IV. ENVIRONMENTAL IMPACT ON THE FISH RESOURCES IN THE BLACK SEA

Over 40 abiotic and biotic parameters were analysed in an attempt to establish the factors determining stock fluctuations of commercially valuable fish. The most important of the biotic factors are predator-prey interrelationships and trophic competitions between the fish species. Among the abiotic ones are environmental alterations induced by natural and anthropogenic causes. The fishing mortality has a direct influence on the most intensively exploited fish stocks, this being the grounds for the extensive and thorough research and discussions of this factor in population dynamics theory. As a result a great number of models and criteria have been founded for assessing the optimum exploitation level - MSY (maximum sustainable yield), TAC (total allowable catch), "acceptable catch" (DINUMERS), maximum entropy method, harmonic weight method, etc. Notwithstanding, the abundance of certain fish species has frequently diminished disastrously, owing to the complex character of the environmental impact. That is why a number of models, such as PROBUB, DINUMERS (Taivisto and Levastu, 1989), ECOPATH II (Christensen and Pauly, 1992), etc. have been developed, which consider an ecosystem as a whole, making attempt to ascertain the so called "acceptable catch" for all living organisms subjected to commercial exploitation. For this purpose, for instance using the DINUMERS model, in some cases it has been necessary to find a single solution to more than 200 differential equations that would meet the terms of steady equilibrium of the ecosystem at certain exploitation patterns of the commercially important species. This is extremely hard to do since the interrelations between the species in an ecosystem depend to a great extent on environmental factors. These are incessantly changing under the influence of natural and anthropogenic causes. Some scientists therefore think that the term "maximum sustainable yield" is devoid of real sense. Nevertheless, in this respect, an attempt has been made to clarify the principle causes that have brought the fish resources to the present state in the Black Sea.

In Figure 31 the fluctuations in the spawning biomass of anchovy and sprat (B1+) are shown as well as those of horse mackerel and whiting (B1+). In the same Figure the biomasses of their most abundant predators - spiny dogfish (B4+) and turbot (B2+) are also presented.

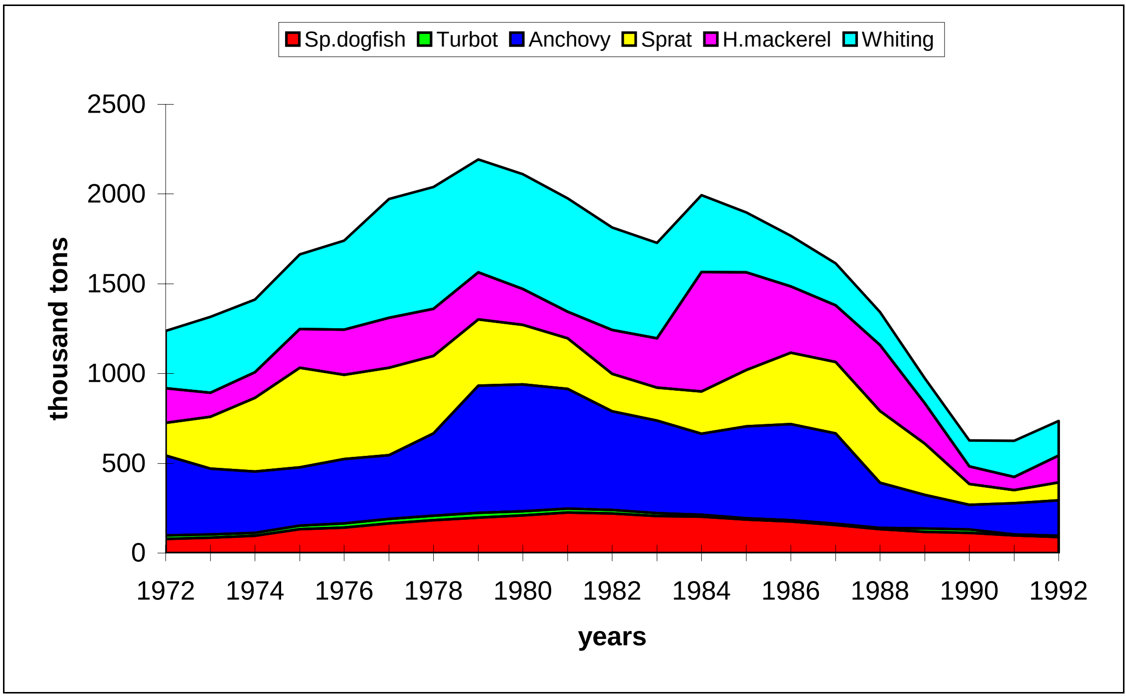


FIGURE 31. Biomasses of spiny dogfish, turbot, anchovy, sprat, horse mackerel and whiting during 1972-1992

The whiting biomass is assessed separately for the eastern and western parts of the basin since the weights by age in the eastern part need specifying (in our opinion these are excessively high for ages over 3 years). For this reason the species biomass in this part of the Black Sea is presumably overestimated. The sprat biomasses assessed relate to the western part of the basin, i.e. they are sizeably greater in the entire basin but since almost no sprat fishery occurs in the eastern part the assessment of sprat biomass by VPA in this region is not possible.

Figure 32 shows the year class abundance of the last four species, the anchovy and sprat being prey to the rest, the horse mackerel and whiting however being predators on the former, but also prey to dogfish and turbot.

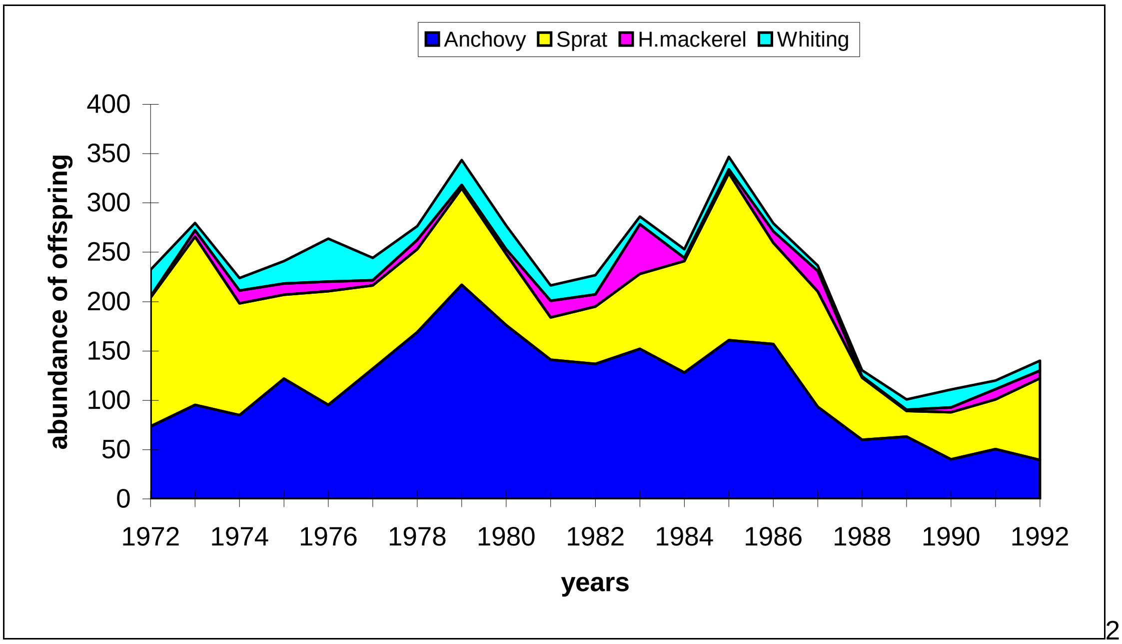


FIGURE 32. Year class abundance in numbers (x10^{-9}) of anchovy, sprat, horse mackerel and whiting during 1972-1992

It is seen from the above Figure that in the early 1970s the sums of the mentioned biomasses of the 4 species were around 1 200-1 300 thousand tonnes, but at the end (1978-1980) they were 2 039-2 193 thousand tonnes; i.e. they had increased on average by 69.3%. In the beginning of this period their combined catch ranged from 189.8 to 197.0 thousand tonnes: U = Y/B = 0.1497 - 0.1534. By the end of the 1970s, together with the combined biomass rise, increase in catches also occurred. During these years, catches reached 483.4 and 575.1 thousand tonnes, respectively - U = 0.2204-0.2725. After 1980, their combined biomass began to decline, with only insignificant increases in 1984 and 1985. However, the catches continued to rise, reaching their maximum in 1986 and 1987: 622.5 (U = 0.3522) and 666.0 (U = 0.4126) thousand tonnes respectively. Given mean values of the natural mortality coefficient of the order of 0.45 (horse mackerel) - 0.95 (sprat) this means that the fishing mortality coefficient has varied between 0.65 and 0.80 on average for the 4 species. In 1988 ***F*** approached its maximum value with a mean of 0.87 (U = 0.4343). Negative changes in the ecosystem have simultaneously occurred - frequent phytoplankton blooms causing in some cases mass mortality of bottom and near bottom fish, pollution has increased in the basin, with various chemical compounds - heavy metals, chlor-organic compounds, pesticides, etc. The organic surplus and the heavy fishery, coupled with specific population parameters of the ctenophore, *Mnemiopsis leidyi*, led to its outburst, and resulted in a sharp decline of the small zooplankton (Copepoda) biomass, especially in summer, which acts still more negatively on the fish population.

As is seen from Figure 32, the combined abundance of offspring decreased steadily in 1988 to 130.4 x 10^9 specimens. During the next few years (1989-1992) these varied between 100.8 x 10^9 (1989) and 140.2 x 10^9 number of specimens. On this account the combined biomass of the 4 species remained low - between 625.3 (1991) and 774.3 thousand tonnes (1992).

The fishing mortality impact on the combined biomass of these 4 species has been explored by means of the following functions:

(20) $B = a*U*\exp[-(b*U)]$

(21) $B = a*U*\exp[-(b*U + cB1)]$

where: B is the combined biomass ; U is exploitation rate (U = Y/B ; Y is combined catch); B1 is Mnemiopsis biomass in July-August

In Table 95, the parameters of the mentioned equations are presented.

Table 95. Parameters of production models for anchovy, sprat, horse mackerel and whiting

Parameters	Equation	Equation
a	26081.642	19340.134
b	5.2003417	3.7816159
c		0.0264923
U_{opt}	0.1923	0.2644*
B_{max}	1845.1	1881.2*
r	0.5940	0.8449
D%	35.29	71.39
S%	64.71	28.61

* the values of U_{opt} and B_{max} are computed at B_1=0

In the end of the 1970s and early 1980s, the largest biomass was of the jellyfish *Aurelia aurita*. According to Grishin, Covalenko and Sorokolit (in press - personal communication) at that time the *Mnemiopsis* outburst was recorded, it had dropped around 15-20 fold. During this period this jellyfish had consumed about 60% of the production of nutritious zooplankton, while the anchovy, sprat and horse mackerel hardly used 6-7% (Shulman and Urdenko, 1989). Consequently up to the 1980s, the Black Sea trophic base has been under jellyfish control, primarily by *Aurelia aurita*. During this period, the eutrophication of the basin still has had positive effects on the pelagic fish populations. At present, the ctenophore *Mnemiopsis leidyi* being most abundant has the decisive importance for the ecosystem while the biomass of the native jellyfish has been greatly reduced. Most fish populations also decreased in biomass; heavy fishing being the other major factor. Fish are more active predators on zooplankton and with reduced fishing effort, they could overcome the unfavourable trophic conditions. According to equation (21), the optimum mean value of ***F*** for the mentioned species is around 0.45 (U_{opt} = 0.2644) provided the ctenophore biomass is equal to 0. However, as was already pointed out, before *Mnemiopsis leidyi* entered the basin, the dominant species were the jellyfish and the native ctenophore *Pleurobrachia pilleus*. After 1990, the coefficient of exploitation was considerably lowered which was the major reason for the observed trend toward increase of the anchovy, sprat and whiting stocks. The fishing mortality impact is still better expressed in the case of the Azov anchovy. Its biomass has recovered after temporary cessation of the fishery, although the *Mnemiopsis* biomass in the Sea of Azov continues to be rather high.

The remaining abiotic and biotic factors also exert substantial influence on the fish population abundance. In Table 96 is presented a correlation matrix that reflects the impact of 42 environmental parameters. It is seen that there is a clear trend towards a decline in the quantity of silicon, both in the eastern (r = -0.930) and western parts of the Black Sea (r = -0.862). As it is well-known the silicon is one of the basic elements in the cell structure formation of diatoms (Bacillariophyta). This established relationship is very important, since so far, the decline in the biomass of these algae has been related only to variations in solar activity (Petrova-Karadjova and Apostolov, 1988). The next in reliability is the trend towards a decrease of the biomass of the jellyfish *Aurelia aurita*, especially in the eastern part of the basin (r = -0.882). The trend to the aggravation of the oxygen regime in the Black Sea is well expressed too. The self-purifying capability of the basin, especially in its western part, has declined with time (r = -0.659). The correlation coefficients between the latter, on the one hand, and the oxygen concentration and the phytoplankton biomass on the other, are 0.675 and -0.540 respectively. The interrelationship between the oxygen concentration in the near bottom layers and the phytoplankton biomass is also negative.

The zooplankton biomass in the western part of the Black Sea also shows a tendency to decline, particularly in summer (r = -0.729). As regards fish, the trend towards a decline of the turbot exploited biomass is well expressed (r = -0.668).

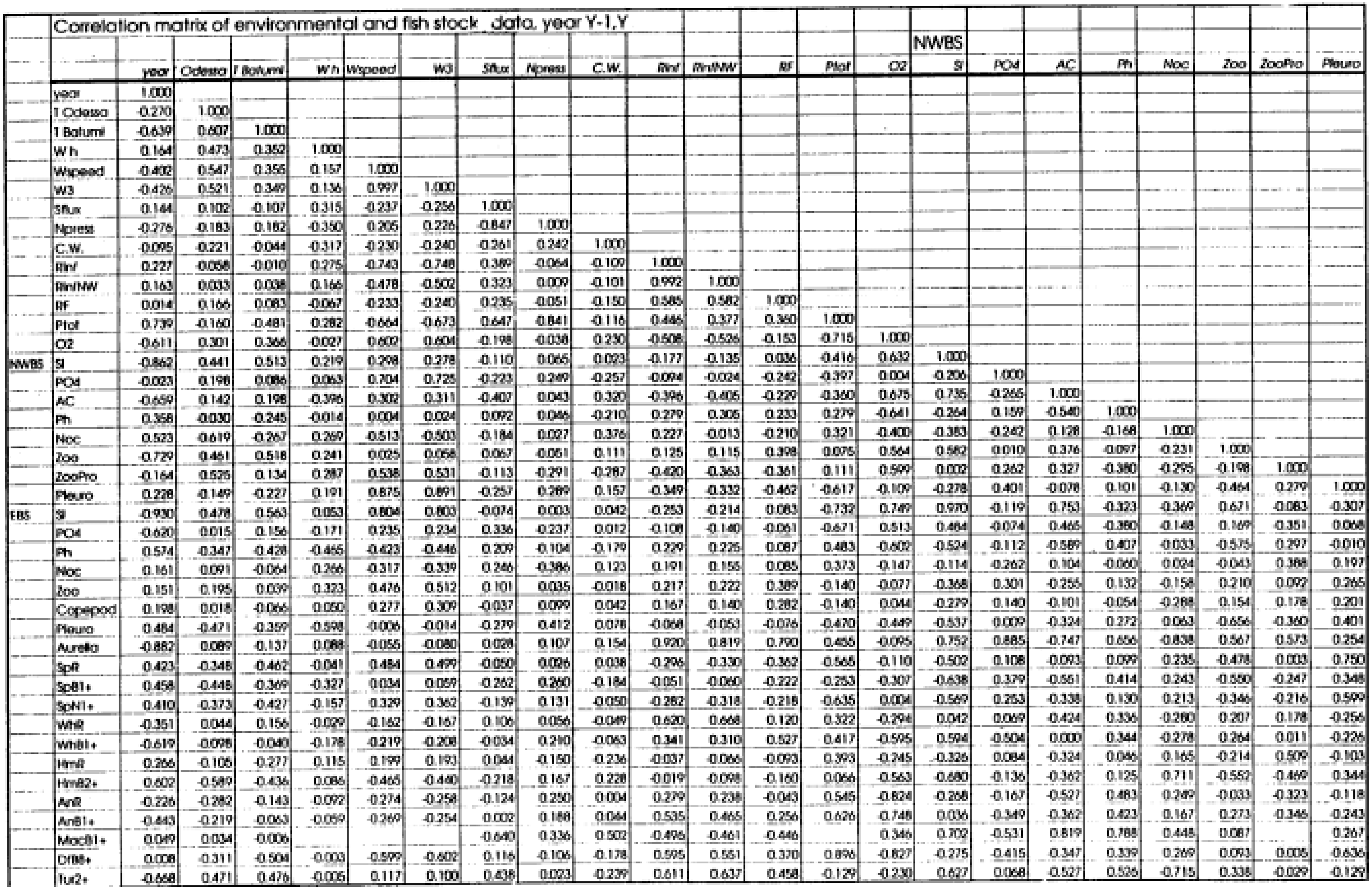
On the basis of these interrelationships between the biotic and abiotic environmental parameters, a multi-factorial correlation analysis was performed to establish the most significant factors determining fish species abundance. For this purpose, linear, parabolic and exponential functions were applied.

According to the parameter values in the linear equations used, the abundance of anchovy offspring is positive related to the total phosphorus concentration, the amount of river inflow and the phytoplankton biomass in the eastern part of the Black Sea, and negatively related to the sea water temperature (according to data for the temperature in the Odessa bay), to the phytoplankton biomass in the western part of the basin, and to the zooplankton biomass in the whole Black Sea (Table 97). The last one is due to the fact that the zooplankton biomass is defined residual, i.e. its concentration (mg/l) depends on the abundance of its predators, including that of the anchovy, the latter being typical zooplanktivores. The reliability of the established relationship is extremely high: 99.9%.

The effect of the most abundant fish species on the strength of the anchovy year classes is shown in Table 98. It is seen that the abundance of the year classes is directly proportional to the anchovy spawning biomass (B1+), to the strength of the year classes of horse mackerel, sprat and whiting in the western part of the basin, to the biomasses of horse mackerel (B1+), sprat (B1+), turbot (B2+) and of whiting (B1+) in the western part, and inversely proportional to the spiny dogfish biomass (B4+), and to the year class strength and biomass of whiting in the eastern part of the basin. In this case the correlation coefficient approaches 0.9594, which shows that the equation fits precisely VPA data for the stock size of the mentioned fish species.

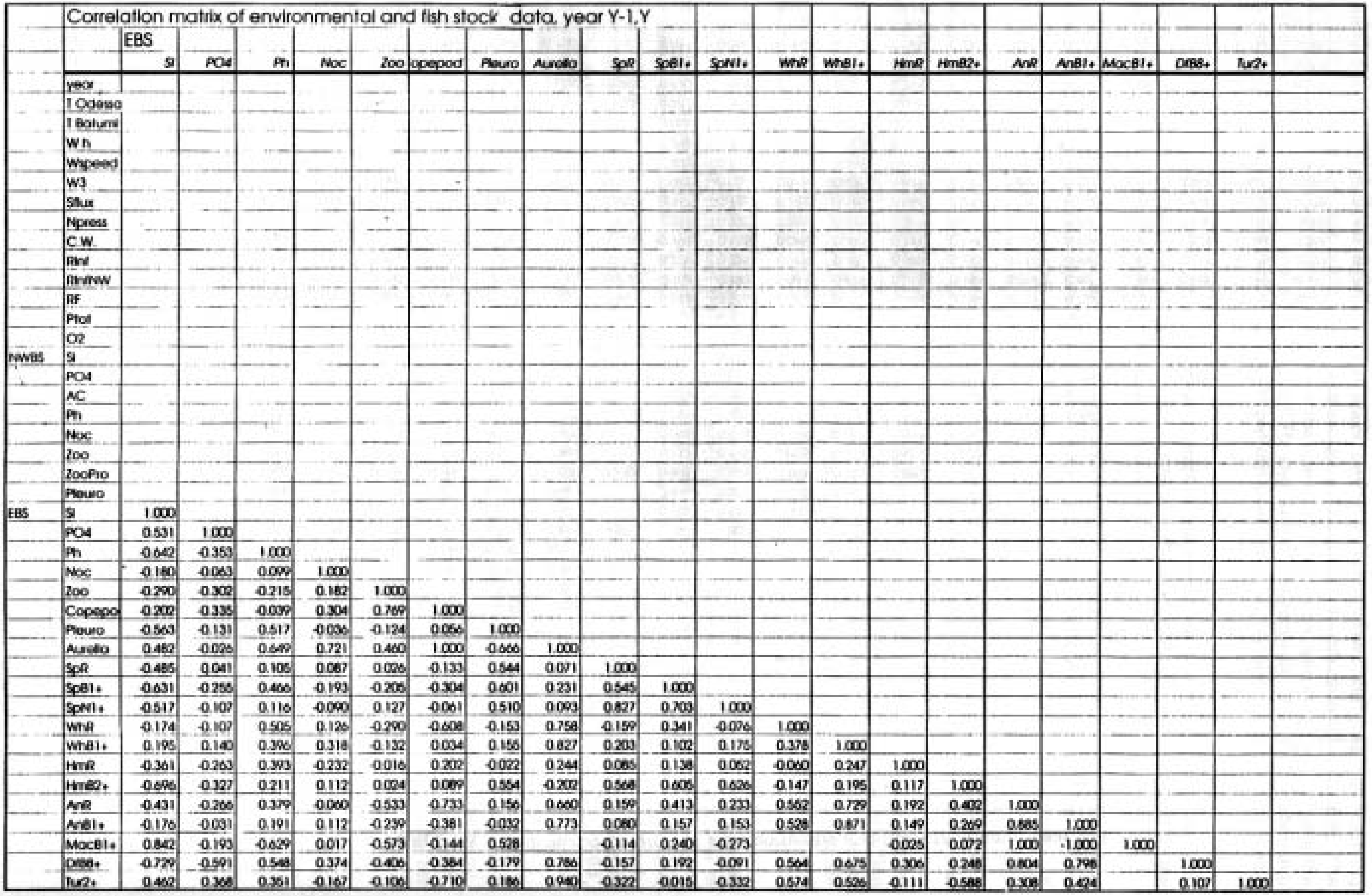
The equations derived show that when including each new member, reflecting the influence of the relevant factor, the values of the parameters at the independent variables change constantly, inclusive from positive to negative in spiny dogfish and whiting from the eastern part of the basin. Both species are predators of the anchovy, especially in winter during the wintering of the latter off the Anatolian coast of Turkey and also off the Caucasian coast.

Table 96. Correlation matrix of environmental and fish stock data, year y-1, y



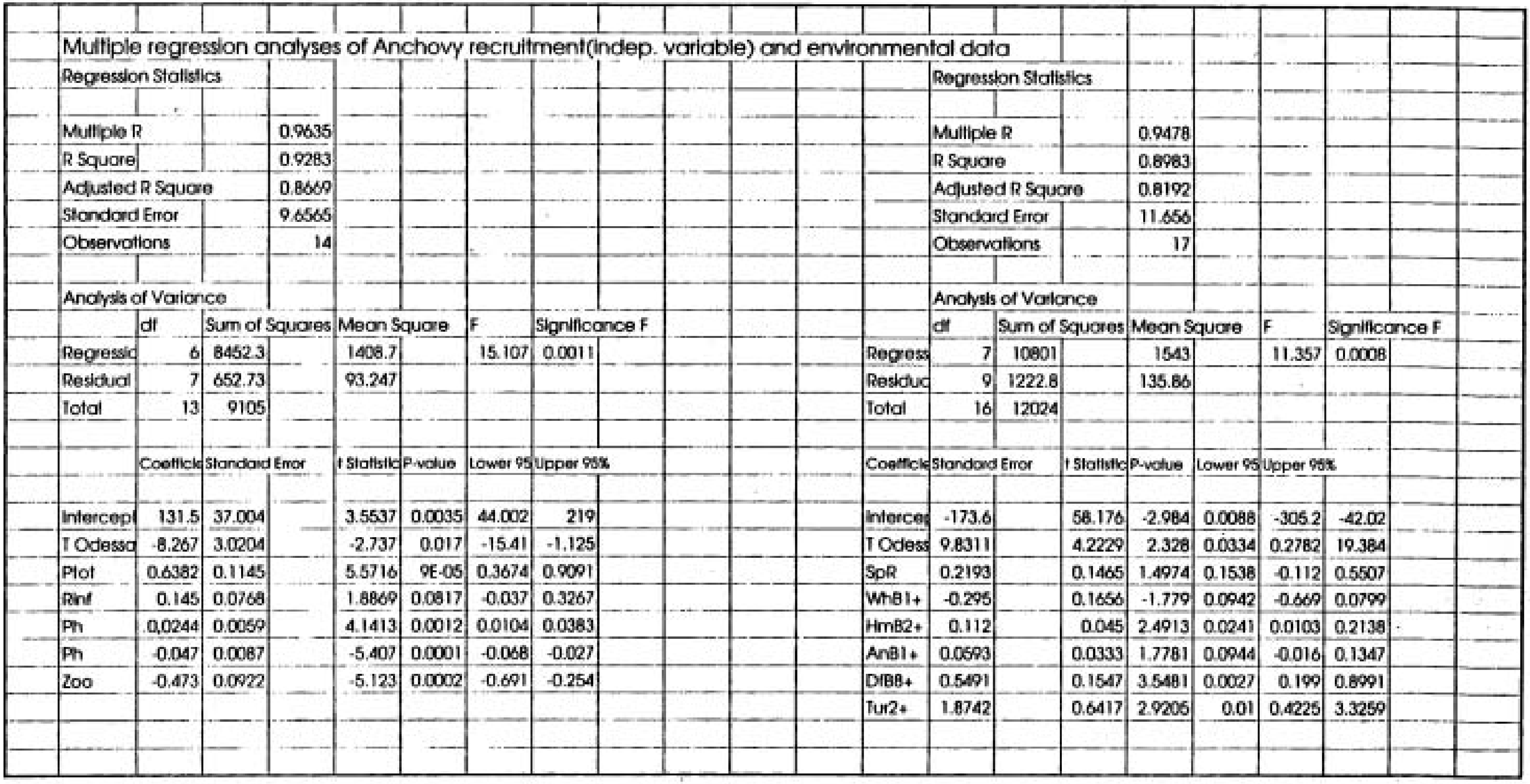
	Correlation matrix of environmental and fish stock _data, year Y-1,Y																						
															NWBS								
		year	T Odessa	T Batumi	W h	Wspeed	W3	Sflux	Npress	C.W.	Rinf	Rinf/NW	RF	Ptot	O2	Si	PO4	AC	Ph	Noc	Zoo	ZooPro	Pleuro
	year	1.000																					
	T Odessa	-0.270	1.000																				
	T Batumi	-0.639	0.607	1.000																			
	W h	0.164	0.473	0.352	1.000																		
	Wspeed	-0.402	0.547	0.356	0.157	1.000																	
	W3	-0.426	0.521	0.349	0.136	0.997	1.000																
	Sflux	0.144	0.102	-0.107	0.315	-0.237	-0.256	1.000															
	Npress	-0.276	-0.183	0.182	-0.350	0.205	0.226	-0.847	1.000														
	C.W.	-0.095	-0.221	-0.044	-0.317	-0.230	-0.240	-0.261	0.242	1.000													
	Rinf	0.227	-0.058	-0.010	0.275	-0.743	-0.748	0.389	-0.064	-0.109	1.000												
	Rinf/NW	0.163	0.033	0.038	0.166	-0.478	-0.502	0.323	0.009	-0.101	0.992	1.000											
	RF	0.014	0.166	0.083	-0.067	-0.233	-0.240	0.235	-0.051	-0.150	0.585	0.582	1.000										
	Ptot	0.739	-0.160	-0.481	0.282	-0.664	-0.673	0.647	-0.841	-0.116	0.446	0.377	0.360	1.000									
	O2	-0.611	0.301	0.366	-0.027	0.602	0.604	-0.198	-0.038	0.230	-0.508	-0.526	-0.153	-0.715	1.000								
NWBS	Si	-0.862	0.441	0.513	0.219	0.298	0.278	-0.110	0.065	0.023	-0.177	-0.135	0.036	-0.416	0.632	1.000							
	PO4	-0.023	0.198	0.086	0.063	0.704	0.725	-0.223	0.249	-0.257	-0.094	-0.024	-0.242	-0.397	0.004	-0.206	1.000						
	AC	-0.659	0.142	0.198	-0.396	0.302	0.311	-0.407	0.043	0.320	-0.396	-0.405	-0.229	-0.360	0.675	0.735	-0.266	1.000					
	Ph	0.358	-0.030	-0.245	-0.014	0.004	0.024	0.092	0.046	-0.210	0.279	0.305	0.233	0.279	-0.641	-0.264	0.159	-0.540	1.000				
	Noc	0.523	-0.619	-0.267	0.269	-0.513	-0.503	-0.184	0.027	0.376	0.227	-0.013	-0.210	0.321	-0.400	-0.383	-0.242	0.128	-0.168	1.000			
	Zoo	-0.729	0.461	0.518	0.241	0.025	0.058	0.067	-0.051	0.111	0.125	0.115	0.398	0.075	0.564	0.582	0.010	0.376	-0.097	-0.231	1.000		
	ZooPro	-0.164	0.525	0.134	0.287	0.538	0.531	-0.113	-0.291	-0.287	-0.420	-0.363	-0.361	0.111	0.599	0.002	0.262	0.327	-0.380	-0.295	-0.198	1.000	
	Pleuro	0.228	-0.149	-0.227	0.191	0.875	0.891	-0.257	0.289	0.157	-0.349	-0.332	-0.462	-0.617	-0.109	-0.278	0.401	-0.078	0.101	-0.130	-0.464	0.279	1.000
EBS	Si	-0.930	0.478	0.563	0.053	0.804	0.803	-0.074	0.003	0.042	-0.253	-0.214	0.083	-0.732	0.749	0.970	-0.119	0.753	-0.323	-0.369	0.671	-0.083	-0.307
	PO4	-0.620	0.015	0.156	-0.171	0.235	0.234	0.336	-0.237	0.012	-0.108	-0.140	-0.061	-0.671	0.513	0.464	-0.074	0.465	-0.380	-0.148	0.169	-0.351	0.068
	Ph	0.574	-0.347	-0.428	-0.465	-0.423	-0.446	0.209	-0.104	-0.179	0.229	0.225	0.087	0.483	-0.602	-0.524	-0.112	-0.589	0.407	-0.033	-0.575	0.297	-0.010
	Noc	0.161	0.091	-0.064	0.266	-0.317	-0.339	0.246	-0.386	0.123	0.191	0.155	0.085	0.373	-0.147	-0.114	-0.262	0.104	-0.060	0.024	-0.043	0.388	0.197
	Zoo	0.151	0.195	0.039	0.323	0.476	0.512	0.101	0.035	-0.018	0.217	0.222	0.389	-0.140	-0.077	-0.368	0.301	-0.255	0.132	-0.158	0.210	0.092	0.265
	Copepod	0.198	0.018	-0.066	0.050	0.277	0.309	-0.037	0.099	0.042	0.167	0.140	0.282	-0.140	0.044	-0.279	0.140	-0.101	-0.054	-0.288	0.154	0.178	0.201
	Pleuro	0.484	-0.471	-0.359	-0.598	-0.006	-0.014	-0.279	0.412	0.078	-0.068	-0.053	-0.076	-0.470	-0.449	-0.537	0.009	-0.324	0.272	0.063	-0.656	-0.360	0.401
	Aurelia	-0.882	0.089	-0.137	0.088	-0.055	-0.080	0.028	0.107	0.154	0.920	0.819	0.790	0.455	-0.095	0.752	0.885	-0.747	0.656	-0.838	0.567	0.573	0.254
	SpR	0.423	-0.348	-0.462	-0.041	0.484	0.499	-0.050	0.026	0.038	-0.296	-0.330	-0.362	-0.565	-0.110	-0.502	0.108	-0.093	0.099	0.235	-0.478	0.003	0.750
	SpB1+	0.458	-0.448	-0.369	-0.327	0.034	0.059	-0.262	0.260	-0.184	-0.051	-0.060	-0.222	-0.253	-0.307	-0.638	0.379	-0.551	0.414	0.243	-0.550	-0.247	0.348
	SpN1+	0.410	-0.373	-0.427	-0.157	0.329	0.362	-0.139	0.131	-0.050	-0.282	-0.318	-0.218	-0.635	0.004	-0.569	0.253	-0.338	0.130	0.213	-0.346	-0.216	0.599
	WhR	-0.351	0.044	0.156	-0.029	-0.162	-0.167	0.106	0.056	-0.049	0.620	0.668	0.120	0.322	-0.294	0.042	0.069	-0.424	0.336	-0.280	0.207	0.178	-0.256
	WhB1+	-0.619	-0.098	-0.040	-0.178	-0.219	-0.208	-0.034	0.210	-0.063	0.341	0.310	0.527	0.417	-0.595	0.594	-0.504	0.000	0.344	-0.278	0.264	0.011	-0.226
	HmR	0.266	-0.105	-0.277	0.115	0.199	0.193	0.044	-0.150	0.236	-0.037	-0.066	-0.093	0.393	-0.245	-0.326	0.084	-0.324	0.046	0.165	-0.214	0.509	-0.103
	HmB2+	0.602	-0.589	-0.436	0.086	-0.465	-0.440	-0.218	0.167	0.228	-0.019	-0.098	-0.160	0.066	-0.563	-0.680	-0.136	-0.362	0.125	0.711	-0.552	-0.469	0.344
	AnR	-0.226	-0.282	-0.143	-0.092	-0.274	-0.258	-0.124	0.250	0.004	0.279	0.238	-0.043	0.545	-0.824	-0.268	-0.167	-0.527	0.483	0.249	-0.033	-0.323	-0.118
	AnB1+	-0.443	-0.219	-0.063	-0.059	-0.269	-0.254	0.002	0.188	0.044	0.535	0.465	0.256	0.626	-0.748	0.036	-0.349	-0.362	0.423	0.167	0.273	-0.346	-0.243
	MacB1+	0.049	0.034	-0.006				-0.640	0.336	0.502	-0.496	-0.461	-0.446		0.346	0.702	-0.531	0.819	0.788	0.448	0.087		0.267
	DfB8+	0.008	-0.311	-0.504	-0.003	-0.599	-0.602	0.116	-0.106	-0.178	0.595	0.551	0.370	0.896	-0.827	-0.275	-0.415	-0.347	0.339	0.269	0.093	0.005	-0.636
	Tur2+	-0.668	0.471	0.476	-0.006	0.117	0.100	0.438	0.023	-0.239	0.611	0.637	0.458	-0.129	-0.230	0.627	0.068	-0.527	0.526	-0.715	0.338	-0.029	-0.129

Table 96 – Continued



		Correlation matrix of environmental and fish stock data, year Y-1,Y																			
		EBS																				
		Si	PO4	Ph	Noc	Zoo	opepod	Pleuro	Aurelia	SpR	SpB1+	SpN1+	WhR	WhB1+	HmR	HmB2+	AnR	AnB1+	MacB1+	DfB8+	Tur2+	
	year																					
	T Odessa																					
	T Batumi																					
	W h																					
	Wspeed																					
	W3																					
	Sflux																					
	Npress																					
	C.W.																					
	Rinf																					
	RinfNW																					
	RF																					
	Ptot																					
	O2																					
NWBS	Si																					
	PO4																					
	AC																					
	Ph																					
	Noc																					
	Zoo																					
	ZooPro																					
	Pleuro																					
EBS	Si	1.000																				
	PO4	0.531	1.000																			
	Ph	-0.642	-0.353	1.000																		
	Noc	-0.180	-0.063	0.099	1.000																	
	Zoo	-0.290	-0.302	-0.215	0.182	1.000																
	Copepo	-0.202	-0.335	-0.039	0.304	0.769	1.000															
	Pleuro	-0.563	-0.131	0.517	-0.036	-0.124	0.056	1.000														
	Aurelia	0.482	-0.026	0.649	0.721	0.460	1.000	-0.666	1.000													
	SpR	-0.485	0.041	0.105	0.087	0.026	-0.133	0.544	0.071	1.000												
	SpB1+	-0.631	-0.256	0.466	-0.193	-0.205	-0.304	0.601	0.231	0.545	1.000											
	SpN1+	-0.517	-0.107	0.116	-0.090	0.127	-0.061	0.510	0.093	0.827	0.703	1.000										
	WhR	-0.174	-0.107	0.505	0.126	-0.290	-0.608	-0.153	0.758	-0.159	0.341	-0.076	1.000									
	WhB1+	0.195	0.140	0.396	0.318	-0.132	0.034	0.156	0.827	0.203	0.102	0.175	0.378	1.000								
	HmR	-0.361	-0.263	0.393	-0.232	-0.016	0.202	-0.022	0.244	0.085	0.138	0.062	-0.060	0.247	1.000							
	HmB2+	-0.696	-0.327	0.211	0.112	0.024	0.089	0.554	-0.202	0.568	0.605	0.626	-0.147	0.195	0.117	1.000						
	AnR	-0.431	-0.266	0.379	-0.060	-0.533	-0.733	0.156	0.660	0.159	0.413	0.233	0.552	0.729	0.192	0.402	1.000					
	AnB1+	-0.176	-0.031	0.191	0.112	-0.239	-0.381	-0.032	0.773	0.080	0.157	0.153	0.528	0.871	0.149	0.269	0.885	1.000				
	MacB1+	0.842	-0.193	-0.629	0.017	-0.573	-0.144	0.528		-0.114	0.240	-0.273			-0.025	0.072	1.000	-1.000	1.000			
	DfB8+	-0.729	-0.591	0.548	0.374	-0.406	-0.384	-0.179	0.786	-0.157	0.192	-0.091	0.564	0.675	0.306	0.248	0.804	0.798		1.000		
	Tur2+	0.462	0.368	0.351	-0.167	-0.106	-0.710	0.186	0.940	-0.322	-0.015	-0.332	0.574	0.526	-0.111	-0.588	0.308	0.424		0.107	1.000	

TABLE 97. Multiple regression analyses of Anchovy recruitment (indep. variable) and environmental data



Multiple regression analyses of Anchovy recruitment(indep. variable) and environmental data

Regression Statistics

Multiple R	0.9635
R Square	0.9283
Adjusted R Square	0.8669
Standard Error	9.6565
Observations	14

Analysis of Variance

	df	Sum of Squares		Mean Square		F	Significance F
Regressio	6	8452.3		1408.7		15.107	0.0011
Residual	7	652.73		93.247			
Total	13	9105					

	Coefficie	Standard Error		t Statistic	P-value	Lower 95	Upper 95%
Intercept	131.5	37.004		3.5537	0.0035	44.002	219
T Odessa	-8.267	3.0204		-2.737	0.017	-15.41	-1.125
Ptot	0.6382	0.1145		5.5716	9E-05	0.3674	0.9091
Rinf	0.145	0.0768		1.8869	0.0817	-0.037	0.3267
Ph	.0,0244	0.0059		4.1413	0.0012	0.0104	0.0383
Ph	-0.047	0.0087		-5.407	0.0001	-0.068	-0.027
Zoo	-0.473	0.0922		-5.123	0.0002	-0.691	-0.254

Regression Statistics

Multiple R	0.9478
R Square	0.8983
Adjusted R Square	0.8192
Standard Error	11.656
Observations	17

Analysis of Variance

	df	Sum of Squares		Mean Square		F	Significance F
Regress	7	10801		1543		11.357	0.0008
Residua	9	1222.8		135.86			
Total	16	12024					

Coefficie	Standard Error		t Statistic	P-value	Lower 95	Upper 95%	
Intercep	-173.6		58.176	-2.984	0.0088	-305.2	-42.02
T Odess	9.8311		4.2229	2.328	0.0334	0.2782	19.384
SpR	0.2193		0.1465	1.4974	0.1538	-0.112	0.5507
WhB1+	-0.295		0.1656	-1.779	0.0942	-0.669	0.0799
HmB2+	0.112		0.045	2.4913	0.0241	0.0103	0.2138
AnB1+	0.0593		0.0333	1.7781	0.0944	-0.016	0.1347
DfB8+	0.5491		0.1547	3.5481	0.0027	0.199	0.8991
Tur2+	1.8742		0.6417	2.9206	0.01	0.4225	3.3259

TABLE 98. Parameter values in the multiple correlation, reflectingthe relationships between anchovy recruitment and the stocks of the most abundant fishes in the Black Sea

Para-meters	R = f(B)	R = f(B,B1)	R = f(B,B1, B2)	R = f(B,...R2)	R = f(B,...B3)	R = f(B,...B4)
a	18.1208	0.7997	-1.1952	1.2233	-43.4978	-32.8737
b	0.2343	0.1491	0.1546	0.1458	0.2263	0.2766
c		0.3493	0.3289	0.3778	-0.2685	-0.3855
d			0.0096	-0.0006	0.1515	0.1737
e				-0.3157	0.4763	0.7243
f					0.2005	0.2416
g						-02343
r	0.7512	0.8103	0.8107	0.8145	0.8623	0.8947
D%	56.43	65.66	65.72	66.34	74.36	80.05
S%	43.57	34.34	34.28	33.66	25.64	19.95

TABLE 98 - continued

Para-meters	R = f(B....B5)	R = f(B,...R5)	R = f(B,...R3)	B = f(B,...R4)	B = f(B,...B6)
a	-89.4231	-107.4902	-116.0028	-186.4526	-244.5723
b	0.2712	0.2400	0.2587	0.2827	0.2255
c	-0.3070	-0.1182	-0.2677	-0.5977	-0.0602
d	0.1623	0.1250	0.1333	0.1638	0.1612
e	0.6941	0.5775	0.4946	0.8130	0.7894
f	0.1782	0.1557	0.1568	0.0229	-0.2254
g	0.0031	0.0296	0.1683	0.7148	0.5052
h	0.0913	0.0997	0.1404	0.2727	0.2801
i		0.1344	0.0975	0.0091	0.1768
j			-1.0702	-2.2406	-29920
k				3.9739	2.6217
l					6.0629
r	0.9220	0.9246	0.9301	0.9439	0.9594
D%	85.01	85.49	86.51	89.09	92.04
S%	14.99	14.51	13.49	10.91	7.96

R and B are the abundance of recruitment (x10^{-9}) and spawning biomass odf anchovy (in tonnes x 10^{-3}) respectively; B_1 - spiny dogfish biomass (B4 in tonnes x 10^{-3}); B_2 - horse mackerel biomass (B1+ in tonnes x 10^{-3}); R_2 - horse mackerel recruitment (N x 10^{-9}); B_3 - whiting biomass in the eastern part of the Black Sea (B1+ in tonnes x 10^{-3}); B_4 - whiting biomass in the western part of the Black Sea (B1+ in tonnes x 10^{-3}); B_5 - sprat biomass (B1+ in tonnes x 10^{-3}); R_5 - sprat recruitment (N x 10^{-9}); R_3 - whiting recruitment in the eastern part of the basin (N x 10^{-9}); R_4 - whiting recruitment in western part of the basin (N x 10^{-9}); B_6 - turbot biomass (B2+ in tonnes x 10^{-3}).

The stock-recruitment relationship was explored using Ricker and Ivanov's equations. The correlation coefficients are 0.8070 and 0.8102 respectively. Hence, the multi-factorial correlation analysis describes more precisely the VPA results, since by this analysis the complex influence of different biotic and abiotic factors can be established, as well as the influence of the 6 most abundant fish species in the Black Sea. The latter are connected with various interrelations -from competition for food resources to rapacity of some species in relation to other species. Since the equation reflects the interrelationships between the 6 fish species unambiguously it shows that the component part of the ecosystem at each state of the environment aspires to a finite state of balance. Therefore, when the trophic conditions in the Black Sea deteriorated after the *Mnemiopsis* outburst, the biomass of fish species sharply declined (Figure 31). The impact of the remaining factors is less significant, although in particular years they may be the determining factor for offspring abundance of a fish species.

In Table 99 are presented the parameters of the equations reflecting the relationships between sprat offspring abundance and some environmental factors. As it is apparent from this Table, the values of "*r*" do not exceed 0.712, which suggests a weak dependence of the offspring abundance on the investigated factors, since the influence of random variation does not decrease below 49.3%.

In Table 100 are presented the values of the parameters of the equations reflecting the relationships between sprat offspring abundance along the Bulgarian coast and its spawning biomass (B1+), the fishing mortality rate (F), the duration (X1 and X3) and the average speed of winds with a western component (X2 and X4) during November-December and January-March, the intensity of cosmic rays (X5) and solar activity (X6). As it is evident from the table, the coefficient "*r*" reaches the value 0.869 which means that the influence of random factors is 24.53%. Among the examined variables the western wind speed during November-December and January-March proves to be of greatest significance, i.e. when the sprat is intensively spawning at depths of 25-100 m. It is well known that winds with a westerly component impose an upwelling of deep waters and displaces them shorewards. As these waters are rich in nutrients during the summer months, they could contribute a lot to phytoplankton bloom initiation. Because of their low temperature and low oxygen content, they could be responsible for regional zoobenthic mortality as well as fish species. As these water masses contain hydrogen sulphide, it may be hypothesised that indirectly they could also contribute to the mortality events. In winter, similar upwelling of deep waters take place, but unlike in summer their temperature is higher than that at the surface.

TABLE 99. Parameter values of equations reflecting the relationships between the abundance of sprat fingerlings and some environmental factors

Para-meters	R=f(B)	R=f(B,.. X1)	R=f(B,.. X2)	R=f(B,.. Z)	R=f(B,.. X3)	R=f(b,.. X4)	R=f(B,.. X5)	R=f(B,.. X6)
a								
b	0.06847	0.07213	0.05075	0.06702	-0.06473	-0.08325	-0.03402	-0.11140
c		-0.00731	-0.00459	-0.00434	0.04437	0.04914	0.05284	0.03108
d			-0.22171	-0.32742	-0.30074	-0.44648	-0.45368	-0.27971
e				-32.6592	-24.0001	-28.5162	-27.0093	-25.3243
f					-1.30726	-1.22958	-1.67992	-1.36845
g						-3.67857	-5.60691	-5.67867
h							-0.12479	-0.14030
i								-190.6102
r	0.137	0.144	0.207	0.323	0.667	0.683	0.687	0.712
D%	1.88	2.07	4.29	10.44	44.49	46.65	47.20	50.70
S%	98.02	97.93	95.71	89.56	55.51	53.35	52.80	49.30

R is abundance of sprat fingerlings (N x 10^{-9}); B - sprat spawning biomass (B1+); X1 - phytoplankton biomass; X2 - zooplankton biomass; Z - total mortality rate; X3 - sea water temperature; X4 - solar activity; X5 - cosmic ray intensity; X6 - Earth's geomagnetism

TABLE 100. Parameter values in the equations reflecting the relationships between sprat fingerlings along Bulgarian Black Sea coast and the investigated environmental factors

Para-meters	R=f(X1)	R=f(X1,.. X2)	R=f(X1,.. X3	R=f(X1,..X4	R=f(X1,..B)	R=f(X1,.. F)	R=f(X1,.. X5)	R=f(X1,..X6)
a	41.979	-73.012	-55.894	-192.629	-187.076	-152.426	-153.762	75.698
b	-0.0005	-0.0685	-0.0653	-0.02133	-0.0185	-0.0210	-0.0209	-0.0171
c		16.2959	15.5275	8.7793	8.0138	7.9136	7.9090	4.1665
d			-0.0233	-0.0654	-0.0551	-0.0526	-0.0522	-0.0624
e				21.3136	20.1659	17.9572	17.9165	21.6886
f					0.0485	-0.0079	-0.0083	0.0935
g						-39.2660	-39.1342	-14.4874
h							0.0004	-0.0520
i								-0.2607
r	0.107	0.543	0.558	0.843	0.845	0.855	0.855	0.869
D%	1.14	29.46	31.12	71.02	71.41	73.02	73.02	75.47
S%	98.86	70.54	68.88	28.98	28.59	26.98	26.98	24.53

B is the spawning biomass; F the fishing mortality rate; X1 and X3, X2 and X4 are the duration and average speed of winds with a western component during November-December and January-March respectively; X5 is the intensity of cosmic rays; X6 is the solar activity.

As it appears from Table 100, wind velocity has a favourable effect while its duration is negative. The integral impact of these variables on the sprat fingerling abundance is considerable - the value of "r" is 0.843 (D% = 73.02; S% = 26.98). The further complication of the equation by introducing the rest of the variables does not result in a significant increase in the value of "*r*" that suggests that the sprat fingerlings do not depend to a great extent on other factors. According to Stoyanov (1966) the sprat generations and spawning biomass depend both on the predator abundance and on the number of days with water temperature below 6°C during November-March. The same author pointed out that the influence of water temperature is indirect via the food web. Bryantzev (1990) also showed the great importance of the character of the atmospheric circulation during different years for the productivity of the Black Sea. The same author noted that this relation is better expressed in anchovy and less so in sprat.

Table 101 shows the results of multiple correlation analysis including these factors of major importance for sprat offspring abundance. It is seen that this is directly proportional only to spawning stock size and inversely proportional to the thermal background in the Black Sea, to the river inflow in the western part of the basin, to the amount of phosphates, and to the phyto- and zooplankton biomass.

The relationship between the catchability and sprat stock density was investigated by equation (9). It was established that this is typical of many gregarious fishes, showing negative density dependent catchability (Figure 33). The reason for such a relationship is the gregarious behaviour resulting in greater fish availability to the fishery. The value of coefficient "*b*", is close to -1, showing that the CPUE is not proportional to the biomass, but rather to the catch (Ulltang, 1980). That means that the CPUE will remain unchangeable when the biomass varies. On the other hand, this shows that unchanged fishing effort will give constant catches with reduction of stock abundance and will provoke an immediate rise of fishing mortality. This phenomenon was observed in most cases of sprat stock reduction (Figure 15). It was most conspicuous during 1954-1957, when the effort (number of trapnets) was quasi constant.

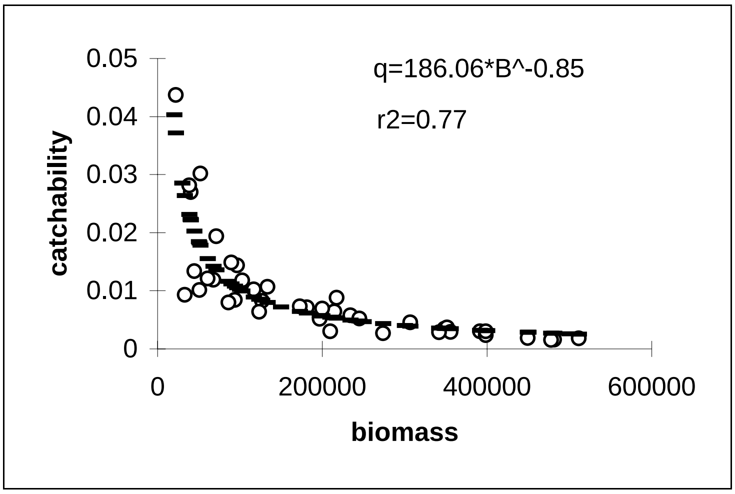


FIGURE 33. Relationship between catchability and sprat biomass

TABLE 101. Multiple regression analyses of Sprat recruitment (indep.variable) and environmental data

Multiple regression analyses of Sprat recruitment(indep. variable) and environmental data

Regression Statistics

Multiple R	0.8792
R Square	0.7729
Adjusted R Square	0.7048
Standard Error	24.215
Observations	27

Analysis of Variance

	df	Sum of Squares	Mean Square	F	Significance F
Regressio	6	39924	6654	11.347	2E-05
Residual	20	11728	586.39		
Total	26	51651			

	Coefficie	Standard Error	t Statistic	P-value	Lower 95	Upper 95%
Intercept	202.75	230.54	0.8794	0.3872	-278.2	683.66
T Batumi	-5.838	13.971	-0.418	0.6795	-34.98	23.304
RinfNW	-0.085	0.1493	-0.567	0.5758	-0.396	0.2268
PO4	-2.379	3.2802	-0.725	0.4748	-9.221	4.4637
Zoo	-0.464	0.1516	-3.061	0.0051	-0.78	-0.148
Ph	-0.038	0.0219	-1.742	0.0933	-0.084	0.0075
SpN1+	0.3934	0.0909	4.3262	0.0002	0.2037	0.5831

Regression Statistics

Multiple R	0.9839
R Square	0.968
Adjusted R Square	0.9361
Standard Error	8.9381
Observations	17

Analysis of Variance

	df	Sum of Squares	Mean Square	F	Significance F
Regress	8	19358	2419.7	30.289	3E-05
Residuc	8	639.11	79.889		
Total	16	19997			

	Coefficie	Standard Error	t Statistic	P-value	Lower 95	Upper 95%
Interce	-57.28	28.775	-1.991	0.0639	-123.6	9.0788
Ph	-0.02	0.0139	-1.441	0.1689	-0.052	0.012
Zoo	-0.132	0.0899	-1.47	0.1609	-0.34	0.0752
HmB2+	-0.116	0.0429	-2.699	0.0158	-0.215	-0.017
WhR	3.6002	1.1776	3.0572	0.0075	0.8846	6.3159
WhB1+	0.81	0.1281	6.3255	1E-05	0.5147	1.1053
DfB8+	-0.148	0.1111	-1.336	0.2001	-0.405	0.1077
Tur2+	-3.344	0.7761	-4.308	0.0005	-5.133	-1.554
SpN1+	0.8561	0.1021	8.3887	3E-07	0.6208	1.0915

In order to study the evolution of the stock in relation to the exploitation intensity, the interrelation between yield/biomass and fishing mortality was explored, assuming stable reproduction conditions are met (i.e. conditions of equilibrium). As is seen from Figures 34A and 34B, two states of equilibrium were differentiated with characteristic differences in the model parameters (Table 102). For the first period, all the parameters were considerably lower (except for *r* max) than those for the second period.

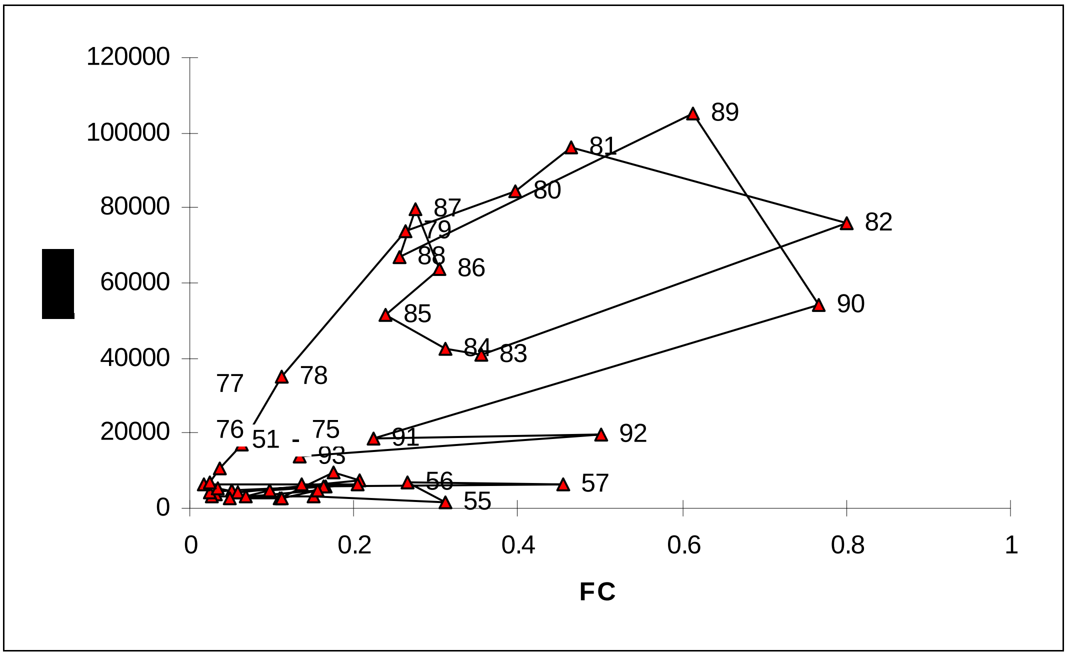


FIGURE 34a. Plot and trajectory of sprat yield on fishing mortality (FC)

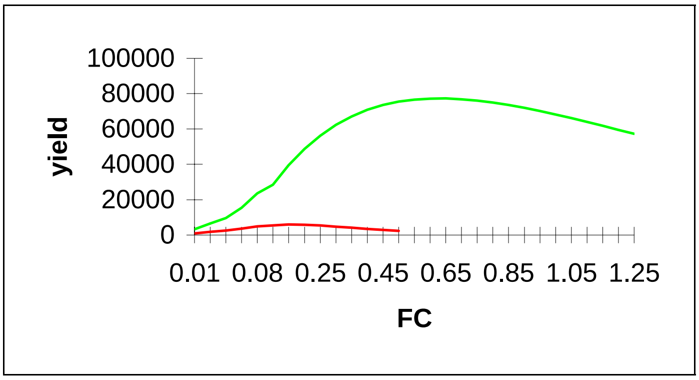


FIGURE 34b. Surplus production curves over periods 1951-1953 and 1974-1990

TABLE 102. Parameters in the empirical relationships between biomass, yield and fishing mortality in two periods of assumed equilibrium

Parameter	Boo (a)	r max (a/b)	MSY	Fmsy
1951-1973	158966.0	0.64	6010.6	0.164
1974-1990	452113.8	1.00	77334.3	0.629

As is seen, the values of MSY and Fmsy for the two periods differed significantly. In many cases, the optimum values of F were surpassed during both periods. Concerning the first period, this occurred during 1953-1958, 1964-1965, 1968 and 1972, and in the second period, during 1980, 1981, 1987 and 1989. After the high yield in 1981, the trajectory changed direction from ascending to descending (Figure 34A), resulting in a gradual decline of yield and exploitation level. After 1983, the ascending course of the trajectory changed again showing the recovery of the sprat stock. This continued till 1989 when the stock came out of equilibrium and the coordinates for 1991 and 1993 became close to those for 1951-1953.

The analysis of the stock-recruitment relationship showed a weak positive correlation (linear r = 0.533, non-linear r = 0.60) (Figure 35). The value of the parameter "c" is 0.88, i.e. very close to 1.0. This parameter determining the type of curve shows that it is near to the Beverton and Holt curve, but with less expressed protuberance (usually an ascendant straight line is obtained when c = 0.5). This curve type more frequently occurs in pelagic fish with a short life span than that with the exponential (Ricker, 1954) or parabolic (Ivanov, 1977) that involves stronger negative stock-dependent recruitment (enhanced offspring mortality as a result of cannibalism or interspecies competition).

The low value of "*r*" confirms the conclusion that sprat offspring abundance depends on environmental conditions to a greater extent than on the parent stock size.

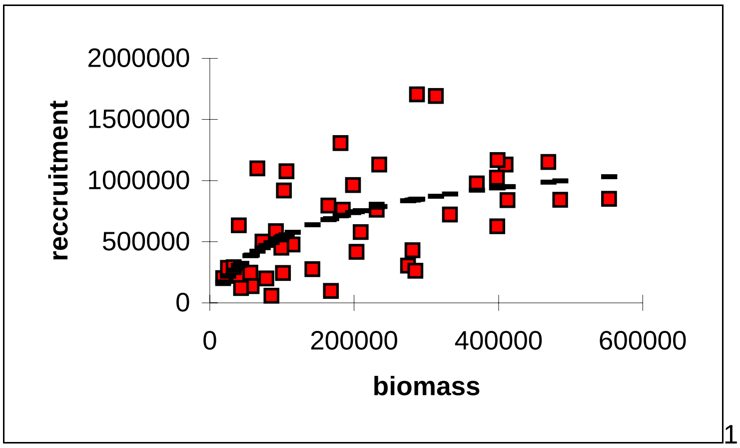


FIGURE 35. Sprat stock-recruitment relationship

The impact of fishing mortality rate on the whiting fingerling abundance is established by the followed equations:

(22) $R = a*B - b*B^2 - c*B*F$

(23) $R = a*B - b*B^2 - c*B*F - d*B^2*F$

The parameter values of these equations are presented in Table 103. It is evident from the data that the fishing mortality rate exerts a significant impact on stock-recruitment relationships. The influence of random factors decreased from 68.09% (according to Ivanov's equation) to 36.6%.

TABLE 103. The parameter values in equations 22 and 23, reflecting the influence of fishing mortality rate on the stock-recruitment relationships of whiting in the western part of the Black Sea

Equations	a	b	c	d	r	D%	S%	Bopt	Rmax
22	1.1356	0.0041	1.4732		0.771	59.47	40.53	139.8	79.4
23	1.1082	0.0035	0.9109	0.0092	0 796	63.40	36.60	158.0	87.5

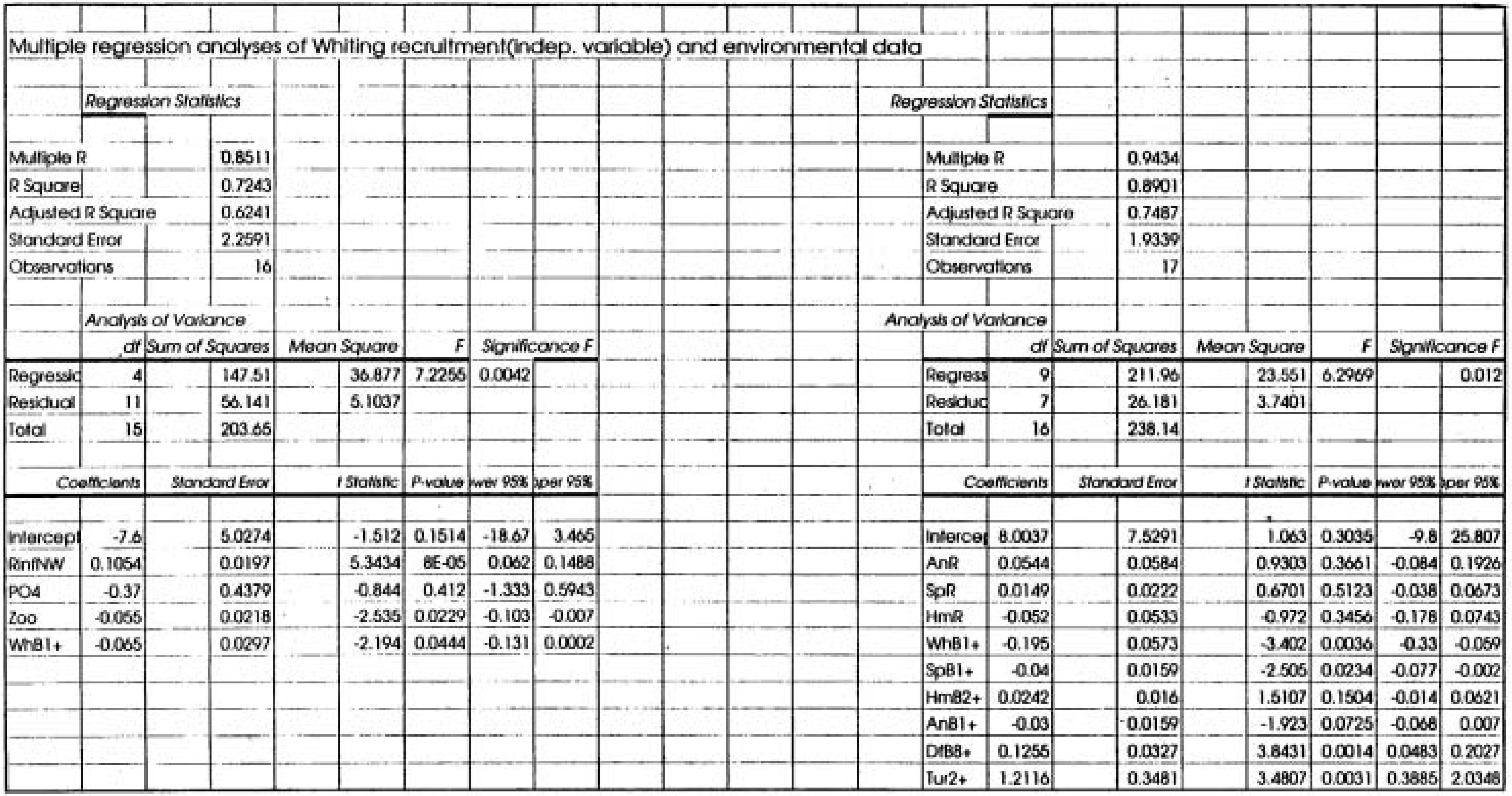
In Table 104 results of the multiple correlation analysis are shown, reflecting the relationship between whiting offspring abundance in the Black Sea and environmental factors. It is apparent that offspring abundance is directly proportional to the level of river inflow, and inversely proportional to phosphate concentration, zooplankton biomass and spawning biomass. The latter probably is due to the fact that whiting cannibalism occurs.

It is clear from the above that the abundance of the different year classes of the fish species in consideration depends on many and different abiotic and biotic factors. Determinant for the fish part of the ecosystem are the fishing mortality rate and the changes in food webs, as to the mass development of *Mnemiopsis leidyi* and the more frequent phytoplankton blooms provoked by the eutrophication of the basin.

In anchovy, and partially in horse mackerel and sprat, the first factor is of prime importance for the reduction of their biomasses. The first two fish species reproduce in the summer months in almost the whole Black Sea (Figure 36). During these months the *Mnemiopsis* biomass is highest, and because of this its negative impact is the highest. Besides, this ctenophore inhabits mainly the layers over the thermocline, i.e. the layers the eggs and larvae of anchovy and horse mackerel are developing in. As previously pointed out, larvae, although in small quantities, serve as food of *Mnemiopsis leidyi*, thus it exerts a direct influence on species abundance. The observed decline in the small zooplankton (Copepoda) in summer months also lowers the survival of the larvae and alevins of the two species. All this ultimately caused the dramatic decline in the anchovy stock in 1990 and 1991. The reduced fishing mortality during the next years is the major reason for the positive trends towards an increase of its biomass.

The reasons for the depletion of sprat biomass in the western part of the basin after 1987-1988 also has a complex character. On the one hand, the environmental conditions deteriorated, and on the other the fishing mortality increased. This disproportion inevitably led to the depletion of heavily fished stocks. In such cases, the best approach is to reduce the fishing mortality which would enable the relevant species to resist the unfavourable conditions until their improvement (Prodanov, 1989). It is seen from Figure 37, that the sprat also spawns in almost the entire Black Sea waters, which allows it to adequately utilise the trophic potential of the whole basin. After reducing the fishing effort its stocks also show a rising trend. A similar trend is observed for the stock of whiting and especially that of shad. In the case of the turbot, spiny dogfish, and Russian sturgeon, the situation is much more complicated since their catches are seriously understated. Furthermore, the regulation measures prohibiting the catch of immature fish, primarily in the case of turbot and Russian sturgeon, are not observed.

Table 104. Multiple regression analyses of whiting recruitment (indep.variable) and environmental data



Multiple regression analyses of Whiting recruitment(indep. variable) and environmental data

Regression Statistics

Multiple R	0.8511
R Square	0.7243
Adjusted R Square	0.6241
Standard Error	2.2591
Observations	16

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regressic	4	147.51	36.877	7.2256	0.0042
Residual	11	56.141	5.1037		
Total	15	203.65			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*wer 95%*	*per 95%*
Intercept	-7.6	5.0274	-1.512	0.1514	-18.67	3.465
RinfNW	0.1054	0.0197	5.3434	8E-05	0.062	0.1488
PO4	-0.37	0.4379	-0.844	0.412	-1.333	0.5943
Zoo	-0.055	0.0218	-2.535	0.0229	-0.103	-0.007
WhB1+	-0.065	0.0297	-2.194	0.0444	-0.131	0.0002

Regression Statistics

Multiple R	0.9434
R Square	0.8901
Adjusted R Square	0.7487
Standard Error	1.9339
Observations	17

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regress	9	211.96	23.551	6.2969	0.012
Residuc	7	26.181	3.7401		
Total	16	238.14			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*wer 95%*	*per 95%*
Interce	8.0037	7.5291	1.063	0.3035	-9.8	25.807
AnR	0.0544	0.0584	0.9303	0.3661	-0.084	0.1926
SpR	0.0149	0.0222	0.6701	0.5123	-0.038	0.0673
HmR	-0.052	0.0533	-0.972	0.3456	-0.178	0.0743
WhB1+	-0.195	0.0573	-3.402	0.0036	-0.33	-0.059
SpB1+	-0.04	0.0159	-2.505	0.0234	-0.077	-0.002
HmB2+	0.0242	0.016	1.5107	0.1504	-0.014	0.0621
AnB1+	-0.03	0.0159	-1.923	0.0725	-0.068	0.007
DfB8+	0.1255	0.0327	3.8431	0.0014	0.0483	0.2027
Tur2+	1.2116	0.3481	3.4807	0.0031	0.3885	2.0348

The depletion of the stocks of mullets is determined by the reduction of the surface area of the near shore lakes, and their pollution from industry. This concerns practically all Black Sea countries. The almost complete disappearance of bonito and blue fish along the Bulgarian, Romanian and Ukrainian coasts, also confirms a change for the worst in the western part of the Black Sea.

The remaining fish species (thornback-ray; sting-ray: striped mullet, etc.) are not subject to commercial fishery, but they have a substantial importance for the fish component of the ecosystem, being predators or competitors for food resources of all heavily exploited fish species. This also influences the stock dynamics of the latter, and therefore has to be kept in mind when assessing their "optimum" (allowable) catches. The lack of regular ichthyological research for these species does not permit formal stock assessments. For the time being, stocks can be estimated approximately by trawl surveys using the standard scheme. This would enable a more complete understanding of the interrelationships between the most abundant species of the ichthyopopulation in the ecosystem which would make the forecast of the year class strength more precise, which would be of great significance for commercial fish species with a short life span.

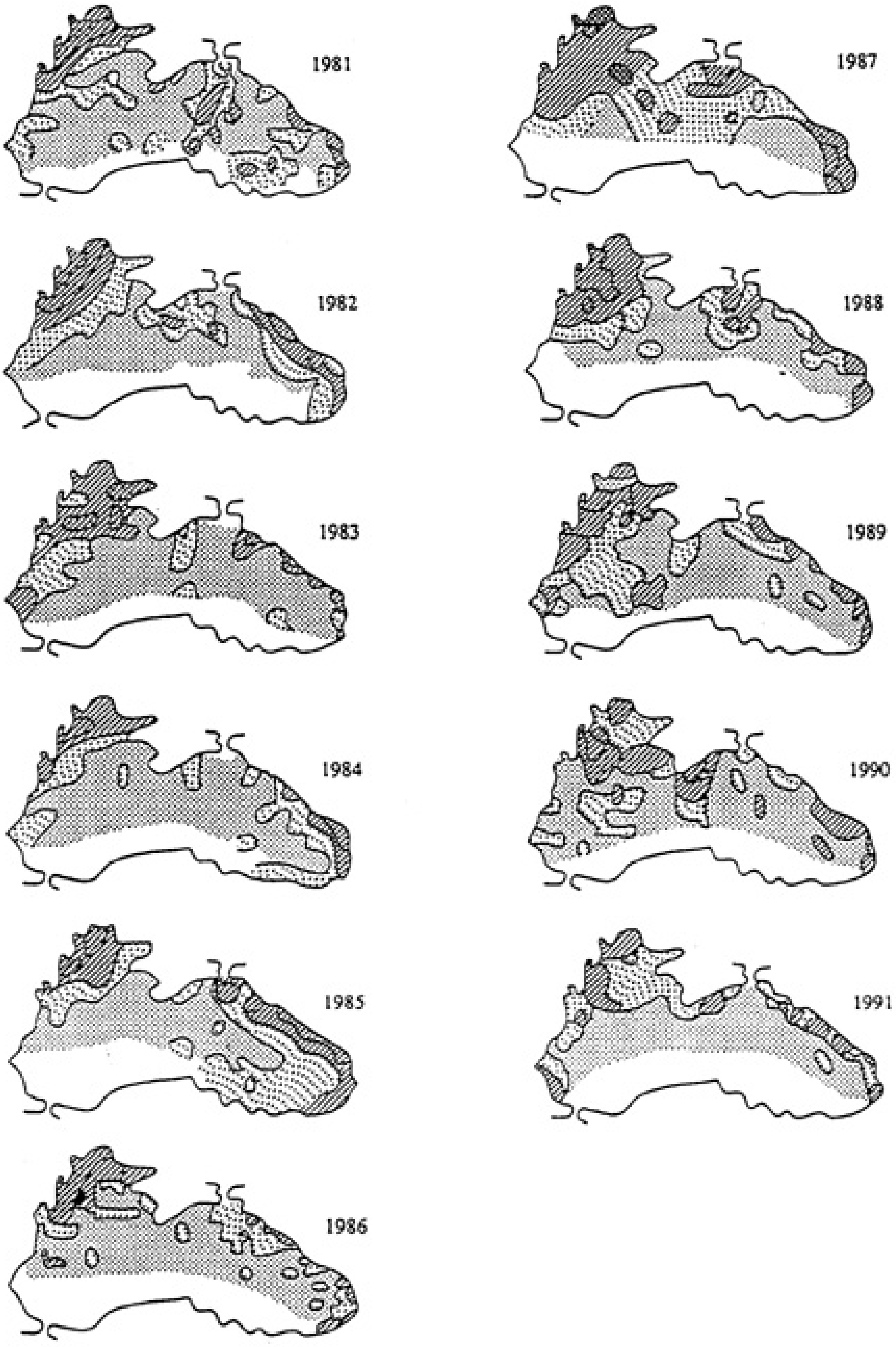


Figure 36. Distribution of the anchovy offspring in July-August 1981-1991

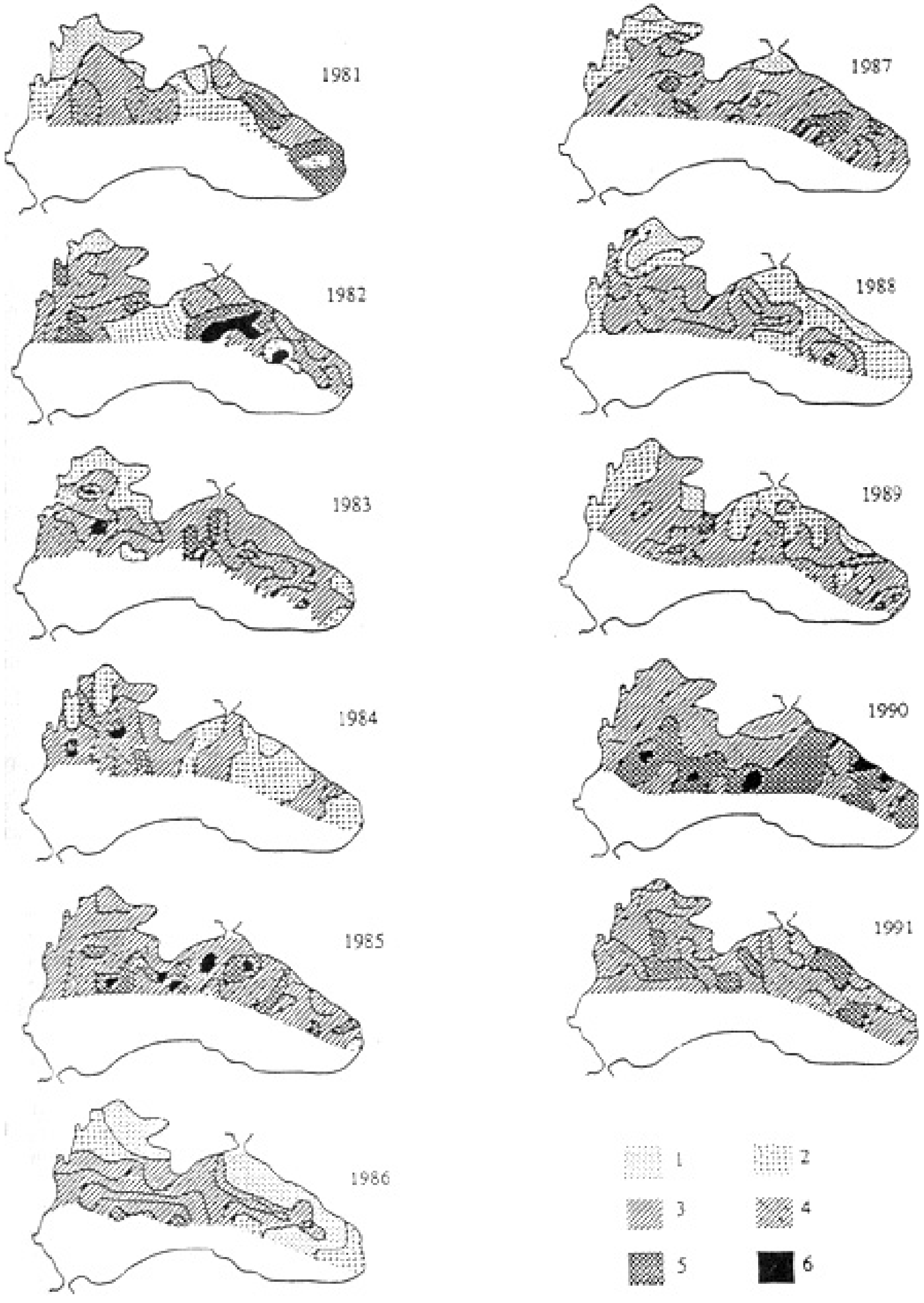


Figure 37. Distribution of sprat offspring in April-May 1981-1991 (in numbers/m^2) (from Arkhipov, 1993):

1: 0-10; **2**: 11-100; **3**: 101-1000; **4**: 1001-10000; **5**: 10001-100000; **6**: >100000