DELIVERABLE D3.2

# Results of the problem based science analysis

3.2.4) The Vistula Lagoon, Poland-Russia

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Integrated water resources and coastal zone management in European lagoons in the context of climate change

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# 1. Introduction

## 1.1 General description of the Vistula lagoon

The Vistula lagoon is situated at the southern coast of the Baltic Sea. The state border between the Kaliningrad region (Russia) and Poland divides the lagoon into two parts (Figure 1). The size of the lagoon (area of 838 $km^2$, length of 91 km, width from 2 to 11 km and water volume of 2.3 $km^3$) makes it the second largest lagoon in the Southern Baltic. The lagoon is separated from the open sea by a stable sand barrier. At the Polish part it is called the Vistula Spit, whereas its extension on the Russian side is named the Baltiyskaya Kosa. The above mentioned sand barrier, covered by pine forest, has a length of 55 km and a width of 0.5-2 km. The only connection with the sea is the Baltiysk Strait. The inlet length, width and depth are 2 km, 400 m and 10-12 m, respectively.

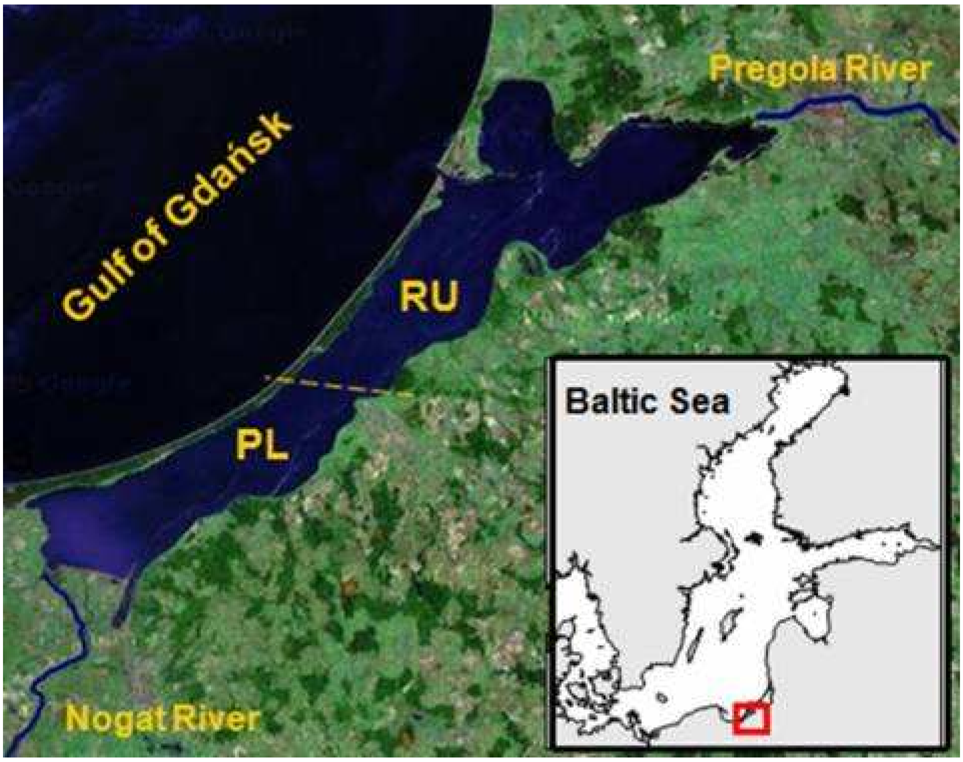



**Figure 1. Geographic location of the Vistula Lagoon**

The lagoon is a relatively shallow water body with a maximum natural depth of 5.2 m and an average depth of 2.7 m.

Marine water inflow accounts for 17 $km^3a^{-1}$ (Lazarenko and Majewski 1971) and predominate the rivers runoff. The largest rivers in the lagoon catchment are Pregolia river with 1.53 $km^3$ $a^{-1}$ runoff (41% of total river runoff), Nogat (0.66 $km^3$ $a^{-1}$) and Pasłęka (0.5 $km^3$ a-$^1$). The catchment area covers almost 24,000 $km^2$ (Silicz 1975) of which 61% belongs to Poland and 39% to Russia (Figure 2).


**Figure 2. The drainage basin of the Vistula Lagoon**

Arable lands constitute 64% and 50.5% of the Polish and Russian parts of the drainage basin, respectively. Forests cover 18.3% of the drainage basin in Poland and 11.6% in Russia (Przedrzymirska 2003). The largest cities in the region are Kaliningrad (430,000 inhabitants) and Elbląg (130,000 inhabitants).

The recent hydrological regime is the result of an artificial cutting off the discharge of the Vistula River to the lagoon in 1916. Since this time the hydrological and sedimentation regimes have changed and the lagoon evolved from a freshwater toward an estuarine water body with an average salinity of ca. 3.5 PSU.

With respect to salinity the Vistula Lagoon is considered a transitional area. The salinity changes both seasonally and spatially. The highest salinity, reaching 6.5 PSU, is observed in the vicinity of the Baltiysk inlet, whereas the lowest, i.e. almost zero, near the Pregolia and Nogat river mouths.

The temperature of water vary from -0.2°C to 25-26°C. The highest temperature occurs usually at end of July or at the beginning of August. The ice cover in the coldest years maintains from December until March.

## 1.2 The Vistula Lagoon natural values

Coastal lagoons are very vulnerable to human land use and overuse of the coastal zone for recreational purposes (Munsterhjelm 2005).

The Habitats Directive mentions coastal lagoons as a European natural habitat type in danger of disappearance and calls for special conservation (Anon. 2007). Two protected areas have been established in the region of the Vistula Lagoon within the framework of Natura 2000 Networking Programme. The first of the aforementioned is a Special Protected Area for birds. This area is part of one of the most important bird migration routes in Europe, being thereby an Important Bird Area of European importance. At least 27 species of birds from Annex 1 of the Wild Birds Directive were noted here, and furthermore, at least 9 species from the Polish Red Data Book of Animals. During the breeding season the following birds can be encountered: red-crested pochard, common shelduck, grey heron and sea eagle. Moreover, the Vistula lagoon serves as home for the largest breeding population of the cormorant in Poland, constituting 50% of the whole country’s population. It is furthermore the only permanent wintering ground of Canada goose (up to 1,300 birds).

A Special Area of Conservation (SAC) have been established in the area of the Vistula Lagoon, the Vistula Spit and a narrow strip of land adjacent to the southern shores of the Lagoon within the framework of Natura 2000. The area encompasses a lot of important European natural habitats including three water habitats:

1150 - coastal lagoons - a priority natural habitat type;

1130 - estuaries;

3150 - natural eutrophic lakes with Magnopotamion or Hydrocharition - type vegetation

In the area of SAC, 36 important European species listed in Annex 2 of the Habitats Directive and in Annex 1 of the Wild Birds Directive are encountered, including 13 marine bird species and six fish species.

Apart from the areas of SPA and SAC, there are also conservation areas established by the national law (e.g. nature reserves and landscape parks) in the region of the Vistula Lagoon (Figure 3).

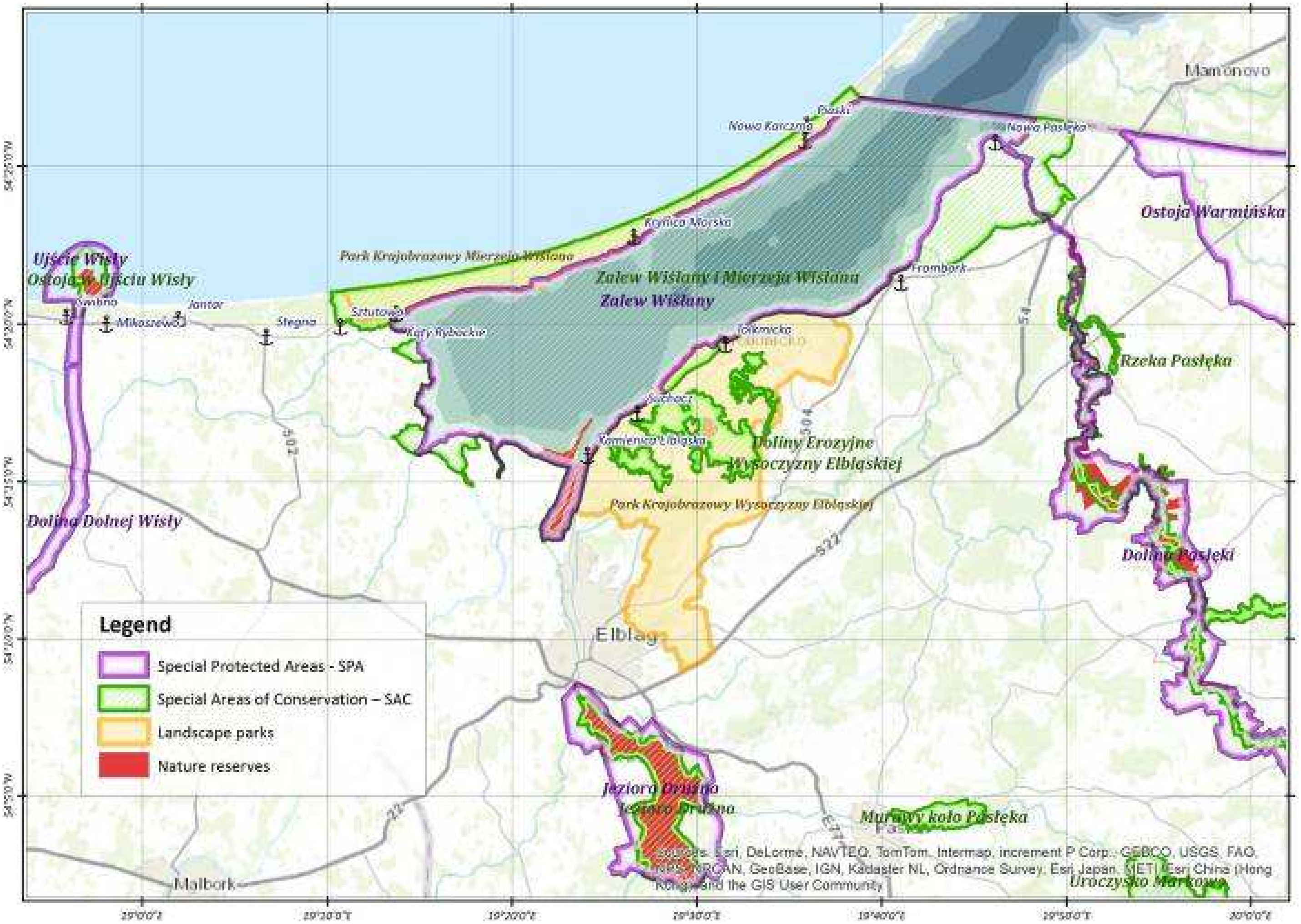



Figure 3. The areas of nature protection in the Vistula Lagoon region

Due to its productivity, the Vistula Lagoon provides favourable conditions for many fish species. Observations of the Vistula Lagoon confirmed that this basin supports over forty fish species of various ecotypes. The dominant freshwater species are accompanied by fewer brackish water species and some of marine species (Borowski 2000). Six species (river lamprey, *Lampetra fluviatilis*: sea lamprey, *Petromyzon marinus*; twaite shad, *Alosa fallax*; amur bitterling, *Rhodeus sericeus*; spined loach, *Cobitis taenia*; and sichel, *Pelecus cultratus*) have been included in Annex 2 of the Habitats Directive. The lagoon provides spawning grounds for typical marine species, such as herring, *Clupea harengus*, as well as different freshwater species, including pikeperch, *Stizostedion lucioperca*; bream, *Abramis brama*; roach, *Rutilus rutilus*; and perch, *Perca fluviatilis*.

## 1.3 Environmental changes in the Vistula Lagoon over last 100 years

Two major changes have occurred in environmental conditions of the Vistula Lagoon over last 100 years and both have been caused by human impact: changes in hydrological regime and in the trophy of the water body.

### 1.3.1 Changes in hydrological regime

At the beginning of the 20$^{th}$ century, the lagoon was nearly a freshwater basin supplied with fresh water by two main rivers: the Vistula and Pregolya. The Vistula River regulation and changing its course at the beginning of the 20$^{th}$ century as a result of frequent flooding have considerably modified the hydrological regime of the lagoon. Consequently, the inflow of the Vistula water to the lagoon had decreased from about 8-9 km$^3$ to 0.7 km$^3$ (Łazarenko and Majewski 1971). These changes have contributed to the increase in salinity and thus significantly affected the flora and fauna inhabiting this water basin (Pliński 2005).

### 1.3.2 Changes in the trophy of the Vistula Lagoon

The Vistula Lagoon due to its small depth, limited water exchange and relatively high population density of the catchment area is prone to eutrophication. The intensive development of agriculture and industry, as well as population growth in the drainage basin of the Vistula Lagoon after World War 2 have resulted in a rapid increase in the supply of nutrients to the Vistula Lagoon and thereby in eutrophication dating back to the 1960s.

The process of accelerated eutrophication which started at the beginning of 1960s is reflected in high primary production (ca. 300 and 180 g C m$^{-2}$ a$^{-1}$ in Polish and Russian part, respectively) (Renk 2001 et al. 2001, Aleksandrov 2004) and frequent cyanobacteria blooms (Andrulewicz et. al 1994). Furthermore, the high primary production together with resuspension result in very low water transparency (tens of centimetres) for the major part of the lagoon. Consequently, the range of submerged vegetation is limited. According to Pliński (Pliński 1995), between mid-seventies and

1990s a significant decrease of vegetation covering the bottom at the Polish part of the lagoon was noted. The depletion of areas where higher vegetation occurred is very disadvantageous for fish that use these plants as a spawning substrate or as a fry nursery area.

Due to eutrophication, an increased demand for oxygen necessary for decomposition of organic matter leads to periodic oxygen shortages in the near-bottom water layers. The decomposition of organic matter processes is observed which may cause periodic oxygen deficits at the bottom.

Despite the considerable progress as regards the construction of sewage treatment plants in last years of the previous century and the decrease in the supply of nutrients from point and diffuse sources, the nutrient concentrations in the lagoon waters noted between 1998 and 2000, remained at similar levels as those observed in the 1970s. Similarly, no considerable changes in the water transparency measured with Secchi disc or the chlorophyll content in the lagoon waters between 1970s and 1998-2000 (Witek et al. 2010) were reported. It may result from the constant internal supply – an influx of nutrients accumulated in bottom sediments to the water column. The recent trophic status of the Lagoon is polytrophic/eutrophic (Chubarenko and Margoński 2008).

# 2. Benthic flora and fauna of the Vistula Lagoon

## 2.1 Macrophytobenthos

There are 22 macrophyte taxa in the Vistula Lagoon, among which 18 belong to submerged water plants (elodeids), 2 to free-floating water plants (pleustophytes), 5 to water plants with floating leaves (nympheids) and 4 to emergent plants (helophytes) (Gajewski ed. 2010, Rothmaler et al. 1976).

*Elodeids, pleustophytes and nympheids*

The submerged plants and the ones with floating leaves cover the largest areas of the bottom in the western part of the Vistula Lagoon and in a nature reserve Elbląg Bay. Their communities are much less developed in the central and eastern part of the Vistula Lagoon, where they usually assemble in the vicinity of the emergent plants communities. The elodeids and nympheids do not occur in the northern part of the Vistula Lagoon. The total area of the bottom covered by the submerged plants and plants with floating leaves is about 28.882 $km^2$, which corresponds to 9.54% of the Polish area of the Lagoon.

The clear dominant among elodeids are *Potamogeton* species. Their frequency in elodeid patches reaches up to 89%. They occur in vast areas as multi-species patches in the western part of the Lagoon and include *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Zannichellia palustris* and Charales. They grow throughout the vegetative period, some of them also overwinter as vegetative shoots. It is noteworthy that the rare and endangered in Poland *Potamogeton rutilus* (Rothmaler et al. 1976), as well as resistant to fluctuations in water level *Chara globularis* were found.

The elodeid meadows are not that abundant in other areas of the water body and are mainly created by *Potamogeton pectinatus* and *P. perfoliatus* (Figure 4 and Figure 5) which are resistant to waves. They usually occur in patches of tens of square metres, directly by the belt of the emergent plants, at a depth of about 1 m. Due to eutrophication and development of periphyton, the macrophytes in the form of above-ground shoots grow for a relatively short time - from May to September.

In the western part of the Lagoon, apart from *Potamogeton*, often but not numerously occur algae from genus *Cladophora* and *Enteromorpha* with 45% frequency in habitats occupied by macrophytes.

Among pleustophytes, in the coastal zone of the Lagoon only one rare species *Salvinia natans* can be occasionally encountered. Nonetheless, it does not build permanent populations here.

Nympheid communities (*Nuphar lutea*, *Nymphoides peltata*) in the main basin of the Lagoon are poorly developed and are encountered only at the mouth of the Szkarpawa River.


**Figure 4. Single-species pond-weed meadows of *Potamogeton pectinatus* (left) and *P. perfoliatus* (right) in the Vistula Lagoon, about 4 km west from Tolkmicko. August 2010 (Photo: R. Kornijów)**

**Figure 5. Single-species patches of *Potamogeton pectinatus* at the mouth of Pasłęka River. October 2011 (Photo: R. Kornijów)**

In comparison to the Vistula Lagoon, the vegetation in Elbląg Bay is entirely different (Figure 6). Its bottom is almost completely covered by underwater elodeid meadows (mainly *Potamogeton* sp., *Ceratophyllum demersum* and *Myriophyllum spicatum*) and extensive patches of pleustophytes (*Salvinia natans*, *Lemna minor*) and nympheids, among which the species that does not occur in other parts of the Lagoon (*Ranunculus* sp.,

*Nymphea alba)* or are rare country-wide (*Nymphoides peltata* i halofilny *Ranunculus baudotii*) can be encountered.

**Figure 6. Multi-species macrophyte communities in the southern part of Elbląg Bay. July 2012 (Photo: K. Banaś)**

*Helophyte*

The emergent water plants occur at a major part of the Polish coastal zone of the Vistula Lagoon (Pliński 2005, Chubarenko, Margoński 2008, Gajewski 2010). Their abundance is low and includes only four species (*Phragmites australis, Scirpus lacutrsis Acorus calamus* and *Typha angustifolia*). Common reed (*Phragmites australis*) is the most common one (76% of frequency) and often forms single-species dense and extensive patches (Figure 7). Its mean abundance in the southern part of the Lagoon is about 120 shoots/$m^2$. *Scirpus lacustris* (27% of frequency) occurs in clusters between the reed belt and open-water surface, usually at a river mouth (Nogat, Szkarpawa, Wisła Królewiecka), as well as along the south-eastern coast, between Elbląg Bay and Frombork town. *Acorus calamus* (15% of frequency) and *Typha angustifolia* (9% of frequency) are relatively rare.

**Figure 7. Single-species extensive patches of helophytes created by *Phragmites australis;* south-western part of the Lagoon in the vicinity of Cieplice (left), about 2 km west from Frombork (right). October 2011 (Photo: R. Kornijów)**

The total area occupied by helophytes is about 6.5 km$^2$, which corresponds to 2.1% of the Polish area of the Lagoon. The largest patches and the most diversified in terms of species are localized by the western and south-western coast of the Vistula Lagoon.

Helophyte do not occur in the north-eastern part of the Vistula Lagoon along the section from Krynica Morska to the country border, by a high cliff coast.

Low abundance of reed beds by the south-eastern coast of the Vistula Lagoon - along the section from the country border to Frombork results most probably from a local practice of cutting down (mowing) reeds during winter.

All of the aforementioned species representing the emergent plants occur in Elbląg Bay. The common reed dominates here, other species are of accessory importance and are often encountered among the multi-species communities of submerged water plants and water plants with floating leaves.

The above description indicates that the vegetation is typical of a highly eutrophic water body. The emergent water plants, strongly developed along almost the entire coast of the Polish part of the Lagoon, are dominant here. The submerged water plants and water plants with floating leaves are abundant only at the river mouths and in Elbląg Bay. They encompass species that have already extinct in most parts of the Lagoon.

## 2.2 Macrozoobenthos

There are two main characteristic features of the Vistula Lagoon macrozoobenthos: the domination of euryhaline organisms of marine and freshwater origin and the important role of the non-native species.

A quite detailed description of the benthic fauna structure and its changes over last 100 years based on the publications published in years 1928 - 2004 are presented in the LAGOONS Deliverable D2.1a http://lagoons.web.ua.pt/wp-content/uploads/ downloads/ 2012/11/LAGOONS_Report_Vistula.pdf

## 2.3 Characteristics of the benthic fauna of the Polish part of the Vistula Lagoon in 2008-2011

### 2.3.1 Littoral zone

The littoral studies were a pilot project and limited to one location only. Nevertheless, they enabled to confirm the dependence of the qualitative and quantitative composition of macrozoobenthos on the development of macrophytic communities. The subfamily of Tubificinae (Figure 8) and psammofilous insects larvae of Chironomidae (Figure 9) were most abundant in typical psammolittoral.

**Figure 8. Representative of the family Tubificidae**

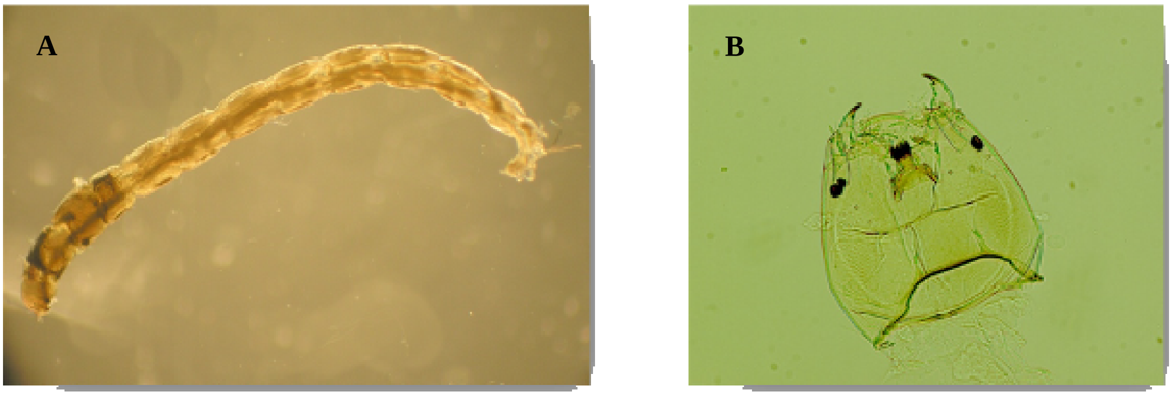



**Figure 9. Larvae of Chironomidae (A); head capsule of a chironomid from subfamily *Pelopinae* (B)**

As regards the biomass, the most dominant was an invasive polychaeta from genus Marenzelleria.

Numerous Tubificidae and larval Chironomidae, as well as abundant crustaceans (*Asellus aquaticus*, *Dikerogammarus* sp, *Gammarus tigrinus*) and clams (*Dreissena polymorpha*) occur in phytolittoral with a bottom covered by emergent and submerged macrophytes.

### 2.3.2 Sublittoral zone

Macrozoobenthos samples were collected in summer at almost 50 sampling stations which were distributed so as to best reflect the variability of environmental conditions (depth, salinity, sediment type) (Figure 10).

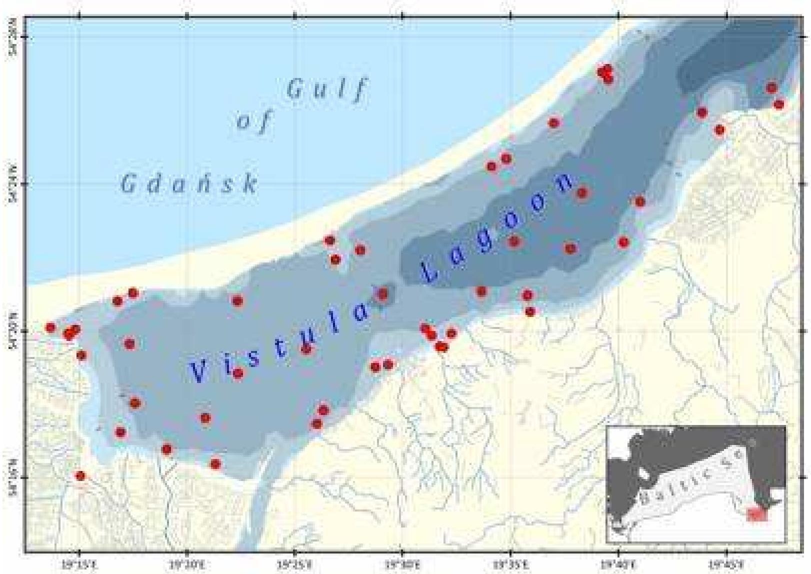



**Figure 10. Location of benthic sampling points between years 2008-2011**

At each station three samples were taken with Haps corer (sampling area 0.023 m$^2$).

### 2.3.2.1 Taxonomic composition, abundance and biomass of the main taxa

The occurence of 26 taxonomic groups was noted in the study area. Five alien species (*Dreissena polymorpha*, *Marenzelleria spp*, *Rangia cuneata*, *Rhitropanopeus harrisii* and *Gammarus tigrinus*) were found among them. *Marenzelleria spp.*, *Oligochaeta* nd. and *Chironomus semireductus* were the most common taxa in the study area (Table 1). The most diversified group were insect larvae form family Chrronomidae (15 taxa belonging to three subfamilies).

**Table 1. List of macrofauna taxa found in the samples taken in the sublittoral area and their frequency (the percentage of stations that have a given taxon)**

| Higher taxonomic level | Taxon | Frequency [%] |
|---|---|---|
| **Nemertea** | *Prostoma obscurum* | 13 |
| **Polychaeta** | *Bocardiella ligerica* | 4 |
| | *Marenzelleria spp.* | 88 |
| **Oligochaeta** | Oligochaeta nd. | 98 |
| **Bivalvia** | *Dreissena polymorpha* | 13 |
| | *Rangia cuneata* | 42 |
| **Gastropoda** | *Hydrobiidae nd* | 6 |
| **Amphipoda** | *Gammarus sp.* | 21 |
| | *Gammarus tigrinus* | 6 |
| | *Dikerogammarus sp.* | 4 |
| **Decapoda** | *Rhitropanopeus harrisii* | 2 |
| **Insect larvae** | *Chironomus f.l. semireductus* | 85 |
| | *Cladotanytarsus gr. mancus* | 4 |
| | *Cryptochironomus gr. defectus* | 15 |
| | *Dicrotendipes gr. nervosus* | 8 |
| | *Endochironomus sp.* | 4 |
| | *Microchironomus sp.* | 8 |
| | *Glyptotendipes gr. gripekoveni* | 21 |
| | *Polypedilum gr. nubeculosum* | 13 |
| | *Polypedilum gr. scalaenum* | 2 |
| | *Orthocladiinae nd* | 17 |
| | *Cricotopus gr. sylvestris* | 6 |
| | *Procladius sp.* | 17 |
| | *Endochironomus gr. albipennis* | 4 |
| | *Paratanytarsus sp.* | 2 |
| | *Tanypodinae nd* | 2 |

The clear dominants, as regards both abundance and biomass were *Marenzelleria* spp., *Chironomidae* and *Oligochaeta* nd.

The distribution of abundance and biomass of the dominant species is presented in figures 11-14.

*Chironomidae* larvae, *Marenzelleria neglecta* and *Oligochaeta* were noted in the whole study area. *Chironomidae* and *Oligochaeta* did not indicate definite preferences for the bottom type or depth, whereas *Marenzelleria neglecta* preferred a shallow and sandy bottom, creating concentrations of over 6,000 individuals and 400 g of wet wight. *Prostoma obscurum*, a species belonging to phylum Nemertea, was encountered only in the coastal zone and was not noted in the western part of the Lagoon.

Lower abundance in deeper areas of the lagoon in places with muddy bottom may be related to seasonal oxygen deficits at the bottom. High content of organic matter in the sediment, which results inter alia from eutrophication, is associated with high intensity of degradation processes. The combination of high temperature and a lack of wind mixing might entail the deterioration of oxygen conditions or even temporary anoxia. The research performed between years 2008-2013 in the south-western part of the Polish zone confirmed the occurrence of major, following a few hours, changes of oxygen content in the near-bottom water, which finally resulted in dissolved oxygen content decrease below 1ml/l or even anoxia.

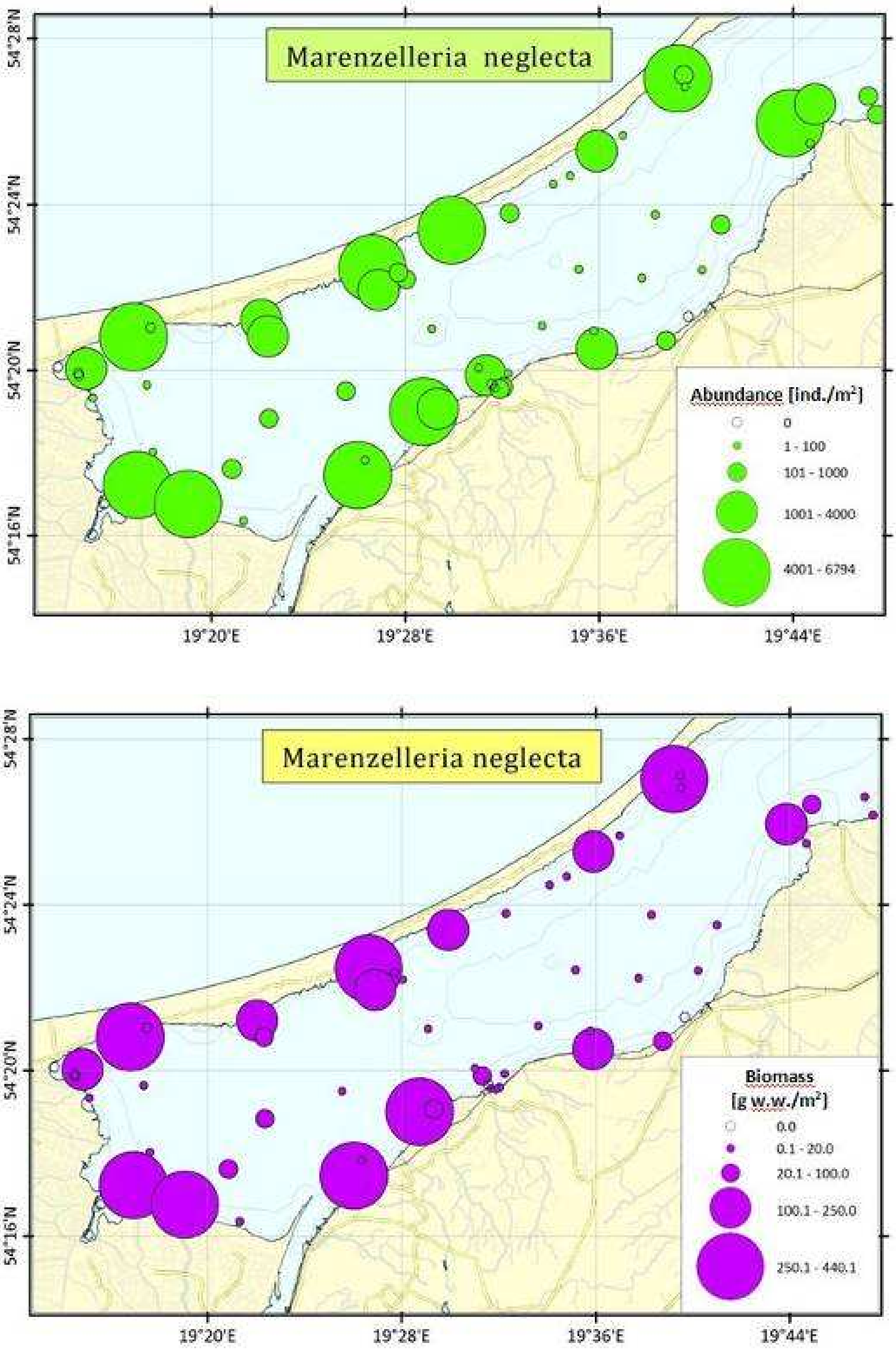



**Figure 11. Distribution of abundance and biomass of *Marenzelleria neglecta* in the Vistula Lagoon between years 2008-2011**

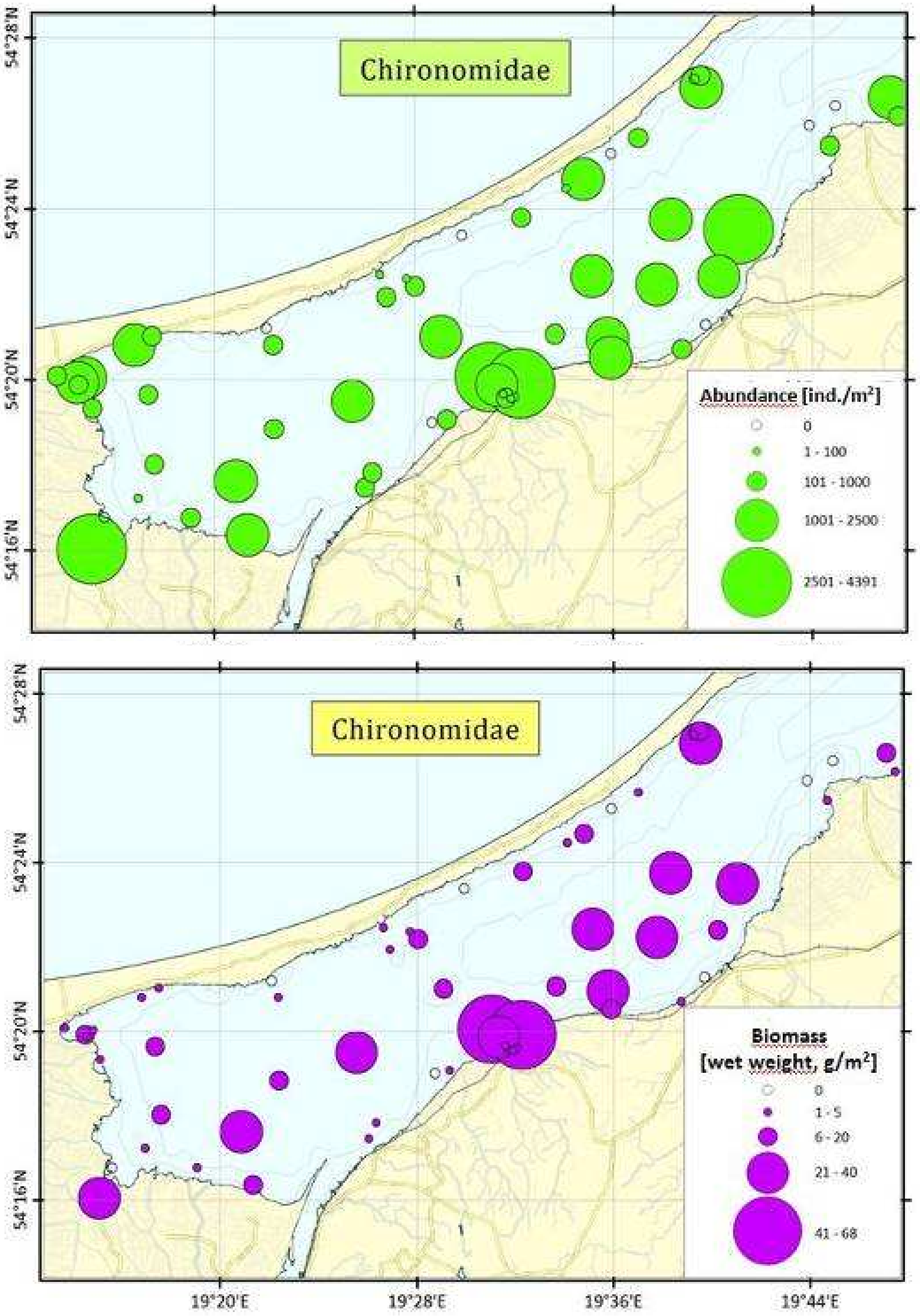
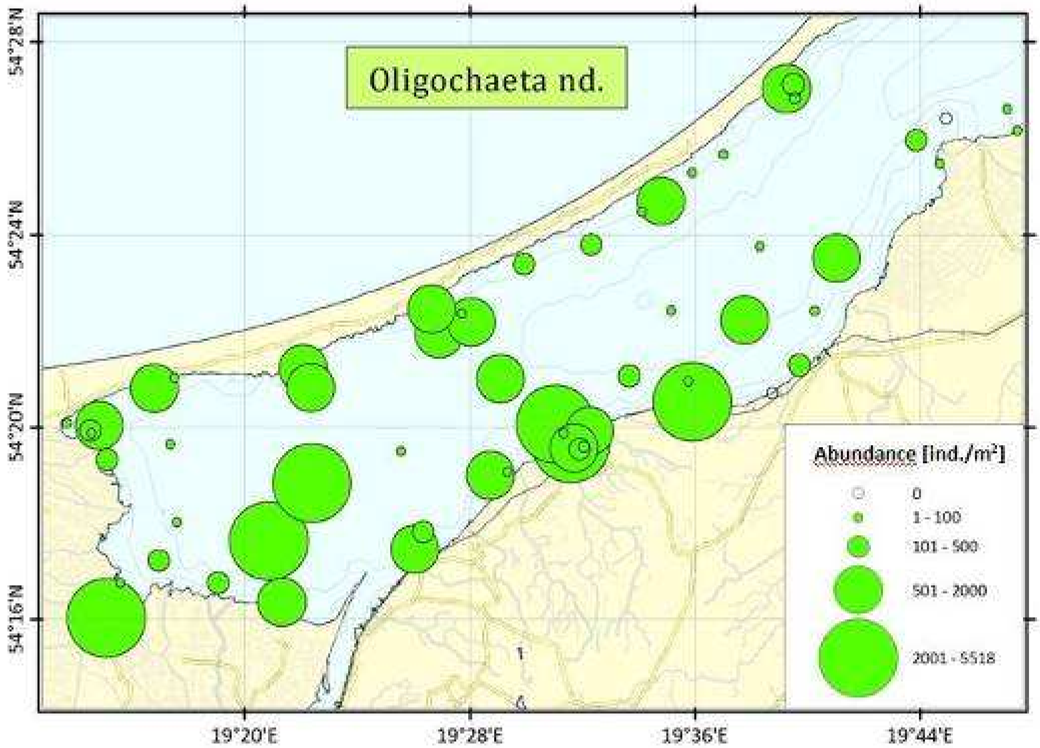



**Figure 12. Distribution of abundance and biomass of insect larvae *Chironomidae* in the Vistula Lagoon between years 2008-2011**



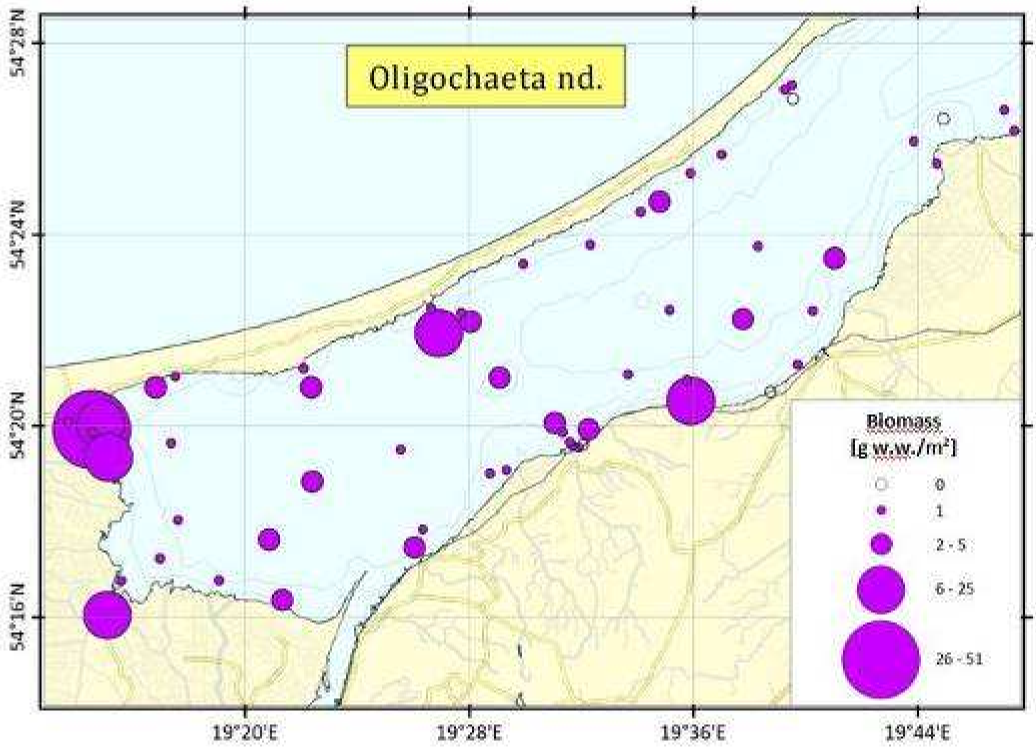
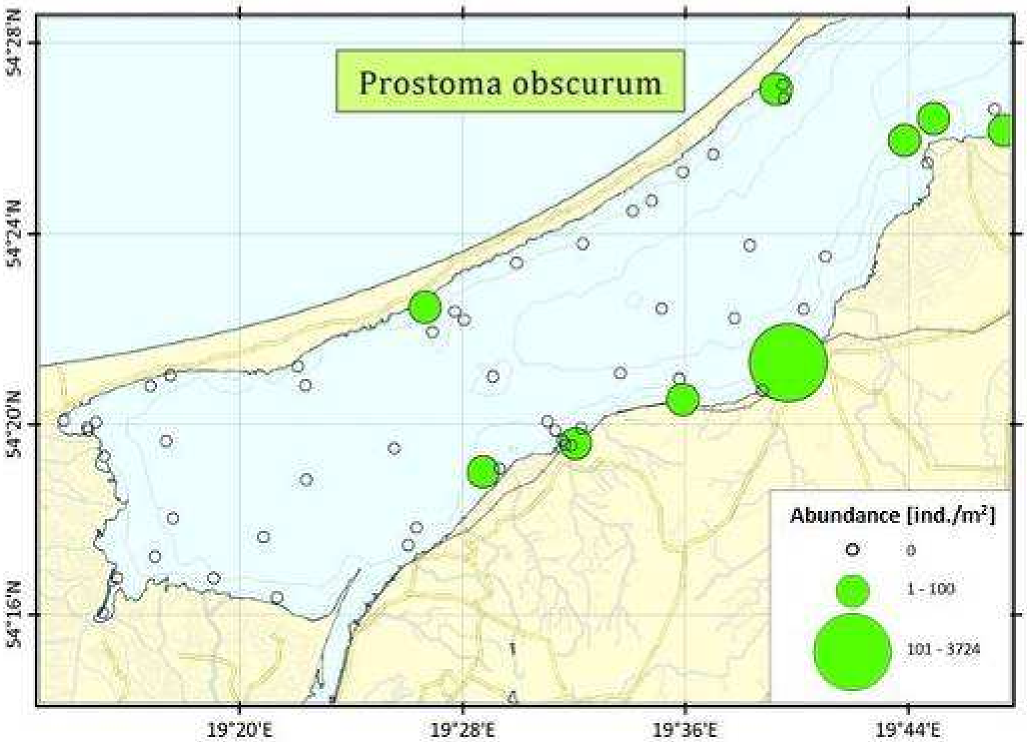




**Figure 13. Distribution of abundance and biomass of *Oligochaeta nd.* in the Vistula Lagoon between years 2008-2011**



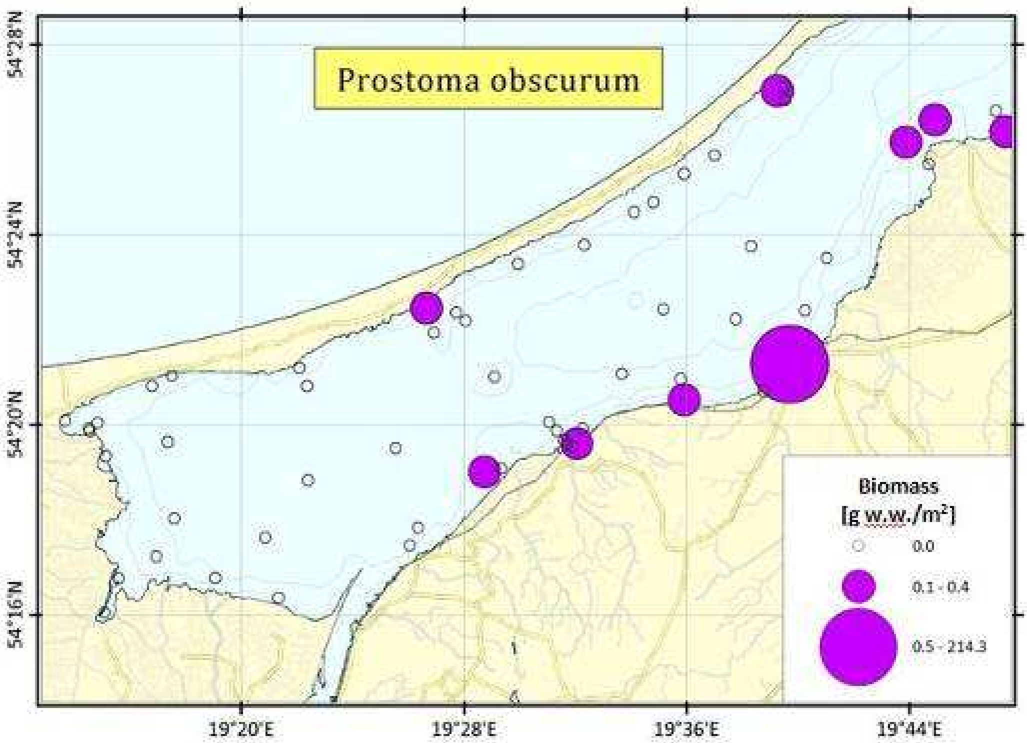




**Figure 14. Distribution of abundance and biomass of *Prostoma obscurum* in the Vistula Lagoon between years 2008-2011**

### 2.3.2.2 Benthic diversity and assemblages structure

Basing on the results of taxonomic composition and the abundance, the Shannon index (log2 base) was calculated. Higher diversity (higher Shannon index values and number of taxa) were observed at the shallow sandy bottom. The maximum values usually coincided with the occurrence of submerged plants. Lower diversity in deeper areas covered by muddy sediments may be caused, at least partly, by the above mentioned hypoxic/anoxic conditions.

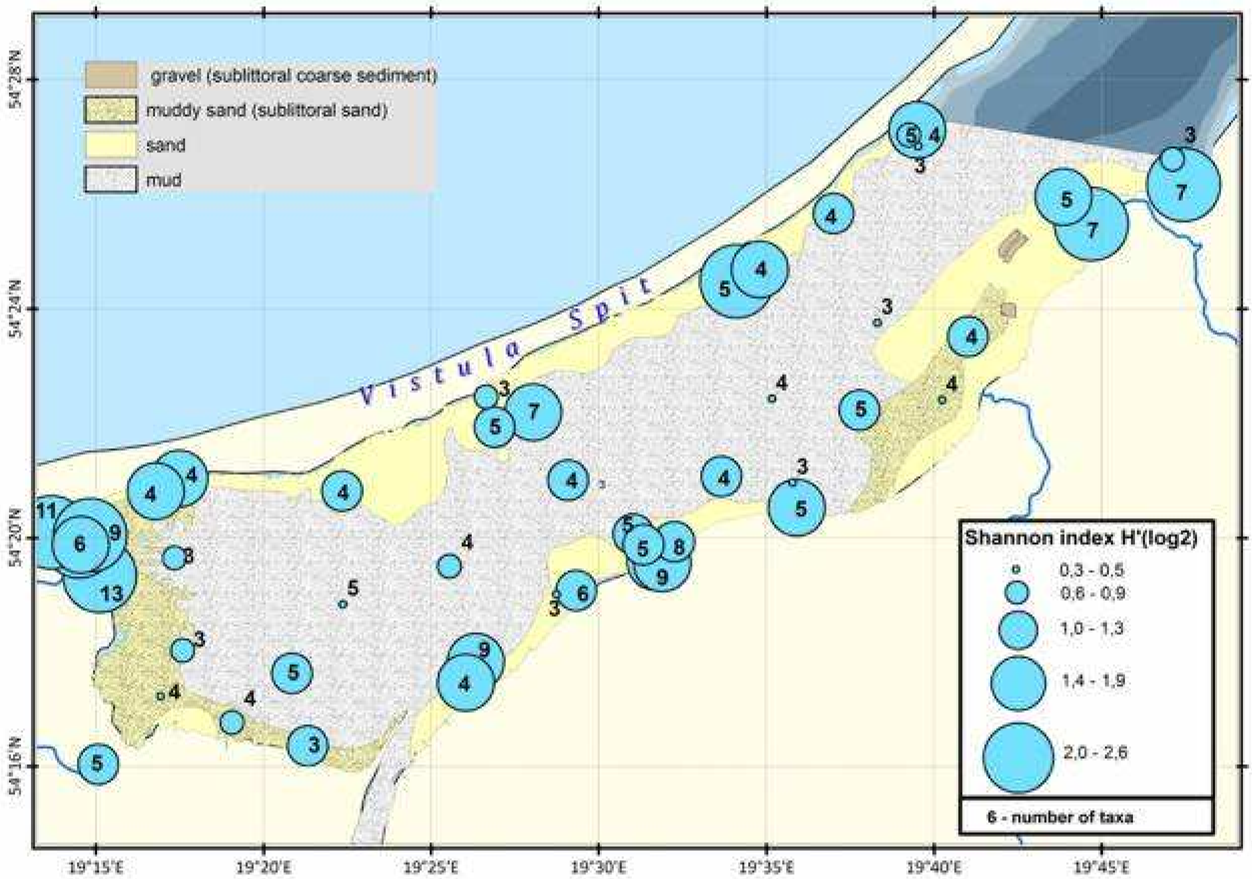



**Figure 15. The Shannon (H' log2) index and number of taxa observed at the stations located in sublittoral zone of the Vistula Lagoon**

In order to identify benthic fauna assemblages, multivariate data analysis was performed following the methods described by Clarke (1993) using the PRIMER (Plymouth Routines in Multivariate Ecological Research) software package. Analyses were carried out on the square root transformed abundance data. Similarity of the taxonomic composition between sampling points was calculated using Bray-Curtis method.

In preliminary selection, species with a frequency of less than 6% at all stations, as well as stations with less than 3 taxa were eliminated from the classification analyses (eg. Stephenson et al 1971, Glockzin and Zettler 2008). The new alien bivalve Rangia cuneata found first time in autumn 2011 was excluded from the analyses because lack of sufficient data on distribution and abundance.

Basing on the cluster routine (group average mode), two main groups of stations can be identified at the similarity level of 50% while some sampling points remain non-grouped (

Figure 16).

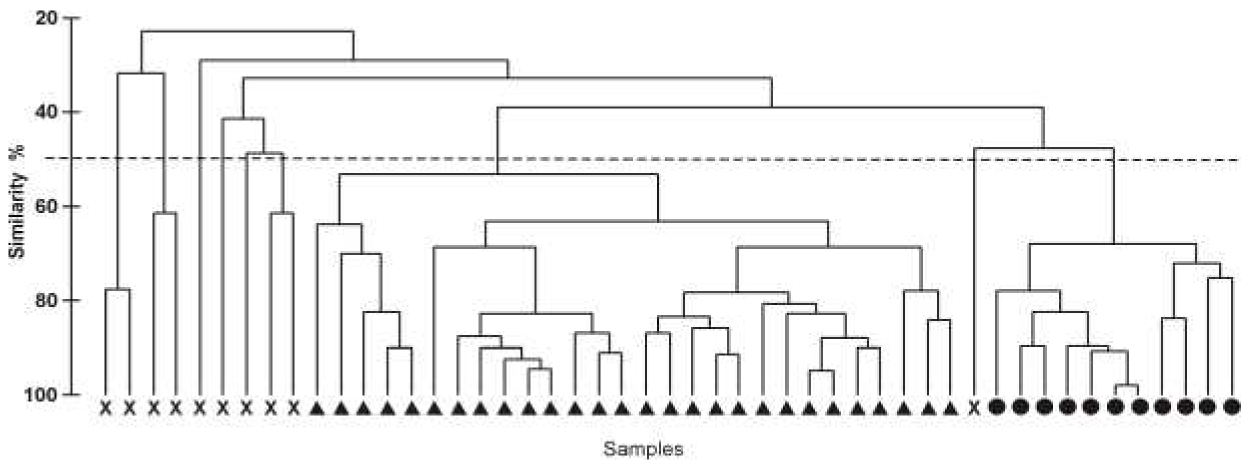



**Figure 16. The results of cluster analyses of the benthic fauna abundance (square root transformation)**

The composition of taxa was similar in both groups; the differences were only in their density. In order to analyse the spatial range of both assemblages, the grouping results have been superimposed on the map of the lagoon (Figure 17).

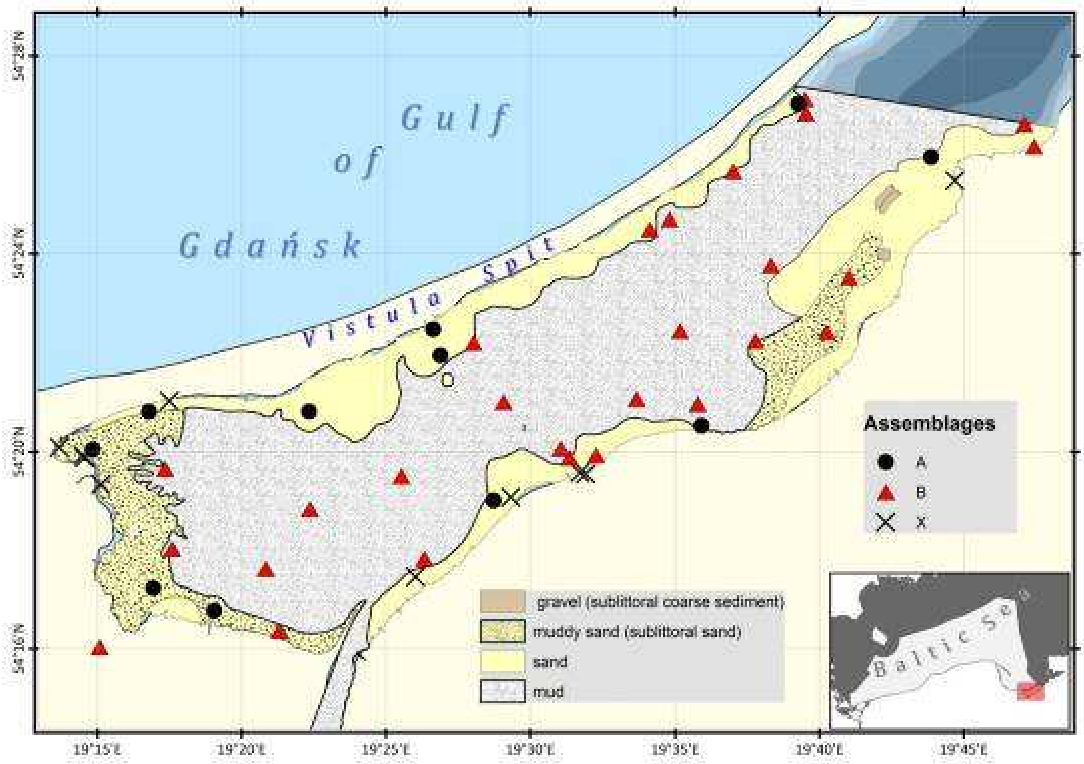



**Figure 17. Spatial distribution of the benthic assemblages identified by clustering procedure**

Taking into account the taxonomic composition and domination structure, spatial distribution and functional structure following the characteristics of the two assemblages can be presented as follows:

**Assemblage A:**

Taxonomic and domination structure:

19 taxonomic groups, domination of *Marenzelleria sp.* followed by *Oligochaeta* nd. and *Chironomus* f.l. *semireductus*

Spatial distribution:

sandy bottom at a depth range of 1.4-1.9 m

Functional structure:

domination of facultative suspension/deposit feeders (*Marenzelleria spp.*), then deposit feeders. Important share of deeply burrowing bioturbators (*Marenzelleria* up to 30 cm).

**Assemblage B:**

Taxonomic and domination structure:

13 taxonomic groups, domination by *Chironomus semireductus* and then *Oligochaeta* nd. and *Marenzelleria* spp.

Spatial distribution:

muddy bottom at a depth range of 2-3.6 m

Functional structure:

domination of deposit feeders (*Chironomus semireductus* and *Oligochaeta*), as well as facultative suspension/deposit feeders (*Marenzelleria spp*.).

# 3. Main bottom habitats and ecological importance of benthic biocenosis in the Vistula Lagoon

## 3.1 The Vistula Lagoon bottom habitats

<u>*Bottom types*</u>

The bottom of the lagoon is covered by three main types of sediments: sand, muddy sand and mud. The sandy and muddy-sandy sediments predominate in the shallower littoral zone, while muddy bottom ones prevail in the deeper central area of the lagoon (Figure 18).

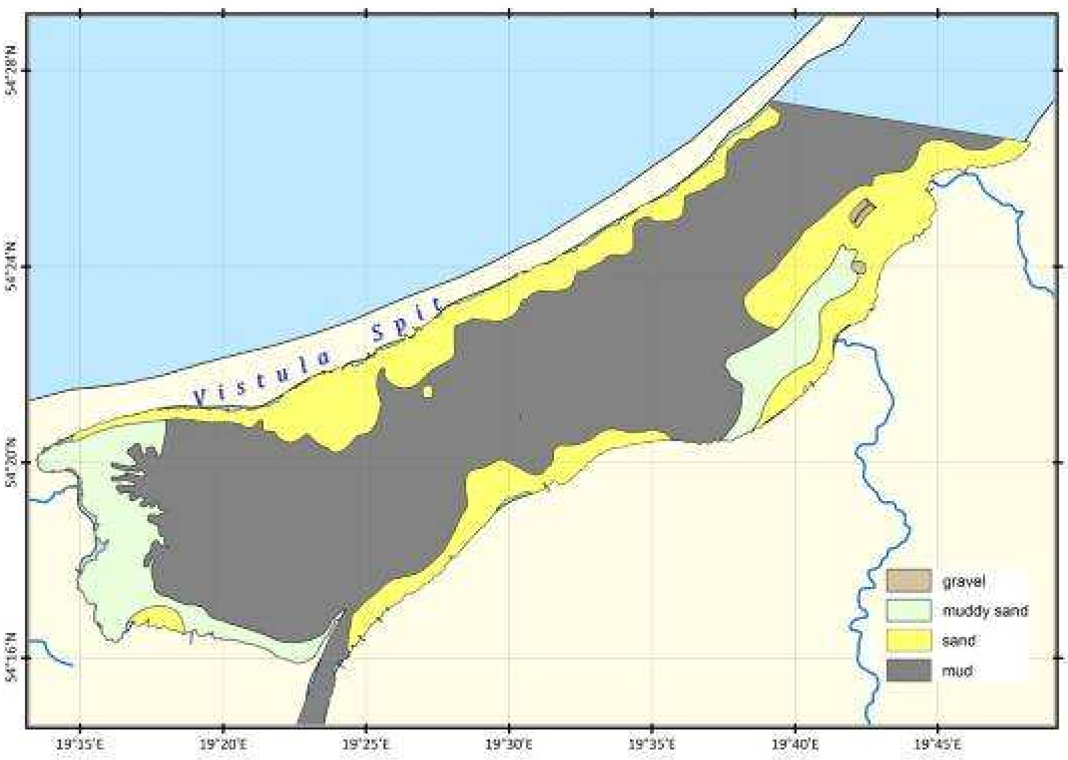



**Figure 18. Bottom sediment types in the Polish part of the Vistula Lagoon (*source:* Gajewski ed. 2010)**

<u>*Presence of benthic macrophytes*</u>

Helophytes occur at the major part of the Polish coastal zone of the Vistula Lagoon except for a high cliff coast along the section from Krynica Morska to the state border.

Larger and more extended areas overgrown by submerged water plants can be encountered only in the western region (Figure 19).

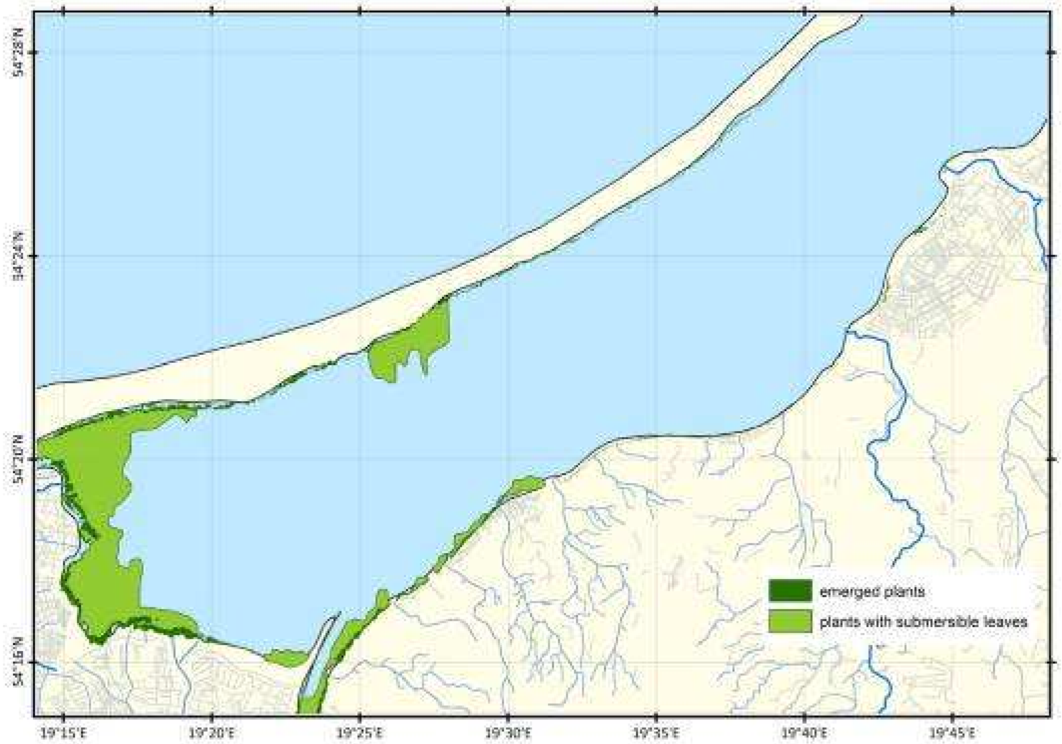



**Figure 19. Spatial distribution of the benthic macrophytes (*source:* Gajewski ed. 2010)**

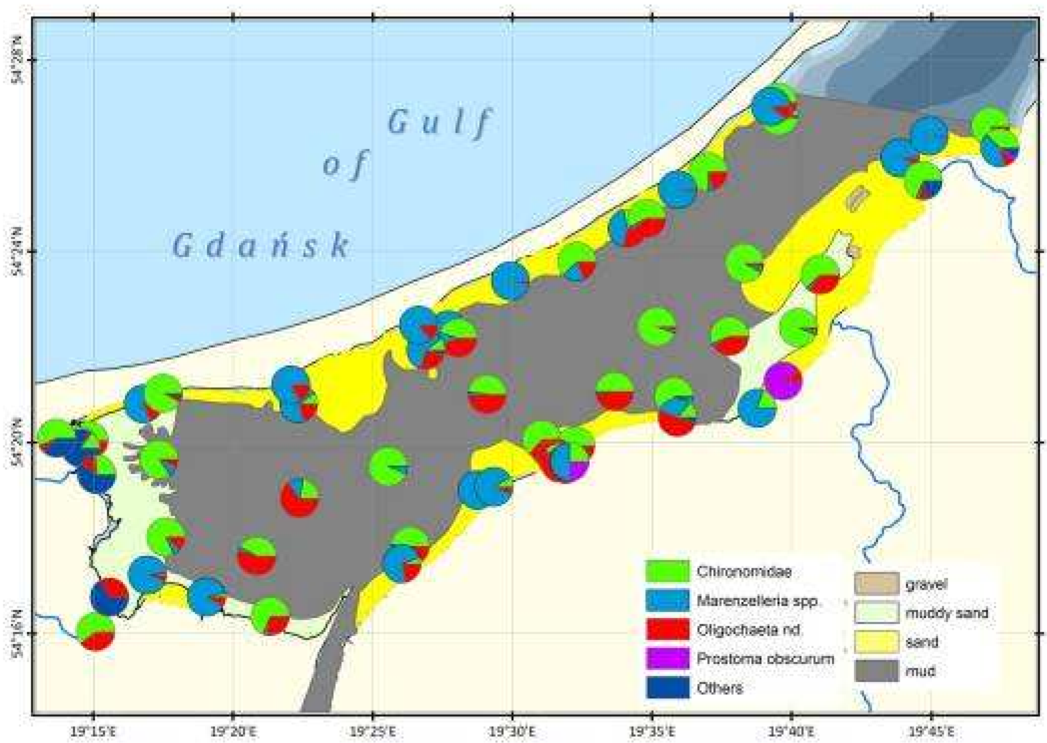



**Figure 20. The domination structure of the benthic fauna in the Vistula Lagoon between years 2008-2011**

Basing on the above information as well as the spatial distribution and domination structure of the benthic fauna (Figure ) the following habitat types can be identified:

**Photic mud characterized by emergent vegetation:**

Photic mud characterized by common reed (*Phragmites australis*);

**Photic mud characterized by submerged rooted plants;**

**Photic sand characterized by emergent vegetation:**

Photic mud characterized by common reed (*Phragmites australis*);

**Photic sand characterized by submerged rooted plants:**

Photic sand characterized by pondweeds;

**Photic sand characterized by infaunal polychaetes:**

Photic sand dominated by *Marenzelleria sp.;*

**Photic sand characterized by infaunal insect larvae:**

Photic sand dominated by midge larvae (Chironomidae);

**Aphotic sand characterized by infaunal insect larvae:**

Aphotic sand dominated by midge larvae (Chironomidae);

**Aphotic sand characterized by infaunal polychaetas:**

Aphotic sand dominated by *Marenzelleria sp.*;

**Aphotic mud characterized by infaunal polychaetes:**

Aphotic mud dominated by *Marenzelleria sp.*;

**Aphotic mud characterized by infaunal insect larvae:**

Aphotic mud dominated by midge larvae (Chironomidae);

## 3.2 The ecological importance of benthic biocenosis

Macrophytes play a major role in biogeochemical cycle, productivity and ecosystem functioning (e.g. Carpenter and Lodge 1986, Hemminga and Duarte 2000). Regardless of the place of occurrence, the macrophyte communities are of paramount importance in terms of habitat creation - organic matter is accumulated here, wave energy is reduced and the diurnal light and temperature range is decreased. Furthermore, they serve as a place where diversified communities develop, including periphyton, benthic fauna, as well as breeding/spawning and feeding/nursery grounds for birds and fish. In addition, they modify interactions within the food web (Mattila 1992, Orth et al. 1984, Jeppesen et al. 1998).

The dense assemblages of benthic macrophytes are likely to remove nutrients from the water column and from the sediments. In some cases they are also sufficient enough to reduce nutrient concentrations in the overlying waters (Grall and Chauvaud 2002), influence the phytoplankton density (Carpenter and Lodge 1986) and mitigate eutrophication processes.

In comparison to 1950s, the changes of environmental conditions connected with the eutrophication processes have resulted in the significant decrease of the submerged plants range in the Vistula Lagoon. Although they are still important as regards habitat creation, due to a narrow range, their role in binding and recirculation of nutrients is limited to a local scale.

Contrary to the submerged water plants, the emergent plants, of which over 90% is represented by reed (*Phragmites australis*), did not change their range considerably. The aboveground biomass of reed in the Polish part of the Lagoon between years 1975-76 exceeded 42,000 tons (Pliński et al. 1978). This plant is characterised by high growth rate and a great capacity for nutrient accumulation in its stems, roots, and rhizomes (Asaeda et al., 2002; Baldatoni et al., 2003). According to Zhao (2013), a higher nutrient loading in the surface water and sediments positively influenced the reed nutrient storages, and reed seemed to be well adapted to the higher nutrient loading status. Taking the above mentioned information into account, it can be assumed that this plant community can play an important role in controlling the lagoon eutrophication. Higher water levels decrease the shoot emergence and density of reeds, which subsequently results in lower aboveground biomass (Zhao 2013). As a consequence, future climate changes related to a rise of water-level can be a potential factor negatively influencing the role of *P.australis* in mitigating the eutrophication processes.

The benthic macroinvertebrates play an essential role in transferring energy and nutrients across the border between the sediment and water column and participate in the food web both as food items and consumers.

One of the most important functional groups in terms of their ability to improve water quality in eutrophic water bodies are suspension feeding bivalves. They can exert both top-down and bottom- up

control on phytoplankton in coastal waters. There is evidence (e.g. Strayer et al. 1999; Phelps 1994), that bivalves can reduce water turbidity by consuming high level of phytoplankton. In consequence, the increase of light penetration enable the submerged aquatic vegetation to re-establish in the areas previously abandoned because of too low photosynthetically active radiation (Phelps 1994).

Large mussel beds of a freshwater bivalve *Dreissena polymorpha* occurred in the Polish part of the Vistula Lagoon in 1950s. According to Żmudziński (1957), the maximum biomass reached 900 g w.w. /m$^2$ excluding shells. The studies conducted in 1970s indicated, similarly to a current situation, that only few specimens were observed. The lack of an essential element of the ecosystem, i.e. suspension feeders, may hinder the improvement of the ecological status of the water body. Nonetheless, the occurrence a new alien species of a bivalve, i.e. common rangia (*Rangia cuneata*) found first time in 2010 in Russian part of the lagoon (Ezhova 2012, Rudinskaya and Gusev 2012), may greatly affect the ecosystem of the basin, not only because of the aforementioned features of filtering organisms, but also due to the possible involvement in the diet of fish which feed on benthos or a potential habitat creation role for other organisms. As the environmental conditions such as low salinity, high turbidity and a substrate of mud, sand and vegetation are the most favourable habitat for this species (Traver 1972), the Vistula Lagoon seems to be a proper environment for this invader.

In the Russian part of the Lagoon, *R. cuneata* colonized and inhabited a large area of the lagoon, reaching maximum abundance of 4040 indiv./m$^2$ in the areas adjacent to the Kaliningrad sea channel (Rudinskaya and Gusev 2012). The presence of common rangia in the Polish part of the Lagoon was also noted (Figure 18).

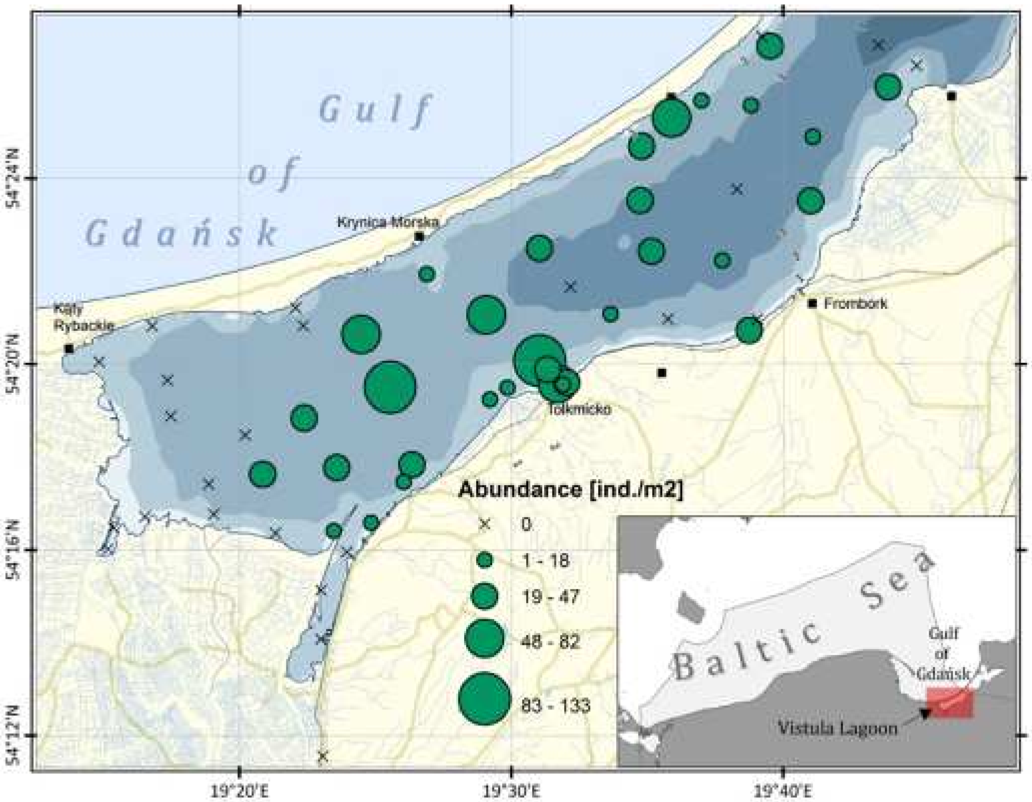



**Figure 18. The distribution and abundance of *R. cuneata* in the Polish part of the Vistula Lagoon in 2012**

Nevertheless, the high number of empty shells, both juvenile (2-4 mm) and larger (2-3.5 cm) may denote a limiting influence of environmental conditions such as unfavourable oxygen conditions, most likely related to the eutrophication effect. Another reason for higher mortality are harsh winters. This possibility is supported by the observations of high mortality after a strong winter in Chesapeake Bay (Gallagher and Wells 1969). In addition, breeding success in the Polish part of the lagoon, which is subjected to lower salinity fluctuations, is less likely than in the vicinity of Pilawska Strait, where significant changes of this parameter are noted. According to Cain (1975), the water temperature above 15°C is probably the main factor influencing initiation of gametogenesis, while salinity is responsible for spawning and recruitment. However, not just the salinity level itself but also the salinity changes are the factors that induce spawning. The range of this change (decrease or increase) is about 5 ppt (Cain 1975). It seems that it is too early to clearly state whether the population of *R. cuneata* is stable in the Vistula Lagoon. If it becomes a constant element of benthos, it may perform a major role as a taxon mitigating the effects of eutrophication.

Higher temperatures resulting from climate changes might prove to be favourable for the population development due to a longer breeding period, which is limited by temperature, as well as by reducing mortality due to the rarer occurrence of severe winters.

The invasion of marine polychaete from genus *Marenzelleria* at the end of 1980s dramatically changed the macrobenthic community structure of the Vistula Lagoon. Its occurrence not only increases the biomass of macrofauna by one order of magnitude, but also changes the functional structure of benthic fauna. Marenzellaria is a facultative deposit- and near-bottom suspension feeder while the resident macrofauna feed mainly on detritus deposited in sediments. At the same time, this organism penetrates the sediment up to 20 cm, much deeper than the resident fauna. Consequently, Marenzelleria seems to occupy an open niche and its deep burying behaviour and feeding strategy represent a new function in the invaded ecosystem. However, the deep bioturbation does not appear to significantly enhance the oxygen condition in the sediment (Urban-Malinga et al. 2013).

The domination of the eurytopic alien species in the macrozoobenthos is the most characteristic feature of the benthic community of the Vistula Lagoon and supports the thesis that lagoons are especially susceptible to invasion (Carlton 1996). According to Olenin and Leppäkoski (1999), alien species can contribute to the ability of the system to receive an impact without a significant alteration in structural or functional parameters. Thus, the resistance of the lagoon to stress, also the one connected with climate change, may benefit from a high share of invaders.

# 4. Benthic ecological quality and its distribution

Based on the taxonomic structure of the benthic sublittoral fauna, the AMBI index was calculated for the areas determined by the sediment type (Table 2).

**Table 2. The AMBI index calculated for main bottom types**

| Bottom type | Ecological Groups share | | | | | Mean AMBI | Disturbance Clasification | EcoQ (sensu WFD) |
|---|---|---|---|---|---|---|---|---|
| | I(%) | II(%) | III(%) | IV(%) | V(%) | | | |
| Muddy | 0 | 16,4 | 52,5 | 0,4 | 30,7 | 3,556 | Moderately disturbed | Moderate |
| Sandy | 0,2 | 62,6 | 13,7 | 2,5 | 20,9 | 3,03 | Slightly disturbed | Good |
| Mixed | 29 | 30,1 | 7,7 | 16,9 | 16,4 | 2,825 | Slightly disturbed | Good |

The most abundant ecological group at the muddy bottom was the disturbance- tolerant species (EG III), while at the sandy and mixed sediments the disturbance-indifferent species from EG II group prevailed.

Basing on the values of the AMBI index, it may be concluded that the lowest disturbance level characterizes the benthic biocoenoses at the bottom covered by mixed and sandy sediments, while the highest level is typical of the muddy bottom fauna. A similar rating of the disturbance level was obtained on the basis of the diversity indices (H' and S) (Table 3).

**Table 3. The comparison of AMBI index, Shannon index (log2) and the number of species at the main bottom types**

| Bottom | AMBI | | Shannon index (H') | | Number of species (S) | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Mud | 3,555 | 0,751 | 1,044 | 0,452 | 4,2 | 1,1 |
| Sand | 3,03 | 1,213 | 1,139 | 0,672 | 5,7 | 2,9 |
| Mixed | 2,825 | 1,347 | 1,833 | 0,451 | 6,8 | 2,3 |

Although the bottom type rating performed on the basis of the environment disturbance level obtained through the AMBI index seems to reflect the reality well, the qualification of single types to categories *moderate* and *good* (sensu WFD) assigns an inflated status. Scoring "good to moderate" is not consistent with the ecological status of the Vistula Lagoon based on other indices. Biological assessment performed on the chlorophyll “a” concentrations noted in 2007 corresponded to a moderate status and in 2008 - to a poor status. However, in some other publications from 2008, the status was bad with respect to chlorophyll “a” concentrations (LAGOONS 2102).

# 5. Fisheries

The total catch in the Vistula Lagoon in 2010 reached almost 5,000 tons (2.6 and 2.3 thousand tons in Russian and Polish part, respectively). Herring is a dominant fish species in commercial catches in both parts of the lagoon. In addition to herring, the most important fish species are eel, pikeperch, and bream.

A detailed description of the fisheries status in the Vistula Lagoon is presented in the report entitled "The current state of Vistula Lagoon Polish fisheries: Perspectives for development" http://www.balticlagoons.net/artwei/wp-content/uploads/2012/05/PSUTY-Vistula-Lagoon-Fishery_final-m1.pdf

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