Marine Environmental Conditions and Fishery Productivity in the Black Sea

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ABSTRACT

Some relationships between the marine environment and fishery productivity in the Black Sea are reviewed with emphasis on the coupling of oceanographic processes, plankton cycles and fish production in space and time. Reproductive niches of anchovy *Engraulis encrasicolus ponticus* and sprat *Sprattus sprattus*, the two most abundant fish species in the Black Sea, have been analyzed in relation to enrichment, concentration and retention processes. Non-linear statistical analyses (general additive models) were performed using time series of fish recruitment, adult biomass, sea surface temperature, wind speed, turbulence, river outflow and phosphorus discharge. Both species show clear relation between recruitment and adult stock. Conclusions can be drawn that sprat which is reproducing in the more severe winter conditions is generally more dependent on large scale environmental variability. The distribution and abundance of its progeny is associated with open sea divergence/ convergence process. Anchovy spawns, in summer, in coastal waters. Its recruitment shows a strong dependence on adult stock size, but is also related to river plume zones, and enrichment processes therein. The distribution of anchovy and sprat relative to SST corresponds to their known temperature preferenda.

RÉSUMÉ

Les relations entre l'environnement marin et la production halieutique en mer Noire sont étudiées. Les patterns d'association des processus océanographiques avec les cycles du plancton et la reproduction des poissons dans l'espace et le temps sont examinés et comparés. Les niches reproductives de l'anchois *Engraulis encrasicolus ponticus* Alex et du sprat *Sprattus sprattus* L., les deux espèces les plus abondantes en mer Noire, sont analysées en fonction de la biomasse des géniteurs et des processus d'enrichissement, de concentration et de rétention. Dans ce but, des analyses statistiques non linéaires (modèles additifs généralisés) ont été effectuées en utilisant des données chronologiques de recrutement, de biomasse d'adultes, de température de surface de la mer, de vitesse du vent, de turbulence, de ruissellement des rivières et d'apports en phosphore. Une nette relation entre le recrutement et le stock adulte est mise en évidence. On peut tirer la conclusion que le sprat se reproduit en hiver dans des conditions plus sévères qui sont dépendantes de la variabilité environnementale à grande échelle. La distribution et l'abondance de la progéniture sont associées aux processus de divergence/convergence au large. L'anchois se reproduit en été dans les eaux côtières. Une forte dépendance de son recrutement en fonction du stock d'adulte est démontrée et son abondance est apparemment liée aux zones de panaches des grandes fleuves et à l'enrichissement produit par eux. Les relations avec la température de la mer sont en accord avec les préférences thermiques pour l'anchois et le sprat.

INTRODUCTION

The peculiar oceanographic conditions and the high biological productivity of the Black Sea have already been pointed out by a great number of authors (Grese, 1979; Sorokin, 1982; Ivanov and Beverton, 1985; Vinogradov *et al.*, 1992). Yet the role and the mechanisms through which different marine environmental factors impact on the formation of biological production are still not fully clarified. The present paper is an attempt to review the relations between the physical conditions and the productivity in the Black Sea, based on hypotheses for the matching mechanisms of physical processes and production cycles of marine populations proposed by Cushing and Dickson (1976), Lasker (1985), Cury and Roy (1989) and Mann (1993).

1. THE PHYSICAL ENVIRONMENT AS A BASIS OF PRODUCTIVITY

The specific structure of Black Sea waters was noted at the very onset of oceanographic study. First of all is the existence of two layers, highly different with respect to hydrological parameters and divided by a permanent picnocline (halocline). The deep part (below 50-100 m), comprising 90% of the sea volume (Vinogradov *et al.*, 1992), remains relatively isolated from the surface layer, where the aerobic processes take place. Thus, below the basic picnocline layer, an anoxic zone is formed, preceded by an oxygen deficit zone where organic matter is oxidized to sulfates. Then, by anaerobic bacterial reduction, the sulfates are reduced to hydrogen sulfide. The latter is spread widely in the anoxic zone below 150-200 m (Sorokin, 1992). The geostrophic circulation in the surface layer of the basin is presented by the Main Black Sea Stream (MBS) which generates, in the central east and west regions, extensive cyclonic gyres and a multitude of smaller cyclone and anticyclonic gyres (Fig.1). At the external boundary of the MBS, due to its interaction with the continental slope, a ring of anticyclonic eddies is formed which generates a quasi homogenous Convergence Zone (CZ). Despite the persistence of the picnocline, recent studies show that the water column has an intense vertical dynamics, especially in Winter. Strong North and North-East winds elevate the main cyclonic gyre domes (20-30 m from the surface in some areas) which break the picnocline apart and leads to increase of the convective mixing with an average speed of 0.02 cm/s (Ovchinnikov and Popov, 1987). In this Divergence Zone (DZ), covering an area of about 40 000 km^2, 3-4 000 km^3 are upwelled, which exceed the volume of the river inflow by a factor of ten (Vinogradov *et al.*, 1992). The deep waters, lifted to the surface, mix with the cooled surface layer in a 1:5 ratio and generate the so called 'Cold Intermediate Layer' (CIL), typical of the three-layer summer hydrostructure. The CIL then downwells from the domes of the picnocline to the periphery of the cyclonic gyres until reaching the MBS which spreads them throughout the basin.

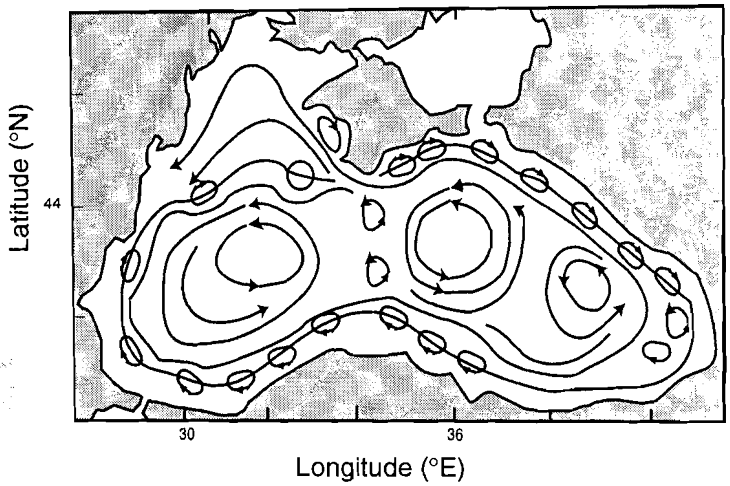

Fig. 1: Surface circulation in the Black Sea (Anon., 1990).

The upwelling of water in the DZ of the central basin is compensated by its downwelling in the CZ above the continental slope, which coincides with CIL downwelling to the periphery of the cyclonic gyres (Ovchinnikov *et al.*, 1991). Downwelling in CZ water is compensated by an intensification of the DZ upwelling as well as by the active upwelling of water on the shelf. Coastal upwelling occurs in some areas, due to geomorphologic particularities of the coast and bottom, and the local winds (e.g., Cape Kaliakra: Dimitrov *et al.*, 1987; Odessa Bay: Vinogradova and Vassileva, 1992; Peninsula of Crimea: Blatov and Ivanov, 1992).

In winter time, due to the impact of the low temperatures and the strong winds, the shelf zone is subjected to intense vertical mixing which covers the total water column from the surface to the bottom. In spring, the surface layer is heated and a seasonal thermocline occurs in the 25-30 m layer. Thus, the typical warm season three-layer structure is observed in the open sea, comprising an upper, quasi-homogeneous layer with the seasonal thermocline as its lower limit, 6-8°C cold intermediate layer between the seasonal thermocline and the permanent picnocline, and an anaerobic zone below the picnocline. Under this stratification, vertical mixing is negligible, ranging from $1 - 1.6 \times 10^{-7}$ cm/s (Boguslavsky *et al.*, 1979). In the North Western Part (NWP) of the Black Sea, the summer vertical stratification is even stronger, due to river inflow. The Danube inflow forms an extensive river plume, which impacts the western coast all the way to the Bosphorus (Rozhdestvensky, 1954). The distribution of basic hydrochemical parameters, as well as that of organic matter and of living communities, depends on these structural peculiarities of the Black Sea waters.

2. PLANKTON PRODUCTIVITY CYCLES

The hydrophysical processes as well as the dynamics of the bio-production differ considerably in the central open sea and shelf zones, which will be considered separately. The latter includes the coastal ecosystems and the shallow NWP, impacted by the inflow of large rivers. The growth of phytoplankton in the open sea depends on the climate conditions, it begins in January-February and reaches its maximum as a winter bloom in February-March. The main prerequisite for it is the elevation of the constant picnocline above the critical depth of photosynthesis (Vinogradov *et al.*, 1992). Obviously, this period offers a combination of conditions (nutrient enrichment and stability) favorable for blooms and similar to those in upwelling zones (Mann, 1993). It can be assumed that, in the center of the cyclone gyres, there are 'pulses' of vertical mixing, followed by stable periods. Moreover, the cyclonic gyres and the picnocline form retention areas for plankton.

The more intensive blooms, caused mainly by *Nitzschia delicatissima*, *Risosolemia calcaravis* and other large diatoms, are noted, in the center of the cyclonic gyres, and, with equal, intensity on the surface to the picnocline, and average production reaches 0.5 - 0.7 $gC.m^2.day^{-1}$ (Vinogradov *et al.*, 1992). At the end of March, the degradation of the bloom begins, wherein the microalgal cells sink and form a vertical distribution maximum on top of, and in the picnocline. The role of the heterotrophs and mixotrophs in the succession increases. In summer, with the establishment of the seasonal thermocline and with the exhaustion of the nutrients during the bloom, production decreases and the peridineans and euglenophytes start to dominate the plankton (Vinogradov *et al.*, 1992). Nazarov *et al.* (1991) distinguish three successions of the phytoplankton in NWP. The first begins in April, after the winter mixing and the increased river inflow. In April-May begins the spring phytoplankton bloom, reflecting the stabilization of the production layer above the thermocline. Summer, autumn and winter maxima are also observed every year. The summer (July-August) maximum is strongest. Mashtakova and Roukhiyaynen (1979) pointed out that, during the years with calm winters in NWP, the phytoplankton has a more pronounced seasonal maximum in April-May while, during the years with stormy winters, this maximum occurs in July-August. This relation is reciprocal in the eastern part: during the years with stormy winters, the biomass maximum occurs in February-March, while for calm winters, this maximum occurs in the summer period. These results lead to the conclusion that, in the deeper water eastern part, which resembles the central regions, the winter bloom is the key production cycle. The strong mixing and cooling of the NWP waters in stormy winters delays the optimum bloom conditions, which shifts the succession to the summer months. This, together with the increased influence of the river inflow, results in a seasonal maximum in July-August. Local upwelling events replacing periods of stability are also important for the initiation and the growth of the blooms in the shelf ecosystems. Zooplankton production is tuned at various spatial and time scales to the maxima of primary production. In the open sea, as well as in the shelf ecosystems, its minimal biomass and production occurs in winter. The thermophobic bathyplankton complex, with *Calanus helgolandicus* and *Pseudocalanus elongatus* as key species, is dominant in the open sea, at all seasons (Petipa, 1991). Its maximal biomass and production occur in spring while the minima occur in summer. Zooplankton growth on a mass scale begins in March in the 10-30 m layer and, after the establishment of the seasonal thermocline; the maximum biomass then spreads above and below this thermocline (Vinogradov *et al.*, 1992). Summer is the most productive season for all zooplankton, including eurythermic species such *Acartia clausi*, and the thermophilic species groups such as *Cladocera*. In summer, the pelagic larvae of zoobenthos species also occur in the plankton. Overall, the highest horizontal zooplankton densities are observed in CZ, on the periphery, between the main cyclonic gyres and in the river plume fronts.

3. FISH PRODUCTION PATTERNS IN RELATION WITH ENVIRONMENTAL CONDITIONS

Rass (1949) divides the Black Sea fish fauna into 4 main groups, based on their origins and ecology peculiarities:
1. Freshwater species;
2. Brakish Ponto-Caspian relicts;
3. Typical sea coldwater species with Boreal-Atlantic origin;
4. Typical sea warmwater species with Mediterranean origin.

The last two groups include the most widely spread and commercially important species in the Black Sea basin. Group 3 consists of: sprat (*Sprattus sprattus)* and whiting (*Merlangius merlangus euxinus*). Group 4 consists of: anchovy (*Engraulis encrasiclus ponticus*), horse mackerel (*Trachurus mediterraneus ponticus*), mackerel (*Scomber scombrus*), and bonito (*Sarda sarda*) (the last two species over winter in the Marmara Sea and feed in the Black Sea.). Reproduction of the coldwater species occurs mainly in winter (December-February) and is coupled with the dynamics of the thermophobic bathyplankton complex, while the warmwater species reproduce and feed in summer, in the warm surface layer, in relation to the dynamics of the summer epiplankton complex (Petipa, 1991). Consequently, it is appropriate to distinguish the main life patterns of the fish populations, related to the peculiarities of the annual production cycle presented below (Fig. 2).

Due to the intensive winter vertical mixing in DZ, the phytoplankton begins to bloom in the open sea in February-March. A maximum of sprat spawning is observed in December-February which may cover the entire basin (Arkhipov, 1993). Whiting spawns in the shelf zone, then the larvae are spread in the basin by horizontal streams. The thermophobic bathyplankton complex spawns during the whole year, with a maximum production in March-April, before the formation of the seasonal thermocline. Sprat and whiting larvae have maximum concentrations in April-May in the open sea as well as

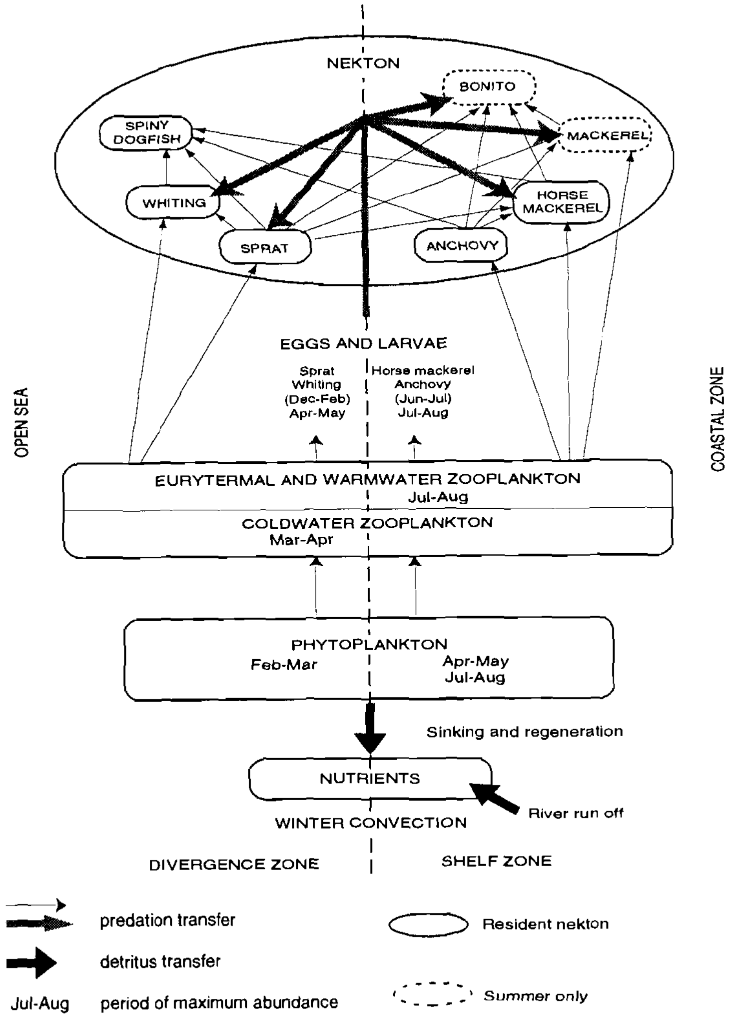

Fig. 2: Major trophic pathways in the Black Sea pelagic ecosystem.

in the shelf zone, in the 0-100 m layer, with maximal densities above the continental slope and on the edges of the main cyclonic gyres. Following the spring warm up of the waters, the larvae/juveniles withdraw below the seasonal thermocline, where they find favorable feeding conditions (zooplankton larvae) in the 10-50 m layer. Adult sprat and whiting undertake feeding migrations in the shelf zone during the spring period of homothermia. In summer they reside below the thermocline and, in some cases, when winds blow from the shore, they migrate to the coast together with the plankton complex, their main food.

In March-April the bloom begins in the shelf zone, using the nutrients from winter mixing and from river outflow. Maximum production in this zone occurs in the surface layer, in summer. At this time, the warm water fish migrate in NWP and in the coastal zones, for both feeding and spawning .

4. REPRODUCTIVE NICHES OF COLD WATER AND WARM WATER FISHES AS EXEMPLIFY BY SPRAT AND ANCHOVY

A comparative study of small pelagic clupeoid fishes should examine the three factors responsible for their reproductive success and thus for the high productivity of these species (Bakun, 1994):

- enrichment with nutrients;
- concentration of fish larvae and their food in a stable environment;
- retention of the concentrated patches favorable for fish growth and survival.

The components of Bakun's 'triad' are strongly dependent on the physical processes in the sea. Thus, enrichment is mainly caused by divergence, upwelling or river run-off, while concentration and retention (by convergence or stratification) are associated with active oceanographic structures such as currents, fronts, eddies or coastal upwelling. The niche concept (Hutchinson, 1978) is assumed as n-dimensional hyperspace occupied by the community, any point of which is defined by some value of environmental variables. We call a 'reproductive niche' the realized niche as a function of the reproductive population interacting with its environment. The reproductive population is characterized by both spawning stock and eggs, and larvae abundance and survival which account for the recruitment success sustaining the population. The niche space is determined by abiotic and biotic environment and, as well, by species preferences. On the basis of current knowledge in ecology and of statistical analyses we performed, we attempted to define elements of the reproductive niches of the two most abundant fish species in the Black Sea: anchovy and sprat, in relation with the above mentioned 'triad'. Coldwater and warm-water fishes differ by their seasonal pattern. In the Black Sea, the seasonal gradients of the hydrographic parameters are stronger than in the open ocean. As mentioned above, Black Sea fishes have different origins. Their specific preferences for environmental conditions predetermine their adaptation in the Black Sea. The clear seasonality of reproductive behavior in these species underlines that temperature is an important factor defining their niche.

In relation to the first factor from the 'triad', the enrichment, it was shown above that the spawning of sprat can be associated with the winter divergence and the winter/early spring plankton maxima. Winter presents rather adverse weather conditions so the reproductive niche of fish is situated such as to ensure optimal concentration and retention for eggs and larvae. Those are found mostly offshore in the 10-50m subsurface layer: a zone stabilized by the permanent picnocline. Horizontally, sprat eggs and larvae are concentrated in the CZ and on the edges of the main cyclonic gyres (Fig. 3). The most abundant Black Sea species is the anchovy, which spawns during summer when, intensive feeding and growth occurs as well. The enrichment processes underlying the summer production maxima in coastal waters and the NWP are more difficult to explain. Their complex patterns include temporal decay in plankton successions, due to intensified cooling of this zone in comparison with the open sea, river runoff with maxima in late spring, increasing importance of the regenerated production for food webs, local upwellings, intrusions through thermohaline fronts, internal waves, etc. The main feature characterizing the summer habitat is the strong stratification of the water, due to the seasonal thermocline, which is reinforced in coastal waters and the NWP by the plumes of the large rivers. Anchovy spawns mainly in the surface layer of these warm and stratified areas (Fig. 4). In this manner eggs and larvae are retained in the coastal layer, stabilized in depth by the thermocline and protected from offshore drift by thermohaline fronts. Trukhchev and Demin (1992) show that the NWP presents a local minimum of the surface wind driven velocity that is directed onshore.

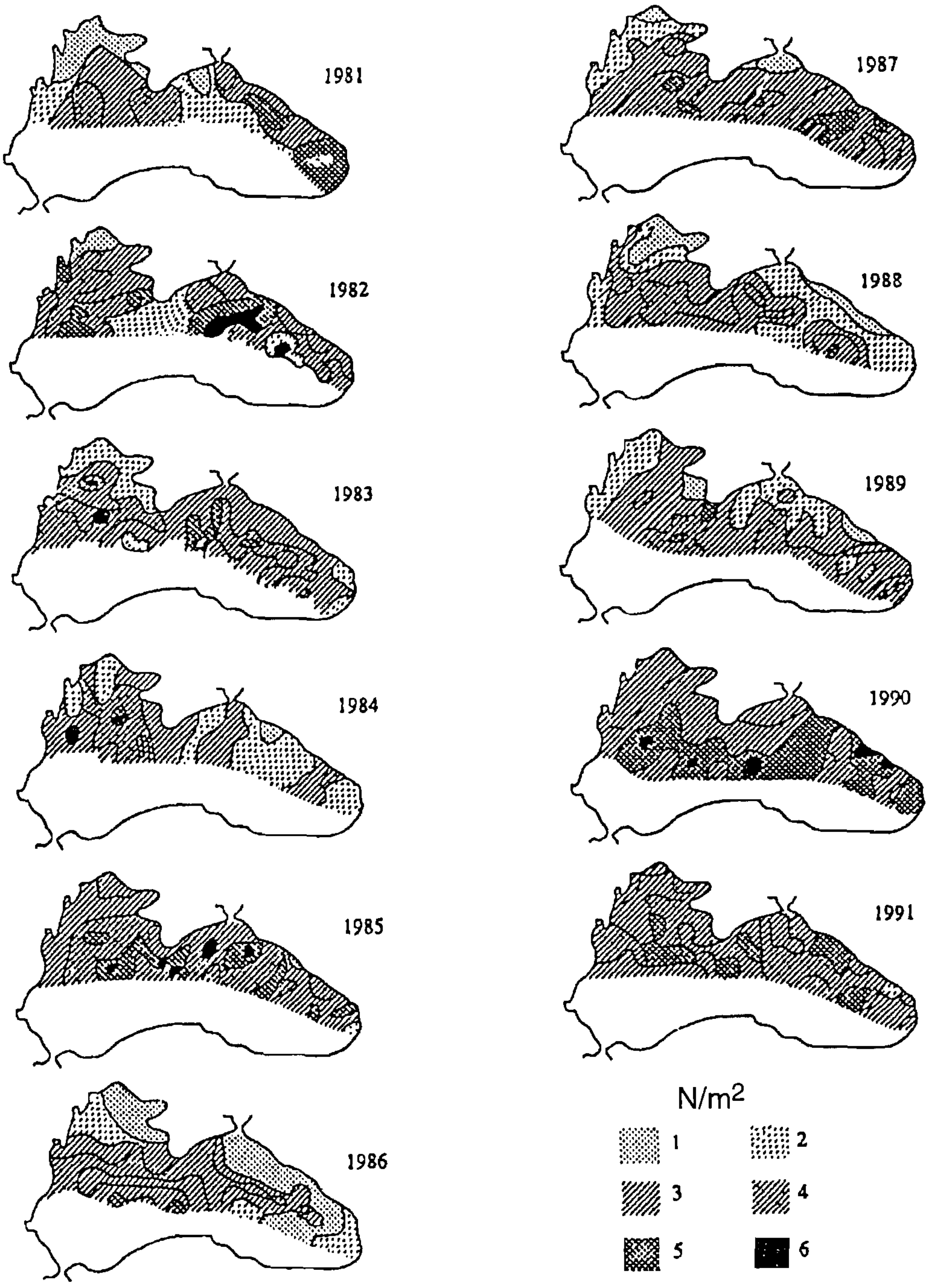

Fig. 3: Distribution of Black Sea sprat larvae and early juveniles in April-May 1981-1991 (after Arkhipov, 1993).

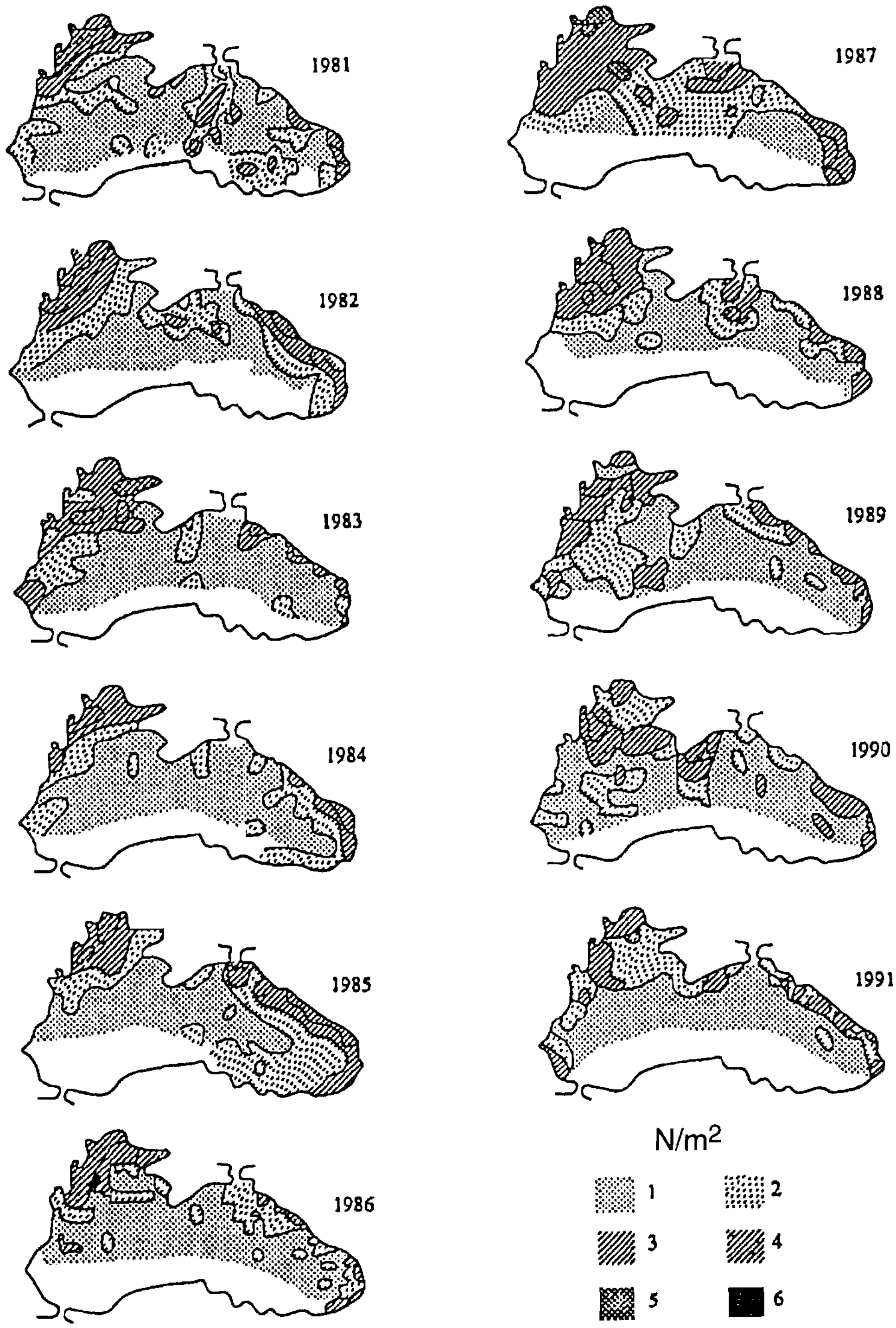

Fig. 4: Distribution of anchovy larvae and early juveniles in July-August 1981-1991 (after Arkhipov, 1993).

The sprat, as a cold water species of boreal origin, prefers the winter season when enrichment and plankton blooms occur offshore. It finds relative stability in the layer near the picnocline and in the CZ. During the summer sprat is then found in the cooler waters under the thermocline together with its preferred food, *Calanus* and *Pseudocalanus*.

In this manner the two most abundant fish populations anchovy and sprat 'share' their reproductive habitat in space and time. The overlapping between their adult trophic niches is also negligible (Petipa, 1991; Konsulov, 1975). Such a relative lack of competition allows these species to maintain large biomasses, while coupling them with the annual production cycle.

Statistical analyses can be used to study further the niche of anchovy and sprat. Relationships between recruitment, parental biomass and environmental factors are usually non-linear; so transformations of data should be performed to maximize the correlation among them. We have applied the generalized additive model of Hastie and Tibshirani (1990) to explore the appropriate forms of relationships between variables. The ACE algorithm (Alternating Conditional Expectations; Breiman and Friedman, 1985) has been used to estimate optimal transformations of the response variable and predictor variables for multiple regression. This method was used previously in recruitment studies by Cury and Roy (1989) and allowed them to define the 'optimal environmental window' concept. The use of the general additive model in fisheries science is discussed in details in Cury *et al.* (1995). Data used are shown in Tables 1 and 2. Recruitment and biomass series were estimated using VPA (Prodanov *et al.*, 1995). Monthly mean values of sea surface temperature (SST), wind speed and the wind speed cubed were extracted from COADS (Comprehensive Ocean-Atmosphere Data Set, CEOS Program, 1994) using the CODE program (Roy and Mendelssohn, this vol.), and averaged over the main spawning seasons: November- March for sprat and April-August for anchovy, for the area from 42°S-46°N and 28°W-34°E. The wind speed index is related to the wind-driven currents i.e., divergence/convergence and thus, with enrichment, concentration and retention on one hand, and instability and dispersion on the other hand. Wind cubed is a rough index of mixing in the upper layer (Bakun and Parrish, 1982). Data on river discharge and phytoplankton biomass are from Anon. (1992) and total phosphorus data in the Danube delta, from Juravleva and Grubrina (1993).

Both species anchovy and sprat show clear relation between recruitment and parental biomass. Transformations are close to logarithmic in shape, so density dependent regulation of recruitment can be assumed (similar to the Beverton and Holt stock-recruitment model). However, only 39% of sprat recruitment variance is explained by the model (Fig. 5a), while anchovy recruitment is highly determined by the stock size ($R^2=0.87$, Fig. 6a). On the other hand, if the analysis is restricted to a recent period (1966-1990), so that data are more reliable, the model, with a similar form of the functional relationship, explains 81% of sprat recruitment variance ($R^2=0.81$). From Figures 5b, c, d we can see that 67%, 66% and 77% respectively of sprat recruitment variance are explained by different combinations of hydroclimatic variables. The relationship with SST is negative and more pronounced above 10°C mean winter SST (November-March). The transformation of scalar wind speed, plotted against its original values, presents an optimum between 6.5 and 7 m/s and the transformation of the wind cubed, has an optimum near $600 m^3/s^3$ (Fig. 5b, c) These figures are similar to those originally documenting the 'optimal environmental window' concept of Cury and Roy (1989).

In his comparative study on three highly productive large marine ecosystems inhabited by clupeoid stocks, Bakun (1993) found that values of the wind mixing index $<250\ m^3/s^3$ characterized sardine and anchovy spawning grounds. However, other reproductive sites mentioned in this paper as Agulhas Bank in the Benguela system and the Patagonia Shelf in south-eastern South America present much higher turbulence. In these regions the suitable reproductive habitat is assumed to occur in more stable subsurface layers. Similarly, the habitat of sprat is assumed to be in the 10-50m layer stabilized by the permanent picnocline and around eddies in the CZ, so the influence of surface turbulence would be reduced. In the last model presenting recruitment as a function of SST, wind and turbulence (Fig. 5d) the shape of the transformation for wind

	Sprat		Anchovy		River outflow	Total phosphorus
Year	Recruitment ($N.10^9$)	Parental biomass ($t.10^3$)	Recruitment ($N.10^9$)	Parental biomass ($t.10^3$)	($Km^2.year^{-1}$)	(t)
1955	28.43	25.4	—	—	—	—
1956	22.03	40.4	—	—	—	—
1957	63.35	40.3	—	—	—	—
1958	91.8	102.9	—	—	—	—
1959	79.66	164.4	—	—	—	—
1960	96.23	198.4	—	—	—	—
1961	76.21	231.5	—	—	—	—
1962	41.66	203.3	—	—	—	—
1963	27.47	142.2	—	—	—	—
1964	58.72	91.8	—	—	—	—
1965	24.36	101.5	—	—	384.9	—
1966	19.97	78.3	—	—	399.3	—
1967	13.67	57.9	75.1	294.8	371.7	—
1968	12.05	43.5	60	438.6	314.2	—
1969	29.03	33.2	64	484.2	352.7	—
1970	24.52	56.4	68.6	492.0	491.6	—
1971	110.01	65.8	54	509.2	306.6	21.6
1972	130.64	181.2	48.7	446.1	301.2	10.3
1973	170.5	287.4	63.2	367.4	287.5	15.7
1974	113	409.7	56.5	342.4	335.3	18.2
1975	85.13	553.5	81.2	325.2	369.7	27.6
1976	115	469.1	63.4	358.9	312.4	33.1
1977	84.37	485.9	87.3	355.9	359.7	30.7
1978	84.12	412.7	112	458.7	371.6	32.1
1979	97.68	370.1	144	708.1	395.2	75.5
1980	72.2	332.9	116	705.9	437.2	—
1981	43.05	280.9	93.4	667.2	416.7	93.2
1982	57.92	209.2	90.7	549.3	359.2	98.8
1983	76.09	184.6	101	515.3	280.6	56.9
1984	113	234.7	84.7	451.3	291.6	68.7
1985	169	313.2	107	512.1	321.2	52.2
1986	102	397.8	104	534.9	—	56.4
1987	117	398.7	62	501.6	—	51.8
1988	62.69	398.6	39.9	252.3	—	—
1990	47.61	115	26.7	137.5	—	—

Table 1: VPA estimates of recruitment and parental biomass of Black Sea sprat and anchovy (Prodanov *et al.*, 1995); river outflow into the Black Sea (Anon., 1992), and total phosphorus amount in the Danube River delta (Juravleva and Grubrina, 1993)

cubed shows a negative relation with recruitment. In such a model, however, one must be weary of the high degree of colinearity between the last two wind related variables, which can affect model reliability. Figure 6b presents the relation of the anchovy recruitment with SST and the wind variables. The model explains 52% of the variance, and the relation with wind speed is positive. The transformation of the wind mixing index has a negative slope. The relation with SST is positive, but the contribution of this variable to total explained variance (as shown by the range of the transformed values) is negligible. Figures 6c, and d show the dependence of anchovy recruitment on river discharge. The high coefficient of determination ($R^2=0.73$) of total phosphorus discharged by the Danube River identifies out river outflow as an important source of enrichment for summer production.

	Winter			Summer		
Year	SST	Wind speed	Turbulence	SST	Wind speed	Turbulence
1965	9.6	6.1	473.3	17.4	5.5	463.9
1966	10.8	6.9	647.9	19.3	5.5	340.3
1967	11.1	6.8	597.8	18.7	4.8	287.5
1968	10.3	7.3	764.4	18.8	5.2	332.7
1969	9.9	7.7	824.4	17.6	5.9	426.3
1970	10.9	7.5	615.2	17.9	4.0	238.4
1971	9.9	6.4	671.2	18.7	3.8	145.9
1972	9.7	5.4	758.1	19.7	4.2	278.8
1973	9.5	6.5	705.6	18.3	5.2	287.9
1974	8.6	7.2	687.0	16.8	4.3	196.8
1975	10.3	6.8	630.3	18.4	5.4	356.8
1976	9.1	7.3	833.5	17.5	4.7	260.1
1977	9.9	6.4	575.3	18.3	4.8	301.0
1978	9.2	6.4	579.6	17.7	4.1	202.0
1979	9.9	7.1	624.0	18.7	5.5	371.2
1980	9.5	7.0	693.0	17.9	4.2	180.9
1981	10.3	6.8	753.2	18.2	4.5	267.8
1982	9.4	7.5	811.6	17.6	6.0	382.3
1983	9.8	6.9	600.3	18.9	5.3	308.3
1984	9.5	7.0	600.5	17.6	5.9	368.0
1985	9.0	7.2	608.6	17.4	4.6	214.6
1986	10.0	6.0	370.9	18.9	4.7	279.0
1987	8.6	6.2	677.6	17.3	4.5	239.4
1988	9.1	7.2	735.7	18.8	4.2	344.2
1989	8.8	5.9	480.1	18.0	4.9	251.1
1990	8.8	7.3	892.3	18.1	3.9	193.4

Table 2: Sea surface temperature (°C), scalar wind speed (m/s) and turbulence index (wind speed cubed, m^3/s^3) from COADS (1994) averaged over November-March (winter) and April-August (summer).

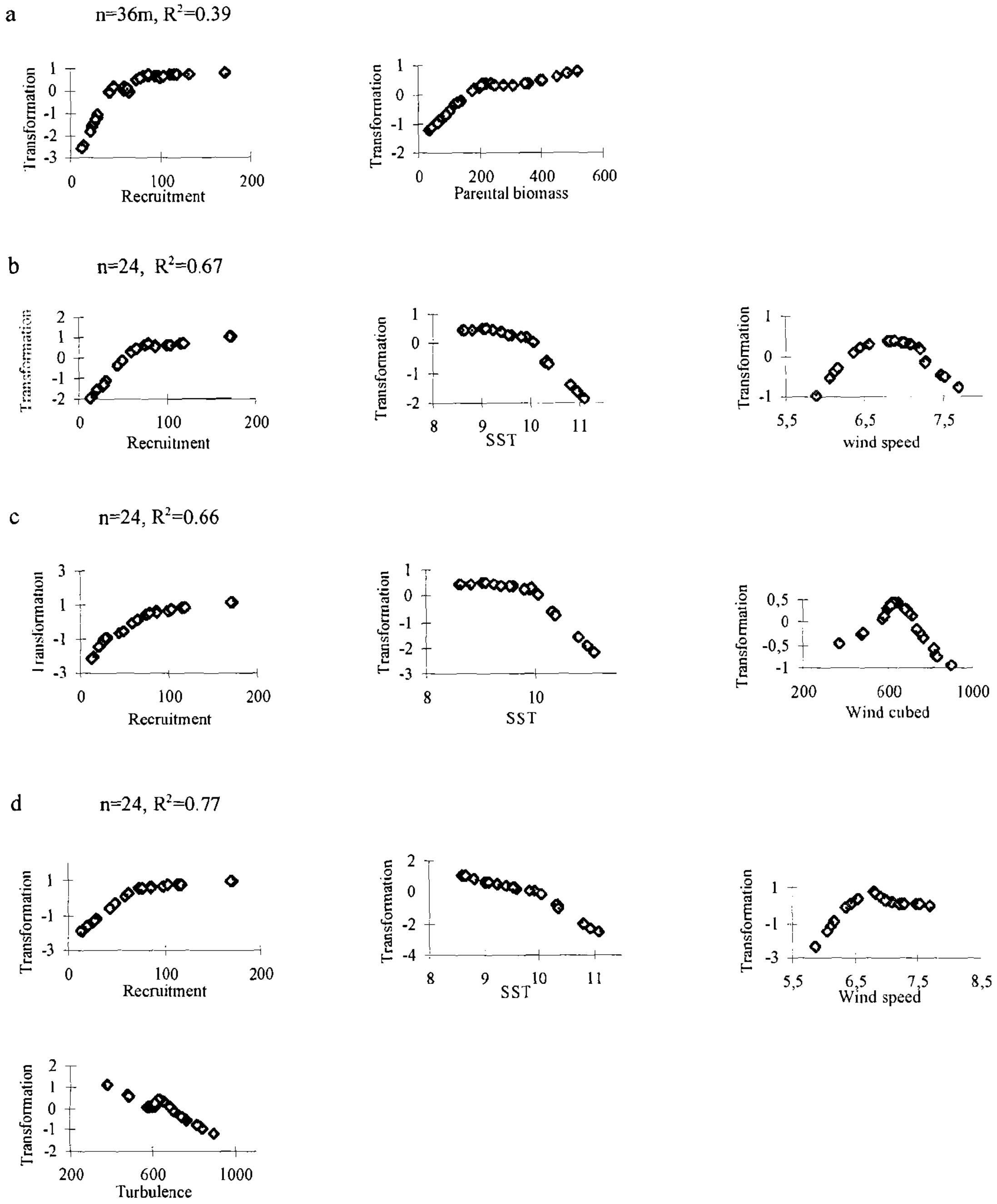

Fig. 5: Regressions of sprat recruitment as a dependent variable on parental stock biomass and different environmental factors (independent variables) using the ACE algorithm (data from Tables 1 and 2):

a) Recruitment vs. parental biomass;
b) Recruitment vs. SST and wind speed;
c) Recruitment vs. SST and turbulence index;
d) Recruitment vs. SST, wind speed and turbulence index.

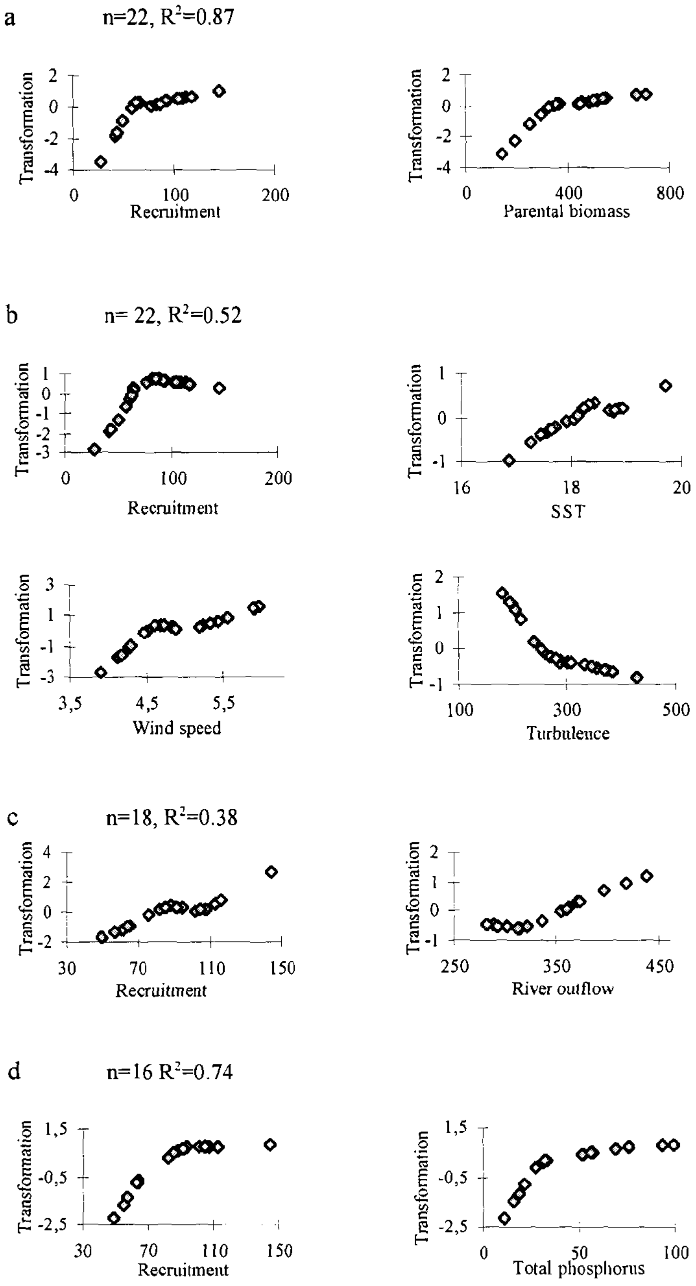

Fig. 6: Regressions of anchovy recruitment as a dependent variable on parental stock biomass and different environmental factors (independent variables) using the ACE algorithm (data from Tables 1 and 2):

a) Recruitment vs. parental biomass;
b) Recruitment vs. SST, wind speed and turbulence index;
c) Recruitment vs. total river outflow in the Black Sea;
d) Recruitment vs. total phosphrus in the Danube River delta.

5. CONCLUSIONS AND SUGGESTED OBJECTIVES FOR FUTURE INVESTIGATIONS

In the last 20 years, the Black Sea ecosystem suffered considerable changes due to the increased anthropogenic impact. The commercial fisheries, based mainly on pelagic species, peaked in the late 1970s. In the 1970s the eutrophication of the Black Sea became evident, characterized with increased rate of red tides, incidences of hypoxia in the bottom biocenoses, community alterations and advent of immigrants (Caddy and Griffiths, 1990). The sharp decrease of the top marine predators, together with the increased impact of the eutrophication led to increases of planktophageous species. The outburst of plankton not used in the food web itself led planktophageous megaloplankton which also feed on fish eggs and larvae. The negative human impact (overfishing, pollution) has led to destabilization of the ecosystem in the second half of the 1980s, and to a decrease of the biodiversity and the biological resources (Zaitsev, 1993). The increase impact of anthropogenic factors, relative to natural factors of the marine environment, is a subject of numerous debates in the scientific community. Expeditions conducted in the 1980s for the study of the open sea regions (Petipa, 1991) led to a realization of the importance of the winter circulation for the hydrological structure of the basin and for the annual production cycle (Ovchinnikov *et al.*, 1991). The concentration of the majority of the studies in the coastal zone and in the warm season, typical of the early period of the Black Sea marine science, led to overestimating the importance of the shelf systems in comparison with the open pelagic ecosystem, considered oligotrophic by some early investigators. The latest studies show sharp fluctuations of the fish stocks (Ivanov and Beverton, 1985; Daskalov and Prodanov, 1995a, 1995b.; Prodanov *et al.*, 1995). There is also a well-known variability of the primary and secondary production to consider, along with the hydrological and hydrochemical factors of the environment (Anon., 1992; Ovchinnikov and Osadchiy, 1991).

The high production and the peculiar dynamics of the system, its oceanography and biological studies dating for more than a century offer possibilities for long time series data analysis. Moreover, the unique features of the Black Sea — one of the cradles of European civilization — make this basin a very interesting object for comparative analysis. Bakun and Parrish (1982) developed this idea and pointed out the main criteria for comparative time series analysis of environment and fishery systems in upwelling regions. Caddy (1993), similarly, proposed a comparative evaluation of the fishery ecosystems of semi-enclosed seas. Since 1992 a group of fisheries scientists from the Black Sea region joined in a project 'Environmental management of fish resources', funded by The Central European University Foundation, devoted to the assessments of the main commercial fish stocks and diagnosis of their dynamics in relation to environmental changes and human impact (Prodanov *et al.*, 1995). The methods, the criteria and the general research framework are similar to those proposed by ICES, FAO Fisheries Department, ICLARM, and are based on the traditions of the Research Institutions for Black Sea. The objective is the preparation of a large operational data base on the status of fish resources and the conditions of the environment in order to identify regularities of their dynamics. This sould help model and manage the stocks in an ecological context.

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