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THE RATE OF RECOLONIZATION IN THE MEDITERRANEAN SEA FOLLOWING THE TERMINATION OF THE S_1- SAPROPEL ECOLOGICAL CRISIS

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ABSTRACT : *Mediterranean sapropels are relics of the anoxic conditions that deliterously affected the marine fauna. Following the last sapropel event, S_1, recolonization commenced, with a reintroduction of marine species from the Atlantic Ocean. By comparing modern benthic foraminiferal populations, it appears that the western Mediterranean has achieved a greater degree of equilibrium with the Atlantic source than has the eastern Mediterranean. Moreover, in the eastern Mediterranean, the south coast of the Levant Basin has attained a greater degree of recovery, as it is closer in line with the long shore current to the inlet source, than has the northern part of the eastern Mediterranean. The dispersion recovery model for the Mediterranean following the last ecologic crisis is in agreement with the recovery model proposed for the Black Sea.*

Mediterranean as well as the Bosphorous. To date the preliminary studies of Parker (eastern Mediterranean and Aegean Sea, 1958), Moncharmont Zei (Lebanon's shelf, 1968), Abdou et al. (continental shelf off the Nile Delta, 1991) and Meriç and Sakınç (Bosphorous, 1990) remain the most detailed references. Detailed environmental and taxonomic investigations of the western Mediterranean foraminifera have been carried out by many authors. The most comprehensive modern information is found in the research of Blanch-Vernet (1969), Daniels (1970), Cimerman (1984), Jorissen (1987, 1988); Langer (1989) and Cimerman and Langer (1991).

For a period of 20 years prior to this work, extensive background studies on present and Quaternary benthic foraminifa (taxonomy, morphology, density, diversity, etc.) had been carried out by the senior author in the Black sea (Yanko, 1979, 1982, 1989 , 1990, 1991; Yanko & Troitskaja, 1987). The environments that were studied here included deltas, open and closed lagoons, bays, and shelf extending from 0-220 m. The bottom water salinity ranged from 1-26%o.

In the Black Sea living benthic foraminifera are distributed to a maximum water depth of 220 m. Foraminifera are not found beyond this depth, in contrast to the Mediterranean, due to the continuous presence of H_2S in the water.

3. SAMPLING AREA DESCRIPTION

With the exception of the Black Sea and the Israeli coast, the other comparative data has been taken from the literature. Therefore, no further description will be given here for these sites (Fig.1 A,B).

Israel's Mediterranean coast (Fig. 1A). Foraminifera were collected from four sites, at a depth interval of 6-50 m. Site 1 (6 stations) is situated off Hadera (24 m water depth). Site 2 (2 stations) was taken at the entrance to Haifa Harbour (6-12 m water depth). Site 3 (4 stations) is located off the beach of Nitzanim (20 to 50 m water depth). Site 4 (6 stations) is situated off Palmachim (20-50 m water depth). Salinity at all of the sites was constant, averaging 39%o. Salinity of the western Mediterranean varies between 37.8%o and 38.1%o (Tyrrhenian Sea), 38.5-38.8%o (Adriatic Sea). The salinity of the Bosphorous is 35%o.

The Black Sea. Surface material was collected by grab and box-cores from selected areas (Fig. 1B). The north-western shelf is represented by 350 stations (3-70 m water depth, salinity 11-18.6%o). 134 stations were taken along the western shelf (8-70 m water depth, salinity 17- 19.6%o). 10 stations were taken at sites located in the vicinity of the area near to the Bosphorous (100-120 m water depth, salinity 26.2%o). Despite the greater depth here, we decided to include these stations for comparison. This site demonstrates the primary influence of salinity on the benthic foraminiferal distribution. Shallower depths are within Turkish territorial waters and could not be sampled at that time.

1. INTRODUCTION

After the Last Glaciation, a drastic oceanographic change affected both the Mediterranean and Black Sea. The Black Sea received increased discharge from by the major rivers that drain central Europe. This significantly lowered the salinity and destroyed its meromictic structure. This lowering of salinity resulted in a major ecological crisis for many marine organisms (e.g. ostracods, molluscs, foraminifers). For example, a near total extinction took place of the Black Sea's shallow benthic foraminifera (Yanko, 1989, 1991). Likewise, the Mediterranean Sea was affected by the sea level changes and the increased fresh water in flow. A meromictic state was created. Circulation was impeded. Low salinity surface water prevented the reoxygenation of the deep water which became anoxic (Olausson, 1961). This state is strikingly denoted by the creation of sapropels. The sapropels are found almost exclusively in the eastern Mediterranean, though, some evidence exists for periods of reducing conditions in the deep western Mediterranean as well. The periods of Mediterranean stagnation were also periods of ecological stress; though, the extent of crisis is less well known and perhaps less severe than that which transpired in the Black Sea. Here too are recorded changes in the benthic foraminiferal populations. Changes in faunal assemblages occurred for deep water benthic foraminifera in response to oscillating oxic-anoxic-oxic conditions. It was noted though that the recovery was relatively slow. The eastern Mediterranean, as reflected in the deep water benthic foraminifera, has not, even today, recovered from the last stagnation (sapropel event, S_1) of about 8000 years ago (Mullineaux & Lohmann, 1981). Relatively little data is available for modern shallow (<60 m) benthic foraminifera from the Mediterranean as a whole. Less is known about earlier benthic foraminiferal populations (such as during formation the periods of sapropel formation).

The present work presents a summary of the published data as well as more recent data in an attempt to synthesize a model for understanding the present distributions of shallow benthic foraminiferal populations both in the Mediterranean and Black Seas. The study intends as a first step to consider some basic questions of today's Levant benthic foraminiferal distribution. A comparative distribution study with the rest of the Mediterranean, coupled with an understanding of the oceanographic processes that led to ecologic stresses at the beginning of the Holocene, may provide insight into the migration pathways into the eastern Mediterranean and Black Sea by benthic foraminifera.

2. PREVIOUS STUDIES

With the exception of a short paper by Reiss et al., (1961) and Yanko et al., (1992) no information is available on benthic foraminifera of the Israeli offshore.

Also there is only limited information concerning benthic foraminifera of the eastern

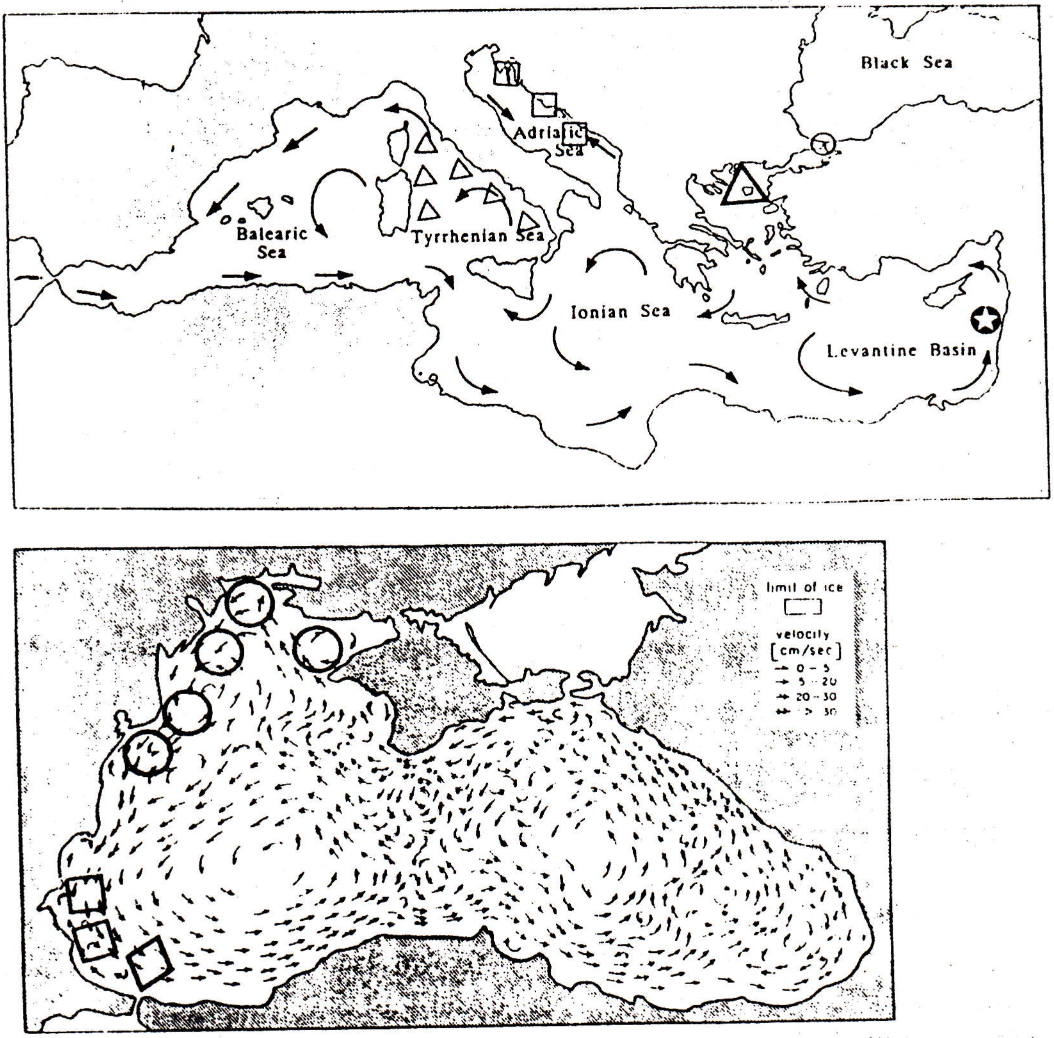

Fig.1 Current systems (after Cimerman, 1991 and Zenkevich, 1963; Shimkus & Trimonis, 1974) and location map in the (A) Mediterranean Sea(), (B) Black Sea

A) □ Adriatic Sea (Cimerman, 1991)

△ Tirrhenian Sea (Cimerman, 1991)

△ Aegean Sea (Parker, 1958)

✪ Levant (Yanko et al., 1992)

○ Bosphorous (Meric & Sakinc, 1990)

B) ○ north western shelf (Yanko, 1989, 1991)

□ western shelf (Yanko, 1989, 1991)

◇ near Bosphorous area (Yanko, 1989, 1991)

The data base taken from the literature is restricted to shallow benthic foraminifera (approximately 50 m water depth) (a species that were found to exist both at water depths shallower and deeper were also included).

4. MATERIALS AND METHODS

Samples from the eastern Mediterranean (71 samples) were obtained by grab and box core during the summer months of 1986-1991 by workers of National Oceanographic Institute (Haifa) N.Kress and H.Hornung; from the Black Sea (474 samples) by the senior author during 1971-1986.

Benthic foraminifera were studied by standard methods (Feyling-Hanssen, 1983; Yanko & Troitskaja, 1987). The Rose Bengal dye (Walton, 1952) was used to distinguish between dead and living specimens at all stations in the Black Sea. The Israeli study was mainly based upon surface cores collected a few years previously, which did not contain living material. 5 g dry samples (Israel's eastern Mediterranean) and 100 g (the Black Sea) were used. All numerical characteristics of foraminifera are normalized to a 5 g mass of sediment. When possible 300 specimens of foraminifera from the >0.125 mm fraction were counted for each sample. Statistical analysis of 30 specimens of each investigated species was carried out to estimate the variation of foraminiferal test sizes. In certain cases when the number of specimens was less than 300 (for example, at the sites 1 and 4 in the Israel's offshore), the number of each species specimens was normalized to 300.

5. RESULTS

A location map is presented in Fig.1 from which the major areas and sampling sites for the Mediterranean and Black Sea are presented. Included on this map are the major flow directions of the currents in the basins (included in this in the SW-NW surface current direction at the entrance to the Adriatic Sea). The salinity of the Mediterranean varies from west to east (37‰) to (39‰) which is slightly higher than the Atlantic water (35‰). Four sites were sampled in the Black Sea. The salinity into the Black Sea decreased from the Bosphorous northeastwards.

The results of the population distribution, at the family and the species level, of the shallow water (0-60 m) benthic foraminifera from the western Mediterranean, eastern Mediterranean, Bosphorous, Aegean Sea, and Black Sea is represented on Fig.2. It can be seen that in all cases, two families Hauerinidae and Elphidiidae dominate. The eastern Mediterranean is represented by distinctly fewer species than the western. The western basin is most similar (57 families and 285 species) to the Atlantic Ocean assemblages (61 families and at least 300 species) (Michalevich, 1982). The Atlantic Ocean is the only possible source for the foraminiferal reentrance into the Mediterranean. Within the eastern Mediterranean the Israeli coast is richer than the benthic assemblage of the Aegean, which is similar to that of the Bosphorous assemblage. The Bosphorous assemblage, which was taken from core data, did not entail a living assemblage. It must be considered to approximate a minimal value of the present day assemblage. This (the Bosphorous) assemblage is richer than that for the Black Sea which shows a geographical population distribution in relation to the Bosphorous inlet (which itself is the sole source for recolonized of the Black Sea by marine fauna). Further along the coast, away from the Bosphorous, the salinity decreases and the benthic foraminiferal populations become poorer in diversity.

The diversity of the foraminiferal species as a function of geography can be best visualized in Figs. 2, 3. These figures present the number of species of shallow water benthic foraminifera that have been found in the various geographic regions .The species diversity is seen to follow a geographical trend.

6. DISCUSSION

The distribution of benthic foraminifera can be influenced by a variety of factors such as temperature, salinity, pollution and oxygen supply of the water, as well as the type of substrate that they colonize. Variations of course do exist along the shelf of the Mediterranean. However, each of the regions discussed in the Mediterranean, are in effect, a compilation of many individual sampling sites representing many ecological habitats. Still the differences between the western and eastern portions of the sea, as well as the differences along the shelves of the eastern basin itself are so great as to make suspect these factors as being the sole or even the primary reason for the magnitude of the diversity difference between inter and infra-basinal assemblages. Rather, another process appears to be of greater importance.

A geographic versus population diversity trend is observed in both the Mediterranean and Black Sea. These are two distinctly different oceanologic bodies of different chemistry and environments; yet, the population distribution within both of these seas may in a sense be regarded as related to a similar process. This process is the, as yet, incomplete population recovery following the ecological crisis that affected (in different degrees) the two water bodies. Both water bodies now appear to be undergoing a marine recolonization. The Black Sea being much less marine in character still serves as a barrier against the less hardly and less adaptive of marine organisms. The more adaptive are represented the Hauerinidae and Elphidiidae families. These have penetrated furthest into the Black Sea from their source of introduction (the relatively shallow Bosphorous (96 m)). Closest to the Bosphorous with its near marine conditions is found the assemblage most similar to that of the eastern Mediterranean (e.g.Aegean). As the marine conditions give way to fresher water conditions fewer benthic foraminiferal forms are able to penetrate at present. The Black Sea is still far from attaining a benthic foraminifera population that is in equilibrium with the eastern Mediterranean's. Within

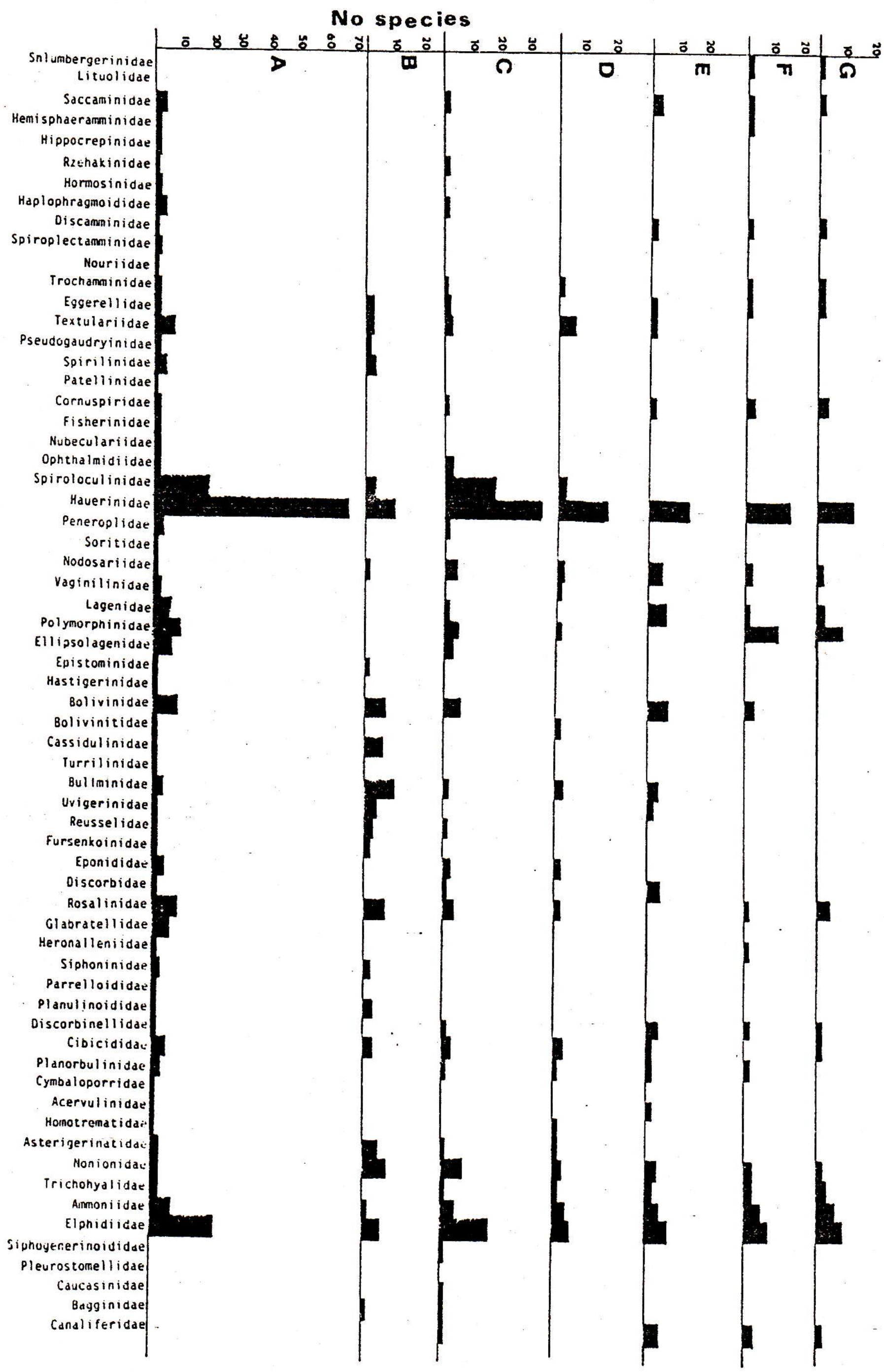

Fig.2 Number species in different basins
A - Tirrhenian and Adriatic Seas
B - Aegean Sea
C - Levant (Israel's coast)
D - Bosphorous
E-G - Black Sea (E - near Bosphorous Area, F - western shelf, G - north western shelf)

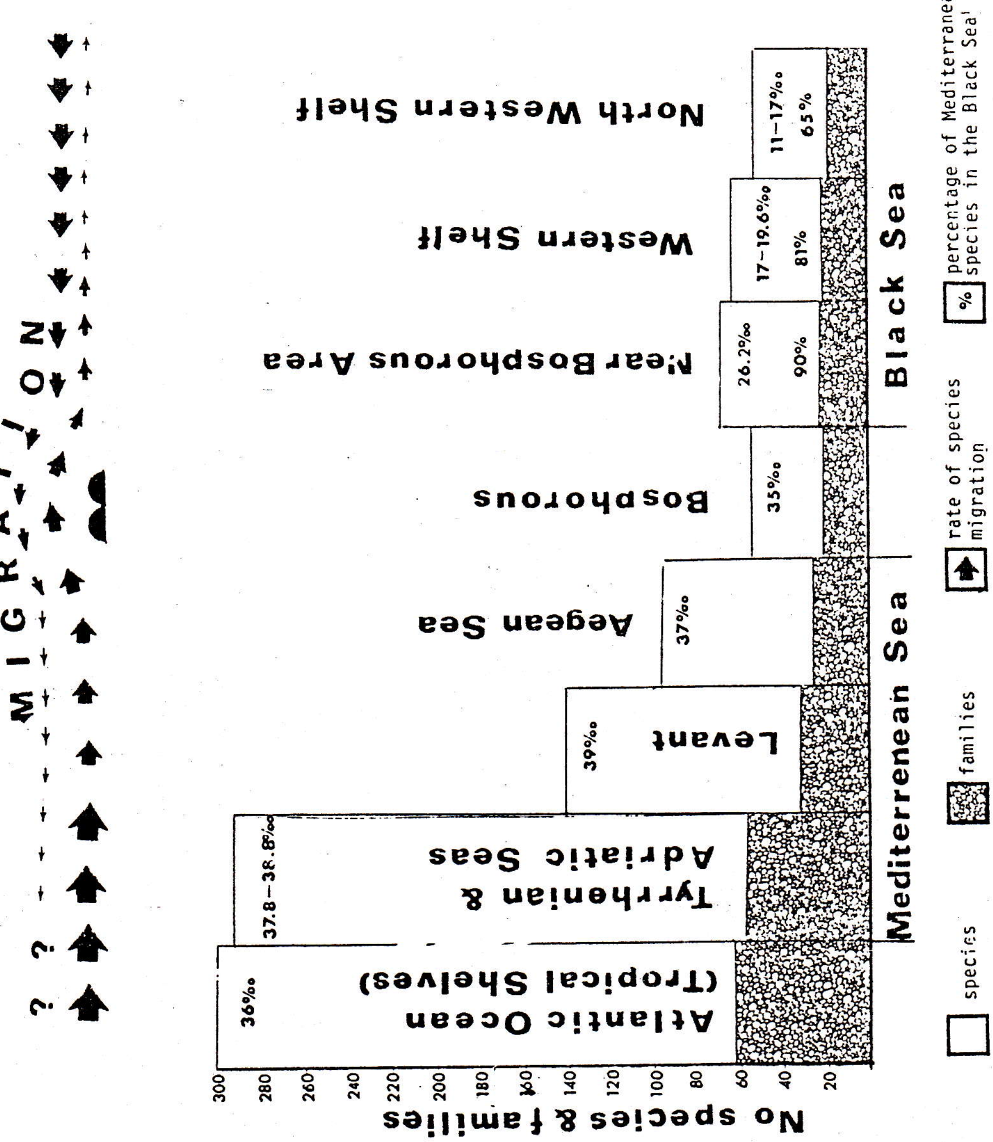

Fig.3 Number of benthic foraminifera families and species, and their migration rate and ways in different basins

the Mediterranean as a whole, the temperature and salinity gradients are less significant, certainly compared to the gradients within the Black Sea, in regards to restricting the benthic foraminiferal dispersion. Within the Mediterranean Sea, the sea floor is marked by deep basins that serve as geographical barriers against the rapid foraminifera distribution of the shallow water foraminifera. The benthic foraminifera are able to best disperse, upon their arrive from the Atlantic Ocean (Straits of Gibraltar) by migrating along the shallow continious shelf. The well established long shore currents within the basin may help to determine rates of migration; for, it should be easier to migrate with, rather than against, such fixed and relatively strong currents (Fig.1). It may be that the greater diversity in the western Mediterranean ocean and its close similarity to the Atlantic assemblage, is a result of the dispersion - process attaining a greater degree of equilibrium with the Atlantic input source due to their closer proximity. Within the eastern Mediterranean, the difference between the eastern Mediterranean assemblage (as represented by the Israeli coast) and the western assemblage as a whole, may be a result of the, as yet, incompleteness of the progress of population diffusion. A rapid dispersion, as the organisms migrated from the Atlantic Ocean, was assisted by taking a route that is in line with the flow direction of the long shore currents across the north African coast shelf. Likewise the oceanographic pattern may explain the diversity between the Israeli coast and the Bosphorous and Aegean regions. This flow pattern would place the Israeli coastline in closer proximity to the Atlantic inlet source than the northern coast of the eastern Mediterranean (Fig.1). Other factors may locally serve as barriers hinder or diversify the species distribution; but, these should be subordinate effects.

7. CONCLUSIONS

The distribution of shallow benthic foraminiferal populations within the Mediterranean and Black Sea can be affected by a variety of local factors. However, the data presented as representing the different Mediterranean locations, has, in effect integrated a wide variety of local marine conditions. This thereby, takes into consideration much of the differences between sites and minimizes the local marine environmental factors between regions. A very large assemblage difference then still remains between the western and eastern basins, as well as between the southern and northern shelves of the eastern basin. This may be less a function of the variations in marine conditions, than the degree to which a benthic population that has equilibrated with the total recolonizing population undergoing dissemination from the Atlantic Ocean. It is seen (Fig.2) that the population assemblages further from the source are comprised of a larger percentage of adaptive "pioneer" taxa relative to the total population. The Black Sea by comparison has not reattained marine conditions that existed previously during the Pleistocene (Stage 5) (Yanko, 1991). However, the same "Pioneer" forms are dominant in this region. A greater percentage of the assemblage is dominated by the adaptive forms away from the Bosphorous (marine) inlet. By analogy with the Black Sea, the Mediterranean dispersion though being more advanced, probably has not as yet attained its full extent of recovery since the termination of the early Holocene ecological crisis (approximately 8000 years ago).

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