Bulletin of the Mineral Research and Exploration

Volume 2024 | Issue 173 Article 9

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İPEK F. BARUT
barutif@istanbul.edu.tr

Engin MERİÇ
if.barut@gmail.com

Mustafa ERYILMAZ
meryilmaz@mersin.edu.tr

Atike NAZİK
anazik@cu.edu.tr

Feyza DİNÇER
fdincer@nevsehir.edu.tr

See next page for additional authors

Recommended Citation

BARUT, İPEK F.; MERİÇ, Engin; ERYILMAZ, Mustafa; NAZİK, Atike; DİNÇER, Feyza; and KAM, Erol () "Evaluation of radioactive properties and microfaunal evidence in the Bosphorus and the Dardanelles straits and Golden Horn sediments," *Bulletin of the Mineral Research and Exploration*: Vol. 2024: Iss. 173, Article 9.
DOI: https://doi.org/10.19111/bulletinofmre.1315735

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Bull. Min. Res. Exp. (2024) 173: 203-233

Bulletin of the Mineral Research and Exploration

http://bulletin.mta.gov.tr

Evaluation of radioactive properties and microfaunal evidence in the Bosphorus and the Dardanelles straits and Golden Horn sediments

İpek F. BARUT[a*], Engin MERİÇ[b], Atike NAZİK[c], Mustafa ERYILMAZ[d], Feyza DİNÇER[e] and Erol KAM[f]

[a] Istanbul University, Institute of Marine Sciences and Management, 34134 Vefa-İstanbul, Türkiye
[b] Moda Hüseyin Bey Sokak No: 15/4, 34710 Kadıköy-İstanbul, Türkiye
[c] Cukurova University, Department of Geological Engineering, 01330 Balcalı-Adana, Türkiye
[d] Mersin University, Department of Geological Engineering, 33343 Yenişehir-Mersin, Türkiye
[e] Nevsehir University, Department of Geological Engineering, 50300 Nevşehir, Türkiye
[f] Istanbul Technical University, Department of Environmental Engineering 34469, Maslak-İstanbul, Türkiye

Research Article

Keywords:
Bosphorus and Dardanelles Straits (Türkiye), Sediment, Golden Horn (Istanbul), Gross alpha and beta, Microfauna (benthic foraminifera, ostracoda).

Received Date: 15.12.2022
Accepted Date: 16.06.2023

ABSTRACT

The aim of this study is to investigate radioactive pollutants from pollution loads transported from the Black Sea to the Aegean Sea by the Turkish Straits System and their effects on microfauna (benthic foraminifera and ostracoda) assemblages. In the study, the effects of gross alpha and beta activity on the species number, species diversity, dominant species and species richness of benthic foraminiferal and ostracoda assemblages were investigated in 16 bottom sediments taken from different depths in the Golden Horn, Bosphorus and Dardanelles straits. In the studied sediment samples examined 61 genera and 64 species of benthic foraminifera, 23 genera and 26 species of ostracoda were identified. In addition two migratory foraminifera species were observed as *Spiroloculina antillarum* of Atlantic-Pacific origin and *Peneroplis pertusus* of Indo-Pacific origin. A relationship between the abundance of microfauna and high gross alpha and beta values was found in the Dardanelles samples, but not in the Bosphorus and Golden Horn samples. In this study, the highest radioactivity value was observed in the deepest bottom sediment samples. Consequently, the gross alpha and beta values were seen to be close to each other in the Dardanelles Strait and Golden Horn samples, and they had a broad-spectrum in the Bosphorus samples.

1. Introduction

Certain conditions can determine the rate of transport of radionuclides within and between the components of the ecosystem. These conditions are the mechanisms that cause transport, the concentration levels of radionuclides in the biotic and abiotic components of ecosystems, and the geochemical and ecological processes that affect the transport (Meriç et al., 2012; Barut et al., 2013; Zorer and Öter, 2015; Van et al., 2018).

Many research point out radionuclides fall out-derived pollutants that accumulate for a long time in living things such as invertebrate, fish, fungi and lichens and helping to evaluate the activity concentration (Kılıç et al., 2014; Biswas et al., 2015; Savino et al., 2017; Borcia et al., 2017; Duong Van et al., 2020). In a study by Kılıç et al. (2014), the activity concentrations of natural and artificial radionuclides were determined in the mussel species *Mytilus galloprovincialis* (Mollusca: Bivalvia: Mytilidae) from Mediterranean

Citation Info: Barut, İ., F., Meriç, E., Nazik, A., Eryılmaz, M., Dinçer, F., Kam, E. 2024. Evaluation of radioactive properties and microfaunal evidence in the Bosphorus and the Dardanelles straits and Golden Horn sediments. Bulletin of the Mineral Research and Exploration 173, 203-233. https://doi.org/10.19111/bulletinofmre.1315735

*Corresponding author: İpek F. BARUT, barutif@istanbul.edu.tr

mollusc species and in samples taken from the Golden Horn sediment. According to the results of the study, the concentrations of radioactivity in the particles in the <63 µm fraction of the sediment were generally higher than those found in *Mytilus galloprovincialis*. Therefore, the interaction of these radionuclides, which are the main indicators of the radiological state of the environment, and their usability in biological updates take place in various biogeochemical cycles (Mandic et al., 2010).

Again, the movements and distribution of radionuclides were influenced by differences in the sedimentation rate in the sediments of aquatic environments (lakes, estuaries, oceans and coastal seas) and atmospheric features such as floods and droughts. Therefore, it is important to evaluate the time, quality, quantity and accumulation of material together with environmental changes in past or current sediments (Carroll and Lerche, 2003; Ayçik et al., 2004; Li et al., 2006; Dai et al., 2007; Yang et al., 2009; Ruiz-Fernandez and Hillaire-Marcel, 2009).

Marine sediments have include natural records, a wealth of environmental information for organic and inorganic toxic pollutants, and high-resolution chronological transitions, that enable the examination of the anthropogenic origin of environmental changes in the past (Callaway et al., 1996; Vongunten et al., 1997; Fuller et al., 1999; Dai et al., 2007; Zhou et al., 2015; Hanfi et al., 2019, 2021). Radionuclides that are found locally in river and lake bottom sediments above certain limit values (^{3}H, ^{90}Sr, ^{137}Cs, ^{238}U, ^{234}U, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am, gross alpha, gross beta ve gross gama) are caused by air particles dispersed into the atmosphere as a result of surface nuclear weapons test studies and passing to other environments with radionuclide fallouts and radioactive clouds (McLin and Lyons, 2002).

Various pollution loads are transported from the Black Sea to the Marmara and Aegean Seas via the Bosphorus and Dardanelles Straits. An important part of the pollution in the Black Sea is the waste brought by the Danube River (Rank et al., 1990; Pantelic et al., 2002; Maringer et al., 2015; Borcia et al., 2017). The study of radiochemical processes has been revelead the existence of radioactive and chemical pollution risks in the lower parts of the Danube, in the Black Sea coastal region where some complex processes occur together with the Danube spill area in the Black Sea (Bologa and Patrascu, 1997; Borcia et al., 2017). For example after the Chernobyl accident, some of the activation products that emerged in the marine environment samples as a result of radioactive fallout in the ecosystem, as well as some of the other fission products were transported to the Eastern Black Sea Region and other regions (Bologa, 1994; Bologa and Patrascu, 1997; Bologa et al., 1998; Patrascu, 2002). Besides, the Dnieper, Dniester, Kuban, Don, Çoruh, Kızılırmak, Sakarya and Yeşilırmak rivers and their tributaries around the Black Sea are also effective in transporting pollution in general and industrial pollution in particular.

Radioactivity in the water comes from three main sources: natural radioactivity, radioactive precipitation and radiological facilities. Examination of qualitative and quantitative content of the radioactivity concentration levels found in nature is important in assessing of the environmental risk and the case (Tuncer and Tuğrul, 1992; Er and Tuğrul, 1995; Şahin, 2000; Tuğrul et al., 2001). Natural radionuclide concentrations in the aquatic ecosystem are connected to the physicochemical conditions and the geological features of the region.

Another recent study (Savino et al., 2017) conducted after the Chernobyl accident, starting from September 1986, included four monitoring periods to assess the activity concentration of four isotopes (^{134}Cs, ^{137}Cs, ^{103}Ru and ^{106}Ru). Moreover, Savino et al. (2017), twenty-eight years after the accident in December 2014, carried out another sampling process. Only ^{137}Cs was revealed beyond the detection limits, measuring activity concentrations ranging from 20 to 40 Bq/kg, while other radionuclides were no longer observed due to their shorter half-life (Savino et al., 2017). Beacuse of the elements and radioactive contaminants in the soil transported and distributed by water, aquatic ecosystem is effected by radioactive materials (Santschi and Honeyman, 1989). Particulate matter containing dissolved organic and inorganic substances are transported from the land to the sea via rivers.

Owing to the presence of uranium in disequilibrium with its daughter isotopes in lake and river sediments, the radioactivity is low. In contrast, the oceanic sediments contain an important value, radionuclides. At the same time, the oceans serve as a redistribution agent for radioactive elements (Friedlander et al., 2005). Some radionuclide concentrations in the Black Sea are higher than those in the Mediterranean. However, studies on the radiological results of the radionuclides measured in the oceans and the Mediterranean show that the radiation dose emitted from Black Sea anthropogenic radionuclides is low (Emiroğlu, 2014). Studies are ongoing for countries surrounding the Black Sea to develop regionally coordinated monitoring and emergency response programs for radionuclides in the marine environment and to evaluate key processes that control the fate of the pollutants in the Black Sea using radioactive tracers (Topçuoğlu, 2000).

The elements that are carried out to seas and coastal ecosystems, and have a pollutant effect are causing a change in the quality of the sea water, deterioration of the environment at the seabed, disappearance of dissolved oxygen in the bottom mud and emergence of anaerobic conditions. At the end of this process, the ecological balance deteriorates with the change of living conditions in the marine environment. Radioactive contaminations that cause abnormal formations on fauna and flora classified by the World Health Organization (WHO) are among these pollutants.

The distribution and abundance of benthic foraminifera individuals are mainly controlled by the temperature, salinity of the sea surface water (Thunell, 1979; Sen Gupta, 1999). Benthic foraminifera are very sensitive to changes in physicochemical and biological characteristics of the ecological environment (sea water temperature, salinity, pH, dissolved oxygen, availability of food, etc.). The distribution and abundance of benthic foraminifera individuals are affected by ecological conditions in the marine environment. Therefore, the properties of benthic foraminifera tests, including their morphology, abundance, stable isotopic and trace metal composition, provide valuable information on past climatic and oceanographic changes such as sea level, monsoons density, temperature, salinity, and ocean circulation (Saraswat and Nigam, 2013).

In general, both natural and anthropogenic factors of the marine environment affect the abundance and distribution of different microfauna (benthic foraminifera, ostracoda) genera and species, abnormal morphological deformations and coloration of their foraminifera tests or ostracoda carapaces. In some recent studies (Meriç et al., 2008, 2009, 2012, 2017, 2018*a, b*, 2020; Barut et al., 2013; Yokeş et al., 2014) carried out at different locations of the Eastern Aegean Sea, highly different ecological conditions including radioactivity concentrations and geochemical properties of the sediment were found to be influenced by the presence of potential sub marine thermal springs. Likewise, while the physical, chemical and radioactive properties of seawater were effective on benthic foraminiferal assemblages in terms of genera and species abundance, distribution, abnormal individual and colored shell formation, they did not show any effect on ostracoda individuals (Barut et al., 2018; Meriç et al., 2018*a, b*; 2020).

In the study by Meriç et al. (2018*a*) carried out at Aliağa Cove (İzmir), the gross alpha and gross beta (Bq/l) values in water collected from the sea and inside the cave at the location were higher than the reference values. Besides, according to the results of their study, it is in question that among ecological conditions, both differences in temperature value limits and the radioactive properties of waters may be effective on the distribution of the genera and species of certain benthic foraminifera (Meriç et al., 2018*a*).

Our study aims to investigate the effects of radioactive pollutants transported from the Black Sea to the Aegean Sea through the Turkish Straits System on microfaunal assemblages. In this context, multidisciplinary analyses were carried out including paleontological analyses, radioactivity analyses and statistical analyses in the sediment samples. The Bosphorus, the Dardanelles and the Golden Horn were selected as the areas of study because they are significant transportation routes of bottom sediments reaching the Marmara and Aegean Seas from the Black Sea (Figure 1).

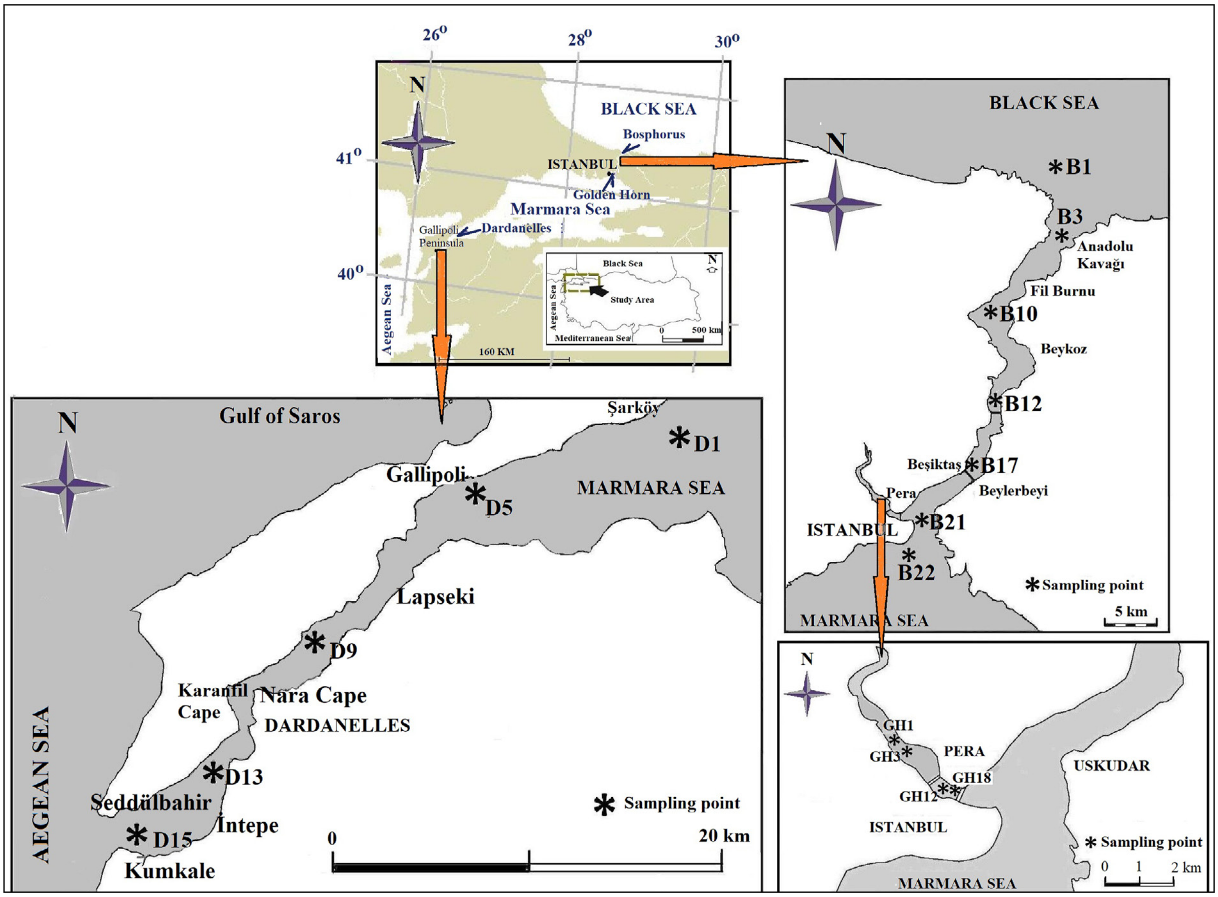

Figure 1- Location map of the study area.

The results of our studies conducted in environments with different ecological characteristics including thermal submarine freshwaters in gulfs, bays and surroundings of the Eastern Aegean coasts were evaluated together with the results obtained in this study. Therefore, this study investigates the effects of gross alpha and beta activity concentrations on the number of individual species, number of species diversity, number of dominant species and species richness of benthic foraminifera and ostracoda assemblages (Figure 1).

2. Oceanographic Features of the Bosphorus

The surface water temperature was measured along the profile in the Bosphorus, with average values between 8.0-9.0°C in spring and 19.0 - 24.0°C in summer. The surface water temperature is measured around 18.5-19.0°C in autumn. The temperature of the bottom water is around 14.5°C. In winter, the surface water temperature drops to around 5.5- 6.5°C. The temperature of the bottom water does not change in general and is around 14-14.5°C in all seasons (Eryılmaz, 1995, 1997, 2002; Eryılmaz et al., 2000; Yücesoy-Eryılmaz et al., 2003*a, b*) (Figure 2).

The presence of two layers in the Bosphorus may be observed more easily with salinity data (Figure 2). Surface salinity is measured as 17.68‰ in spring, while it is 36.0‰ at 30 m and 36.8‰ at 60 m of depth. It is 17.89‰ on the surface in summer, 34.19‰ at 30 m, and 38.28‰ at 60 m of depth. It is 17.38‰ on the surface in autumn, 17.59‰ at 30 m, and 38.46‰ at 60 m. It is 17.15‰ in winter, 26.49‰ at 30 m, and 37.25‰ at 60 m of depth (Eryılmaz, 1995, 1997; Eryılmaz et al., 2000; Yücesoy-Eryılmaz et al., 2003*a, b*).

In the Bosphorus, two different waters pass in opposite directions, the surface and bottom currents are caused by the level and density differences between the Black Sea and the Aegean Sea. These currents differ based on meteorological factors and seasons. It

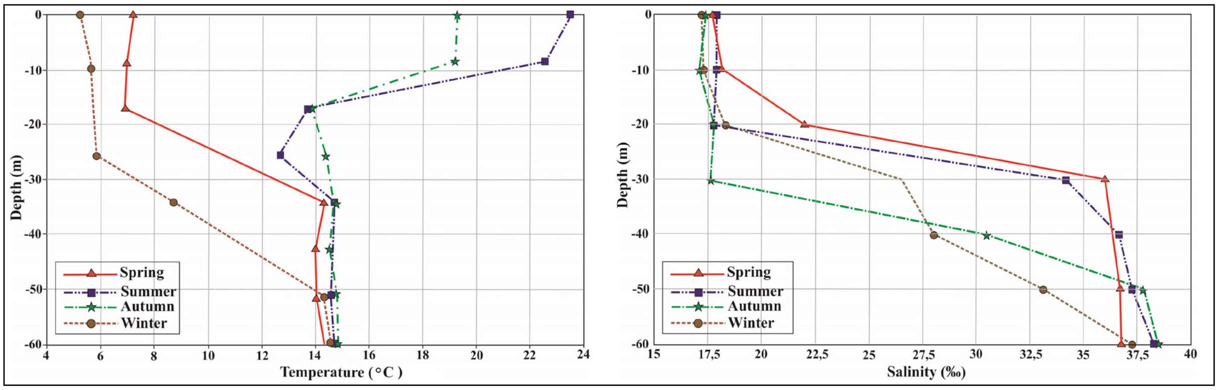

Figure 2- Seasonal change of average sea water temperature (°C), salinity (‰) by depth in the Bosphorus.

was observed that the surface current velocity at the northern entrance of the Bosphorus is 0.5-0.7 knots, ½ knots at Fil Burnu (Figure 1), 1-1.5 knots in front of Anadolu Kavağı, 2-3 knots in front of Çubuklu, 4-5 knots in front of Akıntı Burnu and Beylerbeyi, the narrowest parts of the strait, and between 3 and 4 knots in Üsküdar-Beşiktaş (Figure 1). However, this velocity increases to 7-8 knots with northern winds (Figure 2) (Eryılmaz, 1995, 1997; Eryılmaz et al., 2000; Yücesoy-Eryılmaz et al., 2003*a, b*).

3. Oceanographic Features of the Dardanelles

The reverse currents of Mediterranean and Black Seas origin waters observed in the Bosphorus Strait are also seen in the Dardanelles. However, contrary to the Bosphorus, the thickness of the Mediterranean origin water is higher and the thickness of the Black Sea origin water is lower. This factor is one of the most important elements that affect the vertical temperature distribution in the water of the Dardanelles Strait. The water temperature on the surface in the spring is 16.8-17.6°C and 14.8-15.2°C at 40 m depth. It is 19.8-22.3°C on the surface in summer and 15.4-15.7°C at 45 m. It is 16.4-17.7°C on the surface in autumn and 15.7-17.2°C at 75 m of depth. It is 13.0-13.2°C in winter, 15.5-16.6°C in 80 m of depth (Figure 3) (Eryılmaz, 1998; Eryılmaz et al., 2001; Yücesoy-Eryılmaz and Eryılmaz, 1998, 2000, 2002).

Surface salinity in spring is 22.7-23.0‰, it is 38.9-39.1‰ at 30 m of depth. In summer, it is 23.5-28.0‰ at the surface and 38.6-39.1‰ at 30 m depth. In autumn, it is 23.6-26.4‰ at the surface and 39.0‰ at 30 m depth. It is 23.5-26.4‰ in winter and 38.9-39.0‰ at 30 m depth (Figure 3) (Eryılmaz, 1998; Eryılmaz et al., 2001; Yücesoy-Eryılmaz and Eryılmaz, 1998, 2000, 2002).

The surface and bottom currents in the Dardanelles Strait are caused by the level and density differences between the Black Sea and the Aegean Sea. Here, as in the Bosphorus, two different strata of water pass in opposite directions. In the Dardanelles Strait, due

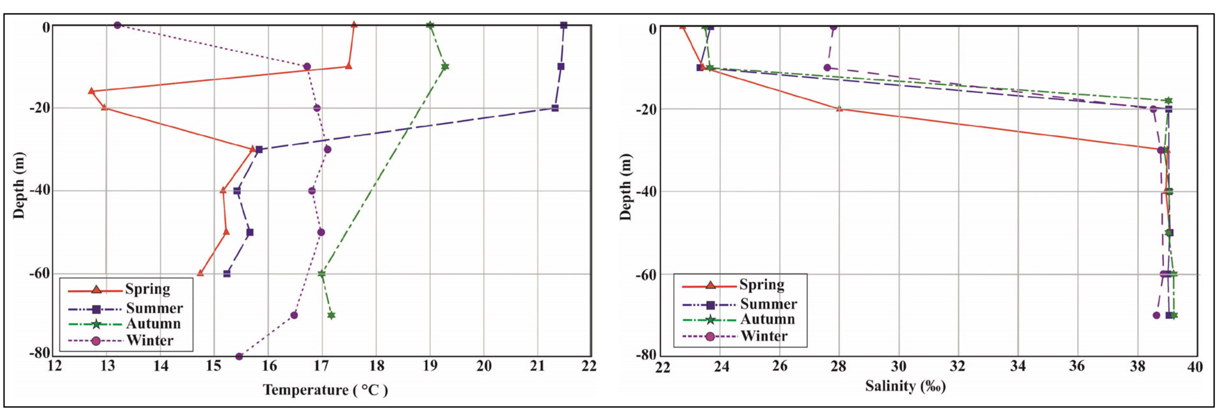

Figure 3- Seasonal change of average sea water temperature (°C), salinity (‰) by depth in the Dardanelles.

to the high density of Mediterranean origin waters coming from the Aegean Sea, they flow from the bottom to the Marmara Sea while the less dense Black Sea origin waters from the Marmara Sea pass into the Aegean Sea from the surface. Surface currents flow into the Aegean Sea in some places like a river conforming to the coastal shape. Current velocities are low at the northern entrance of the strait, but they increase towards south. The surface current velocity is 0.5 knots at the entrance to the Marmara Sea. It is 1.0-1.5 knots between Lapseki and Nara (Figure 1). Under normal conditions, the current velocity in front of Nara Cape is 1.5-2.0 knots and may reach up to 5.0 knots with winds blowing from the northeast. It is 4.0 knots between Çanakkale-Karanfil Cape, 2.0 knots between İntepe and Kumkale, and 2-3 knots between Seddülbahir and Kumkale (Figure 1). While the Dardanalles Strait surface currents increase with northeastern winds, they decrease with southwest winds. The bottom current velocity is 0.2-0.3 knots between Seddülbahir and Kumkale. Between İntepe and the Nara Cape, the undercurrent velocity is 0.2 knots, 0.5 knots in front of Nara Cape, 0.3-0.4 knots between Nara and Gelibolu, and it decreases to 0.1 knots at the Marmara exit of the strait (Figure 3) (Eryılmaz, 1998; Eryılmaz et al., 2001; Yücesoy-Eryılmaz and Eryılmaz, 1998, 2000, 2002).

4. Oceanographic Features of the Dardanelles Inlet (NW Marmara Island) of the Marmara Sea

The temperature distributions measured depending on the depth at the Dardanelles Inlet of the Marmara Sea (NW Marmara Island) are 7.97°C on the surface in spring, 14.64°C at 100 m; 23.55°C on the surface in summer, 14.64°C at 100 m; 19.31°C on the surface in autumn, 14.88°C at 100 m; 13.09°C on the surface in winter, 14.61°C at 100 m (Figure 4) (Eryılmaz, 1995; Yücesoy-Eryılmaz et al., 2003*a, b*).

The measured average salinity values are 24.50‰ on the surface in spring, 38.61‰ at 100 m; 22.15‰ on the surface in August, 38.86‰ at 100 m; 22.84‰ on the surface in autumn; 38.71‰ at 100 m; 26.80‰ on the surface in winter, 38.71‰ at 100 m (Figure 4) (Eryılmaz, 1995; Yücesoy-Eryılmaz et al., 2003*a, b*).

5. The Oceanographic Characteristics of the Golden Horn

In the Golden Horn, the water temperature on the surface in spring is 9.93-10.67°C, 11.15-11.77°C at 10 m of depth, 13.29-14.08°C at 20 m depth, 13.93-14.61°C at 30 m of depth; 24.65-25.12°C on the surface in summer, 11.85-12.26°C at 10 m of depth, 11.68-12.32°C at 20 m of depth, 14.17-14.69°C at 30 m of depth; 19.05-19.60°C on the surface in autumn, 17.82-18.35°C at 10 m of depth, 13.87-14.41°C at 20 m of depth, 13.69-14.53°C at 30 m of depth; 05.44-6.08°C on the surface in winter, 05.74-06.41°C at 10 m of depth; 09.81-10.39°C at 20 m of depth; 12.83-13.51°C at 30 m of depth. Seasonal temperature variations according to depth are given in Figure 5 illustrating the development of a thermocline in spring between 9 and 20 m, in summer between 10 and 26 m, autumn between 8.5 and 19 m and in winter between 14 and 25 m (Figure 5) (Eryılmaz and Kara, 1996; Eryılmaz, 1998, 2002).

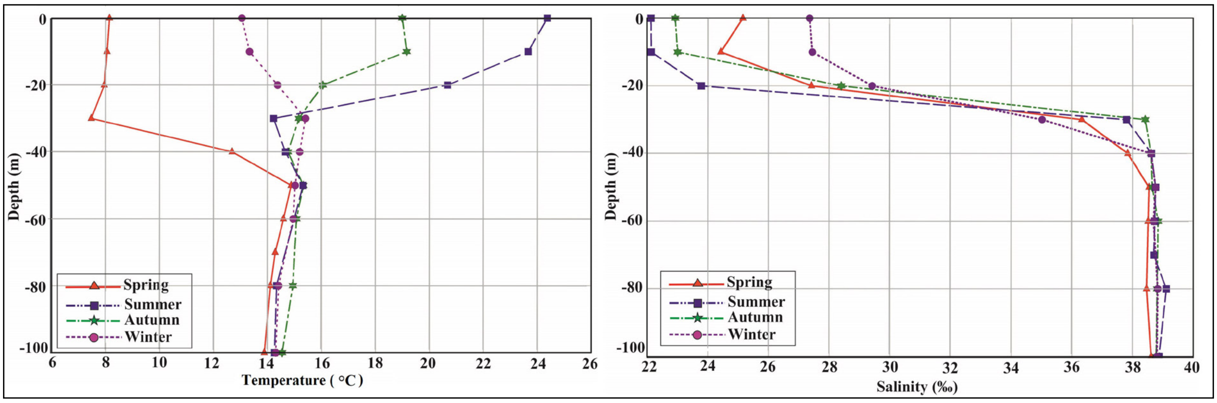

Figure 4- Seasonal change of average sea water temperature (°C), salinity (‰) by depth in the Marmara Sea, entrance of the Dardanelles (NW Marmara Island).

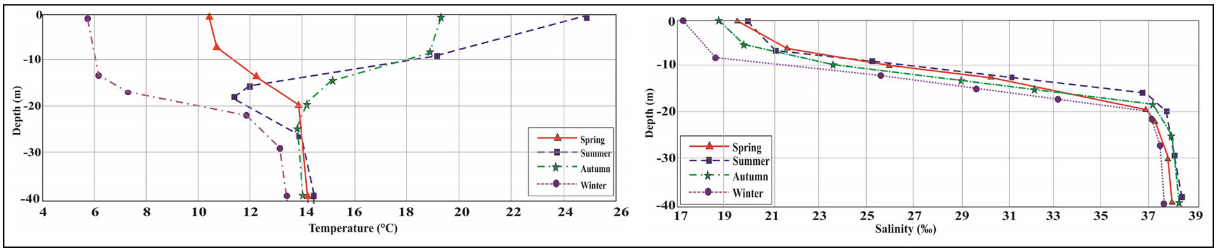

Figure 5- Seasonal change of average sea water temperature (°C), salinity (‰) by depth in the Golden Horn.

The salinity difference between the surface and the substrates is almost absent. Salinity differences in the surface layers depend on meteorological factors. Seasonal average variations of the seawater salinity in the Golden Horn are 19.29‰ on the surface in spring, 25.26‰ at 10 m, 37.01‰ at 20 m, 37.56‰ at 30 m; 19.72‰ on the surface in summer, 26.21‰ at 10 m, 37.77‰ at 20 m, 38.11‰ at 30 m; 18.58‰ on the surface in autumn, 26.22‰ at 10 m, 37.42‰ at 20 m, 38.08‰ at 30 m; 17.19‰ on the surface in winter, 18.44‰ at 10 m, 36.95‰ at 20 m, 37.58‰ at 30 m (Figure 5) (Eryılmaz and Kara, 1996; Eryılmaz, 1998).

6. Materials and Methods

6.1. Study Area and Sampling

Multidisciplinary studies were carried out in the region in the summer mounts of 2005 by the TCG Çubuklu Ship affiliated to the Turkish Naval Forces Command Office Of Navigation, Hydrography and Oceanography (ONHO). Bottom sediment samples from 16 different points and depths, which constitute the basic data of this study, were collected by the Van Veen grab sampler. The depths at which the samples were taken varied between 7.00 and 80.00 m (Figure 1, Table 1).

From the Dardanelles, five sediment samples were taken, while seven were taken from the Bosphorus and four from the Golden Horn. The samples were processed as described below. For each sample, 5 g of dried sediments was weighed, 10% hydrogen peroxide (H_2O_2) was added, and the mix was kept on hold for 24 hours, then washed under tap water after filtering in a 0.063-mm sieve. This way, each sediment sample was oven-dried at 50°C. Following this procedure, the

Table 1- Geographical coordinates, water depths, values of gross alpha and beta activity concentrations of sediment in sampling locations.

	Sample no.	Geographical Coordinates		Water Depth (m)	Gross alpha (Bq/kg)	Gross beta (Bq/kg)
		Latitude	Longitude			
Bosphorus	B1	41° 14'408"N	29° 06'976"E	39	451 ± 53	939 ± 51
	B3	41° 12'22"N	29° 07'22"E	20	87 ±29	203 ± 28
	B10	41° 09'20"N	29° 02'53"E	33	547 ± 57	884 ± 51
	B12	41° 05'30"N	29° 03'40"E	67	253 ± 42	792 ± 47
	B17	41° 02'636"N	29° 01'888"E	47	621 ± 61	893 ± 49
	B21	41° 00'49"N	28° 59'26"E	30	274 ± 42	579 ± 41
	B22	40° 59'952"N	28° 59'061"E	10	315 ± 45	762 ±47
Golden Horn	GH1	41° 02'02"N	28° 57'12"E	7	532 ± 56	987 ± 52
	GH3	41° 01'54"N	28° 57'14"E	10	439 ± 52	918 ± 51
	GH12	41° 01'31"N	28° 57'52"E	36	607 ± 60	991 ± 53
	GH18	41° 01'14"N	28° 58'06"E	52	718 ±65	1005 ± 53
Dardanelles	D1	40° 34'648"N	27° 14'088"E	80	550 ± 57	1062 ± 57
	D5	40° 27'42"N	26° 45'17"E	42	586 ±59	1039 ± 53
	D9	40° 16'17"N	26° 31'21"E	65	535 ± 57	1002 ± 52
	D13	40° 05'12"N	26° 20'42"E	66	435 ± 51	895 ± 50
	D15	40° 01'06"N	26° 15'06"E	59	540 ± 57	988 ± 51

samples were examined under a binocular microscope by sieving them in 2.00-, 1.00-, 0.500-, 0.250- and 0.125-mm mesh sizes. The standard procedure of paleontological studies was followed based on the reports of Babin (1980), Bignot (1985) and Murray (1973).

At the laboratory stage, the benthic foraminifera and ostracoda content of each sample was determined, the species forming the assemblages were separated and named, and they were counted in a foraminifera count plate (5/7 grid). The analyses performed on the foraminifera and ostracoda assemblages in the Paleontology Laboratory were completed by sequencing the forms to be used in the final definitions in a certain order for SEM imaging studies.

6.2. Measurements of the Gross Alpha and Gross Beta Activities

Gross alpha and gross beta activity concentrations were determined in 16 sediment samples collected from the Bosphorus and Dardanelles Straits and the Golden Horn. The gross alpha and gross beta counts of the samples were made at Çekmece Nuclear Research and Training Center (ÇNAEM). For the gross alpha and gross beta counts, the samples were first milled to 200 mesh and then dried. The sample kept in the desiccator was weighed by 12 g, mixed with 3 g wax, placed in a mold 40 mm diameter and turned into pellets using 35 tons of pressure. A Berthol LB770-PC 10 (Low Level Counter) channel low-level Alpha/Beta planchet counter was used for the measurements made on 16 sediment samples that were pelleted under suitable conditions for measurement. The measured results were obtained in units of Bq/kg. The measurement uncertainty was in the range of: ±2σ.

In the calculation of the activity concentrations of the samples, the background correction, self-absorption correction, counting and total uncertainty that occurred during the preparation of the sample for counting were calculated. Accordingly, the total uncertainty was in the range of: ±2σ with 95% confidence interval. The low-level counting system was commonly used for measuring environmental samples with low natural background radiation. Its calibration was carried out with standard solutions that contained known activities of ^{241}Am for alpha values and ^{90}Sr for beta values which were similar to the sample geometry. The minimum detectable activity (MDA) that could be achieved with the detection system was obtained as

$$MDA(Bq/l) = \frac{L_d}{VT\varepsilon 60};$$

where V is the sample volume, T is the duration of the measurements (in min), ε is the counting efficiency (Currie, 1968). L_d was defined as

$$L_d = 2.71 + 4.65\sqrt{C_B T};$$

with C_B being the background level in counts/min.

6.3. Statistical Analysis

The PAST (PAleontological STatistics): paleontological statistics software package for education and scientific data analysis (Hammer et al., 2001) was used for the statistical analysis. In quantitative paleontology PAST is a comprehensive, but simple-to-use software package for executing a range of standard numerical analyses and operations. PAST also includes many functions that are specific to paleontology and ecology, and these functions are not found in standard, more extensive, statistical packages.

7. Results

7.1. Benthic Foraminiferal Assemblages

In our study, 61 genera and 64 species benthic foraminifera individuals were determined in 16 bottom sediment samples taken from the Bosphorus, Dardanelles and Golden Horn. The taxonomic descriptions of previous studies were used (Cimerman and Langer, 1991; Hatta and Ujiie, 1992; Hottinger et al., 1993; Sgarella and Moncharmont-Zei, 1993; Loeblich and Tappan, 1994; Avşar and Meriç, 2001; Avşar, 2002; Meriç et al., 2002*a, b*, 2003*a, b, c*, 2009; Avşar et al., 2006; Avşar and Meriç, 2008). Additionally, the classification of foraminifera by Loeblich and Tappan (1988) was considered.

In this study, which was carried out in recent bottom sediments, it was understood that the benthic foraminifera assemblages in the sediment samples were under the influence of the Aegean Sea and Mediterranean fauna. While microfauna was abundant in the sediment samples from the Dardanelles, it was not abundant in the Bosphorus and Golden Horn samples. In addition to the fact that the bottom sediments of the Dardanelles have a very rich foraminiferal fauna, it was revealed that the warm and salty Mediterranean waters also show an active nature in the Bosphorus.

Additionally, two migratory foraminifera species were observed as *Spiroloculina antillarum* d'Orbigny (in D13 and GH3 samples) of Atlantic-Pacific origin and *Peneroplis pertusus* (Forskål) (in D9, GH3 and GH12 samples) of Indo-Pacific origin. In our study, no abnormal morphological disorder was observed in the collected microfaunal individuals. The dominant species of benthic foraminifera were determined as *Quinqueloculina seminula* (Linne), *Brizalina spathulata* (Williamson), *Cassidulina carinata* Silvestri, *Lobatula lobatula* (Walker ve Jacob), *Ammonia compacta* (Hofker), *A.tepida* (Cushman) (Table 2) (Plates I-II).

Table 2- Distribution counts of benthic foraminifera genera and species in Bosphorus and Dardanelles straits and Golden Horn.

FORAMINIFERA	Sample ID												
	B10	B12	B17	B21	B22	GH1	GH3	GH12	D1	D5	D9	D13	D15
Spiroplectinella sagittula					1						2		
Textularia bocki										1			
Textularia sp.											1		
Adelosina cliarensis											2		3
Adelosina mediterranensis											2	2	
Spiroloculina antillarum							1					2	
Spiroloculina ornata					2								
Spiroloculina tenuiseptata					2				3		2		2
Siphonaperta aspera				2								3	
Cycloforina contorta					2							1	
Cycloforina tenuicollis													2
Cycloforina villafranca				1								1	
Massilina secans								1					
Quinqueloculina berthelotiana							2						
Quinqueloculina bidentata				1									
Quinqueloculina disparilis		2											
Quinqueloculina laevigata				1									
Quinqueloculina lamarckiana			2										
Quinqueloculina seminula	2	3	1		3				3	2	3		5
Miliolinella semicostata											1		
Miliolinella subrotunda										2			
Pseudotriloculina oblonga													2
Phyrgo elongata													3
Sigmoilinita costata											3		4
Sigmoilinita edwardsi									2	2			
Sigmoilopsis schlumbergeri										2	3		
Peneroplis pertusus							1	1			1		
Lenticulina cultrata									2				
Amphicoryna scalaris											3		
Polymorphina sp. 1									1				

Continued Table 2

FORAMINIFERA	**Sample ID**												
	B10	**B12**	**B17**	**B21**	**B22**	**GH1**	**GH3**	**GH12**	**D1**	**D5**	**D9**	**D13**	**D15**
Fissurina sp.											2		1
Brizalina alata					2				1				4
Brizalina spathulata					3				2	4	6		8
Cassidulina carinata					4				3	3	6	2	6
Globocassidulina subglobosa											2		2
Rectuvigerina phlegeri											4		3
Bulimina elongata			1							3	4		6
Bulimina marginata									2		3		
Globobulimina affinis											2		3
Globobulimina pseudospinescens									1				
Reussella spinulosa										2	2		2
Valvulineria bradyana					2					3	4		2
Gavelinopsis praegeri					2								
Neoconorbina terquemi	1				3						3		3
Rosalina bradyi													3
Rosalina globularis											2	2	
Siphonina reticulata											1		
Discorbinella bertheloti					3				2	3	3		
Hyalinea balthica									1				
Cibicides advenum											2		
Lobatula lobatula	1		1		3				1	2	3	2	
Planorbulina mediterranensis											1		
Asterigerinata mamilla							1			1	2	2	
Nonion depressulum									2				
Nonionella turgida									1				2
Melonis pompilioides									3		2		3
Ammonia compacta	1	2	3	2	5	2	2	2		2	4	4	4
Ammonia tepida	8			3	8	2	4	3		4	8	5	6
Cribroelphidium poeyanum	4							1		2			3
Porosononion subgranosum													2
Elphidium aculeatum											2		
Elphidium advenum									1				
Elphidium complanatum					1							3	
Elphidium crispum	2			2						1		2	

7.2. Ostracoda Assemblages

In this study, ostracoda individuals were found to include 23 genera and 26 species in 10 of the 16 sediment samples that were collected. The studies of Van Morkhoven (1963), Hartman and Puri (1974), Breman (1975), Bonaduce et al. (1975), Yassini (1979), Guillaume et al. (1985), Athersuch et al. (1989), Guernet et al. (2003), Joachim and Langer (2008) were utilized for determination of ostracoda genera and species. (Table 3).

The high number of genera and species in Dardanelles is associated with the mixing of Mediterranean and Aegean Sea waters. In our study, genera and species common in the Aegean and

Table 3- Distribution counts of ostracoda genera and species in Bosphorus and Dardanelles straits and Golden Horn

OSTRACODA	Sample ID									
	B10	**B17**	**B21**	**B22**	**GH1**	**D1**	**D5**	**D9**	**D13**	**D15**
Aurila convexa		1		1				1		
Basslerites berchoni							3			1
Bosquetina carinella				1			1	1	1	
Buntonia sublatissima								3		2
Callistocythere intricatoides	1									
Carinocythereis carinata									7	
Carinocythereis rhombica									1	
Costa edwardsii				1		3	14		6	2
Cyprideis torosa									2	
Cytherella alvearium							7	2		3
Cytherella vulgata							2	3	2	
Cytheridea acuminata							13			1
Cytheridea neapolitana							5		3	3
Cytheropteron latum								2		
Heterocypris salinus			2							
Hiltermannicythere turbida									2	
Leptocythere sp.							3		1	
Loxoconcha rhomboidea	1		1	1			4	2	6	1
Neonesidea corpulenta	1			1				1		
Paradoxostoma triste	1									
Pontocythere elongata	3									
Pterygocythereis jonesii							4	2	1	2
Semicytherura inversa		1							3	
Tyrrenocythere amnicola	2									
Urocythereis oblonga								2		
Xestoleberis communis					1			1		1

Mediterranean were determined in the sediment samples in which the ostracoda assemblage was observed. The *Tyrrenocythere amnicola* (Sars) living in low-salt environments, which is also observed only in the B10 sediment sample, reflects the current low-salinity conditions of the Black Sea. *Cyprideis torosa* (Jones) is euryhaline and a cosmopolitan species and was observed only in the D13 sample. *Heterocypris salina* (Brady) was observed in the B21 (30 m) sediment sample. It is a halophilic cosmopolitan species known to tolerate different levels of environmental variables, including high levels of salinity changes. It prefers both small and slightly salty coastal and inland waters. Additionally, it also occurs in pure freshwater habitats (Akdemir and Külköylüoğlu, 2021). Thus, it indicates that the salinity levels in the water body it is in have increased. Considering that it is detemined in the B21 sediment that at the Marmara entrance of the Bosphorus and at 30 m depth, it suggests that it may have been transported.

In the sediment sample D1 that was collected at the deepest location (80 m), ostracoda numbers were low (only three carapaces). Again, in this study, no ostracoda individuals were found in the B1 (39 m), B3 (20 m), B12 (67 m) and GH18 (52 m) sediment samples. Only two ostracoda individuals were observed in the sediment sample B17 (47 m). Additionally, no ostracoda individuals were found in the GH3 (10 m), GH12 (36 m) and GH18 (52 m) sediments, and only one carapace was observed in the GH1 (7 m) sample. The samples of the Dardanelles included a very rich ostracoda assemblage. In the comparison of the ostracoda species richness levels among the sediments, it was determined that the highest number of individuals was in D5 (42 m) with 56 species.

7.3. Determination of Gross Alpha and Gross Beta Radioactivity Concentration in Sediment Samples

In this study, gross alpha and gross beta radioactivity concentrations were determined in the sampled Bosphorus and Dardanelles Straits and Golden Horn sediments (Table 1). In order to determine whether there is radioactive contamination, gross alpha and beta radioactivity values should be determined. In the Dardanelles samples, the gross alpha count was measured in the range of 435 ± 51-586 ± 59 Bq/kg, and the gross beta count was between 895 ± 50 and 1062 ± 57 Bq/kg. In the Golden Horn samples, the gross alpha count was found in the range of 439 ± 52-718 ± 65 Bq/kg, and the gross beta count was between 918 ± 51 and 1005 ± 53 Bq/kg. In addition to these, in the samples of the Bosphorus Strait, the gross alpha count was found in the range of 87 ± 29 and 621 ± 61 Bq/kg, and the gross beta count was between 203 ± 28 and 939 ± 51 Bq/kg. In the sediment samples, the gross alpha concentration was the highest in B17, GH12 and GH18 and the lowest in B3 (Figure 6 a). The gross beta concentration was the highest in D1 and B5 and the lowest in B3 (Figure 6 b). The distributions of the gross alpha and gross beta concentrations according to the sediment samples were in a linear relationship with each other.

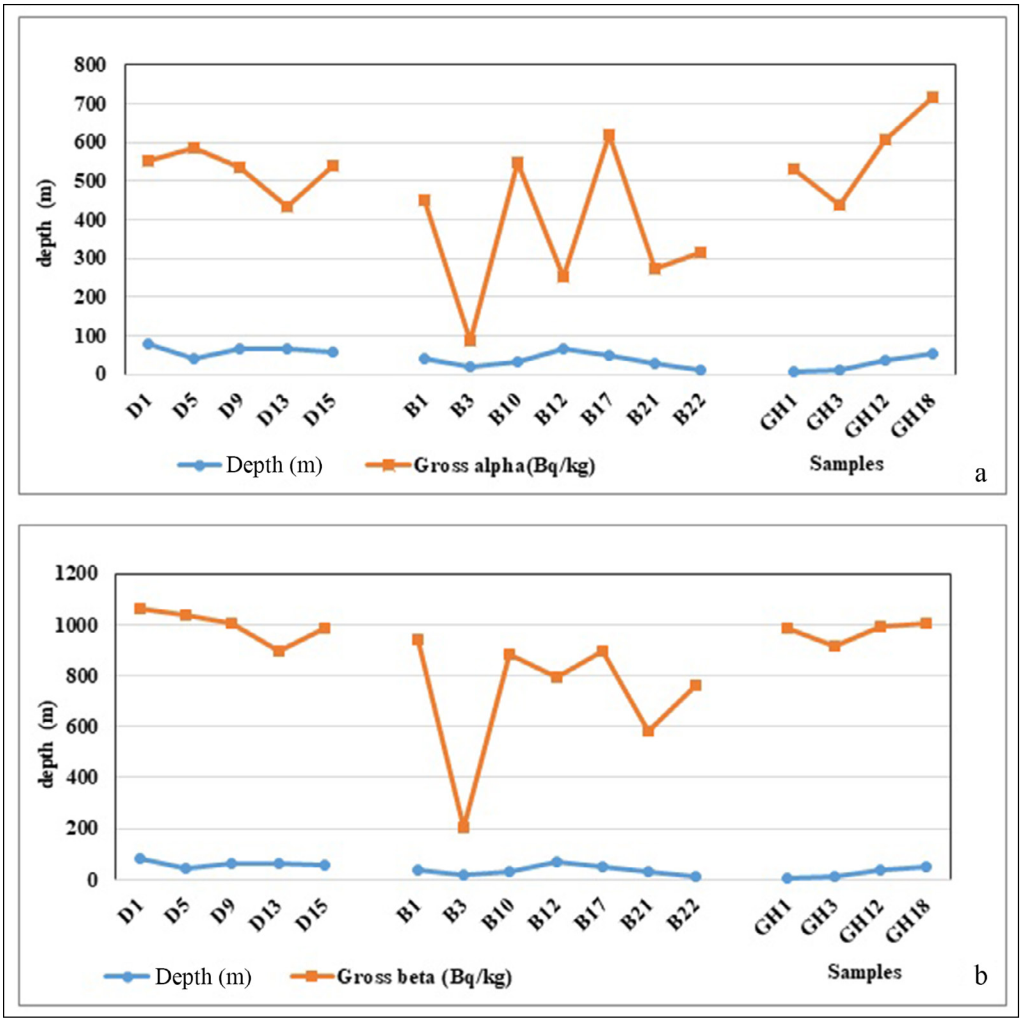

Figure 6- Distribution of, a) gross alpha and b) gross beta values with depth of sediments in investigation area.

While the gross alpha concentration distributions were close to each other in the Dardanelles and Golden Horn samples, they had a substantial variability between 87 ± 29 and 621 ± 61 Bq/kg in the Bosphorus samples. The gross beta concentration distributions were close to each other in the Golden Horn samples but variable in the Bosphorus and Dardanelles samples.

Considering the relationship between depth and gross alpha concentration, the highest activity value (586 ± 59 Bq/kg) was measured only at the minimum depth sediment sample of the Dardanelles Strait (D5, 42 m), thus an inverse proportion with depth was observed (Figure 6 a). While the highest gross alpha value was found (718 ± 65 Bq/kg) in the deepest sedimentary sample (GH18, 52 m) in the Golden Horn, the lowest gross alpha value (87±29 Bq/kg) was found in the sediment sample collected from the minimum depth (B3; 20 m) in the Bosphorus (Figure 6b). A linear relationship was found between gross beta concentration and depth, in the Golden Horn (GH18; 52 m; 1005±53 Bq/kg) and Dardanelles Strait (D1; 80 m; 1062±57 Bq/kg), and the highest activity value was found in these sediment samples collected from the maximum depth (in GH18 and D1 samples).

In the sediment samples collected at the deepest location D1 (80 m), the numbers of benthic foraminifera and ostracoda are low, whereas the gross alpha and beta values are high. The highest gross beta value was measured at B1 (39 m), where benthic foraminifera and ostracoda are not observed, whereas the lowest gross beta was measured at B3 (20 m). In B17 (47 m), the highest gross alpha and beta values and a small number of microfauna are found. The highest abundance (46 numbers) and diversity (16 numbers) of benthic foraminiferal assemblages were determined at a minimum depth in B22 (10 m) from the Bosphorus sediments (Table 2). Also at GH18 (52 m), the gross alpha and beta values are the highest, but no microfauna was found.

7.4. Statistical Analysis for Benthic Foraminifera and Ostracod Assemblages

The parameters that were used in the calculation of benthic foraminifera diversity and species richness (PAST) in this study included the number of species (Taxa_S), species diversity (Simpson_1-D), dominance number of species (Dominance_D), species diversity (Shannon_H) and richness of species (Margalef). In the calculation of benthic foraminiferal diversity and species richness (PAST), Shannon (3.36), Simpson (0.9603) and Margalef (7.094) parameter results were recorded at the highest in D9. The dominance in the sediments was at the highest in D9 based on the Simpson Dominance Index (0.9603). The Simpson's Diversity Index shows the dominance of the environment as inversely proportional to the diversity of the environment. The Shannon Species Diversity and Simpson Population Density relationship was calculated as the highest (3.36; 0.9603) in the D9 sample and the lowest (0.6931; 0.5) in the GH1 sample. When the benthic foraminifera species richness was compared among the sediments, it was determined that D9 contained the most species, with 33 species. For the Margalef Index, the same foraminiferal assemblages are compared in the sediment samples, and this index was found to be highest in D9 and lowest in GH1 (Table 4).

According to the PAST statistical analysis of the distribution of ostracoda, the Shannon parameter was determined in D13 (2.404), the Simpson parameter was determined in D9 (0.9032) and the Margalef parameter was determined in B22 (9.783) (Table 5). The Simpson Dominance Index in the sediments was the highest in D9 (0.9032). Again, the relationship between the Shannon species diversity and the Simpson population density of ostracoda was found to be the highest at D9 (0.9032) and D13 (2.404), the lowest (0) at GH1 and D1 samples (Table 5). When the richness values of ostracoda species in the sediments were compared, it was determined that D5 contained the most species, with 56 species. The Margalef Index was compared for the assessment of the same ostracoda assemblages between different sediment samples and in B22 sample was found to be the highest (Table 5).

8. Discussion and Conclusion

The geology of the Bosphorus Strait consists of terrestrial clayey pebbles of the quaternary sedimentary sequence within the Thrace Formation (Şimşek, 1987). The sediments contain sandstone, siltstone, claystone and quartz pebbles of different

Table 4- The evaluation with PAST of benthic foraminifera.

ID	Count of foraminifera	Taxa_S	Dominance_D	Simpson_1-D	Shannon_H	Margalef
B10	19	7	0.2521	0.7479	1.631	2.038
B12	7	3	0.3469	0.6531	1.079	1.028
B17	8	5	0.25	0.75	1.494	1.924
B21	12	7	0.1667	0.8333	1.864	2.415
B22	46	15	0.09032	0.9097	2.558	3.722
GH1	4	2	0.5	0.5	0.6931	0.7213
GH3	11	6	0.2231	0.7769	1.642	2.085
GH12	8	6	0.2099	0.7901	1.677	2.276
D1	31	17	0.06972	0.9303	2.74	4.659
D5	39	17	0.06772	0.9323	2.757	4.367
D9	91	33	0.03973	0.9603	3.36	7.094
D13	31	13	0.09261	0.9074	2.47	3.494
D15	84	25	0.0496	0.9504	3.109	5.417

Table 5- The evaluation with PAST of ostracoda.

	Count of tracod	Taxa_S	Dominance_D	Simpson_1-D	Shannon_H	Margalef
B10	9	6	0.1827	0.8173	1.747	6.056
B17	2	2	0.5	0.5	0.6931	0
B21	3	2	0.5256	0.4744	0.6673	0
B22	5	5	0.2	0.8	1.609	9.783
GH1	1	1	1	0	0	0
D1	3	1	1	0	0	0
D5	56	10	0.1126	0.8874	2.238	4.502
D9	20	11	0.09685	0.9032	2.365	6.38
D13	35	12	0.09701	0.903	2.404	5.909
D15	16	9	0.1201	0.8799	2.157	5.946

sizes, with short intervals of repetitive pebbles, less silty, very compact sand, dark gray coarse shells, sandy pebbles and especially abundant shells. Again, these sediment distributions consist of mostly gray, poorly graded shell fragmented, very loose-loose-medium compact silty sands (Yıldırım et al., 1992).

In the Bosphorus, due to the undercurrents, the sediments are either absent or very thin in some places at the bottom of the channel. In general, they are represented by gravel, sand, shell fragments and silt in some places. The distribution of the sediments in the Bosphorus consists of three groups including block-rocky, gravel and sand as well as a small amount of silt units (Meriç et al., 2001). In the studies carried out on the recent sediments (Meriç et al., 2001; Avşar and Meriç, 2001), a benthic foraminifera assemblage, which was rich in genera and species, representing mostly a Mediterranean-based shallow marine environment was observed. Again, at the Black Sea exit of the Bosphorus, benthic foraminifera genera and species which represented a shallow marine environment of Mediterranean origin were dominant in some places (Avşar and Meriç, 2001).

The sediments distribution in the Dardanelles is affected by the flow system, the bathymetry and the morphological structure of the strait. In regions where the flow velocity is high, fine-grained sediments does not accumulate, coarse-grained material is generally deposited and, in these places the current sediment thickness is low. In general, sandy units, shell fragments and silt are seen in some places. In places such as small bays, gulfs and harbors on the shores of the strait, sandy and pebbly material and fine-grained silt, clay and mud-composed sediments are deposited. As the bottom current and the slope increase, it is not possible for sediment to accumulate (Yücesoy-Eryılmaz and Eryılmaz, 1998, 2002; Yücesoy-Eryılmaz et al., 2003*a, b*).

The Golden Horn sediments consist of silty clay deposits called "Golden Horn Clay", whose thickness is around 35 meters and is deposited in a stagnant environment. On the sea floor of the Golden Horn, there is a very soft, recent mud layer with high black organic content and a gray sandy clayey gravel string with a thickness of between 2.0 m and 8.5 m. The Golden Horn sediments had characteristics of four environments: river, sea, brackish water and shallow brackish to freshwater conditions, and they contained grains (or particle size) in the size of gravel, sand, mud and clay (Meriç et al., 1988; Derman, 1990). Except for *Ammonia tepida* (Cushman) (Yanko, 1993), which can live in almost every environment, the Golden Horn sediments have benthic foraminifera assemblage (Şamlı, 1996) of Mediterranean and Atlantic origin generally living on the continental shelf where they are dominant (Murray, 1970, 1971; Meriç and Sakınç, 1990; Meriç et al., 1991; Sgarella and Moncharmont-Zei, 1993).

The morphological structure of the strait, the current system and other oceanographic factors have been effective in the development of the ongoing sediments in the Bosphorus and Dardanelles. The bottom sediments of the Dardanelles are composed of sand, silty sand, muddy sand, sandy silt, silt, mud and sandy mud. In a study conducted in the Dardanelles (Meriç et al., 2009), the average gravel was found as 6%, the average grain size of sand was 25%, the average silt was 46%, and the average clay was 22%, and the average mud was 68%. Additionally, the mud distribution which is 68% on average in these samples varies between 27% and 99% and shows differences (Meriç et al., 2009). In the sediments of the Dardanelles and the Marmara Sea transition zone, the most silt was detected in the Dardanelles Strait (72.5%) and the most clay was determined in the Dardanelles Strait-Marmara Sea inlet samples (65.2%) (Yücesoy-Eryılmaz and Eryılmaz, 2002).

Dardanelles sediments have rich benthic foraminifera assemblages (Meriç et al., 2009). The benthic foraminifera assemblages of the region are similar to the genera and species that characterize the Aegean and Mediterranean Seas fauna (Avşar, 2002; Meriç et al., 2004*a, b*; 2009). Moreover, among the foraminifera assemblages identified, *Cushmanina striatopunctata* (Parker and Jones) (Meriç et al., 2009), a species found in the North Atlantic, and *Fissurina* sp. (Hottinger et al., 1993) were also determined in this study. According to our study when the benthic foraminiferal and ostracoda assemblages of the Bosphorus and the Dardanelles are compared; it is revealed that the number of both foraminifera and ostracoda genera and species and the number of individuals belonging to them observed are lower numbers in the Bosphorus and in the Golden Horn than the Dardanelles. In addition as in foraminifera tests, ostracoda valves/carapaces were not affected by ambient conditions and morphological abnormalities were not observed in their valves.

The effect of the sediment feature on benthic foraminifera and ostracoda assemblages is significant on their number of species (Taxa_S), species diversity (Simpson_1-D), dominance number of species (Dominance_D), species diversity (Shannon_H) and richness of species (Margalef). When the benthic foraminifera species richness was compared among the sediments, it was determined that D9 contained the most species, with 33 species. For the Margalef Index, the same foraminiferal assemblages are compared in the sediment samples, and this index was found to be highest in D9 and lowest in GH1. The relationship between the Shannon Species Diversity and the Simpson Population Density of ostracoda was found to be the highest at D9 (0.9032) and D13 (2.404), the lowest (0) at GH1 and D1 samples. When the richness values of ostracoda species in the sediments were compared, it was determined that D5 contained the most species, with 56 species. The Margalef Index was compared for the assessment of the same ostracoda assemblages between different sediment samples and in B22 sample was found to be the highest.

As a result, high gross alpha and beta concentrations in D9 sample resulted in a decrease in species dominance in benthic foraminifera and an increase in the number, diversity and richness of species. Additionally high gross beta values in GH1 sample increased species dominance and resulted in a decrease in species number, diversity and richness. The species diversity in the ostracoda assemblages have increased in D9 sample, which has high gross beta values. While high gross beta concentrations in GH1 and D1 samples indicate high species dominance in the ostracoda assemblages, the number of species, diversity and richness of the species have resulted in a decrease. Again, low gross alpha concentration in B22 sample resulted in low species numbers and high species richness in the ostracoda assemblages.

In our study, six of the sediment samples (D1, D5, D9, D13, D15 and B22) contained a rich benthic foraminifera assemblage. In light of these pieces of information, it is understood that the study area is under the influence of the Aegean Sea and Mediterranean fauna. *Quinqueloculina seminula, Brizalina spathulata, Cassidulina carinata, Lobatula lobatula, Ammonia compacta* and *A. tepida* are the dominant benthic foraminifera species. *Spiroloculina antillarum* (in D13 and GH3 samples) of Atlantic-Pacific origin and *Peneroplis pertusus* (in D9, GH3 and GH12 samples) of Indo-Pacific origin were observed as two migratory foraminifera. According to these data, it is revealed that the current bottom sediments of the Dardanelles have a very rich foraminiferal fauna, and the thermal and salty Mediterranean waters have an active feature in the Bosphorus (Sakınç et al., 2000; Meriç et al., 2004*a*; Barut et al., 2012). According to the results of the correlation analysis there was a negative relationship between the gross alpha and gross beta activity concentrations and depth in the sediment samples taken from the Dardanelles. While the correlation between the gross alpha and gross beta activity concentrations and depth was positive and linear in the B1, B3 and B10 samples taken from the Bosphorus, this correlation was negative in the others (in B12, B17, B21 and B22 samples). There was a positive correlation in all sediment samples except for the GH1 sample taken from the Golden Horn.

In the comparison of the benthic foraminifera and ostracoda assemblages of the Bosphorus and Dardanelles Straits, it was determined that the numbers of genera and species observed in the Bosphorus were lower than those of the Dardanelles. The main factor in the more dominant genera and species of microfauna at the Dardanelles is the effect of the thickness of the Mediterranean water mass (Eryılmaz et al., 2001) on this environment. This means that the effect of the system of sea currents on the biodiversity in the Dardanelles is very significant (Meriç et al., 2018*a*). Thus, microfauna assemblages that originate from the Pacific Ocean, the Indian Ocean, the Red Sea and rarely the Atlantic Ocean are transported on the Suez Canal-Mediterranean-Aegean Sea route under the significant influence of current flow systems and inside the ballast waters of ships traveling to different points of the Aegean Sea. As a result, microfaunal individuals that adapt to the environment in the living area multiply and disperse (Meriç et al., 2018*a*).

At the Dardanelles Strait, where two different masses of water flow in opposite directions, the surface and bottom currents occur as a result of the level and density differences between the Black Sea and the Aegean Sea. While high-density waters with Mediterranean origin flow towards the Marmara Sea from the bottom, the waters of Black Sea origin with a lower density flow towards the Aegean Sea from the surface. The surface water thickness which is 20 m on the side of the Marmara Sea decreases down to 5 m towards the Aegean Sea. This factor is one of the most significant factors affecting the vertical temperature distribution at the Dardanelles Strait (Meriç et al., 2009).

The surface water with 17-18‰ salinity at the Black Sea entrance of the Bosphorus Strait which is represented with a two-layer water system disperses into the Marmara Sea through the Bosphorus Strait, and its salinity values increase up to the range of 20-25‰. At the Aegean Sea entrance of the Dardanelles Strait, the surface water salinity reaches 29‰ due to its mixing with bottom water. The bottom water at the Aegean Sea entrance and the Marmara Sea entrance of the Dardanelles Strait with ~39‰ salinity does not show a noticeable change inside the Marmara

Sea and is limited to values in the range of 37-38‰. At the Black Sea entry of the Bosphorus Strait, the salinity of the bottom water drops down to 35.5% (Beşiktepe et al., 1994). This system is shaped by the entry of the low-saline (18‰) Black Sea water through the Bosphorus Strait and the high-saline (39‰) Mediterranean water through the Dardanelles Strait into the Marmara Sea (ISKI, 2005). Between these two water masses with different densities, the Mediterranean water forms the bottom layer, the Black Sea water forms the top layer, and these develop a constant system of currents that flow opposite to each other. The depth of the intermediate layer separating these two different water masses (pycnocline) is 20-25 m from the water surface (Ünlüata et al., 1990). There need to be certain temperature and salinity values for the living conditions of ostracoda, mollusca and foraminifera genera and species. Besides this, it is known that among ecological conditions, temperature limits are different for some benthic foraminifera species and genera.

In the study of (Meriç et al., 2009), ostracoda assemblages of Mediterranean origin species are very rich in Dardanelles sediment samples. In our study, ostracoda assemblages belonging to rich Mediterranean origin species were dominant in Dardanelles sediment samples, especially in D5 and D13. The depths of sediment samples containing this rich ostracoda genera and species fauna of Mediterranean origin vary between 42 m and 66 m. The relationship between the increase and decrease in the gross alpha values of the D5 and D9 samples and the number of ostracoda genera and species was linear and positive. However, a negative relationship was observed in the other samples (in D13 and D15 samples). Only one ostracoda species with Mediterranean origin was found in the sample GH1 from the Golden Horn. Again, the number of ostracoda genera and species of Mediterranean origin varied between 2 and 9 in the Bosphorus sediments (Figure 7 a, b).

The highest gross alpha and beta values were measured in GH18 sample, and no benthic foraminifera was found. In B17 sample, where the gross alpha value was high, five species were observed, whereas six species were observed in GH17. The abundance of benthic foraminifera assemblages was observed in D1, D5, D9 and D15 samples where the gross beta values were measured to be the highest (Figure 4). The correlation between the gross alpha and gross beta values and the numbers of species of benthic foraminifera assemblages (Figure 5 a, b) appeared to be negative in all samples of the Dardanelles except for D13 and D15.

There was a negative correlation between the gross alpha and beta values and the depths in the Dardanelles samples. Among the Bosphorus samples, in B1, B3 and B10, the relationship between these parameters was positive and linear, while it was negative in the others. In the Golden Horn samples, the correlation was positive except for GH1 (Figure 8). A relationship was found between microfauna density and high gross alpha and beta values in the Dardanelles samples, but not in the Bosphorus and Golden Horn samples.

Karahan (1997) found that the average gross alpha concentration of the Marmara Sea was 1.42 Bq/l, and its average gross beta concentration was 5.47 Bq/l. In the same study, the average alpha activity concentration of Black Sea water was found as 0.375 Bq/l, and the average beta activity concentration of it was 5.63 Bq/l. In another study (Özger, 2005), the alpha activity concentration of Mediterranean water was found to be 0.703 Bq/l, and its beta activity concentration was 6.81 Bq/l. As seen here, the beta activity concentration of Mediterranean water was higher than the beta activity concentration values in the Marmara Sea and the Black Sea. This may be explained by the fact that the salinity value of Mediterranean water is higher than water from the Black Sea and Marmara Sea. The reason for the high alpha and beta activities in sea-water was due to the excess amount of potassium in sea water.

The gross alpha values reported by Karahan (1997), were higher than those found in other studies (Karahan et al., 2000; Otansev et al., 2016) conducted in the Black Sea and Marmara Sea. The gross beta values were determined by Karahan et al. (2000) and Otansev et al. (2016) to be the same, on the other hand. As seen in the Table 6, the values of rainfall and snow water were also similar to the lake for comparison. In the study by Otansev et al. (2016), Marmara gross

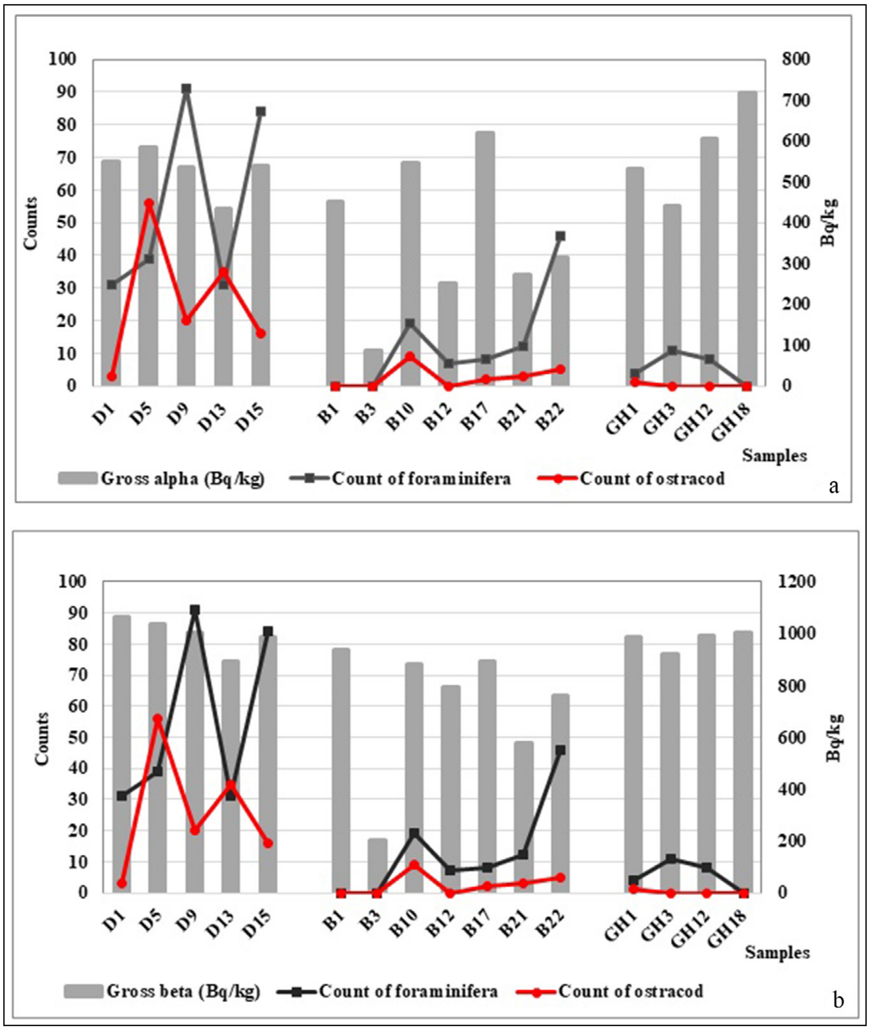

Figure 7- Distribution of benthic foraminifera and ostracoda numbers according to a) gross alpha and b) gross beta values of samples.

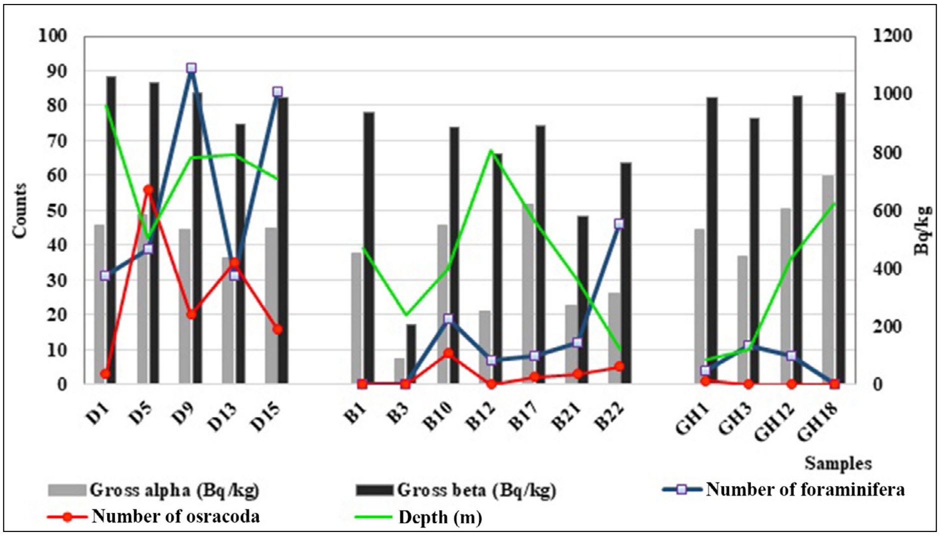

Figure 8- Distribution of benthic foraminifera and ostracoda numbers with gross alpha and gross beta values according to depth of samples.

alpha values were found to be the lowest, while gross beta values were found to be high. The sea water gross beta value of the Romanian coasts was the highest (Patrascu, 2002). In the comparison of sediments, the results were very variable in Romania sediments (30-3000 Bq/kg), but in the results of our study, they were in the same range as submerged sediments.

The natural radionuclide distribution depends on the geological and geographical conditions of each region. The obtained results showed that the geological formation and agricultural areas strongly affected the occurrence of natural radioactivity. It was also shown that the gross-alpha and gross-beta radioactivity concentrations in the soil and sediment samples were found to be relatively higher than those observed in other studies (Yuanxun et al., 2003; Stephen, 2004).

As a result of a recent study (Önce and Kam, 2019) the maximum gross alpha value was found around the investigation areas of Şarköy and Mürefte as 301 ± 15.9 Bq/kg (Şarköy Port, on the southwestern coast of the Marmara Sea-Türkiye), and the lowest value was found as 989 ± 16.5 Bq/kg (Şarköy Port). When these values were compared to the results of our study, both gross alpha and gross beta concentration values were found to be high in our study. The main reason why the gross alpha and beta concentrations were generally high was that fertilizers used in agriculture contain uranium, thorium and their degradation products, as well as natural ^{40}K (Eisenbud and Gessel, 1997). Keser et al. (2013) studied the radioactivity levels in sediment and rock samples of İkizdere and the Kaptanpaşa Valley. They found the gross alpha activity to be generally lower than the corresponding gross beta activity for some rock samples.

The radioactivity of lake and river sediments is generally low in Lake Van in May. The average value of gross alpha activity (Bq/g) was reported as 1.134±0.664, while the average value of gross beta activity (Bq/g) was reported as 0.482±0.181. In August these values were as gross alpha (Bq/g): 1.082±0.642 and gross beta (Bq/g): 5.529±2.541 (Zorer et al., 2009*a*). Again, in the study in question, it was observed that the gross alpha and gross beta radioactivity concentrations ranged respectively from

Table 6- Comparison of gross alpha and gross beta radioactivity levels and in various places and different studies

Sample Locations	Gross alpha	Gross beta	References
Marmara Sea (Bq/l)	1.42	5.47	Karahan 1997
Black Sea (Bq/l)	0.375	5.63	Karahan 1997
K. Çekmece Lake (Bq/l)	0.06±0.04	3±1	Karahan et al., 2000
B. Çekmece Lake (Bq/l)	0.05±0.01	0.3±0.07	Karahan et al., 2000
Terkos Lake (Bq/l)	0.02±0.009	0.2±0.05	Karahan et al., 2000
Ömerli Dam Lake (Bq/l)	0.034±0.008	0.04±0.005	Karahan et al., 2000
İstanbul coasts Sea water (Bq/l)	0.4±0.1	4.9±0.9	Karahan et al., 2000
Black Sea water (Bq/l)	0.4±0.2	5.6±1.1	Karahan et al., 2000
Marmara Sea water (Bq/ l)	0.5±0.1	5.0±1.2	Karahan et al., 2000
Black Sea and Boshporus water (Bq/l)	0.3±0.006	5.3±1.3	Karahan et al., 2000
Rain water (Bq/l)	0.03±0.008	0.13±0.03	Karahan et al., 2000
Snow water (Bq/l)	0.08±0.004	0.14±0.03	Karahan et al., 2000
Marmara Sea water (Bq/l)	0.042	13.402	Otansev et al., 2016
Romanian coast sediment emerged (Bq/kg)		30-8000	Patrascu, 2002
Romanian coast sediment submerged (Bq/kg)		459-980	Patrascu, 2002
Romanian coast Seawater (Bq/l)		3300 -- 7500	Patrascu, 2002
Average of Bosphorus sediment Bq/kg)	364	721.71	**This study**
Average of Golden Horn (Bq/kg)	574	975.25	**This study**
Average of Dardanelles (Bq/kg)	441	831	**This study**

0.782 to 4.596 Bq/g and from 0.482 to 10.372 Bq/g in May and from 0.580 to 5.824 Bq/g and from 0.303 to 9.702 Bq/g in August (Zorer et al., 2009*b*).

The mechanism of the transfer of radioelements from the ocean to pelagic deposits was discussed, and points of uncertainty in the interpretation of the distribution of gross beta-activity were indicated (Arrhenius and Goldberg, 1955). The alpha activity had so far been investigated only in the grain size fraction > 5µ of recent sediments, to a large extent due to radium and its variant elements radon and radium, All of them are stated to be practically completely bound to zeolite minerals such as phillipsite (K- and Na-) (Arrhenius and Goldberg, 1955).

Acknowledgements

The authors sincerely thank Prof. Dr. H. İbrahim Sur (Black Sea Permanent Secretariat Executive Directorate) and ONHO (Turkish Naval Forces Office of Navigation, Hydrography and Oceanography) for their contributions during the sampling stage of the study. The authors also present their special thanks to Mr. Tuğrul Tüzüner (TPAO Research Center-Ankara) for SEM photography (Jeol JSM-5600).

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PLATES

Plate I

1. *Siphonaperta aspera* (d'Orbigny). Side view, Station B21, 30 m, Bosphorus,

2. *Quinqueloculina berthelotiana* d'Orbigny. Side view, Station H3, 10 m, Golden Horn,

3. *Quinqueloculina disparilis* d'Orbigny. Side view, Station B12, 67 m, Bosphorus,

4. *Quinqueloculina lamarckiana* d'Orbigny. Side view, Station B17, 67 m, Bosphorus,

5. *Quinqueloculina seminula* (Linne). a and b, side views, Station B12, 67 m, Bosphorus,

6. *Phyrgo elongata* (d'Orbigny). Side view, Station D15, 30 m, Dardanelles,

7. *Sigmoilinita costata* (Schlumberger). Side view, Station D9, 30 m, Dardanelles,

8. *Sigmoilopsis schlumbergeri* (Silvestri). Side view, Station D9, 30 m, Dardanelles,

9. *Amphicoryna scalaris* (Batsch). Side view, Station D9, 30 m, Dardanelles,

10. *Fissurina* sp. a and b, side views, Station D9, 30 m, Dardanelles,

11. *Brizalina alata* (Seguenza). Side view, Station B22, 30 m, Bosphorus,

12. *Brizalina spathulata* (Williamson). Side view, Station D5, 30 m, Dardanelles,

13. *Rectuvigerina phlegeri* le Calvez. Side view, Station D9, 30 m, Dardanelles,

14. *Bulimina elongata* d'Orbigny. Side view, Station D5, 10 m, Dardanelles,

15. *Globobulimina affinis* (d'Orbigny). Side view, Station D15, 30 m, Dardanelles,

16. *Reussella spinulosa* (Reuss). Side view, Station D5, 10 m, Dardanelles.

PLATE 1

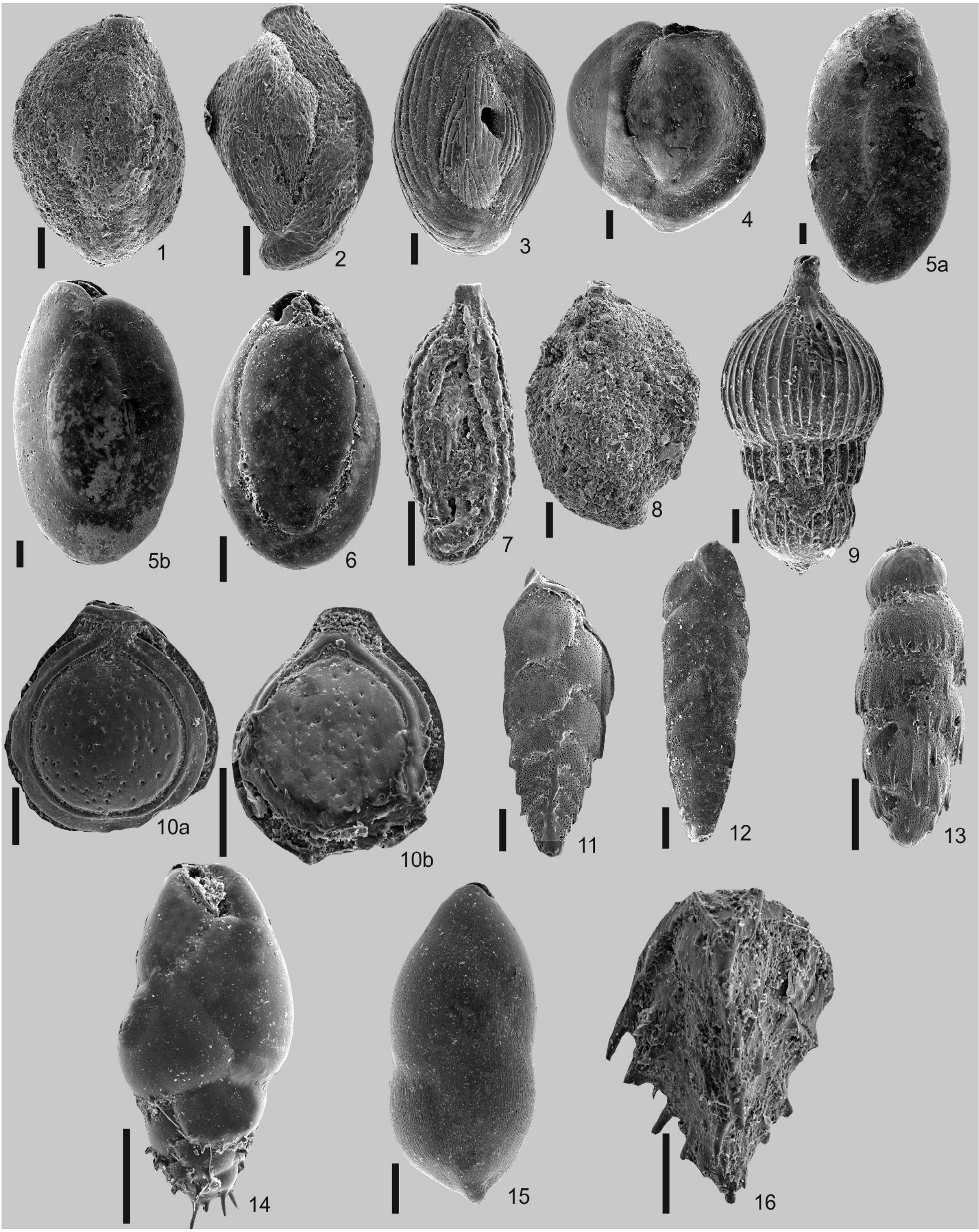

Plate II

1. *Rosalina bradyi* Cushman. Spiral side, Station D15, 30 m, Dardanelles,

2. *Lobatula lobatula* (Walker and Jacob). Spiral side, Station B22, 30 m, Bosphorus,

3. *Melonis pompilioides* (Fichtel and Moll). Side view, Station D1, 30 m, Dardanelles,

4. *Ammonia compacta* Hofker. Spiral side, Station D13, 30 m, Dardanelles,

5. *Cribroelphidium poeyanum* (d'Orbigny). Side view, Station B10, 30 m, Bosphorus,

6. *Elphidium complanatum* (d'Orbigny). Side view, Station D13, 30 m, Dardanelles,

7. *Elphidium crispum* (Linné). Side view, Station D13, 30 m, Dardanelles.

PLATE II