# BENTHIC COMMUNITY STRUCTURE CHARACTERIZATION OF THE BED-SEDIMENT LAYER COMPOSITION IN THE MUSURA BAY AND SAKHALIN AREA

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**Abstract.** The aim of this study was to assess the existing benthic organisms of the Musura Bay and Sakhalin area, in order to evaluate the habitat status within these areas. Musura Bay and Sakhalin Area belong to the avandelta, part of the Danube Delta Biosphere Reserve (DDBR). The ecological evolution of the Musura Bay and Sakhalin Area was significantly distressed by the hydro morphological changes developed in the catchment and by the local environmental circumstances. The two investigated areas are exposed to both continental and marine impacts, been marked by rapid changes in local environmental conditions (*i.e.,* salinity levels, water transparency, temperature, pH, dissolved oxygen concentration, wind speed etc.). At present, salinity has become an extensive threat to the structure and ecological functioning of coastal wetlands. For instance, salinity long-term monitoring showed a variation from 12 ‰ (in 1942) to 0.2 ‰ (at present) for Musura Bay, whereas for Sakhalin area the salinity is 6.9 ‰ (at present). In order to evaluate the interactions of benthic organisms and their natural environment, several analyses were performed (*i.e.,* water quality status and the nature of the bed sediments). Results revealed that the surface water quality is generally included in good-moderate category, even if some inadvertences were encountered as a result of local environmental conditions. Based on the obtained results, the nature of the bed sediments from Musura Bay and Sakhalin area, can be included in the terrigenous (siliciclastic) rich-sediment type with values higher than 50% of the total weight of dry residue. The faunistic research highlighted the presence of 17 taxa belonging to 11 major invertebrate taxonomic groups for the Musura Bay and the presence of 46 taxa belonging to 20 groups in the Sakhalin Area. The average general density of the benthic populations in the Musura Bay was 8 times smaller than in the Sakhalin Area. This study indicated that most of the identified species seem to be extremely tolerant to temperature and salinity variations.

**Key words:** Musura Bay, Sakhalin Area, brackish, marine, freshwater, benthic fauna

## 1. INTRODUCTION

The Predeltaic ecosystem is an important area where Danube Delta habitats and ecosystems have a gradual passage to the shelf located in front of the Danube's mouths.

Here, the currents regime, the intake of freshwaters rich in both nutrients and sediments, are conditioning the formation of a particular habitat. The fauna has a „mixed" character, encountering limnical species with wide euryhalinity limits, but also marine species that tolerate waters from the oligo- and meso-mixohaline register. Low salinity, characteristic of shallow waters, also allows the survival of Ponto-Caspian relicts, rare species, with a very limited distribution in the entire Pontic basin (Rudescu *et al.* 1965).

Systematic studies achieved in this contact area between Delta and the Black Sea began in the 1950's. Băcescu *et al*., 1967, as well as Gomoiu and Skolka, 1998, in a synthesis papers, conducted research on benthic and fish populations, planktonic communities, the results making the object of numerous scientific papers.

The predeltaic area is characterized by the Black Sea eutrophication, a consequence of constant nutrient discharges that stimulate the explosive development of unicellular algal populations (algal blooming), as well as macrophytes and benthic phanerogams.

The predeltaic benthos is characterized by associations that develop on sandy or mud bottoms, but also on a different substrate, "camcaua", made of vegetal detritus; this particular habitat is found in front of the mouths of the Sulina and Sf. Gheorghe arms, but also in the supralittoral zone.

Psammal or pelal associations of organisms from the predeltaic sector are dominated by mollusks, the qualitative palette being completed by the cirriped *Amphibalanus improvisus*, ostracodes, misids, cumaceans and isopods. The worm fauna is represented by nematodes, oligochaetes and iliophile polychaetes (Băcescu *et al.* 1967; Băcescu *et al.* 1971).

Eutrophication phenomena, aggravated in 1980, have changed the benthic population structure on the continental shelf of the predeltic area. Nowadays, the polychaetes *Melinna palmata* (an opportunistic species, that produces very numerous populations), *Hediste diversicolor*, the bivalves *Mytilus galloprovincialis* and *Modiolula phaseolina* and the tanaid *Apseudes ostroumovi* are prevailing. From a quantitative point of view, the same organisms are dominant, only *Apseudes ostroumovi* being replaced by the invasive north-Atlantic bivalve *Mya arenaria*, which, at the end of the last century, achieved 80% of the total biomass (Gomoiu and Skolka, 1996, 1998; Gomoiu *et al.* 2009).

The aim of this study is to investigate the existing benthic organisms of the Musura Bay and Sakhalin Area, in order to evaluate the habitat status within those areas.

## 2. MATERIALS AND METHODS

### 2.1. Study area

The Musura Bay (Panin and Overmars, 2012) located between Chilia (northern part) Arm and Sulina Arm (southern part) is a relatively recent geomorphological unit, crossed by the Romanian-Ukrainian border, with a very low, marshy coast. The evolutionary process of the Musura Bay has begun in the nineteenth century, through alluvial processes, between the delta of Chilia and Sulina branches (Moldoveanu *et al.*, 2014; Samargiu *et al.*, 2015; Sava *et al.*, 2015; Sava ad Samargiu, 2016) (Fig.1). The Musura Bay becomes less deep in the northern part due to sedimentary intake from the southern branches of the Chilia Delta, the Musura channel and the smaller tributaries. In 1943, an underwater dam was built in order to direct the flow of water and sediment of the tributaries of the Ukrainian Chilia to the south, the location of the sandy spit being influenced by it. The sandy spit has a very rapid evolution, extending by 200-300 m/year, at present the distance between the southern end of the spit and the dam located to the north of Sulina measures only a few hundred meters. The tributaries of the Ukrainian Chilia provide continually sedimentary material to the sandy spit, and the coastal sediment flow in the southern area influences Sulina's mouth, bringing sedimentary sand to the spit, along with those brought by Sulina Branch (Panin and Overmars 2012; Zinevici *et al.,* 2006; Coman and Sandu, 2009).

Sakhalin Island is located on the south of Sf. Gheorghe branch, with a shape and length that varies in time (Păunescu, 2012) (Fig.1). Is the only Black Sea island that totally belongs to Romania, which formed right to Sf. Gheorghe branch. Initially, it consisted of two smaller islands: „Big Sakhalin" and „Small Sakhalin", in time merging and forming a single island with an area of over 21000 hectares. The origin and evolution of the Sakhalin Island depend mainly on the Danube sediment input, as well as the erosion and accumulation processes (Keremedchiev and Valchev, 2009). In 2006, Sakhalin Island had a length of over 18 km, with a rate of lengthening of more than 200 m/year. At the same time, the island migrated to the west by over-washing the sediment over 30-70 m/year. The rectified meanders of Sf. Gheorghe led to an increase in sedimentary intake between 6-8%, so the coastal area became more stable, and the development of Sakhalin island became faster (Panin and Overmars, 2012). The study of Sakhalin morphology is important for the quality of the aquatic environment (*i.e.,* clean, brackish water habitats), essential for the survival of sturgeons and other endangered species during their juvenile period.

From the ecological point of view, these areas differ significantly in terms of hydrology, geomorphology, submerged vegetation coverage and benthic fauna.

For the Musura Bay, ecological research highlights the relatively rapid dynamics at the spatio-temporal level. The result of the ecosystem evolution consists of a gradual transition from the marine golf stage to a semi-closed freshwater lake (Moldoveanu *et al.*, 2014). The Sakhalin Area is localized between the Sakhalin Island and the delta itself and is characterized by a brackish regime.

### 2.2. Sample collection and processing

In August 2018, several environmental samples were collected to assess the conservation status of the habitats in Musura and Sakhalin areas, as follows: 18 water samples, 18 bed-sediment samples and 18 quantitative benthic fauna samples. For Musura Bay the samples identification code start from DD18-157 and DD18-162, whereas for Sakhalin area begin from DD18-168 to DD18-177 (Fig. 2).

#### *2.2.1. Water and sediment samples*

Water samples were characterized on-site for some selected physico-chemical water quality parameters using a WTW Multiline P4 Multiparameter portable meter. The samples were collected from the surface water layer (0.5-1m). Parameters that were measured on site were: the water temperature (T°C), water depth (m), transparency (m), DO content (mg/l) and saturation (%), EC level (µS/cm), TDS content (mg/l) and pH (units). After sampling, other parameters as the ORP level (mV), water turbidity (NTU), TSS content (mg/l), N-$NO_2^-$(mg/l), N-$NO_3^-$(mg/l), P-$PO_4^{3-}$ (mg/l), $SO_4^{2-}$(mg/l) concentrations, chlorophyll "a" (Chla)

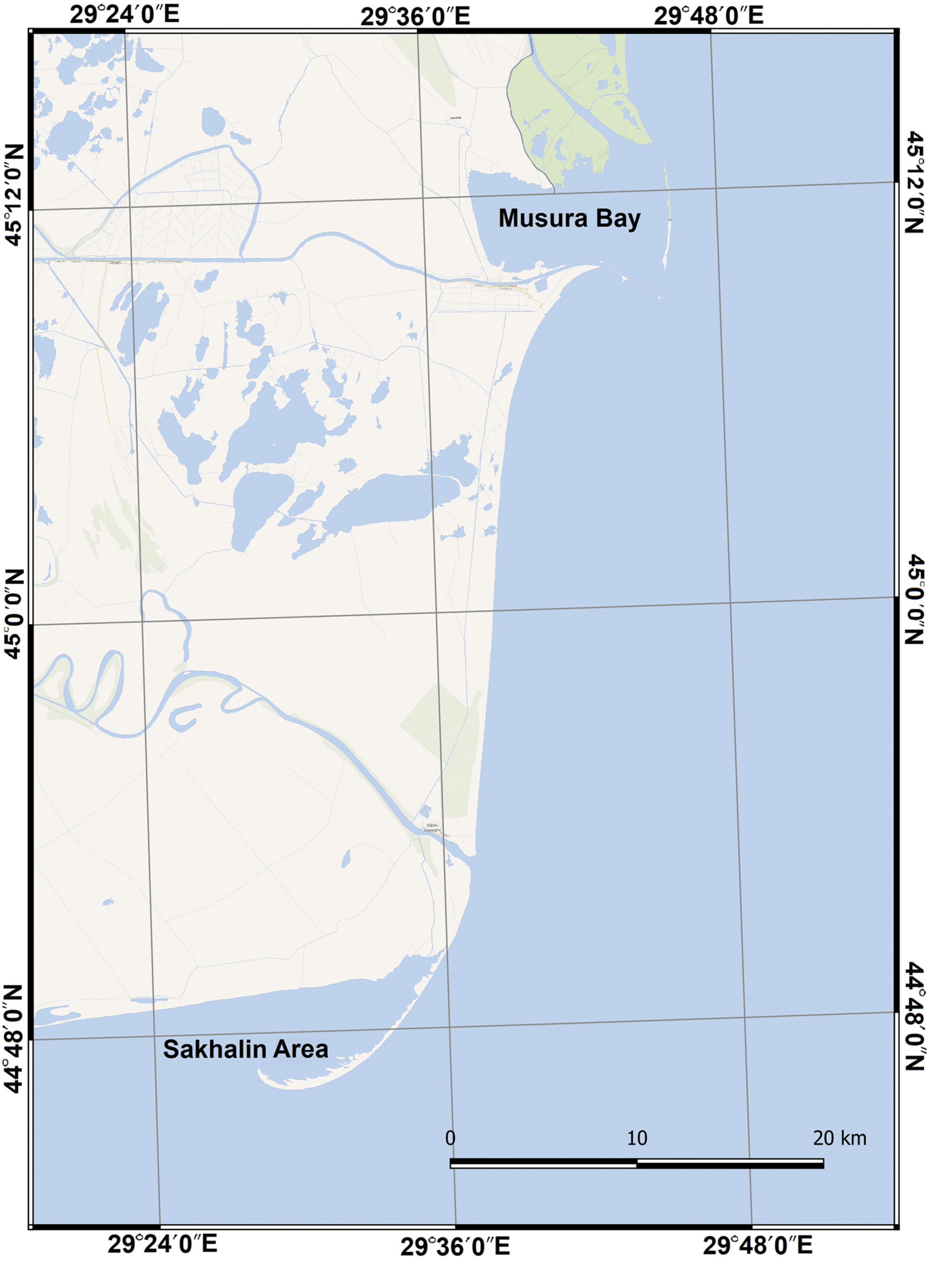


**Fig. 1.** Location of Musura Bay and Sakhalin Area

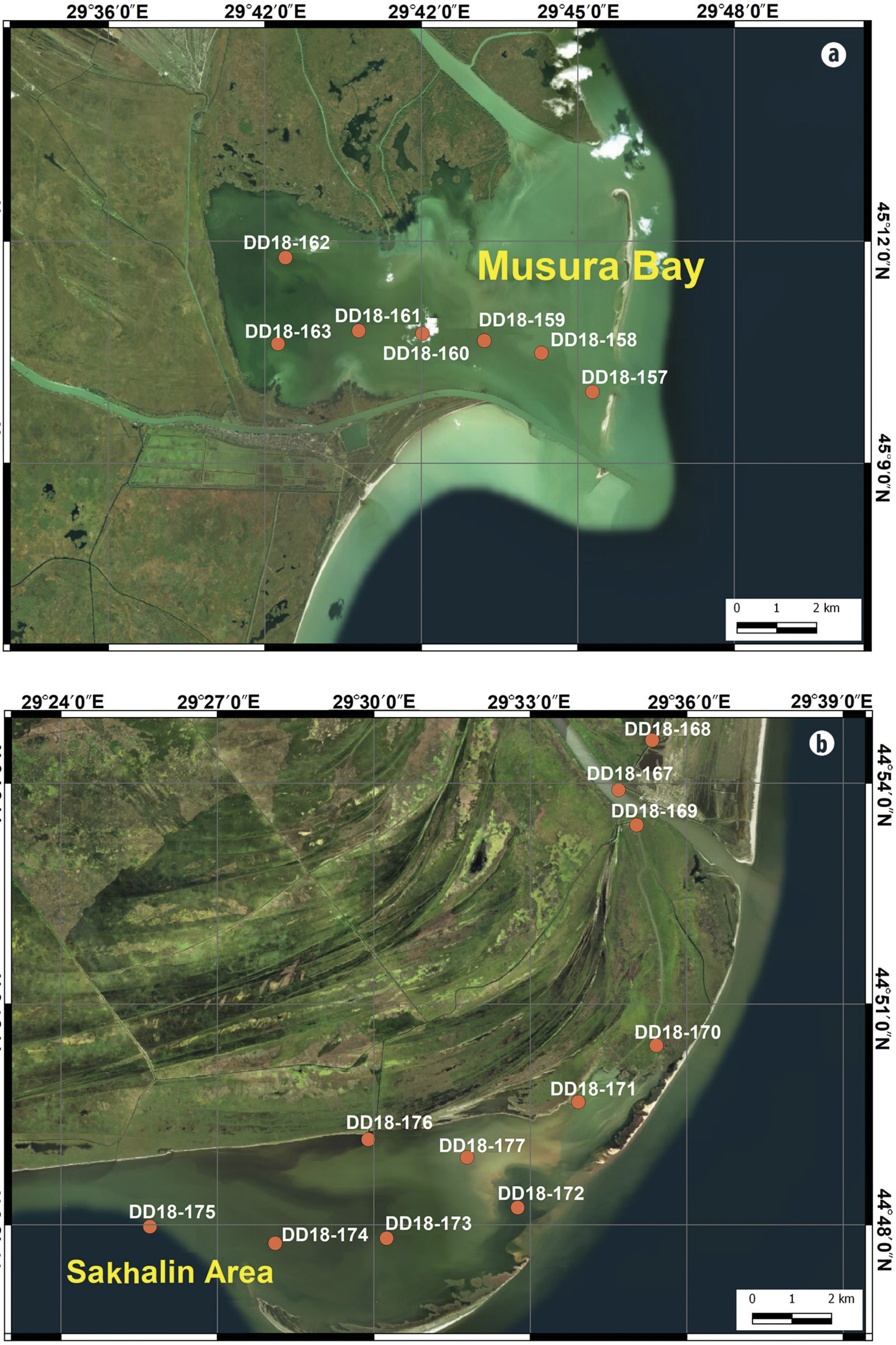


**Fig. 2.** Position of the sample points within the investigation perimeters: (**a**) Musura Bay and (**b**) Sakhalin Area

concentration (mg/l), and silica ($SiO_2$) content (mg/l) were analyzed aboard the RV "Istros", or in other specialized laboratories. The analyses were performed by means of specialized equipment as Hach 2100 P Turbidimeter, Portable Spectrophotometer HACH DR 5000 UV-Vis, DR 2000 and atomic absorption spectrophotometer (AAS).

Sediment samples were characterized for their physical parameters, including total organic matter content, total carbonate content and the percentage of silt-clay, using a standard test method for Weight-Loss on Ignition (LOI), using a calcination furnace SNOL 8.2/1100. Weight-Loss-on-ignition technique (LOI) is a common, widely-used method of approximating the total organic matter content, total carbonates and the percentage of silt-clay of sediment samples, following Dean (1974), Heiri *et al.* (2001) and Santisteban *et al.* (2004).

The total organic matter content (TOM %) and the minerogenic matter/mineral residue (the inorganic non-carbonate fraction) were obtained by calcination at 550°C (Dean, 1974), respectively at 950-1000°C (Digerfeldt *et al.*, 2000). The assessment of the carbonate content was done according to Loss On Ignition (LOI) Protocol (www.geog.cam.ac.uk/facilities/laboratories/.../loi.doc).

### *2.2.2. Benthic samples*

The sampling strategy, according to the SR EN ISO 10870:2012, took into consideration the heterogeneity of substrate, and employed the multihabitat technique (a modified version of AQEM method used for water bodies monitoring in Romania – SR EN ISO 16150: 2012). According to this technique, the habitat types and the proportion between them have been established. Subsequently, a fiche of habitats has been filled in. All habitats with a coverage of more than 5% have been noted and have been classified according to SR EN ISO 16150:2012. In 2018, the quantitative samples were collected by using a small Van Veen grab. The results (number of individuals) were expressed at unit surface (1 $m^2$), using a multiplication factor of 25.2 (SR EN ISO 10870:2012) (Table1).

On board of the small boat, the samples were washed through a limnological net with 125 µm mesh size in order to remove the excessive sediment particles and keep the fauna. A mixed solution of Rose Bengal and buffered formaldehyde 4% was used for fixation, staining and further preservation until subsequent analysis of benthic organisms in the laboratory. In laboratory, the samples were sorted, and the organisms were identified at the lowest taxonomical level possible using a Carl Zeiss SteREO Discovery V8 microscope and an Axiostar microscope. The taxonomic identification was done according to Godeanu (2002). All organisms within a sample have been counted. The sample processing and analysis were carried out according to the SR EN ISO 5661-1:2008.

**Table 1.** Distribution of habitats in stations in the Musura Bay and Sakhalin Area (SR EN ISO 16150:2012)

| Nr.crt. | Sampling station | GPS Coordinates | | Habitat |
|---|---|---|---|---|
| 1 | DD18-157 Musura Bay | 45°09'57.9" | 29°45'16.9" | Pelal |
| 2 | DD18-158 Musura Bay | 45°10'29.4" | 29°44'18.2" | Pelal |
| 3 | DD18-159 Musura Bay | 45°10'39.4" | 29°43'12.5" | Psammopelal |
| 4 | DD18-160 Musura Bay | 45°10'45.0" | 29°42'01.3" | Psammopelal |
| 5 | DD18-161 Musura Bay | 45°10'47.4" | 29°40'48.0" | Pelal |
| 6 | DD18-162 Musura Bay | 45°11'46.7" | 29°39'23.7" | Pelal |
| 7 | DD18-163 Musura Bay | 45°10'36.9" | 29°39'15.1" | Pelal |
| 8 | DD18-167 Sf. Gheorghe's Arm- Tătaru Channel Entrance | 44°53'54.4" | 29°34'41.6" | Psammal |
| 9 | DD18-168 Tătaru Channel | 44°54'35.0" | 29°35'20.3" | Pelal |
| 10 | DD18-169 Tureţchi Stream | 44°53'25.9" | 29°35'02.4" | Pelal |
| 11 | DD18-170 Turcească Stream | 44°50'26.3" | 29°35'25.1" | Psammal |
| 12 | DD18-171 Sakhalin Area | 44°49'40.2" | 29°33'55.3" | Pelal |
| 13 | DD18-172 Sakhalin Area | 44°48'14.0" | 29°32'45.5" | Psammal |
| 14 | DD18-173 Sakhalin Area | 44°47'49.0" | 29°30'14.7" | Pelal |
| 15 | DD18-174 Sakhalin Area | 44°47'44.9" | 29°28'06.5" | Pelal |
| 16 | DD18-175 Sakhalin Area | 44°47'58.5" | 29°25'42.4" | Pelal |
| 17 | DD18-176 Sakhalin Area | 44°49'09.6" | 29°29'53.6" | Psammal |
| 18 | DD18-177 Sakhalin Area | 44°48'55.0" | 29°31'47.3" | Psammopelal |

### *2.2.3. Statistical Analysis*

All statistical tests were performed using Past v. 3 (Hammer *et al.*, 2001) and PRIMER 7 with PERMANOVA + add-on software package, (Clarke and Gorley, 2006; Anderson *et al.,* 2008). Also, the zoobenthic ecological indices like Abundance – A/m$^2$, Dominance – D%, Occurrence number– Noc, Frequency – F%, Average density - Davg ex.m$^{-2}$, Ecological density - Deco ex.m$^{-2}$, Ecological significance index – W were calculated and averaged for each species/group.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Physico-chemical water quality parameters

Generally, the results of the water quality parameter measured in this study showed that the values of the environmental indicators are included within the limits set by the regulations in force and were fairly consistent from a spatial point of view. The evaluation of the water quality was related to the national surface water quality standard classes stated in Order 161/2006, as well as in accordance with other national/international reference standards. Exceptions to the imposed limits will be discussed further on.

Water temperatures were all above 20°C ranging from 26.6°C to 27.2°C in Musura Bay, and, respectively, from 25.7°C to 27.4°C in Sakhalin area, reflecting the climatic conditions of the areas.

The results of the pH measurement showed that the investigated waters were placed near neutral to slightly alkaline conditions, ranging from 7.63 to 8.7 in Musura Bay, and, respectively, from 7.44 to 8.73 in the Sakhalin area. The pH values, from 6.5 to 8.2, generally obtained in this investigation are optimal for most aquatic organisms (Chapman, 1996).

Dissolved-oxygen (DO) concentrations were found to range between 7.53 and 10.72 mg/l in Musura Bay, and, respectively, from 5.76 to 9.26 mg/l in Sakhalin area. The DO concentrations were generally higher during the dry season (August 2018). The obtained values are consistent with the minimum concentration of 5 mg/l of dissolved oxygen that is the minimum amount that will support a large, diverse aquatic organism communities (www.niwa.co.nz).

Nitrite-nitrogen ($N\text{-}NO_2^-$) concentrations investigated within this study were generally within provisions established for Class I of water quality (0.01 mg/l). The same situation is also valid for the nitrate-nitrogen ($N\text{-}NO_3^-$) levels whose values were within acceptable limits established for Class I of water quality (1 mg/l), as suggested by the national reference standard (Order 161/2006). As well, the orthophosphate ($P\text{-}PO_4^{3-}$) levels at all sites were below limits settled for Class I of water quality (0.1 mg/l). The concentrations of chlorophyll-a (Chla) were lower at both investigated aquatic systems, not exceeding the limits settled for Class I of water quality (25 µg/l). The silica level tested within this study was below the range of natural water variation (5-25 mg/l), (Wetzel 2001).

Electrical conductivity (EC) varied greatly among the sampling sites, ranging from 385 to 4000 µS/cm in Musura Bay, and, respectively, from 4000 to 17580 µS/cm in Sakhalin area, reflecting the influence of salt water intrusions from the Black Sea. The total dissolved solids (TDS) ranged from 193 to 2000 mg/l in Musura Bay, and, respectively, from 2000 to 8790 µS/cm in Sakhalin area, which has fallen within the appropriate range suitable for saltwater aquatic domain (1000 - 30000 mg/l TDS) (EPA Method). Sulphate levels ($SO_4^{2-}$) were generally in conformity to the limits settled for Class I of water quality (60 mg/l), but elevated levels of $SO_4^{2-}$ which are characteristic for Class II of water quality (120 mg/l) were noticed in the few samples collected from Sakhalin area. The EC, TDS and $SO_4^{2-}$ results reported in this study are relatively analogous with the outcomes previously reported by Dimitriu *et al.* (2008) in an investigation carried out in a similar brackish water environment.

The results of the turbidity (NTU) values showed that the investigated waters ranged from 7.72 to 42 NTU in Musura Bay, and, respectively, from 6.1 to 76.1 NTU in Sakhalin area. The results were compared to a national standard which stipulated limit of turbidity in drinking water is 5-10 NTU (STAS 6323-88). The higher values observed in the Sakhalin area could be linked to local environmental conditions (river sediment influxes, wind currents and waves).

Total suspended solids (TSS) varied among the sampling sites, ranging from 14 to 53 mg/l in Musura Bay, and, respectively, from 10 to 40 mg/l in the Sakhalin area. These TSS results were compared to the recommendations of the ANZECC Guidelines (2000) that recommended a permissible level of suspended solids of <40 mg/l as acceptable levels of TSS in freshwater, as well as <10 mg/l as acceptable levels of TSS in the marine environment. The highest values of TSS noticed in the Sakhalin area may be related to the constant re-suspension of the settled solids.

The Oxido-Reduction Potential (ORP) levels tested within this study ranged from -9 to +11 mV in Musura Bay, and, respectively, from -72 to +28 mV in the Sakhalin area.The results fall within the ORP range of natural waters (-500 + 700 mV), (Chapman, 1996; Sigg, 2000).

For Musura Bay, research conducted by Moldoveanu *et al.*, 2014 showed a progressively decreasing of salinity value (1942-12‰; 2005-0.18‰) Current analysis highlighted a lower salinity (0.2 ‰). For Sakhalin area, the average salinity is 4.6 ‰, with the highest value recorded in DD18-175 (10 ‰) and the lowest in DD18-171 (0.81 ‰). These large variations of salinity are due to its geographic position and mixing of the flow of Danube freshwater and Black Sea water.

### 3.2. Physico-chemical parameters of sediments

The nature of the collected bed-sediments (sediment type, organic matter content, benthic infauna) in relation to other relevant water and sediment data were used in combination to analyze and describe the soft-bottom benthic habitats of the Musura Bay and Sakhalin area.

The main lithological components of the bed-sediments, as the total organic matter (TOM%), total carbonates (CAR%) and siliciclastic/minerogenic material (SIL%) showed significant variations among investigated sites.

The sediment samples showed a relatively narrow variability of the total organic matter (TOM%) ranging from 12.42 to 39.22% in Musura Bay, and, respectively, from 1.34 to 44.90% in the Sakhalin area. The LOI at 550ºC, which is a proxy for total organic matter content, was relatively low in the sediments of the study areas, with values below 50% of the total weight of dry residue.

The carbonate analysis indicated that the sediment samples displayed a relatively restricted variability of CAR (%) contents, ranging from 10.52 to 13.81% in the Musura Bay, and, respectively, from 6.17 to 14.10% in the Sakhalin area. The LOI at 950ºC, which is a proxy for total carbonate content, was relatively high in the sediments of the study areas, with values above 1% of the total weight of dry residue.

The percentage of siliciclastic material (SIL%), which is a proxy parameter for the silt and clay contents of sediments, usually of detrital origin, ranged from 46.97 to 74.86% in Musura Bay, and, respectively, from 48.93 to 86.75% in the Sakhalin area (mostly with values above 50% of the total weight of dry residue).

A general assessment of the bed sediment composition of these aquatic systems was performed, based on the organic matter, carbonates and minerogenic fraction content, calculated from the total weight of the dry residue. Based on the obtained results, the nature of the bed sediments from Musura Bay and Sakhalin area can be included in the terrigenous (siliciclastic) rich-sediment type with values higher than 50% of the total weight of dry residue. The obtained results within this study are comparable to those previously obtained in the Danube Delta Biosphere Reserve zones with similar environmental conditions (Rădan and Rădan, 2009, 2010, 2011; Catianis *et al.* 2016, 2018). The morphology of the two basins depends on the river waters and particularly on the sediment intake, and also on the marine factors, especially the waves power and sea currents. Also, the distribution of benthic organisms, both marine and freshwater, in the two analyzed areas, is directly influenced by the sedimentary input of terrigenous origin, but also by hydromorphological and anthropogenic changes.

### 3.3. Macrozoobenthic assemblages

In the Musura Bay, there is a gradual passage from the psammopelal habitat type to the pelal one. The presence of psammopelal habitats (in stations DD18-158 and DD18-159), is explained by the accumulation processes of marine sediments transported by the marine currents. These habitats represent about 20%, compared to the pelal habitat who is occupying 80% from the analyzed area, being characterized by muddy sediments, containing organic matter and numerous plant remains, generally derived from the vegetal associations of shore areas (reed, rush, floating reed).

The Sakhalin Area, is characterized by a mosaic of benthic habitats, shore areas (pelal habitats - DD18-168, DD18-169, DD18-171, DD18-173, DD18-174, DD18-175) alternating with sandy areas (psammal type habitats - DD18-167; DD18-172; DD18-176). These habitats intertwine, forming transition areas with mixed sediments, generating the psammopelal habitats (DD18-170, DD18-177).

The faunistic research performed in the studied sectors revealed the presence of 17 invertebrate taxa belonging to 11 major taxonomic groups (Oligochaeta, Polychaeta, Bivalvia, Ostracoda, Amphypoda, Misida, Isopoda, Trichoptera, Chironomidae, Heteroptera, Ceratopogonidae) for Musura Bay and 46 taxa belonging to 20 major taxonomic groups (Oligochaeta, Polychaeta, Turbellaria, Hirudinea, Gastropoda, Bivalvia, Ostracoda, Amphypoda, Isopoda, Misida, Cumacea, Decapoda, Trichoptera, Zygoptera, Ephemeroptera, Lepidoptera, Chironomidae, Heteroptera, Ceratopogonidae, Chaoboridae) for Sakhalin Area (Tables 2 and 3).

Several research conducted by Băcescu *et al.* (1971), Gomoiu and Skolka (1996, 1998) and others, revealed a mixed diversity of predeltaic benthos. Thus, it can be remarked a benthos characterized by gastropods dominated by necrophage species – *Tritia reticulata* (Linnaeus, 1758), *Tritia neritea* (Linnaeus, 1758), *Tritia pellucida* (Risso, 1826). Crustaceans such as amphipods, especially *Pontogammarus maeoticus* (Sovinskij, 1894) – leading species in fine sands biocoenosis from the northern part of the coastline. *Pontogammarus maeoticus* (Sovinskij, 1894) and many other species – *Obesogammarus crassus* (Sars, 1894), *Obesogammarus obesus* (Sars, 1894), *Thalorchestia* sp. constitutes food for a series of fish. The qualitative palette is completed by *Amphibalanus improvisus* (Darwin, 1854), ostracods – *Hiltermannicythere rubra pontica* (Dubowsky, 1939), *Callistocythere diffusa* (Ruggieri, 1953), *Palmoconcha granulata* (Sars, 1866), *Cyprideis torosa* (Jones, 1850), mysids – *Mesopodopsis slabberi* (Czerniavsky, 1882), *Pseudoparamysis pontica* (Bacescu, 1940), *Paramysis (Longidentia) kroyeri* (Daneliya, 2004), Cumacea – *Iphinoe maeotica* (Bate, 1856), *Cumella pygmaea euxinica* (Sars, 1865), *Cumopsis goodsir* (Van Beneden, 1861), *Eudorella truncatula* (Norman, 1867), isopods – *Jaera sarsi* (Valkanov, 1936), *Idotea balthica* (Pallas, 1772), *Stenosoma capito* (Rathke, 1837) and *Apseudes ostroumovi* (Bacescu and Carausu, 1947) from tanaids (only from the

**Table 2.** General characterization of benthic populations from Musura Bay in August 2018

| Crt. number | Species | A /m² | D % | Noc | F% | Davg | Deco | W |
|---|---|---|---|---|---|---|---|---|
| 1 | Oligochaeta | 5210.4 | 24.69 | 4 | 66.67 | 868.4 | 1302.6 | 40.57 |
| 2 | *Streblospio shrubsolii* | 655.2 | 3.10 | 1 | 16.67 | 109.2 | 655.2 | 7.19 |
| 3 | *Alitta succinea* | 993.6 | 4.71 | 3 | 50 | 165.6 | 331.2 | 15.34 |
| 4 | *Hediste diversicolor* | 236.8 | 1.12 | 1 | 16.67 | 39.47 | 236.8 | 4.32 |
| 5 | *Fabricia* sp | 7.4 | 0.04 | 1 | 16.67 | 1.23 | 7.4 | 0.76 |
| 6 | *Corbicula fluminea* juv. | 1265.4 | 6.00 | 1 | 16.67 | 210.9 | 1265.4 | 10.00 |
| 7 | *Cyprideis torosa* | 1814.4 | 8.60 | 3 | 50 | 302.4 | 604.8 | 20.73 |
| 8 | Gammaridae | 821.4 | 3.89 | 1 | 16.67 | 136.9 | 821.4 | 8.05 |
| 9 | Corophiidae | 8904 | 42.19 | 2 | 33.33 | 1484 | 4452 | 37.50 |
| 10 | Misida | 37 | 0.18 | 1 | 16.67 | 6.17 | 37 | 1.71 |
| 11 | *Jaera sarsi* | 44.4 | 0.21 | 1 | 16.67 | 7.4 | 44.4 | 1.87 |
| 12 | Polycentropodidae larvae | 74 | 0.35 | 1 | 16.67 | 12.33 | 74 | 2.42 |
| 13 | *Hydropsiche* sp. larvae | 488.4 | 2.31 | 1 | 16.67 | 81.4 | 488.4 | 6.21 |
| 14 | Chironomidae larvae | 352.8 | 1.67 | 4 | 66.67 | 58.8 | 88.2 | 10.56 |
| 15 | Chironomidae pupae | 75.6 | 0.36 | 1 | 16.67 | 12.6 | 75.6 | 2.44 |
| 16 | Heteroptera larvae | 22.2 | 0.11 | 1 | 16.67 | 3.7 | 22.2 | 1.32 |
| 17 | *Bezzia* sp. | 100.8 | 0.48 | 1 | 16.67 | 16.8 | 100.8 | 2.82 |

(Abundance – A/m², Dominance – D%, Occurence number – Noc, Frequency – F%, Average density – Davg ex.m$^{-2}$, Ecological density – Deco ex.m$^{-2}$, The ecological significance index – W)

**Table 3.** General characterization of benthic populations from Sakhalin Area in August 2018

| Crt. number | Species | A /m² | D % | Noc | F% | Davg | Deco | W |
|---|---|---|---|---|---|---|---|---|
| 1 | *Dugesia tigrina* | 203.6 | 0.11 | 2 | 15.38 | 15.66 | 101.8 | 1.31 |
| 2 | Oligochaeta | 27914.62 | 15.29 | 12 | 92.31 | 2147.28 | 2326.22 | 37.57 |
| 3 | *Stylaria lacustris* | 2142 | 1.17 | 1 | 7.69 | 164.77 | 2142 | 3.00 |
| 4 | *Hypania invalida* | 83 | 0.05 | 4 | 30.77 | 6.38 | 20.75 | 1.18 |
| 5 | *Streblospio shrubsolii* | 44729.29 | 24.50 | 6 | 46.15 | 3440.71 | 7454.88 | 33.63 |
| 6 | *Polydora* sp. | 882 | 0.48 | 2 | 15.38 | 67.85 | 441 | 2.73 |
| 7 | *Alitta succinea* | 4324 | 2.37 | 6 | 46.15 | 332.62 | 720.67 | 10.46 |
| 8 | *Manayunkia caspica* | 151.2 | 0.08 | 1 | 7.69 | 11.63 | 151.2 | 0.80 |
| 9 | *Amphibalanus improvisus* | 1372.8 | 0.75 | 5 | 38.46 | 105.6 | 274.56 | 5.38 |
| 10 | *Fabricia* sp. | 100.8 | 0.06 | 1 | 7.69 | 7.75 | 100.8 | 0.65 |
| 11 | *Helobdella* sp. | 50.4 | 0.03 | 1 | 7.69 | 3.88 | 50.4 | 0.46 |
| 12 | *Corbicula fluminea* juv. | 348.2 | 0.19 | 5 | 38.46 | 26.78 | 69.64 | 2.71 |
| 13 | *Anodonta cygnea* | 7.4 | 0.00 | 1 | 7.69 | 0.57 | 7.4 | 0.18 |
| 14 | *Mya arenaria* | 1008 | 0.55 | 1 | 7.69 | 77.54 | 1008 | 2.06 |
| 15 | *Anadara kagoshimensis* | 126 | 0.07 | 2 | 15.38 | 9.69 | 63 | 1.03 |
| 16 | *Cerastoderma glaucum* | 201.6 | 0.11 | 1 | 7.69 | 15.51 | 201.6 | 0.92 |
| 17 | *Lentidium mediteraneum* | 6375.6 | 3.49 | 1 | 7.69 | 490.43 | 6375.6 | 5.18 |
| 18 | *Abra alba* | 3024 | 1.66 | 1 | 7.69 | 232.62 | 3024 | 3.57 |

Table 3 (continued)

| Crt. number | Species | A /m² | D % | Noc | F% | Davg | Deco | W |
|---|---|---|---|---|---|---|---|---|
| 19 | *Dreissena polymorpha* | 252 | 0.14 | 2 | 15.38 | 19.38 | 126 | 1.46 |
| 20 | *Litoglyphus naticoides* | 25.2 | 0.01 | 1 | 7.69 | 1.94 | 25.2 | 0.33 |
| 21 | *Radix* sp. juv. | 42.2 | 0.02 | 2 | 15.38 | 3.25 | 21.1 | 0.60 |
| 22 | *Planorbis planorbis* juv. | 2 | 0.00 | 1 | 7.69 | 0.15 | 2 | 0.09 |
| 23 | *Theodoxus danubialis* | 1 | 0.00 | 1 | 7.69 | 0.08 | 1 | 0.06 |
| 24 | *Cypridopsis vidua* | 9 | 0.00 | 1 | 7.69 | 0.69 | 9 | 0.19 |
| 25 | *Cyprideis torosa* | 3175.2 | 1.74 | 2 | 15.38 | 244.25 | 1587.6 | 5.17 |
| 26 | *Limnocythere inopinata* | 1166.4 | 0.64 | 2 | 15.38 | 89.72 | 583.2 | 3.14 |
| 27 | *Ilyocypris* sp. | 44.4 | 0.02 | 1 | 7.69 | 3.42 | 44.4 | 0.43 |
| 28 | Gammaridae | 2515 | 1.38 | 7 | 53.85 | 193.46 | 359.2857 | 8.61 |
| 29 | Corophiidae | 69993.72 | 38.34 | 7 | 53.85 | 5384.13 | 9999.103 | 45.44 |
| 30 | Misida | 126 | 0.07 | 2 | 15.38 | 9.69 | 63 | 1.03 |
| 31 | *Jaera sarsi* | 327.6 | 0.18 | 1 | 7.69 | 25.2 | 327.6 | 1.17 |
| 32 | *Schizorhynchus eudorelloides* | 201.6 | 0.11 | 1 | 7.69 | 15.51 | 201.6 | 0.92 |
| 33 | *Rhithropanopeus harrisii* | 98.6 | 0.05 | 4 | 30.77 | 7.58 | 24.65 | 1.29 |
| 34 | Baetidae larvae | 53.2 | 0.03 | 2 | 15.38 | 4.09 | 26.6 | 0.67 |
| 35 | Caenidae larvae | 4 | 0.00 | 1 | 7.69 | 0.31 | 4 | 0.13 |
| 36 | Polycentropodidae larvae | 1995.4 | 1.09 | 4 | 30.77 | 153.49 | 498.85 | 5.80 |
| 37 | Hydroptilidae larvae | 11 | 0.01 | 2 | 15.38 | 0.85 | 5.5 | 0.30 |
| 38 | *Hydropsiche* sp. larvae | 1668.2 | 0.91 | 3 | 23.08 | 128.32 | 556.0667 | 4.59 |
| 39 | Zygoptera larvae | 60 | 0.03 | 2 | 15.38 | 4.62 | 30 | 0.71 |
| 40 | Chironomidae larvae | 7393.8 | 4.05 | 7 | 53.85 | 568.75 | 1056.257 | 14.77 |
| 41 | Chironomidae pupae | 213.2 | 0.12 | 3 | 23.08 | 16.4 | 71.06667 | 1.64 |
| 42 | Lepidoptera larvae | 29 | 0.02 | 2 | 15.38 | 2.231 | 14.5 | 0.49 |
| 43 | *Corixa dentipes* | 8 | 0.00 | 1 | 7.69 | 0.615 | 8 | 0.18 |
| 44 | Heteroptera larve | 26.8 | 0.01 | 2 | 15.38 | 2.062 | 13.4 | 0.48 |
| 45 | *Bezzia* sp. larvae | 50.4 | 0.03 | 1 | 7.69 | 3.877 | 50.4 | 0.46 |
| 46 | *Chaoborus* sp. larvae | 25.2 | 0.01 | 1 | 7.69 | 1.938 | 25.2 | 0.33 |

(Abundance – A/m², Dominance – D%, Occurence number – Noc, Frequency – F%, Average density - Davg ex.m$^{-2}$, Ecological density - Deco ex.m$^{-2}$, The ecological significance index - W)

deep bottoms). From the decapod crustaceans, *Crangon crangon* (Linnaeus, 1758) was very common, forming massive agglomerations, while *Uppogebia pusilla* (Petagna, 1792), in the past years, was richer in specimens, nowadays very rarely encountered, being also mentioned *Liocarcinus holsatus* (Fabricius, 1798) and *Diogenes pugilator* (Roux, 1829). Worm fauna was represented by nematodes *Enoplus quadridentatus* (Berlin, 1853) with very high densities, oligochaetes (species of Tubifex genus), iliophile polichaetes *Melinna palmata* (Grube, 1870), *Nephthys hombergii* (Savigny in Lamarck, 1818), *Terrebelides stroemi* (Sars, 1835), *Alitta succinea* (Leuckart, 1847), *Harmothoe reticulata* (Claparède, 1870), *Spio filicornis* (Müller, 1776), *Lagis koreni* (Malmgren, 1866).

In the present, the molluscs are represented by a small number of species, the most frequent being *Corbicula fluminea* (Müller, 1774) in the Musura Bay, and many species (fresh and marine) like *Corbicula fluminea* juv., *Anodonta cygnea* (Linnaeus, 1758), *Mya arenaria* (Linnaeus, 1758), *Anadara kagoshimensis* (Tokunaga, 1906), *Cerastoderma glaucum* (Bruguière, 1789), *Lentidium mediteraneum* (Costa, 1830), *Abra alba* (Wood, 1802), *Dreissena polymorpha* (Pallas, 1771), *Litoglyphus naticoides* (Pfeiffer, 1828), *Radix* sp. juv, *Planorbis planorbis* juv. (Linnaeus, 1758), *Theodoxus danubialis* (Pfeiffer, 1828) for Sakhalin Area, respectively.

Crustaceans are represented by species belonging to important groups such as Corophiids, Gammarids, Ostracods, Mysids, and one species of Isopods – *Jaera sarsi* (Valkanov, 1936), for Musura Bay. In Sakhalin Area, the crustaceans are represented by more groups, beside the mentioned ones, like the cumacean *Schizorhynchus eudorelloides* (Sars, 1894) and the decapod *Rhithropanopeus harrisii* (Gould, 1841)

In those two areas, the corophiids are the most numerous with an abundance of 69993,72 ex.m$^{-2}$ for Sakhalin Area and 8904 ex.m$^{-2}$ for Musura Bay.

The ostracods are represented by few species that reached very low abundances in Sakhalin Area *Cypridopsis vidua* (Müller, 1776)*, Cyprideis torosa* (Jones 1850)*, Limnocythere inopinata* (Baird, 1843)*, Ilyocypris* sp. (Brady and Norman, 1889), but with high frequency like *Cyprideis torosa* (Jones, 1850) in Musura Bay.

The worms are represented by three groups: Turbellaria, Oligochaeta and Polychaeta. Also, it is remarkable the presence of marine Polychaeta species in both areas. Those species are extremely tolerant to high salinity and temperature variations such as *Alitta succinea* (Kinberg, 1865)*, Hediste diversicolor* (Müller, 1776)*, Fabricia* sp, (Müller, 1774), *Streblospio shrubsolii* (Webster, 1879)*, Polydora sp* (Bosc, 1802) *and Manayunkia capsica* (Leidy, 1859). Besides, was reported the presence of freshwater polychaete, *Hypania invalida* (Grube, 1960), a Ponto-Caspian relict.

The most important representatives of the Insecta Group were Chironomidae and Trichoptera larvae, and seldom Ephemeroptera, Odonata (Zygoptera), Lepidoptera, Heteroptera and Nematocera. Out of the Trichoptera, species from Hydropsychidae, Polycentropodidae and Hydroptilidae families have been reported. The Ephemeroptera larvae are represented by the Caenidae and Baetidae. The insects belonging to the Ceratopogonidae group are dominated by Bezzia (Kieffer, 1899) species, Heteroptera by *Corixa dentipes* (Thomson, 1869) and the Nematocera group is dominated by the species belonging to *Chaoborus* genus.

Studies carried out in 1995 on benthic organisms in the predeltaic area (Musura Bay and Sakhalin Area) showed values of benthic density of 29,000 ex.m$^{-2}$, (worms 43,6%, molluscs 0,014%, crustaceans 22,37%, foraminiferans - 32%) (Gomoiu and Skolka, 1998), Our data show a total density of 3517.3 ex.m$^{-2}$ (crustaceans 55%, worms 34%, insect larvae 5%, molluscs 6%) in the Musura Bay and 14043.28 ex.m$^{-2}$ (crustaceans 43%, worms 44%, insect larvae 7%, molluscs 6%) for the Sakhalin Area, much lower than in 1995.

Comparing the data from the previous years to those made in August 2018, it can be remarked a decreasing trend of benthic organisms in the analyzed areas, both qualitatively and quantitatively, as well as a change in the composition of the marine/freshwater species ratio, this fact being explained by the hydromorphological changes occurring in these two basins.

The greatest abundances are found within DD18-156 station in Musura Bay and in DD18-172, DD18-174, DD18-175 of Sakhalin Area. This can be related to the presence of both marine and freshwater organisms.

For Musura Bay, the highest occurrence frequency in samples is adjudicated by 4 taxons (Chironomidae larvae, Oligochaeta, the polychaete *Alitta succinea* and the ostracod *Cyprideis torosa*), while, for Sakhalin, is assumed by 4 taxons (Oligochaeta, Chironomidae larvae, Corophiidae, Gammaridae).

The similarity index Bray – Curtis, based on the presence/absence transformed abundance data of benthic species within stations, displayed against the association index of species, showed that the euconstant taxa were Oligochaeta, Corophiidae and Chironomida for both studied areas. (Figs. 3, 4).

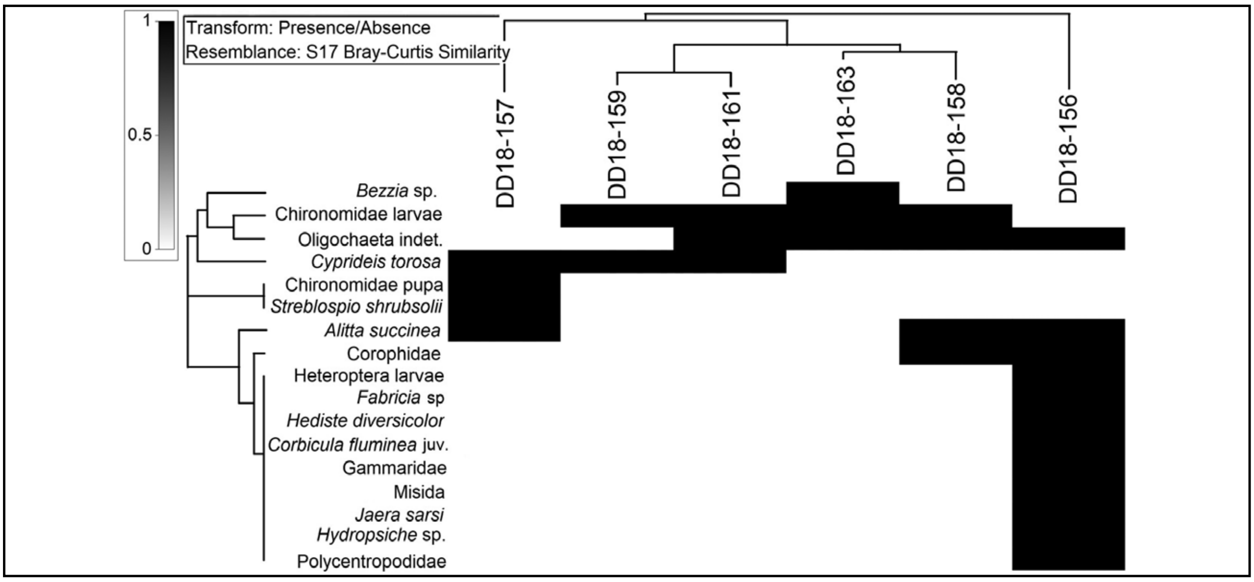


**Fig. 3.** The index of association between macrobenthic species (vertical) and the Bray-Curtis similarity (presence / absence data transformation) between stations (horizontal), for Musura Bay

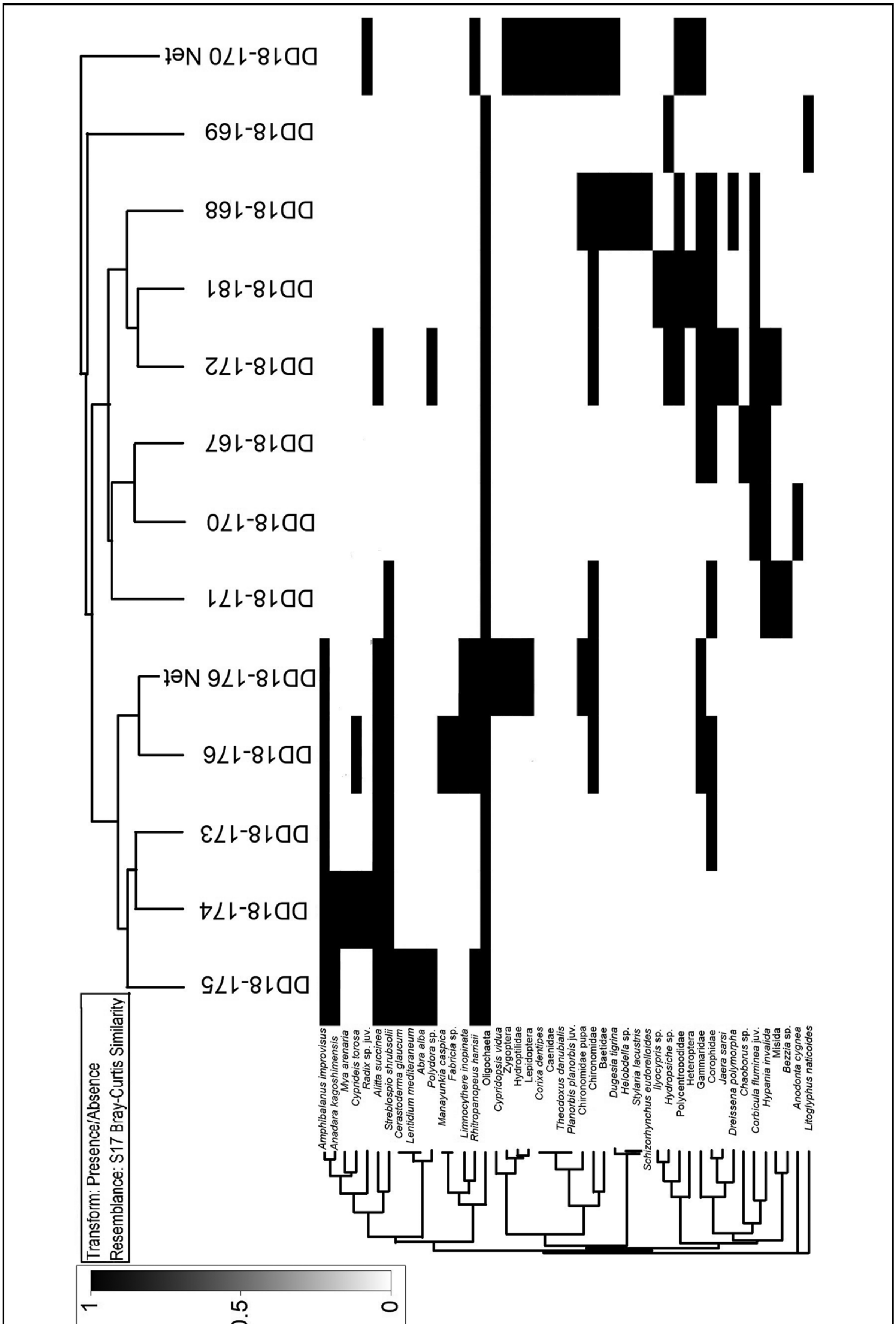


**Fig. 4.** The index of association between macrobenthic species (vertical) and the Bray-Curtis similarity (presence / absence data transformation) between stations (horizontal), for Sakhalin Area

From the total of 17 identified taxa, for Musura Bay, only 5 species are more abundant, constituting over 80% of the overall average density: species of genus Corophium, Oligochaeta, the ostracod *Cyprideis torosa,* the bivalve *Corbicula fluminea* and the polychaete *Alitta succinea*. In Sakhalin Area, from the total of 46 identified taxa, only 5 species are more abundant, making over 80% of the overall average density: *Corophium* species, the polichaete *Streblospio shrubsolii*, Oligochaeta, Chironomidae and the bivalve *Lentidium mediterraneum* (Fig. 5).

In direct correlation with the relatively low salinity, for Musura, the transition into a freshwater environment can also be reflected by the taxonomic composition. Thus, it can be noticed the presence of typical marine Polychaeta species (*Streblospio shrubsolii, Alitta succinea, Hediste diversicolor, Fabricia* sp.), but the abundance of these taxa, as well as the frequency of occurrence in samples being quite low compared to the brackish and freshwater invertebrate benthic species.

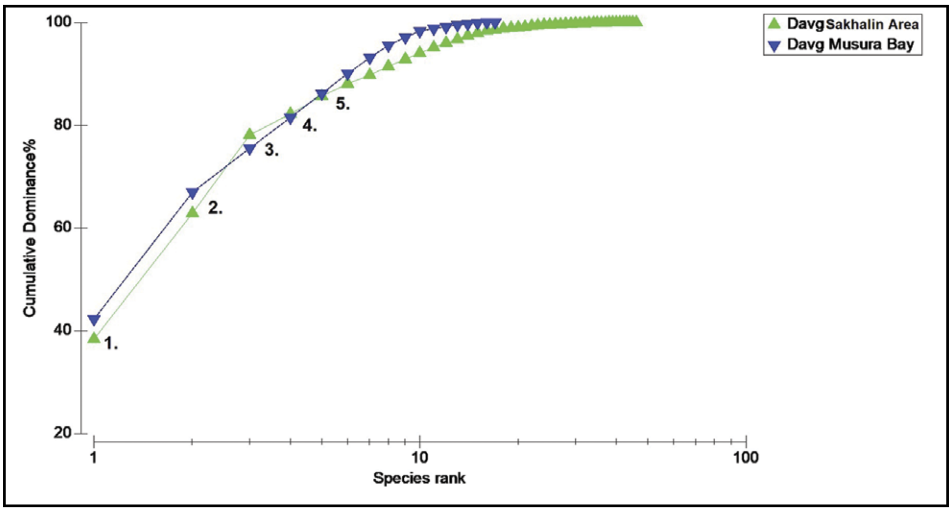


**Fig. 5.** The cumulative curve of the average density of benthic populations from Musura Bay and Sakhalin Area

In Sakhalin area, during the present study, although it was not recorded a constant salinity in the whole basin, it can be stated that it fits into the mixohaline water regime. Therefore, it highlights the presence of certain marine bivalve species, which tolerate wide salinity variations (*Anadara kagoshimensis, Cerastoderma glaucum, Lentidium mediterraneum, Mya arenaria*), as well as other typical marine species (*Polydora* sp.*, Alitta succinea, Streblospio shrubsolii, Amphibalanus improvisus*). Studies carried out in previous years (Mack-Fira, 1974) show that salinity in this area was much lower (varying between 1.5 and 3‰) compared to average salinity recorded in August 2018 (4.6 ‰), underlining the basin tendency to turn into a marine lagoon (Figs. 6a, b).

The most sensitive diversity parameters of the benthic communities which respond to the hydrogeomorphological changes are given by intra and interspecific diversity, taxonomical composition and marine/freshwater species ratio (Samargiu *et al.,* 2015).

## 4. CONCLUSIONS

The results of the complementary analyzes (*i.e.,* water quality status and the nature of the bed sediments), performed within this study in order to evaluate the interactions of benthic organisms and their natural environment, reveal that the water and sediments of Musura Bay and Sakhalin Area maintain appropriate levels that are suitable for the ecological status of the investigated aquatic systems. Generally, with an exception of a few locations, the physico-chemical water quality parameters remained within the range of natural water chemistry. The exceptions are related to local environmental conditions. The impact of marine influence on some physico-chemical parameters was also established.

The analyzes conducted in August 2018 showed that the general average density of the benthic populations in Musura Bay was 8 times lower than in Sakhalin Area. For both analyzed areas, the highest occurrence in the samples is attributed to Oligochaeta, Chironomidae larvae and Corophiidae. A particular importance is the presence of typical marine species (*Allita succinea, Hediste diversicolor, Streblospio shrubsolii, Fabricia* sp. - for Musura, and *Lentidium mediterraneum, Mya arenaria, Anadara kagoshimensis, Cerastoderma glaucum, Abra alba, Amphibalanus improvisus, Rithopanopeus harrisii* - for Sakhalin Area), most identified taxa from these areas being extremely tolerant to wide salinity and temperature variations. Moreover, the presence of both freshwater and brackish fauna (Musura Bay and Sakhalin Area) is attributed, primarily, to the mixing of the Danube freshwater and Black Sea water.

The morphology of the two basins depends on the river waters and particularly on the sediment intake, and also on the marine factors, especially the waves power and

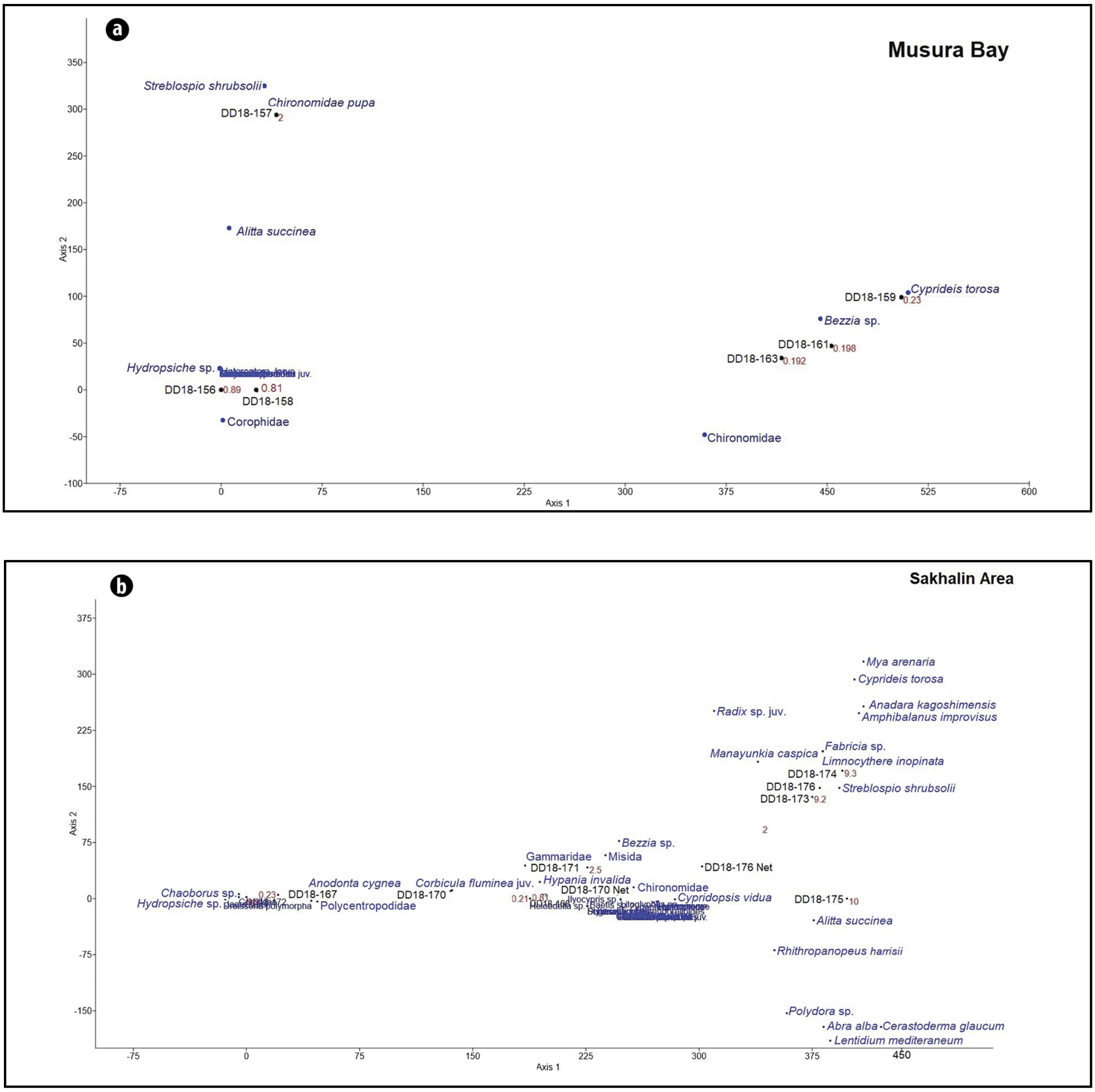


**Fig. 6.** Distribution of zoobenthic fauna in correlation with salinity gradients in the stations from the Musura Bay (**a**) and Sakhalin Area (**b**) (dentrended correspondence analysis)

sea currents. Also, the distribution of benthic organisms, both marine and freshwater, in the two analyzed areas, is directly influenced by the sedimentary input of terrigenous origin, but also by hydromorphological and anthropogenic changes.

According to the studies conducted by Panin and Overmars( 2012) and Stănică *et al.* (2013), it can be noticed an evolution that consists of a gradual transition from the marine golf stage to a continental lake with many freshwater particularities for Musura Bay, in reverse to Sakhalin's tendency in becoming a lagoon with marine features. Our results from the research conducted in August 2018 bring new evidence about the current situation in the two basins.

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