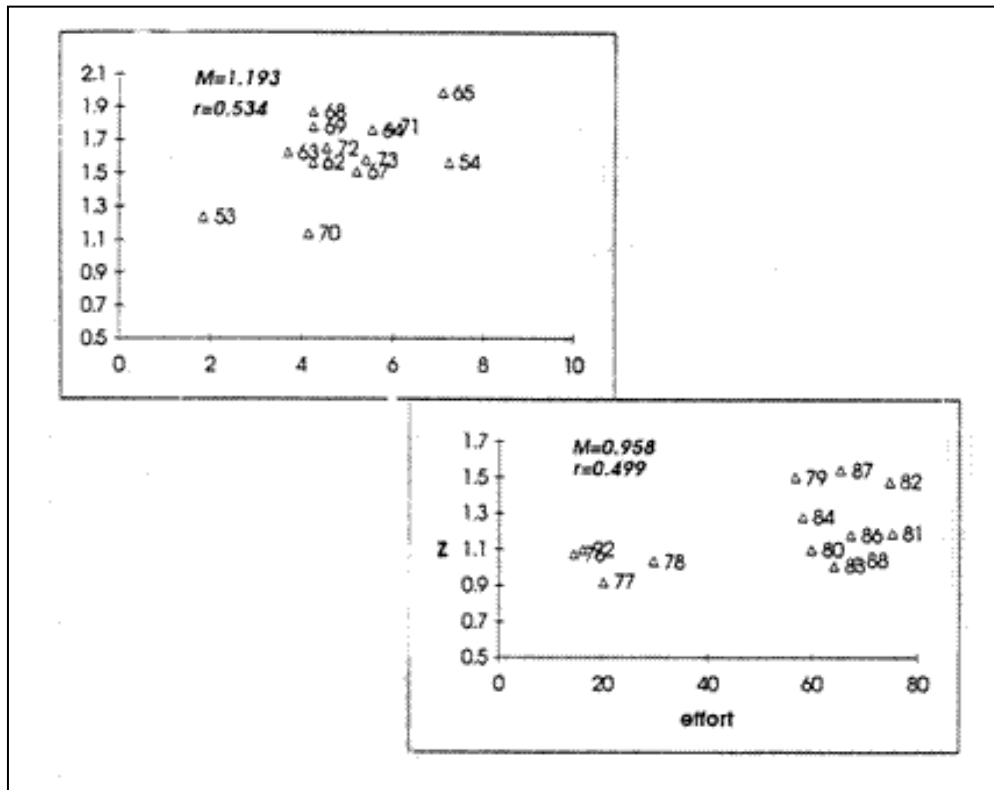

FIGURE 14. Sprat: plot of Z vs effort: a - 1953-1973; b - 1976-1992

The equation we have used is also founded upon assumptions based on the theory of size composition of ecological communities (Kerr, 1974), but it well approximated the empirical data for different species and size of fish and their larvae. Although the authors warn that the relationship derived shows only the common trend in the ecosystem and has not to be used for estimation of natural mortality coefficients for different fish species, the result obtained for sprat: M = 0.719, appears quite realistic (the equation was transformed for calculation of M from 1.07 to 31.12 (a): $M = 0.96*w^{-0.25}$ for w= 3.17 g. Moreover the basic source of mortality is the rapacity as in the case of fish larvae. Besides, the above equation approximates best to data for sizes 0.01 to 10.00 g; the range of weights that most fish larvae lie within.

Since the two estimates, 0.56 and 0.72 are rather suspicious and the choice between them difficult their mean value, M = 0.64, was used for VPA.

The analysis of data for catch at age and fishing effort was carried out using the three methods described above. As plots of fishing mortality and selectivity by age varied in time, constant values were assumed for specified periods, and corresponding proportions of selectivity for the last age in comparison with previous ones, were used for tuning the model. The results are described in **Tables 45, 46, 47, 48** and **Figures 15, 16 and 17**.

TABLE 45. Fishing mortality at age resulting from Extended survivors analysis (Shepherd, 1994)

year age	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
0+	0.0000	0.0000	0.0000	0.0000	0.0000	0.0164	0.0049	0.0031	0.0015	0.0000	0.0113	0.0090	0.0000	0.0012	0.0000
1	0.0266	0.0290	0.1924	1.6309	0.0857	0.3114	0.4805	0.0859	0.0154	0.0369	0.0167	0.0251	0.0605	0.2212	0.1717
2	0.5108	0.0273	0.0812	1.4931	1.5509	0.1910	0.0596	0.2809	0.1661	0.0356	0.0528	0.0682	0.0500	0.1442	0.1925
3	0.2687	0.0281	0.0082	0.0937	0.0491	0.0151	0.0162	0.0110	0.2987	0.1220	0.0145	0.0447	0.0390	0.0316	0.0423
4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0110	0.0048	0.0078	0.0085	0.0132	0.0136
+gp	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F1-3/	0.2687	0.0281	0.0939	1.0726	0.5619	0.1725	0.1854	0.1259	0.1601	0.0514	0.0280	0.0460	0.0498	0.1323	0.1355
F2-3/	0.3898	0.0277	0.0447	0.7934	0.8000	0.1031	0.0379	0.1460	0.2324	0.0562	0.0337	0.0565	0.0445	0.0879	0.1174
FC	0.4102	0.0286	0.1806	1.6227	1.1852	0.2642	0.4550	0.1663	0.1638	0.0514	0.0234	0.0332	0.0574	0.2060	0.1743

year age	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
0+	0.0000	0.0097	0.0085	0.0011	0.0019	0.0004	0.0006	0.0005	0.0004	0.0000	0.0000	0.0007	0.0037	0.0060	0.0013
1	0.1172	0.0566	0.1746	0.0838	0.0656	0.0643	0.0124	0.0144	0.0200	0.0079	0.0115	0.0143	0.0634	0.1706	0.3076
2	0.0266	0.0723	0.1624	0.1726	0.0880	0.1532	0.2545	0.0429	0.0133	0.0362	0.0500	0.0664	0.0891	0.3973	0.5995
3	0.0433	0.0145	0.0790	0.0589	0.0494	0.0704	0.1398	0.2782	0.0065	0.0186	0.0409	0.1061	0.2609	0.3425	0.3252
4	0.0062	0.0048	0.0139	0.0105	0.0122	0.0173	0.0244	0.0201	0.0099	0.0274	0.0455	0.0863	0.1312	0.3454	0.3283
+gp	0.0062	0.0048	0.0139	0.0105	0.0122	0.0173	0.0244	0.0201	0.0099	0.0274	0.0455	0.0863	0.1312	0.3454	0.3283
F1-4	0.0624	0.0478	0.1387	0.1051	0.0677	0.0960	0.1356	0.1118	0.0133	0.0225	0.0370	0.0683	0.1362	0.3140	0.3902
F2-4	0.0350	0.0434	0.1207	0.1158	0.0687	0.1118	0.1972	0.1606	0.0099	0.0274	0.0455	0.0863	0.1604	0.3617	0.4177
FC	0.1097	0.0483	0.1552	0.1112	0.0673	0.0969	0.2052	0.1351	0.0174	0.0252	0.0371	0.0637	0.1123	0.2617	0.3972

year age	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
0+	0.0053	0.0015	0.0006	0.0004	0.0005	0.0008	0.0010	0.0002	0.0063	0.0157	0.0045	0.0005	0.0072
1	0.4063	0.8458	0.3399	0.3247	0.2145	0.1788	0.2160	0.2747	0.6023	0.7252	0.1893	0.1039	0.1013
2	0.6155	0.5433	0.4194	0.1924	0.3120	0.2475	0.3635	0.1475	0.6286	0.9094	0.3302	0.3005	0.2053
3	0.6879	0.1954	0.3260	0.3983	0.1558	0.7505	0.3978	0.2028	0.9677	1.8507	0.0526	1.2647	0.1559
4	0.4699	0.3714	0.3184	0.2579	0.2252	0.4095	0.2962	0.3418	0.8885	0.8913	0.1391	0.2658	0.1253
+gp	0.4699	0.3714	0.3184	0.2579	0.2252	0.4095	0.2962	0.3418	0.8885	0.8913	0.1391	0.2658	0.1253
F1-4	0.5449	0.4890	0.3509	0.2933	0.2269	0.3966	0.3184	0.2417	0.7718	1.0942	0.1778	0.4837	0.1470
F2-4	0.5911	0.3700	0.3546	0.2829	0.2310	0.4692	0.3525	0.2307	0.8283	1.2171	0.1740	0.6103	0.1622
FC	0.4639	0.8004	0.3562	0.3108	0.2390	0.3035	0.2753	0.2566	0.6127	0.7657	0.2250	0.5014	0.1332

TABLE 46.Average fishing mortality (A.) and selectively (B.) over different periods in which exploitation pattern is assumed to be constant

A.

A.

Year	1951-52	1953-58	1959-63	1964-69	1970-73	1974-93
F0+	0.000	0.004	0.004	0.003	0.001	0.003
F1	0.028	0.464	0.031	0.138	0.039	0.256
F2	0.269	0.609	0.075	0.128	0.135	0.323
F3	0.148	0.032	0.104	0.045	0.134	0.425
F4	0.000	0.000	0.006	0.010	0.019	0.299
F+	0.000	0.000	0.000	0.000	0.000	0.298

B.

Year	1951-52	1953-58	1959-63	1964-69	1970-73	1974-93
S0+	0.000	0.007	0.042	0.025	0.006	0.007
S1	0.103	0.762	0.298	1.000	0.291	0.602
S2	1.000	1.000	0.718	0.934	1.000	0.760
S3	0.552	0.053	1.000	0.327	0.999	1.000
S4	0.000	0.000	0.062	0.075	0.137	0.702
S+	0.000	0.000	0.000	0.000	0.000	0.701

TABLE 47. Stock numbers-at-age (x10-6) resulting from XSA

Year age	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
0+	30469	9559	5636	20062	28430	22029	63348	91799	79662	96230	76211	41662	27469	58720	24362
1	105308	16066	5039	2972	10578	14991	11427	33240	48142	41941	50742	39735	21771	14582	30925
2	34	31196	4746	1265	177	2954	3340	2150	9280	14422	12297	15181	11789	6354	3556
3	164	6	9224	1331	86	11	742	957	494	2391	4234	3549	4314	3448	1674
4	0	0	0	0	0	0	0	0	0	111	644	1270	1032	1278	1017
+gp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	135973	56826	26644	25629	39272	39985	78857	128147	135578	155095	144127	101397	66375	84383	61533
N1+	105505	47268	19009	5568	10842	17956	15510	36048	57916	58865	67917	59734	38906	25663	37171

Year age	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
0+	19971	13673	12055	29027	24521	110009	130643	170499	113123	85133	115158	84367	84115	97681	72204
1	12846	10531	7141	6302	15287	12905	57983	68844	89826	59627	44890	60721	46375	44192	51200
2	7924	3476	3028	1824	1764	4355	3682	17423	20631	34051	22879	17162	24192	16834	14411
3	892	2347	984	783	467	491	1137	868	5045	7873	12701	8417	6578	8558	4376
4	488	260	704	277	225	135	139	301	200	1938	2989	4715	3070	1960	2350
+gp	0	0	0	0	0	1	0	1	0	170	179	85	435	71	537
TOTAL	42121	30287	23910	38214	42263	127897	193584	257936	228824	188793	198796	175467	164764	169295	145077
N1+	22150	16614	11855	9186	17743	17888	62941	87437	115701	103660	83638	91100	80649	71614	72873

Year age	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
0+	43046	57918	76085	113061	169236	102358	116641	62693	26188	47606	50108	82694	107690
1	38022	22578	30493	40097	59590	89194	53928	61446	33052	13722	24712	26304	43582
2	14559	9795	3748	8395	11208	18597	28847	16804	18056	6999	2570	7909	9169
3	3060	3042	2200	953	2679	3173	5615	7756	5608	3724	1090	714	2265
4	1223	595	968	614	248	887	579	1459	2449	824	226	400	78
+gp	763	362	320	61	0	0	0	0	0	0	0	29	0
TOTAL	100672	94290	113814	163181	242960	214208	205611	150157	85353	72876	78707	80257	142856
N1+	57626	36372	37729	50120	73724	111851	88970	87464	59165	25269	28598	35356	35165

TABLE 48.Recruitment, r (in Nx10-9); overall fishing mortality, FC; , and parent stock
biomass, B1+ (in tonnes x 10-3) obtained by three alternative methods:
Separable VPA (VPSep), VPA with ad hoc tuning (VPtun) and XSA

| Year	VPsep			VPtun			XSA		
	R	FC	B1+	R	FC	B1+	R	FC	B1+
1951	29.07	0.025	430.8	30.47	0.032	384.7	30.47	0.032	274.8
1952	15.63	0.029	173.6	9.56	0.028	235.3	9.56	0.028	168.1
1953	8.77	0.109	96.3	5.64	0.151	119.8	5.64	0.151	85.6
1954	7.08	0.787	25.5	20.06	1.546	26.0	20.06	1.546	18.6
1955	12.01	0.264	12.7	28.43	0.311	35.6	28.43	0.311	25.4
1956	31.67	0.871	16.6	22.03	0.264	56.5	22.03	0.264	40.4
1957	34.15	0.285	39.6	63.35	0.455	56.4	63.35	0.455	40.3
1958	1620.0	0.160	62.7	91.80	0.166	144.0	91.80	0.166	102.9
1959	54.12	0.177	57.8	79.66	0.164	230.1	79.66	0.164	164.4
1960	118.00	0.121	105.4	96.23	0.051	277.8	96.23	0.051	198.4
1961	64.12	0.039	223.6	76.21	0.023	324.0	76.21	0.023	231.5
1962	54.09	0.034	186.1	41.66	0.033	284.7	41.66	0.033	203.3
1963	52.04	0.049	154.5	27.47	0.057	199.1	27.47	0.057	142.2
1964	46.49	0.108	127.6	59.06	0.206	127.0	58.72	0.206	91.8
1965	31.14	0.207	104.8	23.66	0.176	140.6	24.36	0.174	101.5
1966	19.26	0.084	89.1	20.35	0.113	107.4	19.97	0.110	78.3
1967	12.80	0.045	60.9	13.31	0.048	80.8	13.67	0.048	57.9
1968	12.06	0.167	42.3	11.10	0.158	60.2	12.05	0.155	43.5
1969	44.15	0.119	33.2	25.20	0.117	44.2	29.03	0.111	33.2
1970	23.27	0.055	78.4	20.12	0.076	69.9	24.52	0.067	56.4
1971	99.92	0.074	76.1	77.99	0.114	77.4	110.01	0.097	65.8
1972	171.00	0.218	172.0	88.63	0.256	184.5	130.64	0.205	181.2
1973	288.00	0.159	341.0	125.00	0.178	277.3	170.50	0.135	287.4
1974	140.00	0.011	624.8	76.00	0.024	410.8	113.00	0.017	409.7
1975	68.39	0.017	790.5	70.83	0.035	539.3	85.13	0.025	553.5
1976	74.82	0.028	548.6	89.64	0.057	490.3	115.00	0.037	469.1
1977	68.27	0.060	417.8	71.88	0.092	522.3	84.37	0.064	485.9
1978	74.92	0.147	321.9	76.25	0.144	463.6	84.12	0.112	412.7
1979	82.04	0.344	293.6	85.17	0.312	434.6	97.68	0.262	370.1
1980	68.10	0.445	267.9	63.96	0.423	395.6	72.20	0.397	332.9
1981	47.35	0.508	243.7	38.78	0.502	338.2	43.05	0.464	280.9
1982	57.66	0.616	205.8	50.98	0.808	255.3	57.92	0.800	209.2
1983	89.95	0.314	188.4	69.42	0.383	224.6	76.09	0.356	184.6
1984	120.00	0.236	269.6	134.00	0.325	293.9	113.00	0.311	234.7
1985	162.00	0.193	350.2	152.00	0.225	476.8	169.00	0.239	313.2
1986	88.68	0.226	405.8	84.67	0.311	551.4	102.00	0.304	397.8
1987	104.00	0.273	378.0	102.00	0.289	507.6	117.00	0.275	398.7
1988	50.00	0.270	359.4	49.54	0.277	488.1	62.69	0.257	398.6
1989	28.26	0.721	239.9	23.60	0.736	324.3	26.19	0.613	284.8
1990	47.53	0.790	100.0	50.81	0.877	125.9	47.61	0.766	115.0
1991	59.36	0.187	71.1	61.08	0.228	98.1	50.11	0.225	73.1
1992	38.36	0.317	109.6	82.69	0.559	156.8	82.69	0.501	99.4
1993	93.50	0.127	106.0	93.50	0.109	194.5	108.00	0.133	156.2
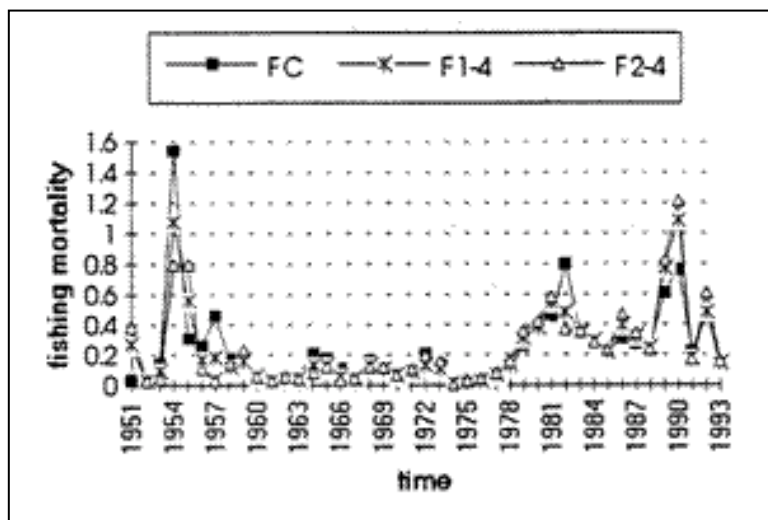
FIGURE 15.Trends in yearly fishing mortality : FC -average weigthed by
yield/recruit-at-age; F1-4 and F2-4 unweighted means over
ages 1-4, 2-4

From Figure 16 and Table 48 it is seen that these methods give the most pronounced
difference for years with maximum biomass. In broad outline XSA showed intermediate values during
this period and due to the high methodological reliability of the method, its results were used for
further analyses. Nevertheless, it is not excluded that for some time periods, the estimates by the
other two methods may be closer to the real values.

The pattern of stock evolution shows conspicuous cyclic recurrence. In the early 1950s 20-40
thousand tonnes decreased and remained at the level till 1957. During the next 10 years period an
increase to 231 thousand tonnes in 1961, and then declines in biomass were recorded. From the
middle of the 1960s until the early 1970s, the stock size was low (30-70 thousand tonnes). In the
early 1970s an increase began which, during 1975-1977, led to record high values (around 400-800
thousand tonnes according to different methods). Until the beginning of the 1980s, a gradual decline
in the biomass followed with a minimum in 1983, but the stock was still considerably higher than
during earlier periods of depression. The rise during 1986-1988 was followed by a sharp decline and
attained its minimum in 1991, when the stock reached figures characteristic for the 1960s (about 70
thousand tonnes). Since 1991, a tendency to increase has been noticed. The contribution of age
groups to the stock size can be seen from Table 47 and Figure 17. Usually the high values of
recruitment were followed in sequence by peaks for stock in age groups 1 and 2 year old fish, 3 and 4
year old participated more appreciably in the years of revival and immediately after (mostly since
1972). The estimates of sprat biomass are akin to those reported by Prodanov et al., 1994 (Figure
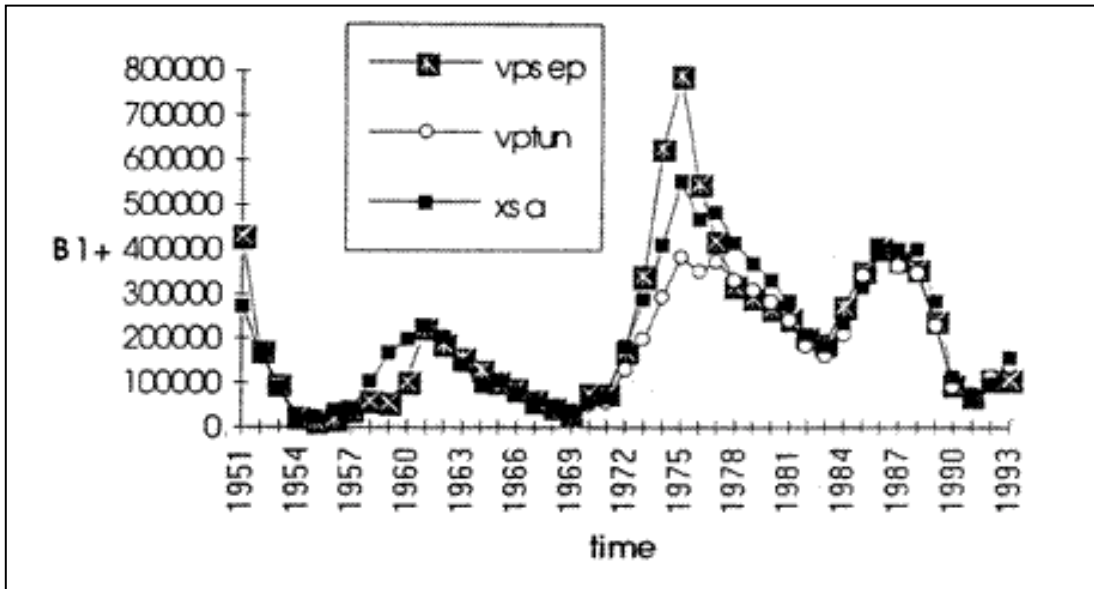18).

FIGURE 16. Sprat biomass (in tonnes) over the years obtained by three methods: Separable VPA; VPA with ad hoc tuning (vptun); XSA
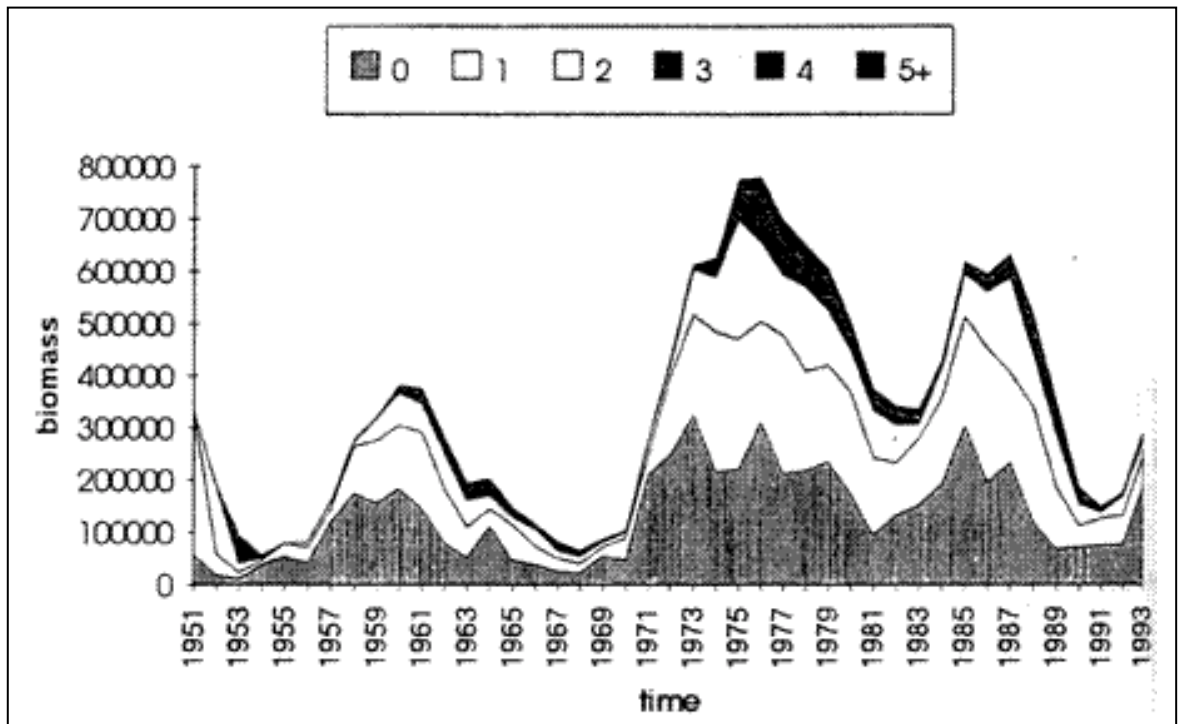
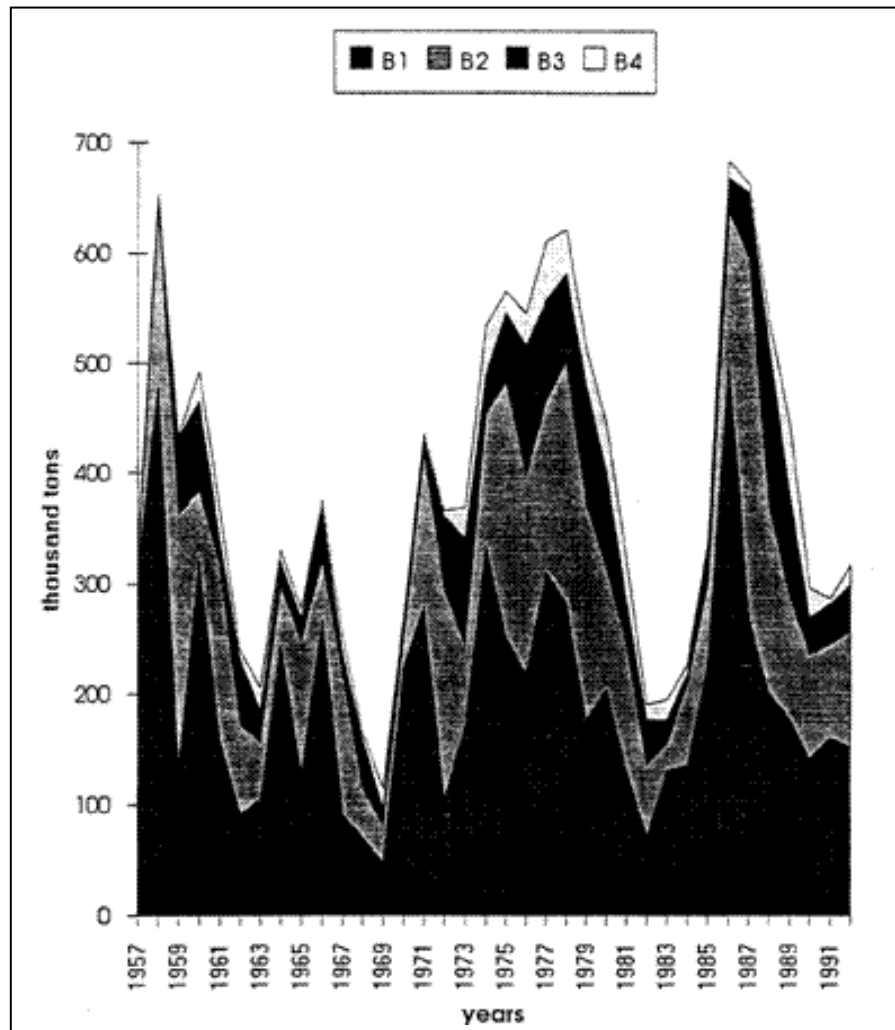**FIGURE 17.** Sprat biomass-at-age (tonnes) over years from XSA

FIGURE 18.Sprat spawning biomass (by age groups) in the western part of the Black Sea
during 1957-1992 (after Prodanov et al., 1994)

The observed cyclic biomass dynamics argue for a stock sensibility to natural environmental parameters, although the fishing effort obviously reinforces natural trends and may also have had a dominant impact in causing stock declines. The results show that F strongly varied between the different ages, due mainly to variable year class strength and changes in the susceptibility of the different cohorts to the fishery (**Table 45**). This variability created conditions for significant increases in fishing mortality in particular years (for instance during 1954-1957, though these values are unrealistically high and probably are an artefact, as a result of errors in age determination). The average plots of mortality and selectivity at age (**Table 46**) also show that in certain periods different age groups (1, 2 or 3 year old fish) have supported peak exploitation. From **Figure 15 it seems** that the major periods of enhanced fishery mortality coincided or preceded the minima for biomass (1954-1957; 1964-1966; 1980-1982; 1989-1990). The reason for this phenomenon may be both the momentum of fishing effort (the fishing effort remains high for some time even after the catch decline due to the persistence of the fleet capacities introduced to the fishery and the need for the implementation of the economic plan) and the specificity of school behaviour (with catchability showing a negative dependance on stock size). High fishing mortality is an especially important factor during times of negative changes in the stock abundance.

Since 1988, a sharp decline of sprat biomass accompanied a fishing mortality increase in 1989 owing to the high fishing effort in the sprat fishery of the former USSR (record high catches of sprat were recorded in 1989). During 1989-1991 the *Mnemiopsis* biomass had also reached maximum values. Up to date there is no direct evidence that the ctenophore feeds on sprat larvae, which is one reason why one may not assert that it was the cause of the weak 1989-1991 year classes. Nevertheless, some data for vertical distribution offshore during the cold season when the spawning peak occurs and a seasonal maximum of the *Mnemiopsis* biomass was observed (Vinogradov *et al.*, 1992); this provides a reason to consider the ctenophore as a possible factor in negative changes in sprat stocks.

Up to now the relationship between plankton-feeding invertebrates and fish was regarded as one way, i.e. the former were pointed out as the reason for the stock decline of the latter. In our opinion, it is possible to postulate a reverse impact: the lowering of fish stocks owing to a heavy and unadjusted fishery may result in a surplus of zooplankton that would favour "outbursts" of megaplankters. In diminishing their biomasses, fish populations respond by enhanced growth rate and condition (owing to increased food availability), as well as by active reproduction and "rejuvenating" of the stock, effects that have occurred for sprat during the period 1991-1993.

The pronounced cyclical recurrence in sprat population dynamics permits comparisons with stock dynamics of other abundant fish species in the World Ocean and argue for some global determination concerning the stock as well as the whole ecosystem, as influenced primarily by climatic factors (Mann, 1993; FAO, 1994). On the other hand, the results obtained by us also indicate the essential influence of two conjugated factors since the beginning of the 1970s, resulting from human activities (over exploitation and eutrophication).

Regardless of the high reproductive potential of sprat populations and existing opinions that the stock is under- exploited, the peculiarities of the ecology and behaviour of this small pelagic species can easily lead to situations with over-exploitation and decreases of the stock. Of the characteristics considered in this work are: the wide variation of recruitment and its sensibility to environmental factors, as well as the reverse stock dependent catchability, owing to enhanced availability of the stock to the fishery even at reduced stock size. Thus the cumulative occurrence under certain circumstances of unfavourable environmental conditions and high fishing mortality, stress the weak "buffer capabilities" of the species due to short age composition = small number of age groups determining the parent stock and enhanced total mortality.

It is of no less concern that the fishermen's activities from those countries exploiting the stock, despite the long existence of the Joint Fishery Commission for the Black Sea, have not led to an organised international research group for conducting a generalised stock assessment; the only way that scientifically founded fishery regulation can be achieved.

The other group of factors having negative influence on the fish populations, is related to negative changes due to the eutrophication. After the initial positive effect, the so-called eutrophication-enhanced fishery production, there follows a period with sharp fluctuations in biota parameters, raised frequency and intensity of plankton blooms, hypoxia, changes in community structure. The greatest impact on the small pelagic fish appears to be through the hyper-productivity of the plankton eating megaplankton.

At present the Black Sea ecosystems and fish in particular are subjected to the impact, both of the natural environmental factors and of increased anthropogenic activities. The cumulative action of these factors has to be considered in order to find an explaination for the chaotic behaviour of the system during the past decades. As it was already stated, small pelagic populations are of utmost significance for the ecosystem "health", because of their place in the trophic web, which makes possible their control of upper and lower trophic levels, as well as the fact that they are the link for a direct anthropogenic impact through the fishery.