J. Black Sea/Mediterranean Environment
Vol 12: 213-231 (2006)

Zooplankton community state in the Northeastern Marmara Sea during early autumn with comments on mass mortality of the Black Sea species due to the salinity gradient

Leonid Svetlichny[1*], Elena Hubareva[1], Ahmet Kideys[2], Melek İşinibilir[3] and Aleksandra Shmeleva[1]

[1] Institute of Biology of the Southern Seas, Sevastopol, Ukraine; Fax: (36) (0692) 55 78 13
[2] Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey and Joint Research Centre of the European Commission, Institute for the Protection and Security of the Citizen, Agriculture and Fisheries Unit, I-21020 Ispra (VA), Italy
[3] Istanbul University, Faculty of Fisheries, Laleli, Istanbul, Turkey

Abstract

In October 2005 species composition and abundance of mesozooplankton collected in the Black Sea (near the entrance of the Bosphorus) and in the Marmara Sea (near the exit of the Bosphorus and Prince Islands) were studied taking into account the number of live and dead individuals. Along the Bosphorus, the numbers of the Black Sea originated Copepoda species reduced whilst the abundance of Cladocera and *Oikopleura dioica* increased towards the Marmara. The Black Sea species constituting 78% of total fodder zooplankton abundance in the Marmara Sea aggregated mainly in the subsurface layers with lower salinity. In the layers deeper than salinity gradient (25-50 m) 57% of the individuals from these taxa were dead being at different stages of decomposition. Respiration rates of copepods also differed among layers of distinct salinity.

Key Words: Zooplankton, *Calanus euxinus*, vertical migration, Marmara Sea

---

[*] Corresponding author: lsvetlichny@mail.ru

Introduction

The Marmara Sea is a transit basin providing water exchange between the Mediterranean and Black Seas. Water masses from these two seas form the unique Marmara ecosystem including biological components with different origin. Surface layers of the Marmara Sea are affected by the Black Sea water with low salinity (~20 ‰) whilst more saline water masses (up to 40 ‰) from the Mediterranean Sea are located at depths > 20 m (Besiktepe *et al.*, 1994). Planktonic organisms cannot resist the current transferring them to the Marmara Sea. However, many zooplankters are able to undertake active vertical migrations due to diel feeding rhythms. At night they ascend to upper phytoplankton-rich layers and during daytime descend to deep waters avoiding visual predators or obtaining a net gain in energy. However, in the Marmara Sea planktonic animals undergo salinity stress during diel vertical migrations. In order to survive, the Black Sea species should increase their salinity range towards high magnitudes whilst the Mediterranean species have to adapt to low-saline water.

Although salinity tolerance range for the zooplankton species may be wide enough, usually particular populations are unable to tolerate the full salinity range of the species. For example, *Acartia clausi* from the Gulf of Fos could survive within the salinity range from 1 up to 65 ‰ while its optimal range was between 24 and 30 ‰ (Cervetto *et al.,* 1995). In *Eurytemora affinis* habitat salinity range (0-40‰) also was significantly wider than optimum range of 10-27 ‰ (Lee and Petersen, 2002). Anraku (1964) showed that salinity changes might become a limiting factor in the distribution of copepods. Acclimation success principally depends on the gradient and rate of salinity changes.

When the salinity dropped from 34.5‰ to 27‰, *Calanus* spp. from Kongsfjorden were alive for many hours, but after salinity decreasing to 24‰ all individuals died within 1 hour and at salinity below 9‰ they died within 15 minutes (Zajaczkowski and Legezynska, 2001). At the same time, living under variable salinity regime gives the unique opportunity to broad physiological tolerance and increase colonization potential of the species, but the effect of salinity on physiological and behavioral parameters in planktonic organisms have rarely been tested (Lee and Petersen, 2002). Nothing is known about the influence of salinity stress on planktonic organisms in the Marmara Sea. It is important that after the exposure to salinity gradients the dead zooplankton sinks and may be the available food source for scavenging benthic fauna in the Marmara Sea.

The aim of the present study is to investigate species composition, abundance, vertical distribution and mortality of zooplankton penetrating into the Marmara Sea from the Black and Mediterranean Seas. We conducted separate experiments to estimate respiration rate of Mediterranean and the Black Seas copepods. Survival of copepods from the *Acartia* genus under conditions of salinity gradient was also studied.

Material and Methods

Zooplankton samples were collected with a closing Nansen net (opening diameter 50 cm, mesh size 200 μm) during the cruise Hedef-1 at the permanent station in the Marmara Sea near the Prince Islands (40^0 51’, 715

N, 28^0 57’ 901 E) on 13 October 2005 separately from the surface layer (0–25m) formed by the Black Sea water (with the salinity of 23.2 ‰ and temperature of 18.3^0C), intermediate layer (25-50 m) and the strata lying under the halocline (50–200 m) consisting of the Mediterranean Sea water (with the salinity of 39.7 ‰ and temperature of 15.4^0C)(Fig 1) One total vertical haul was performed on 16 October 2005 in the 0-50 m layer near the Bosphorus in the Marmara Sea (with the surface water salinity of 18.9 ‰ and temperature of 18.4^0C). The sample collected by Dr B. Anninsky from the layer of 70-0 m (with the surface water salinity of 17.1 ‰ and temperature of 19.1^0C) near the Bosphorus in the Black Sea on 14 October 2005 during the R/V “Parshin” cruise was used for the comparative analysis. Zooplankton samples were immediately preserved with 4% borax-buffered formaldehyde..

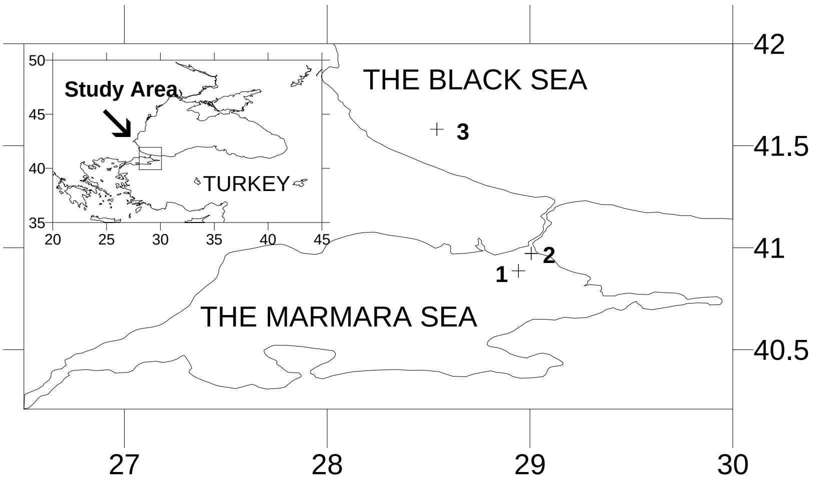

Fig 1. Sampling areas in the Marmara and the Black Sea

In the laboratory an appropriate aliquot of the samples was transferred to a Bogorov chamber, and the species composition and numbers of mesozooplankton were determined under a dissecting microscope. The organisms with destructive changes in muscles and internal organs were identified as dead ones

Also the samples from every station were collected to make the experiments with live copepods. To determine salinity tolerance range of *Acartia clausi* and *A. tonsa*, we studied behavioral response to gradual salinity increasing. 40 – 50 females of each species were placed into 50 ml bowls with the Black Sea water (18.9 ‰, 20^0C) containing alga *Thalassiosira weisflogii*. Salinity was increased gradually from 18.9 to 39.7 ‰ every half an hour by 3 ‰ for 3.5 h by adding the Marmara sea water from the deep layers. After salinity changing we enumerated actively swimming and immovable individuals.

Respiration rate (Q, μg O_2 ind^{-1} h^{-1}) of copepods was determined using experimental and control chambers (identical all-glass syringes of 2.0 ml filled with natural seawater. One female or V copepodite (or 4–5 III-IV copepodites) of large copepods *Calanus*, *Spinocalanus*, *Candacia* and *Euchaeta*, and 10-20 small *Acartia* were transferred by a pipette into an experimental syringe with a protective sieve disc (mesh size 200 μm) before the confluent outlet. To obtain identical initial oxygen and seston content in control and experimental syringes from each pair, we connected the syringes with a plastic tube and pumped the water through it several times. Then the syringes were separated, closed by the stoppers and incubated in the dark chamber at 20±0.5°C for 1-2 h.

Oxygen concentration was measured using a polarographic membrane oxygen sensor joined with the chamber (all-glass syringe) of 0.5 ml volume, with a magnetic stirrer inside (Svetlichny and Hubareva, 2005). The water sample from the experimental or control syringe was transferred to the chamber in six portions through the needle. Four last portions were used to calculate the average oxygen concentration.

Wet weight (W, mg) was calculated as $W = kL_{pr}\, d_{pr}^2$, where L_{pr} and d_{pr}, (mm) are the length and width of prosome, respectively; k is the empiric coefficient (Svetlichny, 1983).

Results and Discussion

In October 2005 total fodder zooplankton abundance (except *Noctiluca scintillans* and Ctenophora) decreased from 127837 ind/m^2 in the Black Sea near the Bosphorus to 88920 ind/m^2 in the Marmara Sea outlet of the Bosphorus Strait, and then increased slightly to 103104 ind/m^2 near the Prince Islands (Fig.2, Table 1a,b). The same tendency for zooplankton number to diminish from the Black Sea towards the Marmara Sea was found by Tarkan *et al.* (2005) in 1999-2000. In October 2005 this trend was due to abrupt (about 10-fold) reduction in summary abundance of four copepod species *Calanus euxinus, Pseudocalanus elongatus, Acartia clausi and A. tonsa* (mainly *A. clausi*) from 101720 ind/m^2 (98% of Copepoda and 80% of total zooplankton) in the Black Sea to 11816 ind/m^2 (24.6% of Copepoda and 11.5% of total zooplankton) in the Marmara Sea near the Prince Islands. On the contrary, the summary abundance of *Paracalanus parvus*, cladocerans (*Penilia avirostris, Pleopis polyphemoides and Evadne tergestina*) and *Oikopleura dioica* increased from 11129 to 69811 ind/m^2

compencating the decrease in the number of the mass Black Sea copepods. We found 30 typical Mediterranean Copepoda species (amounting to 39% and 30.2% of copepods near the Bosphorus and the Prince Islands, respectively), a relatively small number of *Sagitta*, larvae of Cyrripedia, Polychaeta, Bivalvia, Gastropoda, Decapoda, and Hydrozoa in the Marmara Sea samples.

Near the Prince Islands the Black Sea originated copepods, cladocerans, chaetognatha and appendicularia constituted 70.8% of total fodder zooplankton whilst the Mediterranean species made up only 17.2%. 82.9% of the total number of the Black Sea species was in the surface layer of 0-25 m. Deeper than 25 m the abundance of the Black Sea species decreased sharply and the number of dead animals increased, especially in copepods, cladocerans and *Sagitta* (Fig. 3). In the layers deeper than salinity gradient (25-50 m) 57% of the individuals from these taxa were dead being at different stages of decomposition. Particularly high mortality (87.5%) was estimated in *A. clausi* which is the most abundant species in the Marmara Sea all over the year (Tarkan and Erguven, 1988; Tarkan *et al*., 2005). In the layer 50-200 m almost all the Black Sea species were dead. Probably, this phenomenon is due to inability of many Black Sea species to withstand sharp salinity increase. Percentages of mortality in copepods and cladocerans after exposure to the Mediterranean Sea water appeared to be close. However, in contrast to copepods, the number of live epiplanktonic cladocerans inhabiting the Black Sea subsurface layers increased from the Bosphorus towards to the Prince Islands. In our opinion, the development success of Cladocera in the Marmara Sea is due to their spawning type. Cladocerans are sac-spawners carrying their eggs externally on the body, therefore their larvae remain in the subsurface low-saline layers. However, many copepod species (excluding *Oithona* whose abundance also increases in the Marmara Sea) are broadcast-spawners, which shed eggs freely. These eggs descend to deeper, more saline layers of the Marmara Sea (especially heavy diapausing eggs) and can die. It may limit the development of *Acartia* which are deprived of possibility to produce generations from diapausing eggs.

Copepod *Oncaea minuta* dominated the typical Mediterranean species. The main part of *O. minuta* population was attributed to the 25-50 m layer, however, there was a significant number of dead animals (14% of the total) too. This poecilostomatoid species ascends due to high food concentration in the surface layers. However, surface layers are formed by the Black Sea water with lower salinity unsuitable for *Oncaea*. We did not found the significant number of dead individuals of another Mediterranean copepod species in the 0-25 m layer. Probably, it is easier to survive under low salinity for the Mediterranean species than to withstand high salinity for the Black Sea copepods. It confirms the statement of Lee (1999) that invasions of brackish water by marine organisms are the common invasion pathways for many species in Europe and North America.

The results of our previous studies (Svetlichny *et al.*, 2006) showed that the Marmara Sea population of *Calanus euxinus* is formed by the individuals transferred from the Black Sea to the Marmara Sea by the Bosphorus Current. Higher temperature and salinity in the Marmara Sea affect development time, metabolic and growth rates which result in decrease in body length and lipid content of *C. euxinus*.

In October 2005 *Calanus* population was in extremely depressed condition. In the layer of 0-200 m in the Marmara Sea total number of *C. euxinus* did not exceed 140 ind/m^2 whilst in the coastal Black Sea region the number amounted to 3120 ind/m^2 (Table 1). We did not find mature females near the Prince Islands, in contrast to the Bosphorus region. In October 2005 just as in October 2000 (Svetlichny et al., 2006) prosome length in *C. euxinus* copepodites V from the Marmara Sea was significantly lower than that from the Black Sea (Fig. 4) suggesting that in the Marmara Sea at higher temperature and salinity *Calanus* showed accelerated development. To study species-specific salinity tolerance of the Black Sea zooplankton species penetrating into the Marmara Sea, we conducted laboratory experiments with closely related species *A. clausi* and *A. tonsa*.

In *A. clausi* collected near the Bosphorus at 18.9 ‰, during gradual salinity increasing we observed mortality at 30 ‰ and all animals were dead at 39.8 ‰. In contrast, more than 90% of *A. tonsa* from the Bosphorus survived under the same treatment (Fig. 5 A). Only next day after salinity increasing the share of survived *A. tonsa* decreased up to 30%.

In *A. clausi* collected near the Prince Islands (surface salinity of 22.3 ‰), the number of individuals survived after gradual salinity increasing to 39.8 ‰ was more than 90% and reduced up to 20-30% (Fig. 5 B) during long-term high salinity treatment (as in *A. tonsa* from the Bosphorus).

Higher salinity tolerance in *A. clausi* sampled near the Prince Islands (far from the Bosphorus) seems to be a result of long-term acclimation to high salinity in these copepods during their way from the the Bosphorus area.

Table 1. Species composition and abundance (ind m^{-2}) of live and dead mesozooplankton in the Marmara Sea near the Prince Islands and in the regions near the Bosphorus from the Marmara and Black Sea sides (October 2005). The number of dead individuals is in parentheses. (Species occurring in both Black and Mediterranean Seas)

Species and taxonomic groups	Marmara Sea				Black Sea near the Bosphorus
	Near the Prince Islands			Near the Bosphorus	
	200-50 m	50-25 m	25-0 m	50-0 m	70-0 m
Species occurring in both Black and Mediterranean Seas					
Calanus euxinus	25	40	75	85	3120
Pseudocalanus elongatus	0	10	0	5	1800
Paracalanus parvus	83 (1375)	4000 (5500)	8625	16750 (1625)	700
Acartia clausi	83 (1333)	875 (6125)	2875	11375 (375)	87000
Acartia tonsa	0	125	250	5250 (250)	9800
Acartia spp.	0	0	55	625	0
Oithona similis	25 (83)	750	1250	250	0
Centropages kröyeri (ponticus)	0	20	0	10	600
Copepoda nauplii	0	0	0	375	700
Penilia avirostris	(833)	500 (4250)	9250	1875	3700
Pleopis polyphemoides	(167)	625 (500)	3625	4000	29
Evadne tergestina	5	(250)	3000	0	0
Cirripedia Nauplii	83 (83)	625 (375)	750	3500	3300
Cirripedia Cypris	0	0	125	0	500
Sagitta sp.	83	1500 (2250)	1625	2250	9300
Oikopleura dioica	83 (83)	750	15750	4250	6700
Larvae Polychaeta	0	1250	625	500	300
Larvae Bivalvia	125	1500	500	3500	0
Larvae Gastropoda	0	0	375	5600	288
Decapoda	0	140	0	15	0
Hydrozoa	0	1625	750	2625	0
Noctiluca scintillans	0	0	189625	132250	2310

Table 1. Continued

Mediterranean species and groups					
Spinocalanus magnus	130	5	0	0	0
Pseudocalanus sp.	20	0	0	0	0
Paracalanus spp.	0	1125	3875	0	0
Ctenocalanus vanus	0	195	0	0	0
Ctenocalanus spp.	50	0	50	375	0
Clausocalanus paululus	0	5	0	0	0
Clausocalanus pergens	10	65	45	0	0
Clausocalanus sp.	0	105	625	2000	0
Microcalanus pusillus	0	0	0	1375	0
Aetideus armatus	0	0	0	5	0
Aetideus giesbrechti	25	0	0	0	0
Aetideus sp.	20	0	0	0	0
Metridia lucens	130	215	0	3000	0
Lucicutia sp.	0	5	5	0	0
Candacia tenuimana	0	5	0	0	0
Candacia giesbrechti	0	0	0	5	0
Euchaeta marina	10	45	0	10	0
Centropages spinosis	0	10	45	0	0
Centropages chierchiae	5	0	40	0	0
Centropages typicus	0	0	5	5	0
Microsetella sp.	0	0	5	0	0
Euterpina sp.	45	10	0	1875	0
Clytemnestra sp.	25	15	0	0	0
Oithona decipiens	0	0	0	2625	0
Oithona setigera	0	5	0	0	0
Oithona sp.	0	0	750	0	0
Oncaea minuta	42 (375)	4500 (625)	1125	12125 (250)	0
Oncaea conifera	0	5	0	0	0
Oncaea subtilils	0	10	0	0	0
Oncaea media	0	5	0	0	0
Harpacticoida	0	125	0	0	0
Monstrilla sp.	0	0	0	20	0
Evadne nordmani	0	0	5	0	0
Syphonophora	0	10	0	10	0
Other	0	0	750	150	0

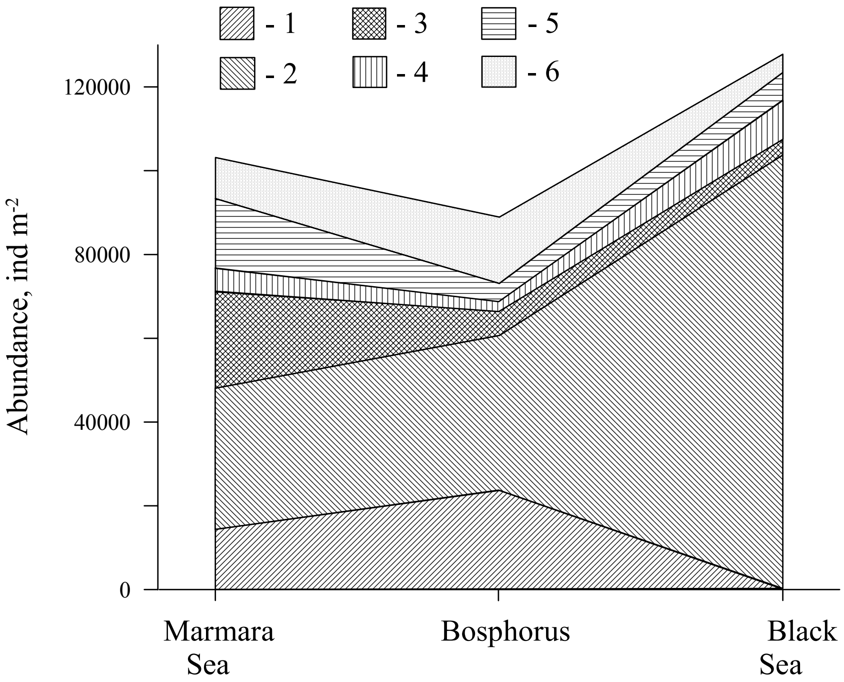

Fig 2. Abundance of fodder zooplankton groups in the Black Sea (near the Bosphorus), in the Bosphorus Strait (near Istanbul), in the Marmara Sea (near the Prince Islands).

1 - Mediterranean Copepoda; 2 - Black Sea Copepoda; 3 - Cladocera; 4 – *Sagitta* sp.; 5 – *Oikopleura dioica*; 6- other groups.

Despite high salinity tolerance in *A. tonsa* collected near the Prince Islands, the abundance was extremely low, probably, due to high food requirements of this species under conditions of lower productivity of the Marmara Sea compared with the Black Sea (Kocataş *et al.,* 1993).

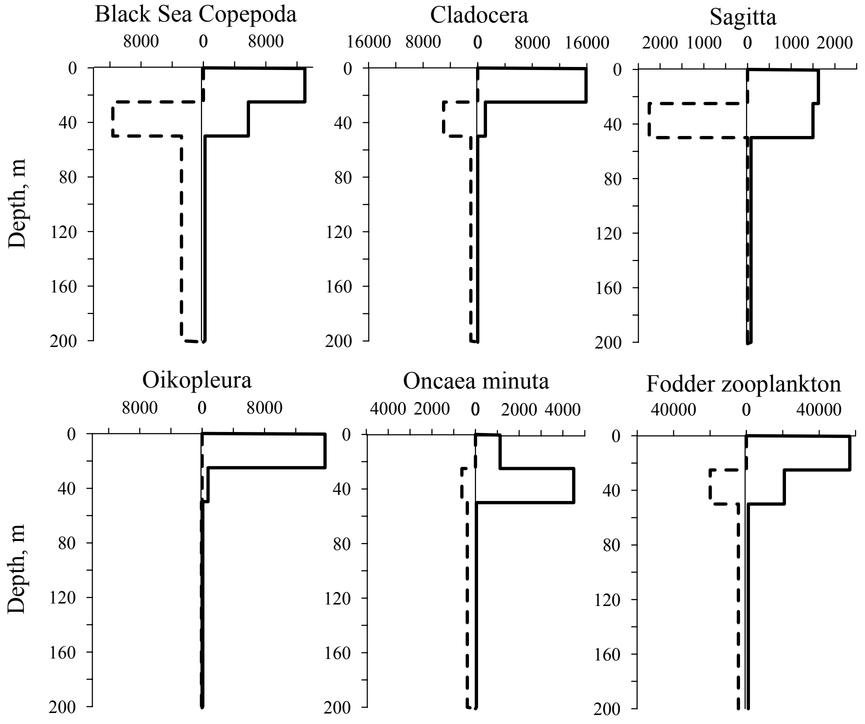

Fig 3. Vertical distribution of live (—) and dead (- - -) organisms (ind m^{-2}) in the Marmara Sea near the Prince Islands.

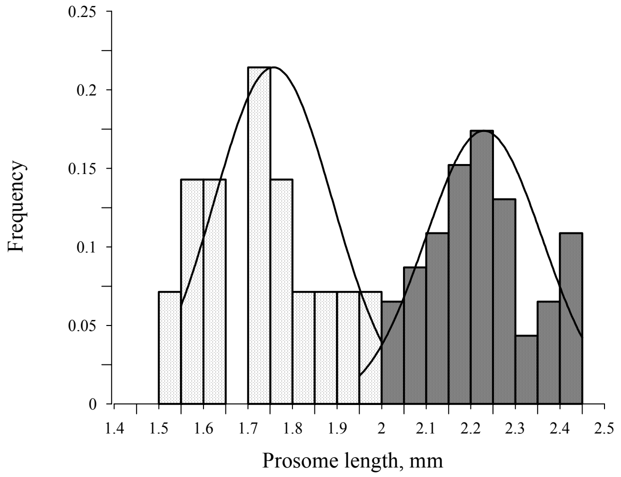

Fig 4. Size-frequency diagrams for stage V copepodites of *Calanus euxinus* from the Marmara (□) and Black (■) Seas in October 2005.

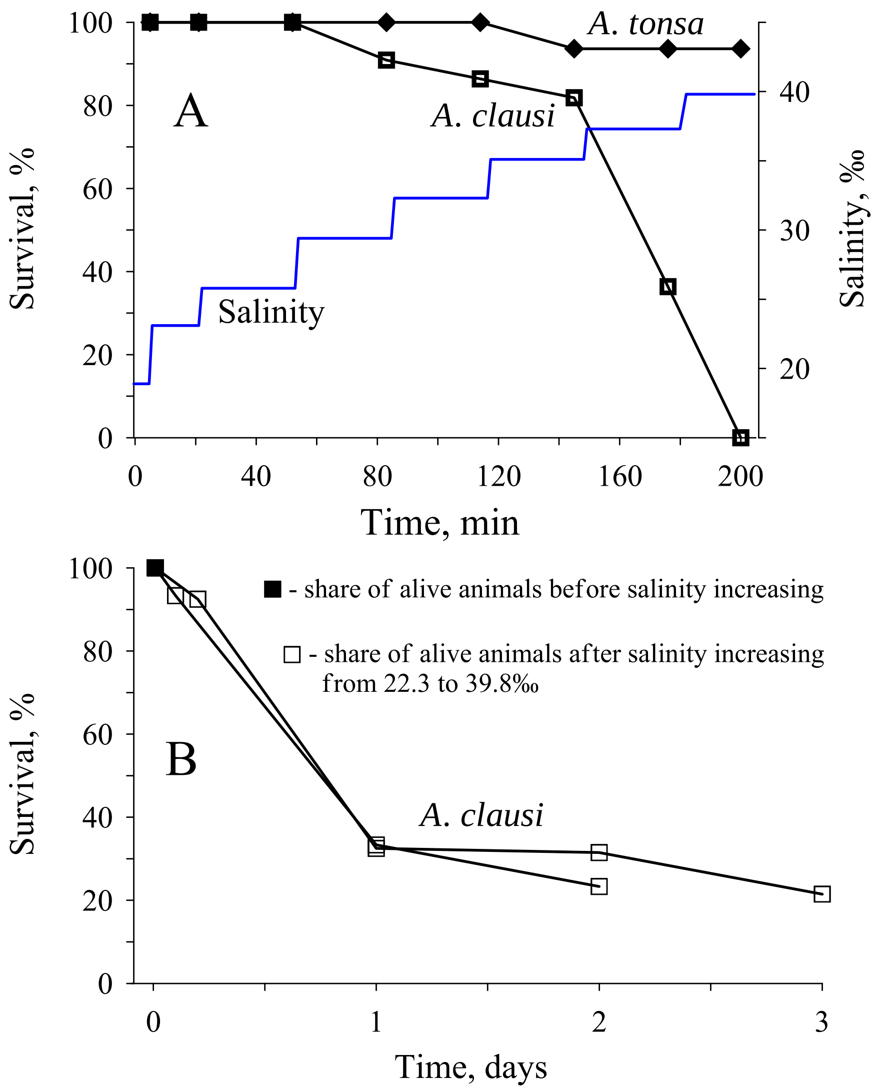

Fig 5. Survival of *A. clausi* and *A. tonsa* from the Bosphorus (A) after changing of salinity from 22.3 to 39.8 ‰ and *A. clausi* from the Marmara Sea (B) during acclimation from 18.9 to 39.8 ‰.

In contrast to *A. clausi*, *A. tonsa* occur only during warm season and every year recommence their life cycle from the resting eggs when the water temperature amounts to 16 ^{0}C (Gubanova, 2000) or 20 ^{0}C (Riccardi and Mariotto, 2000). Since water temperature in the Marmara Sea deeper than 20 m does not exceed 15^{0}C in warm season, *A. tonsa* are not able to complete the life cycles and to maintain the population without the advection of individuals from the Black Sea.

To understand the mechanisms of invasive success in Copepoda, special study should be dedicated to adaptive changes in behavior and metabolism of the Mediterranean species penetrating into the Marmara Sea. Our comparative data on weight-specific respiration rates of Copepoda species from the Black and Marmara Seas are presented in the Fig. 6.

Weight-specific respiration rate in *C. euxinus* found near the Prince Islands were significantly ($p<0.001$) 1.38 times higher than that in *C. euxinus* from the Black Sea. Anraku (1964) also reported about elevated respiration rate in *C. finmarchicus* during salinity increase from 21.5 to 31.5‰. In *A. clausi* weight-specific respiration rate was 1.56 times lower ($p<0.001$) than in sibling species *A. tonsa*. The difference between the metabolism levels in these species are in agreement with the results of Conover (1956) and Anraku (1964) suggesting higher adaptive potential of *A. tonsa*.

Despite pronounced differences in metabolism of the species due to their different ecological specialization, weight-specific respiration rate in copepods depends upon body weight following the equation:

$$Q/W=1.13\ W^{-0.14}.$$

The relationship between respiration rate and body weight during ontogeny as $Q=1.19\ W^{0.99}$ was obtained for interzonal Mediterranean species *Euchaeta marina* studied for the first time in the Marmara Sea (Fig. 7).

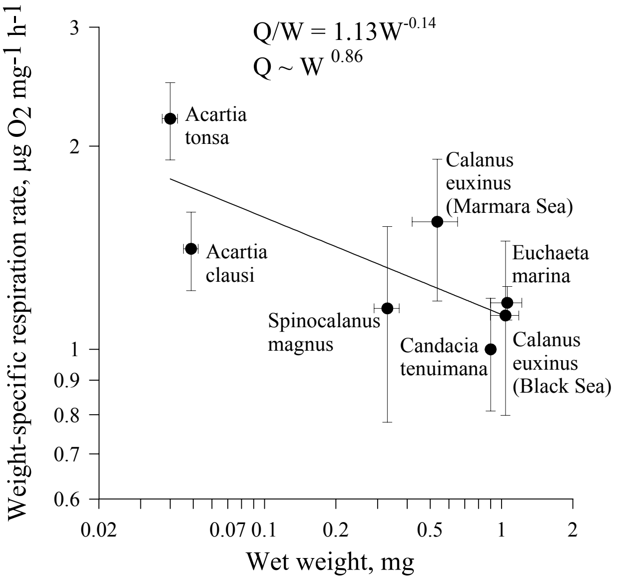

Fig 6. Weight-specific respiration rates of Copepoda species from the Marmara Sea.

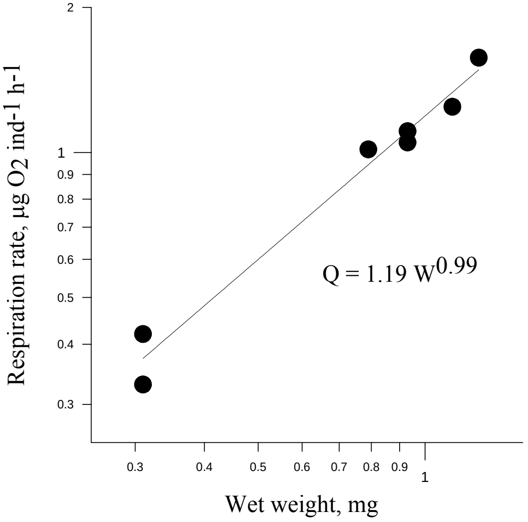

Fig 7. Respiration rate in copepodites V and females of *Euchaeta marina* from the Marmara Sea (Prince Islands).

Conclusions

Due to high surface temperature, in October 2005 copepods *Calanus euxinus* could not develop successfully producing generations within the Marmara Sea without the recruitment from the Black Sea.

During this season another species of epiplanktonic copepods, cladocerans and *Sagitta* constituted the main abundance of fodder zooplankton. Their high mortality in the layers below the salinity gradient indicates that these organisms have penetrated from the Black Sea.

The Mediterranean species made up only 17.2% of the fodder zooplankton number. In October 2005 *Oncaea minuta* dominated the Mediterranean species. High mortality of these copepods near the sea surface points out that low salinity may prevent stenohaline Mediterranean species from the development in the Marmara Sea.

Acknowledgements

This study was partly supported by a TUBITAK (Turkish Scientific Technical Research Council)-NASU (National Academy of the Ukraine) joint project (104Y208)

References

Anraku, M. (1964). Influence of the Cape Cod Canal on the hydrography and on the copepods in Buzzards Bay and Cape Cod Bay, Massachusetts. II. Respiration and feeding. *Limnol.Oceanogr*. 9: 195-206.

Besiktepe, S.T., Sur, H.I., Ozsoy, E., Latif, M.A., Oguz, T., Unluata, U. (1994). The circulation and hydrography of the Marmara Sea. *Progress in Oceanography* 34: 285-334.

Cervetto, G., Pagano, M., Gaudy, R. (1995). Adaptation aux variations de la salinite chez le copepode *Acartia clausi*. *J. Rech. Oceanogr.* 20: 42-49.

Conover, R.J. (1956). Oceanography of Long Island Sound, 1952-1954. VI. Biology of *Acartia clausi* and *A. tonsa*. *Bull. Bingham Oceanogr. Coll.* 15: 156-233.

Gubanova, A. (2000). Occurrence of *Acartia tonsa* Dana in the Black Sea. Was it introduced from the Mediterranean?. *Mediterranean Marine Science* 1/1: 105-109.

Kocatas, A., Koray, T., Kaya, M., Kara, O. F. (1993). Review of the fishery resources and their environment in the Sea of Marmara. Studies and Reviews, General Fisheries Council for the Mediterranean *(GFCM), FAO* 64: 87-143.

Lee, C.E. (1999). Rapid and repeated invasions of fresh water by the saltwater copepod *Eurytemora affinis*. *Evolution* 53: 1423-1434.

Lee, C.E., Petersen, C.H. (2002). Effects of developmental acclimation on adult salinity tolerance in the freshwater-invading copepod *Eurytemora affinis*. *Physiological and Biochemical Zoology* 76: 296-301.

Riccardi, N., Mariotto, L. (2000). Seasonal variations in copepod body length: a comparison between different species in the Lagoon of Venice. *Aquatic Ecology* 34: 243-252.

Svetlichny, L. S. (1983). Calculation of the biomass of planktonic copepods using the coefficients of proportionality between volume and linear dimensions of the body. *Ecologia Morya* 15: 46-58 (in Russian).

Svetlichny, L. S., Hubareva, E. S. (2005). The energetics of *Calanus euxinus*: locomotion, filtration of food and specific dynamic action. *J. Plankton Res.* 27: 671-682.

Svetlichny, L.S., Kideys, A.E., Hubareva, E.S., Besiktepe, S., Isinibilir, M. (2006). Development and lipid storage in *Calanus euxinus* from the Black and Marmara seas: variabilities due to habitat conditions. *J. Mar. Syst.* 59: 52-62.

Tarkan, A.N., Erguven, H. (1988). The main copepod species of Marmara Sea. J. Aquatic Products *2: 71-84.*

Tarkan, A.N., Isinibilir, M., Tarkan, A.S. (2005). Seasonal variations of the zooplankton composition and abundance in the Istanbul Strait. *Pakistan J. Biological Sciences* 8: 1327-1336.

Zajaczkowski, M., Legezynska, J. (2001). Estimation of zooplankton mortality caused by an Arctic glacier outflow. *Oceanologia* 43: 341-351.

Received: 02.08.2006

Accepted: 31.10.2006