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The effect of environmental conditions on the distribution of eggs and larvae of anchovy (*Engraulis encrasicolus* L.) in the Black Sea

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Recent events in the Black Sea have had a severe impact on all compartments of the ecosystem, including ichthyoplankton. The distribution of eggs and larvae of the anchovy, the major commercial fish species, was investigated in relation to ambient conditions in the southern Black Sea during July 1992, August 1993, and June–July 1996. Average highest egg and larva numbers were observed in June–July 1996. Ichthyoplankton distribution was closely connected with the hydrography. Besides surface temperature and salinity, among the numerous biotic parameters tested, abundance of fodder zooplankton and of the ctenophore *Mnemiopsis leidyi* showed significant correlations with the distribution of either eggs or larvae of the anchovy. The results help in explaining the shift observed in the spawning grounds.

Key words: Black Sea, anchovy, ichthyoplankton, distribution.

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Introduction

Analysis of catch data of the anchovy (*Engraulis encrasicolus* L.) discloses interesting events taking place in the Black Sea ecosystem. Since the late 1960s, the Turkish catch of this most abundant fish species of the Black Sea has increased gradually to approximately 500 000 t in 1989 (Fig. 1). The increase is due to new technology in fishing, but also to factors such as the beneficial effects of increased nutrients, particularly on the north-western shelf (Zaitsev, 1992). In addition, predator pressure appears to have decreased. Moreover, the coupling between the benthic and pelagic sub-systems was disturbed owing to mass mortalities of benthic filter-feeders, which may have left a larger proportion of the production available for pelagic fish. Kovalev *et al.* (1998) suggested that increasing nutrient input *via* major rivers was responsible for the significant increase in both phytoplankton and edible zooplankton biomass (excluding gelatinous species), particularly in the deep waters of the eastern Black Sea. The increase in zooplankton, which is the main food for anchovy, could have had a

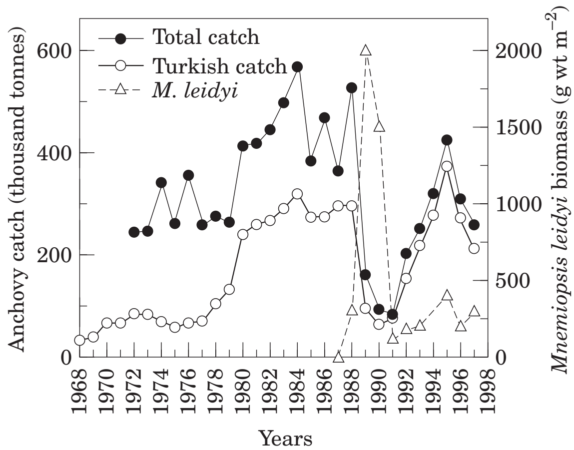

Figure 1. Time series of anchovy catch from the Black Sea and biomass of *Mnemiopsis leidyi* (Turkish catch data from DIE, 1968–1997; total anchovy catch from FAO; *M. leidyi* data for 1991–1993 from Mutlu *et al.*, 1994).

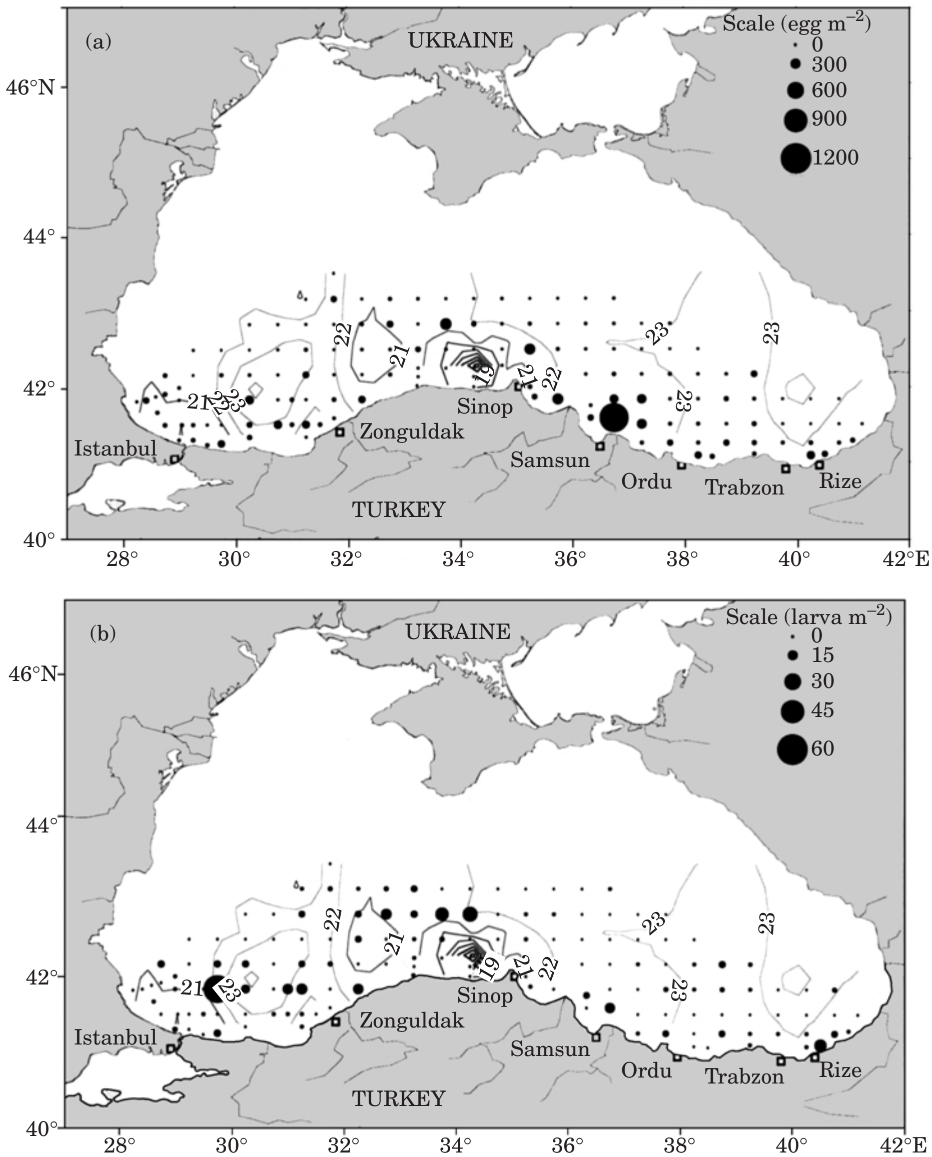

Figure 2. Distribution of [A] anchovy eggs and [B] larvae in the southern Black Sea during the July 1992 survey (N m^{-2}). Surface isotherms (°C at 5 m) are also shown (modified from Niermann *et al*., 1994).

positive effect on the population size of this species. However, eutrophication (particularly in the shallow north-western region) in combination with overfishing and the recent appearance of the competing invader *Mnemiopsis leidyi* (Ctenophora) appears to have caused an abrupt decrease to 60 000 t in the anchovy catch by the end of the 1980s (Kideys, 1994; Fig. 1). After the sudden decline, the catch has again consistently increased to a maximum of 374 000 t in 1995.

Striking changes have also been observed in the reproductive strategy of anchovy, as may be inferred from the long-term distribution of the early life stages. In contrast to earlier studies, numbers of eggs in the south-eastern Black Sea in particular in recent years are higher than in the north-western region (Niermann *et al*., 1994), which was formerly known as the main spawning area (Ivanov and Beverton, 1985). Recent studies confirm that the main spawning areas have now been established along the Turkish coast (Kideys *et al*., 1998). However, the distribution of eggs and larvae in the southern Black Sea is not uniform and the environmental factors responsible for the heterogeneity are not

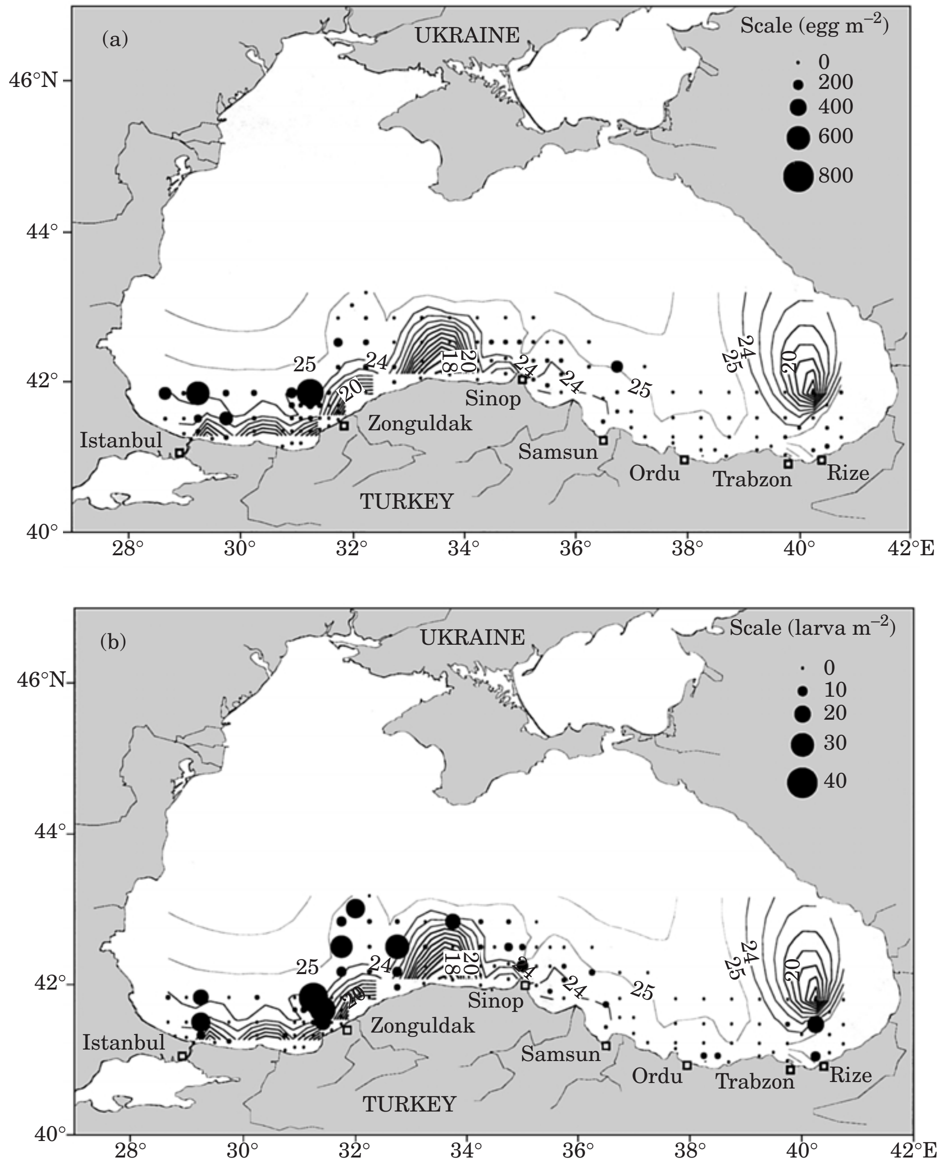

Figure 3. Distribution of [A] anchovy eggs and [B] larvae in the southern Black Sea during the August 1993 survey (N m^{-2}). Surface isotherms (°C at 5 m) are also shown.

known. We investigate the effect that some environmental factors may have had on the distribution of anchovy eggs and larvae.

Materials and methods

During surveys in 1992 (3–26 July; 144 stations), 1993 (4–22 August; 143 stations), and 1996 (20 June–6 July; 120 stations) on board the RV "Bilim", ichthyoplankton was collected from a dense station grid in the Turkish Exclusive Economic Zone covering the entire southern Black Sea. All samples were obtained via vertical tows (towing speed approximately 0.5 m sec^{-1} from the anoxic zone to the surface using a Hensen net (300 µm mesh size and a net opening of 70 cm diameter). The depth of the lower boundary of the oxic zone varies spatially in the Black Sea, but is consistent with a density of $\sigma_t = 16.2$. The appropriate sampling depth was thus derived from density measurements. Bucket contents were filtered using a 2-mm sieve to retain gelatinous organisms, which were quantified only during the July 1996 survey. The volume of each ctenophore (*Mnemiopsis leidyi*) was measured, while diameter was measured for individual ctenophores (*Pleurobrachia*

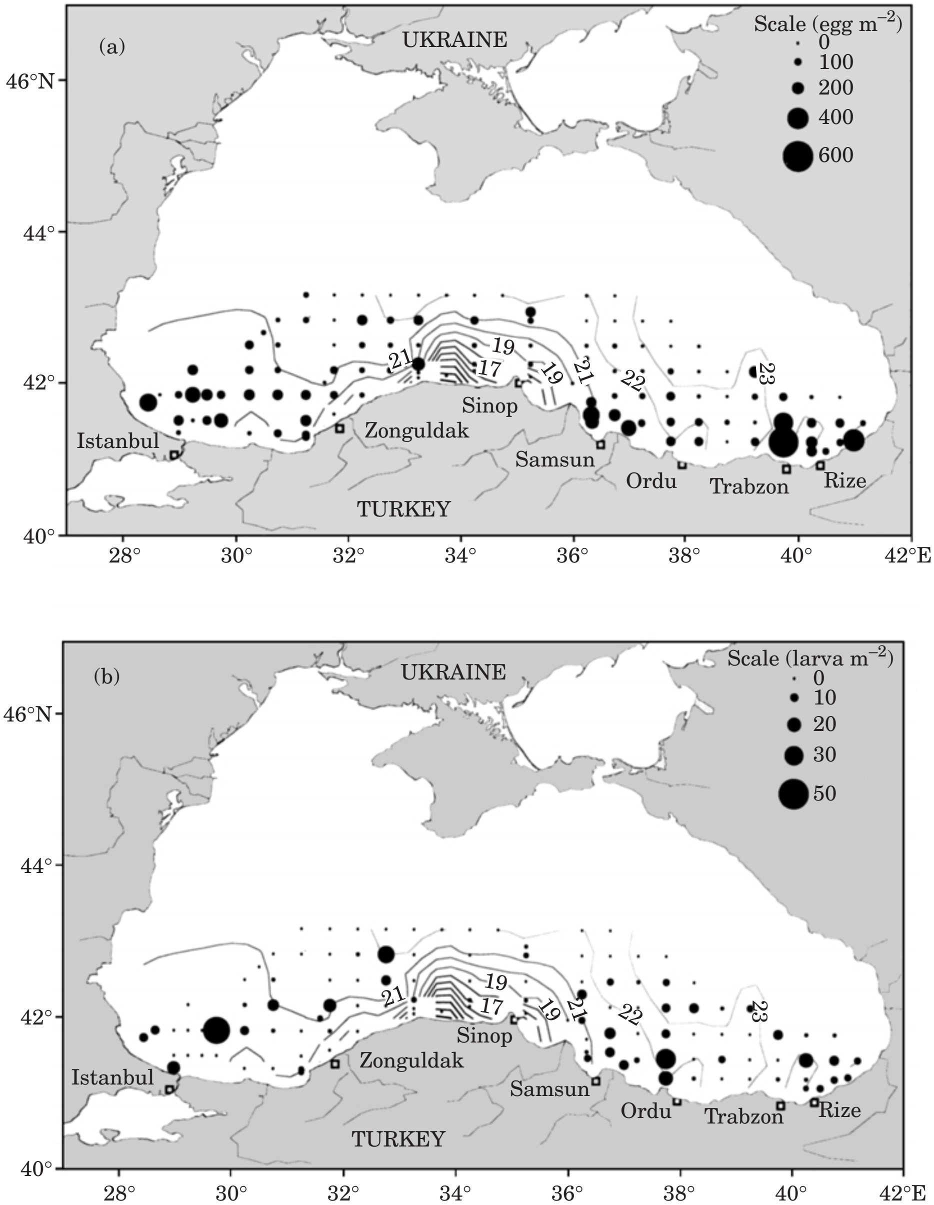

Figure 4. Distribution of [A] anchovy eggs and [B] larvae in the southern Black Sea during the June–July 1996 survey (N m^{-2}). Surface isotherms (°C at 5 m) are also shown.

pileus) and cnidarians (*Aurelia aurita*). The filtrates were fixed with buffered formalin (final concentration of 4%) for sorting in the laboratory under a binocular microscope.

With the exception of the July 1992 cruise, all zooplankton organisms (mainly copepods) were staged and counted along with the ichthyoplankton. Biomass values were calculated using existing conversion values (Petipa, 1957). Temperature, salinity, and density of the water column were measured using a CTD probe at each station until the depth at which $\sigma_t = 16.2$. All tests were performed using the Spearman Rank correlation (Zar, 1984).

Results and discussion

Distributions of eggs and larvae of the anchovy as well as the surface temperatures are shown in Figures 2, 3, and 4 for the surveys in 1992, 1993, and 1996,

Table 1. Densities of anchovy eggs and larvae in the southern Black Sea, 1957–1996.

Year	Month	Egg (N m^{-2}) Range	Egg (N m^{-2}) Mean	Larva (N m^{-2}) Range	Larva (N m^{-2}) Mean	Reference
1957	July	0–321	≃18		≃2	(1)
1991	June	0–29	≃6	0–2	⩽1	(2)
1992	July	0–1167	72	0–55	3.5	(3)
1993	August	0–718	39	0–39	3.1	(3)
1996	June–July	0–577	90	0–44	4.3	(3)

References: (1) Einarsson and Gurturk, 1960, (2) Niermann *et al.*, 1994, (3) This study.

Table 2. Spearman's rank correlation analyses between biotic and abiotic factors by survey (bold numbers are significant; − indicates inverse relationship; E: eggs; L: larvae; T: temperature; S: salinity; N: Noctiluca biomass; Zb: zooplankton biomass; Za: zooplankton abundance; Ma: Mnemiopsis abundance; Mb: Mnemiopsis biomass).

a. June–July 1996	L	T	S	Nb	Zb	Za	Ma	Mb
E	**<0.01**	− 0.83	− **<0.01**	0.11	0.95	**<0.01**	**<0.01**	**<0.01**
L		**<0.01**	− 0.72	0.48	− 0.20	0.73	0.11	0.09
T			− 0.10	− **<0.01**	0.32	− **<0.01**	− **<0.05**	− 0.19
S				0.62	0.51	0.65	− **<0.01**	− **<0.01**
Nb					− **<0.01**	0.80	0.06	0.14
Zb						**<0.01**	0.73	0.60
Za							**<0.05**	**<0.05**
Ma								**<0.01**
b. August 1993	L	T	S	Za				
E	**<0.01**	0.25	0.19	0.61				
L		0.90	0.93	0.36				
T			− **<0.01**	− 0.58				
S				− 0.25				
c: July 1992	L	T	S					
E	<0.01	<0.01	− <0.01					
L		0.22	0.55					
T			<0.01					

respectively, and summaries of the ranges observed and means are given in Table 1. Although the maximum concentrations were obtained in 1992, the mean values for both eggs and larvae were highest in 1996. The numbers of eggs do not reflect the gradual increase in catch values (Fig. 1), but they were probably underestimated in 1993, when sampling was performed towards the end of the spawning season in August. Taking this imperfection into account, the data do suggest that the numbers of eggs and larvae have increased in recent years compared with the 1957 and 1991 values (Table 1). In 1957, the Black Sea was still in an oligotrophic state and, therefore, it could probably sustain only a relatively small pelagic fish stock. In 1991, the lowest numbers of eggs and larvae were observed, which coincides with the period when anchovy catches plummeted to their lowest value. The increase in eggs and larvae by 1996 might be taken as an indication of the recovery of the heavily disturbed Black Sea ecosystem.

During August 1993, the highest egg abundances were limited to the western part (in front of the Bosphorus and off Eregli). Besides the western region, two coastal areas in the eastern Black Sea were the most abundant localities in June–July 1996 (off Samsun and between Trabzon and Rize). The distribution pattern in the 1996 survey was similar but not as uniform as in the July 1992 survey.

The temperature distribution (at 5 m) in the surveys differed notably. During August 1993, the temperature (maximum 28.8°C, average 23.1°C) was a few degrees higher than during the June–July 1996 survey (maximum 24.9°C, average 21.4°C). In 1993 in the western Black Sea there was a frontal current system along the coast, resulting in a sharp gradient. Highest egg and larval densities were observed at the warmer edge of this frontal system. Interestingly, the main downwelling area of the Black Sea, the Batumi Gyre (Oguz *et al.*, 1993) was an upwelling area during this period.

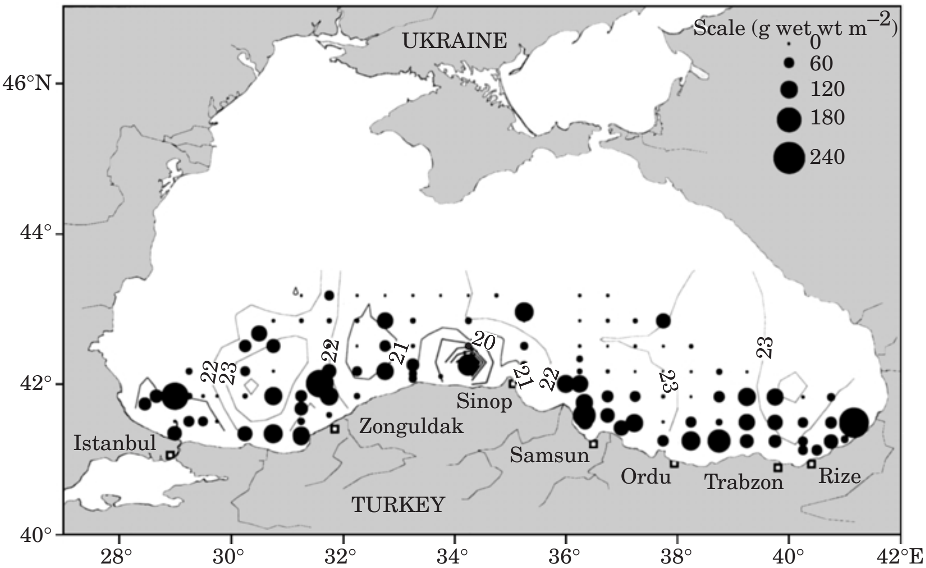

Figure 5. Distribution of *Mnemiopsis leidyi* biomass (g wet weight m^{-2}) in the southern Black Sea during the June–July 1996 survey. Surface isotherms (°C at 5 m) are also shown.

During the 1996 survey, the only sharp gradient in surface temperature distribution was observed between Zonguldak and Sinop, with temperatures down to 17°C in the core. Upwelling in this region appears to be a consistent hydrographical feature during July, as it was also present during the 1957 and 1992 egg surveys (Einarsson and Gurturk, 1960; Niermann *et al.*, 1994). Eggs and larvae were either absent or present in very low numbers in this region. This is not unexpected, because the presence of temperatures higher than 20°C is a prerequisite for maximum spawning of anchovy (Dekhnik, 1973; Demir, 1959). Niermann *et al.* (1994) found correspondingly very low egg numbers overall (without any larvae) in June 1991, when surface temperatures were below 20°C, which is unusual for this month. In contrast, they found plenty of eggs and larvae during the July 1992 survey, with highest densities in the eastern region, which was warmer than the western region. We tested the effect of temperature on egg distribution and found a highly significant correlation for the 1992 survey but not for the 1993 and 1996 surveys (Table 2). For larvae, only the 1996 survey yielded a significant correlation with temperature. Since August is towards the end of the spawning season, the effect of temperature may not be clear at that time. Nevertheless, the lack of a correlation between temperature and egg numbers in the June-July 1996 survey suggests that other factors are also important.

According to Spearman's rank correlation analysis, salinity is another physical factor significantly affecting the distribution of anchovy eggs during both July 1992 and June–July 1996, but not during August 1993 (Table 2). The negative correlation implies that, besides the area in front of the Bosphorus affected by the Danube (Sur *et al.*, 1994), the eastern Turkish coastal areas, which receive a high freshwater supply, should be suitable spawning grounds for anchovy.

The total number of edible zooplankton organisms (excluding gelatinous organisms and the heterotrophic dinoflagellate *Noctiluca miliaris*) also had a highly significant and positive effect on the distribution of anchovy eggs in the 1996 survey, for which extensive plankton data were available. Since anchovy continues feeding during spawning (Dekhnik 1954, cited in Einarsson and Gurturk, 1960), a high abundance of suitable zooplankton prey may enhance spawning concentrations. Similar correlations between the numbers of anchovy eggs and larvae and zooplankton biomass have been noted for Bulgarian waters by Zaika (1968).

Long-term biomass of edible zooplankton on the north-western shelf shows a decreasing trend in recent years, while the southern regions show an increasing trend (Kovalev *et al.*, 1998). The same trends apply to phytoplankton. These changes in plankton biomasses should play a role in the observed shift in main spawning areas of anchovy from the north-western to the south-eastern Black Sea.

In all surveys, numbers of eggs and larvae showed extremely high correlations ($p<0.0001$). This is expected since the development time of an anchovy egg is as short as 24 h, and therefore co-occurrence during sampling is inevitable. However, the high correlations also suggest that the main physical forces acting upon the two life stages are the same. This may partly explain why both abundance and biomass (Fig. 5) of *Mnemiopsis* also showed very high correlations ($p<0.0007$) with egg numbers in 1996.

Abundance and biomass of *Mnemiopsis* were also correlated significantly with the abundance of edible zooplankton in the water column ($p<0.04$). Thus, both *Mnemiopsis* and spawning anchovy, two competing species for food, appear to concentrate in areas where prey abundance is high, even though the competition is disadvantageous for the anchovy, as its eggs and larvae are also consumed by *Mnemiopsis*.

Of the biotic parameters checked (Table 2), only those discussed yielded significant correlations with anchovy eggs and larvae. However, interactions between significant and insignificant parameters, as well as others which have not yet been tested, might influence the distribution of anchovy eggs and larvae. For example, the heterotrophic dinoflagellate *Noctiluca miliaris* competes for food with copepods (Elbrachter and Qi, 1998) and a sudden increase in biomass of the former may cause a decrease in zooplankton biomass. Similarly, quality and quantity of phytoplankton may affect zooplankton composition and thus egg and larval distributions. The factors governing the distribution of planktonic organisms remain intricately interwoven in any ecosystem, as is seen in the Black Sea.

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