



Typology of Polish marine waters

Włodzimierz Krzymiński¹, Lidia Kruk-Dowgiallo², Elżbieta Zawadzka-Kahlau², Rajmund Dubrawski², Magdalena Kamińska¹, Elżbieta Lysiak-Pastuszek¹

¹ Institute of Meteorology and Water Management - Maritime Branch, Poland

² Maritime Institute, ul. Abrahama 1, 80-307 Gdansk, Poland

Abstract

The article presents results of expert work carried out within the frame of a contract between the Polish Ministry of Environment and the consortium of four scientific Institutes. The Maritime Branch of the Institute of Meteorology and Water Management (IMWM MB) from Gdynia and Maritime Institute (MI) from Gdansk have been responsible for the typology of Polish marine waters. The analysis of data collected mainly during more than forty years of oceanographic activity of the IMWM MB allowed to discern the following water categories:

- **transitional waters** including the entire areas of the Szczecin Lagoon, Vistula Lagoon and a part of the Gulf of Gdansk – the internal Puck Bay, called Puck Lagoon, as well as parts of the Gulf of Gdansk and Pomeranian Bay under significant influence of riverine plumes;
- **coastal waters** comprising a band of water defined according to the article 2, par. 7, and taking into account art.2, par.1, of the Water Framework Directive (WFD), excluding the areas of transitional waters;
- **modified waters** comprising waters within the rivers mouth areas along the central Polish coast and corresponding to the issue of internal marine waters in the Polish legislation on marine areas.

1 Introduction

Following the request of the Polish Ministry of Environment regarding the implementation of the EU Water Framework Directive, a consortium of four scientific Institutes has been formed in Poland to elaborate the typology of the Polish surface and ground-waters. The Maritime Branch of the Institute of Meteorology and Water Management (IMWM MB) from Gdynia and Maritime Institute (MI) from Gdansk have been responsible for the typology of Polish marine waters (REPORT... 2004).

The determination of the width of coastal waters and extension of transitional waters in the southern Baltic Sea requires consideration of specific features of this basin. The Baltic is saline water, tides-less sea, and - in the Polish sector - it receives fresh water from two big rivers (Oder and Vistula), a number of smaller rivers and over 200 other watercourses. Depending on the magnitude of the riverine flows, the extents of transitional waters take up varying area.

In the case of transitional waters the criterion of the distance from coastline, as defined for coastal waters by WFD, is not valid, therefore the determination of the mixing zone extents of riverine and marine waters is of great importance. Thus, in some cases the width of coastal water band can exceed the 1 Mm distance, because the border of coastal waters is located at the outer limit of transitional waters. In such cases, the classification into coastal or transitional waters was based on ecological criteria and the possibility to establish representative (e.g. having a long time data series record for trend analysis) stations to monitor and present assessment of the status of individual water bodies. There are two river catchment areas in Poland established as the water management units:

- the Vistula River catchment area comprising besides the drainage area of Vistula located within the territory of Poland also the catchment areas of Dniestr and Danube related via the river Wag, the catchments of the rivers Nemunas, Slupia, Lupawa, Leba, Reda and other rivers which discharge directly into the Vistula Lagoon together with the catchments of the rivers Swieza and Pregel;
- the Oder River catchment area comprising besides the drainage area of the river Oder within the territory of Poland also the catchments of Elbe and Danube - through the river Morava, as well as the catchment areas of the rivers: Rega, Parseta, Wieprza, Úcker and the rivers discharging directly into the Szczecin Lagoon.

The Polish act on marine areas and their administration defines the borders of internal marine waters and these areas correspond to the WFD definition of transitional waters. Hence, the following coastal regions can be classified into the transitional water category: Szczecin Lagoon, Vistula Lagoon and Puck Lagoon – in these basins natural morphological conditions define the transitional character of their waters unequivocally, and internal Gulf of Gdansk as well as the foregrounds of the mouth of rivers discharging directly into the sea, where, especially regarding the Vistula river, the marine waters remain under continuous influence of riverine outflows.

2 Results

2.1 Analysis of data availability

The oceanographical data base of the IMWM MB contains physical and chemical data as well as results of chlorophyll_a measurements from the period 1959-2003. The number of data from various regions and individual stations ranges from 1 to 517. The total number of data collected in the selected coastal regions is presented in Figure 1 (REPORT... 2004)

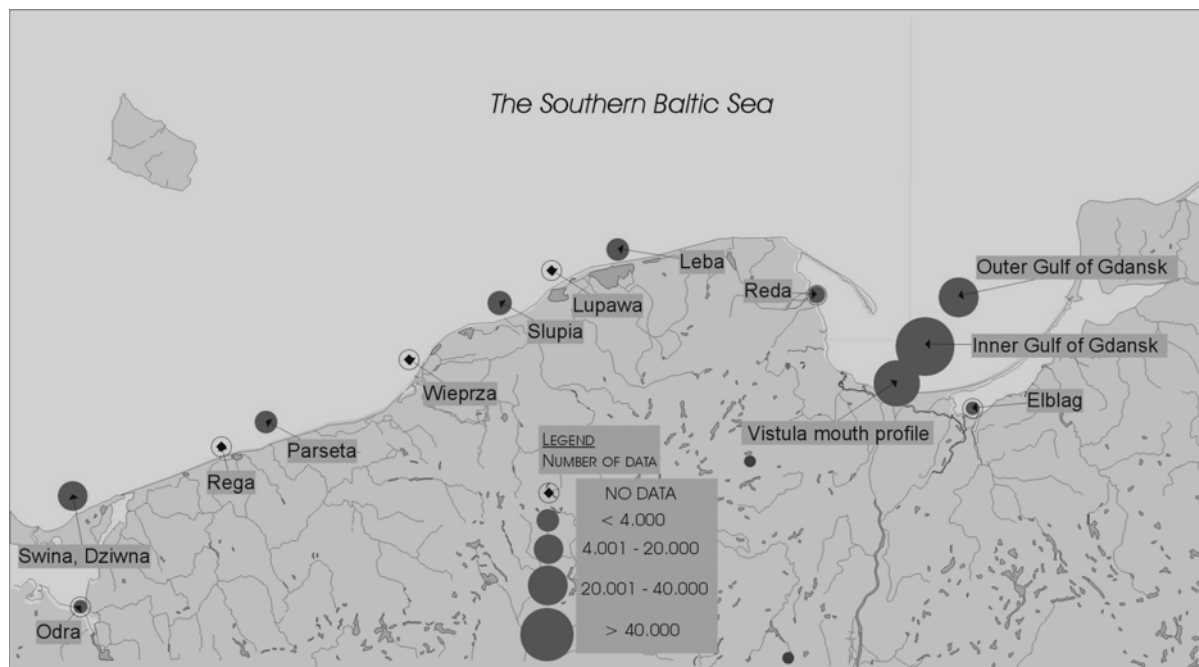


Figure 1: Total number of oceanographic data collected in different areas of the Polish coastal zone of the Baltic Sea.

Szczecin Lagoon

The measurements in the Szczecin Lagoon are carried out with similar frequency as in the Vistula Lagoon – 5 times a year from March/April (depending on the ice cover) till November. The regular measurements started in 1994 and are conducted at 3 stations.

Pomeranian Bay

The frequency and spatial coverage of measurements in the Pomeranian Bay is rather complicated. In the total number of 73 stations, at 23 stations the measurements were done only once – during the outflow of the flood crest of the river Oder in 1997. The earliest measurements in the Pomeranian Bay come from 1966 and the regular measurement series commenced in 1978 and are continued up to now. In 1998 a new station has been established within the HELCOM COMBINE, located at the BSPA marine protected area – Wolin National Park.

River Parseta mouth

The measurements in the mouth of the river Parseta were carried out at 6 stations. The measurements started in 1971-1974 and later were carried out at selected stations and rather irregularly. Only at a single station there is an uninterrupted measurement series from 1984 up to now.

River Slupia mouth

The measurements in the mouth of the river Slupia were carried out at 3 stations – P14, P15 and P16 between 1959-1968. Later the measurements were continued at different time intervals and at different stations. Station P16 has the longest data time series, continuing up to present.

River Leba mouth

The measurements along the profile of the river Leba plume in the sea were carried out at several stations (L4, L7, L8, L9 – at an increasing distance to land). The longest time series of data was collected at the station L7: in the periods 1971-1974, 1976-1980 and since 1985 till today. The measurements at other stations were conducted in different time intervals; the earliest (1966) at L8. Station L4, the closest to the river mouth has the data time series similar to L7.

Gulf of Gdansk

The oceanographic data from the Gulf of Gdansk are available for the entire period 1959-2003. The earliest measurements (since 1959) were conducted in the internal part of the Gulf. The number of visited stations in the Gulf of Gdansk varied from 5 up to 40, depending on the period and scientific programme, but it has to be underlined that measurements at a station established along the Vistula outflow axis have been carried out regularly during this entire period.

Puck Lagoon

The Puck Lagoon, due to its specific regime, was always treated as a separate part in the internal Gulf of Gdansk. Regular measurements (5-12 times a year) in this area started in 1998, with the implementation of the HELCOM COMBINE programme. The measurements are conducted from February/March, depending on ice cover, to November; earlier the measurements were done occasionally.

Vistula Lagoon

Similarly to Puck Lagoon, the regular measurements in the Vistula Lagoon started in 1998 with the implementation of the HELCOM COMBINE programme. At present the measurements are carried out at 4 stations, 5 times a year, from April to November.

2.2 Salinity distribution

To evaluate the extent of riverine waters in the sea, graphs representing the minimal, mean and maximal salinity distribution have been drawn for the surface and near bottom water layer as well as

vertical profiles along the rivers outflows; the latter for the rivers Swina, Dziwna, Vistula, Rega, Parseta, Leba and Pasleka.

Water salinity in the Szczecin Lagoon is low (Fig. 2) and in the analysed data series it fell within the range from 0.211 (in the surface water layer) to 3.836 (in the bottom water layer); salinity values in PSU (Practical Salinity Units). Lower salinity is observed in the southern part of the Lagoon, at the river Oder outlet, and higher values are found in the northern part, close to the Swina Strait. It is the result of the labile water balance in the Lagoon influenced by the intensity of the river Oder outflow on one hand and the back surges of marine waters from the Pomeranian Bay (ZALEW SZCZECINSKI 1980).

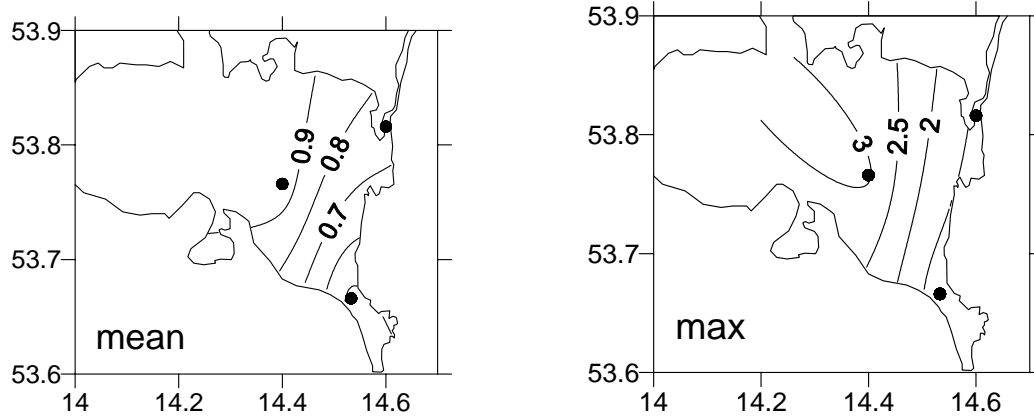


Figure 2: : An extent of the mean and maximal salinity (>0.5) in surface water layer of the Polish part of Szczecin Lagoon.

In the Pomeranian Bay (Fig. 3), the lowest salinity is found close to the Swina and Dziwna mouths and it increases towards the off-shore region. This occurs both in the surface as well as in the bottom water layer (MAJEWSKI 1972). As compared to Dziwna, Swina's outflow is bigger, hence salinity in Swina mouth is usually lower than in Dziwna outlet.

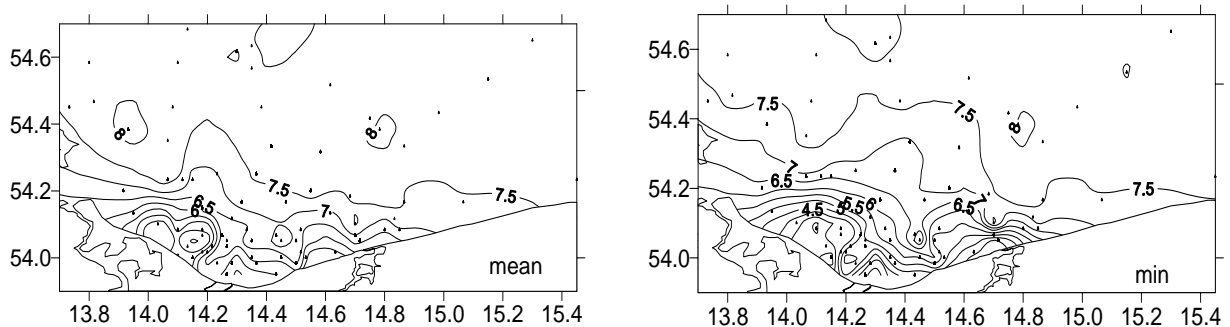


Figure 3: Extent of the mean and minimal salinity in the surface water layer of the Pomeranian Bay (both in German and Polish parts) in the foreground of the river Swina and Dziwna.

The difference is clearly marked when analysing the extent of mean and minimal salinity in both vertical profiles – the mean surface salinity in Swina mouth (Fig. 4) is significantly lower (4.883) than salinity in Dziwna profile (6.537) (Fig. 5). Significant influence of fresh water is well marked at stations close to the rivers mouths; at stations at some distance to the shore the influence of riverine water gradually decreases, however low salinity is still observed in the near surface layer.

Studies conducted by the Danish Hydraulic Institute and confirmed by measurements of coli index indicated that bacteriologically polluted ($c > 1000$ coli/100 ml) water from the river Rega extend up to 2.7 km along the coastline (MINISTRY... 1993).

The measurements carried out in 1995 to facilitate calibration of water quality model (GAJEWSKI 1995A) pointed out that water discharged by the river Parseta extends in the sea up to 1.5 km. In the vertical profile, fresh water (salinity < 0.5) extends only to about 100 m from the river mouth.

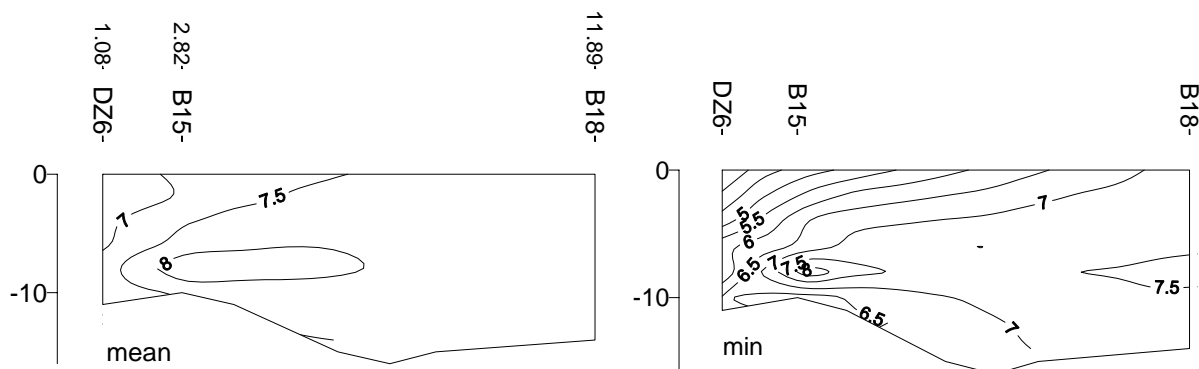


Figure 4: Distribution of salinity in vertical profile from the river Swina mouth towards the open sea. Numbers over the station names indicate distance from the shore in Nm, while vertical scale indicates depth in meters

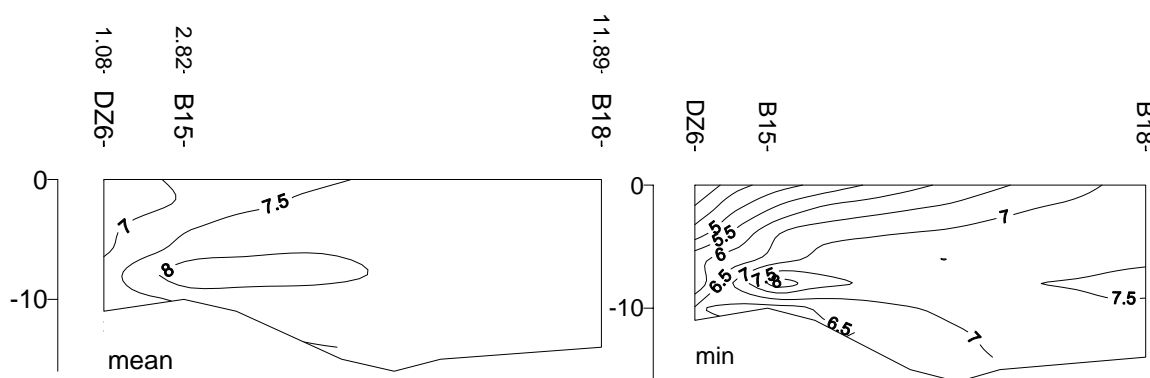


Figure 5: Distribution of salinity in vertical profile from the river Dziwna mouth towards the open sea. Numbers over the station names indicate distance from the shore in Nm, while vertical scale indicates depth in meters.

Studies conducted by the Danish Hydraulic Institute and confirmed by measurements of coli index indicated that bacteriologically polluted ($c > 1000$ coli/100 ml) water from the river Rega extend up to 2.7 km along the coastline (MINISTRY... 1993).

The measurements carried out in 1995 to facilitate calibration of water quality model (GAJEWSKI 1995A) pointed out that water discharged by the river Parseta extends in the sea up to 1.5 km. In the vertical profile, fresh water (salinity < 0.5) extends only to about 100 m from the river mouth.

Similar measurements carried out within the river Leba mouth showed the extent of this river reaching up to 1 km in the surface layer, but the extension of oligohaline water (salinity <6.0) is only ca. 100 m (GAJEWSKI 1995B).

The measurement station at a nearest vicinity to the shore in the river Slupia profile is located at a distance of 3.79 Nm (7.04 km). At this distance the influence of riverine outflow is negligible (Fig. 6). Salinity in the river Slupia mouth profile indicated considerable influence of marine water, hence its range is rather narrow 6.585 (minimal) to 7.782 (maximal).

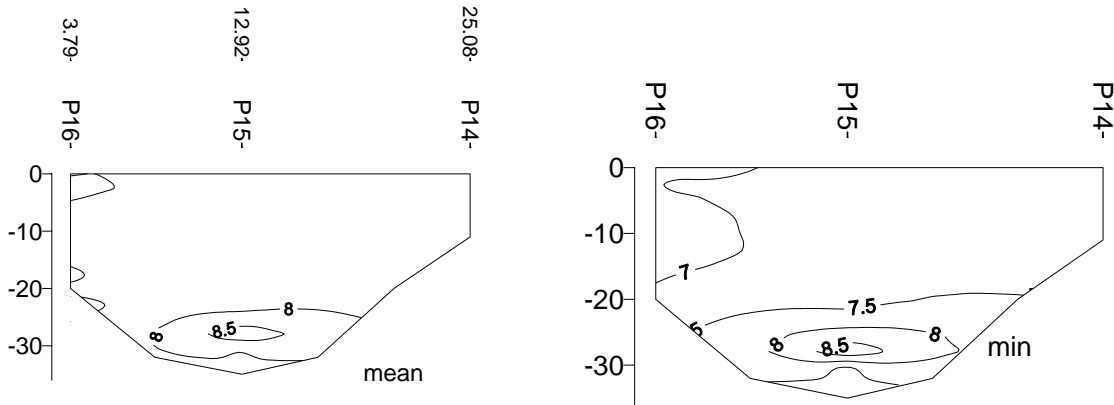


Figure 6: Distribution of the mean and minimal salinity in the vertical profile along the section from the river Slupia mouth towards the open sea. Numbers over the station names indicate distance from the shore in Nm, while vertical scale indicates depth in meters

The lowest salinity in the Polish coastal zone is observed in the foreground of the river Vistula mouth (ZATOKA GDANSKA 1997). The extent of the river plume varies, depending on the river flow intensity and wind direction. Under extreme conditions, salinity <7.00 is noted even as far from the river mouth as the Gdansk Deep. Close to river mouth salinity increases with depth and the gradient can reach several salinity units (Fig. 7).

In the central part of the Gulf of Gdansk, density stratification is observed with permanent halocline at the depth of ca. 70 m. The maximal salinity measured below the halocline reached 14.990 (at station P116 located in the central part of the gulf).

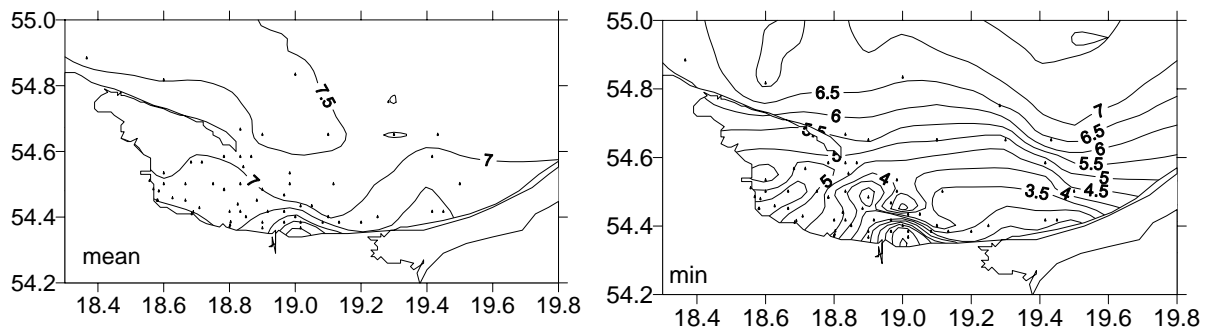


Figure 7: Surface distribution of the mean and minimal salinity in the Gulf of Gdansk.

The Puck Bay is divided into two separate basins by the Seagull Shoal. The inner Puck Bay, called Puck Lagoon, is connected by a narrow channel with the outer one widely opened to the Gulf of Gdansk; hence the exchange of water between the lagoon and the Gulf of Gdansk is considerably obstructed.

The main fresh water source to the Lagoon is the river Reda. The mean salinity in the central part of the Puck Lagoon is 5.320 (Fig. 8). The eastern part of the Puck Bay, located south-eastward to the Seagull Shoal, is affected by the more saline water from the Gulf of Gdansk and its salinity shows much wider range.

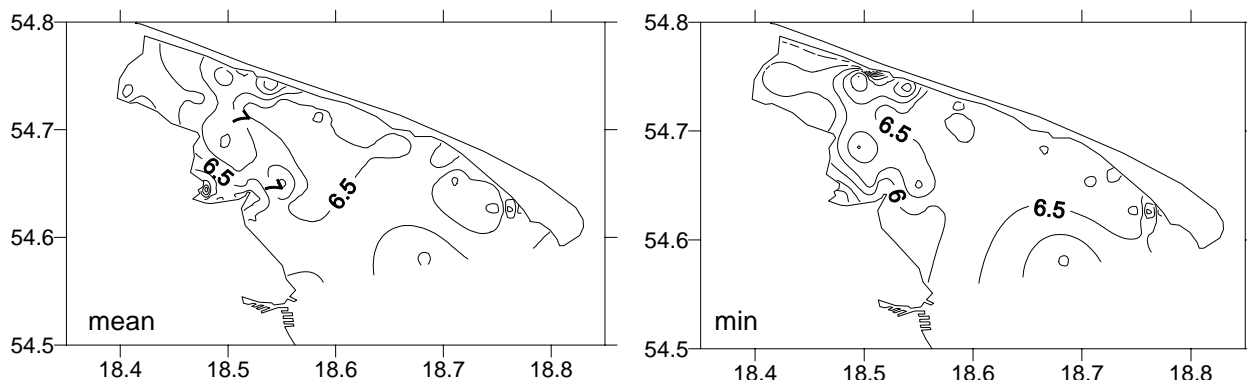


Figure 8: Surface distribution of the mean and minimal salinity in the Puck Bay.

Salinity distribution in the Vistula Lagoon in the surface and bottom water layer is very similar (ZALEW WISLANY 1985). Lower salinity values are observed in water in the south-western part of the Lagoon and higher in the north-eastern (Fig. 9). Hence, the Polish part of the Lagoon is affected by fresh water input from such rivers as Elblag and Pasleka and by the back surges of saline water from the Gulf of Gdansk what leads to considerable salinity variations.

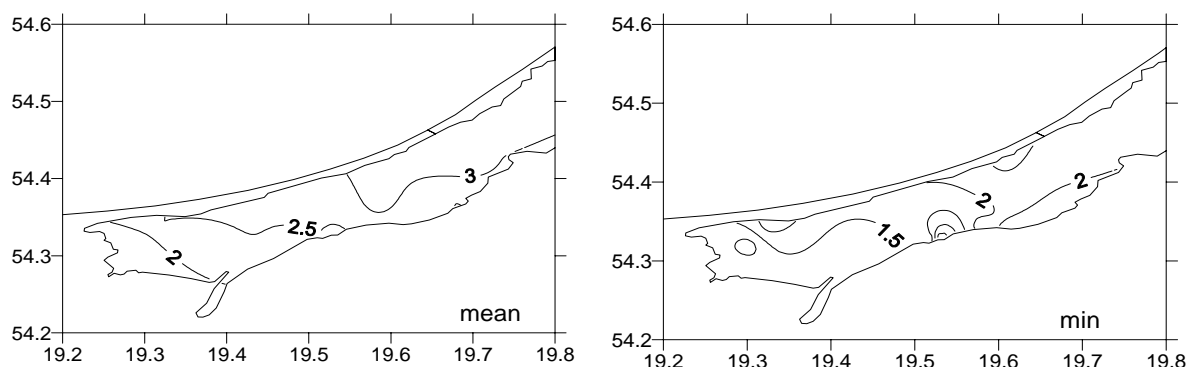


Figure 9: Surface distribution of the mean and minimal salinity in the Vistula

Field studies related to water quality model calibration in the mouth of the river Pasleka allowed to evaluate the extent of the river plume in the Lagoon reaching up to 1 km (GAJEWSKI 1995C). On the other hand the experiments with rodamine tracer showed that water from the Lagoon can be pushed in the river bed to a distance of ca. 2 km.

3 Discussion

Following the recommendations of the Common Implementation Strategy and Guidance of WFD (2000/60/EU), it is proposed to define within the Polish coastal zone transitional and coastal waters with the subsequent determination of respective water bodies within each category (Table 1, Fig. 10). Further on, it is suggested to define port areas (defined in the Polish legislation as the internal marine waters) situated within the river mouths as the modified or heavily modified water bodies.

Transitional waters comprise areas of strong interactions between riverine and marine waters, i.e. estuaries of the big rivers and coastal lagoons. It can be discussed that both forms are estuaries anyway but they differ significantly as regards hydrodynamic conditions which influence their biology and transformation processes of any material discharged into these basins. The proposed division of the Polish coastal zone into transitional and coastal waters based on salinity distribution and morphological conditions is presented in Figure 10; the chart has been made using software GIS ARC-View.

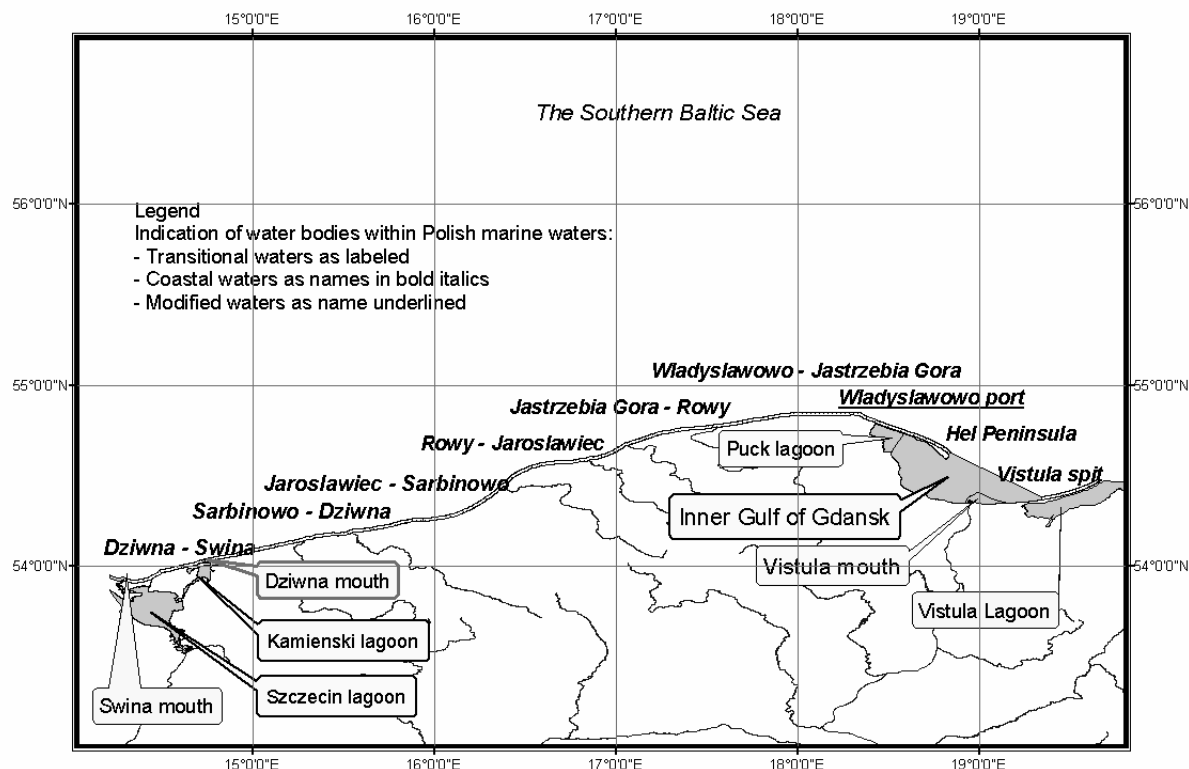


Figure 10: Water bodies determined within Polish coastal marine waters.

Lagoons: The Puck Lagoon and Vistula Lagoon are water reservoirs morphologically nearly completely enclosed and are subject to the influence of fresh water input from the rivers and marine water backflows from the Gulf of Gdansk through narrow straits. Because of relatively small exposition to wind waving is decreased in these basins. Water level as such plays much more important role. The Puck Lagoon should form an individual water body delineated by the shoreline and the line connecting the Seagull Shoal with the Hel Peninsula. The Vistula Lagoon should form a water body delineated by the shoreline and the national border between Poland and Russia (Kaliningrad area).

Estuaries: Water bodies in the estuaries of the rivers Oder and Vistula should be delineated by the riverine borders of the mean location of fresh water plume determined during back surge, while the marine borders should be set at the mean location of isohaline 5 [PSU] (the threshold between oligohaline and mesohaline waters). The establishment of separate water bodies in these estuaries is based on the grounds that these areas are under the influence of riverine water discharging pollutants accumulated from the expansive territory. On the other hand, these water bodies are open to wind action and simultaneously they are much deeper than coastal lagoons, hence they are characterised by much greater dynamics of litho- and hydrodynamic processes (currents, waving, etc.).

- Within the estuary of the river Oder it is proposed to establish four water bodies: the Szczecin Lagoon, delineated by the shoreline and national border between Poland and Germany, the Kamienski Lagoon, and the foregrounds of the rivers Swina and Dziwna mouths into the sea.

- Within the mouth of the river Vistula it is suggested to establish two water bodies: an area in the river mouth foreground reaching to the extent of the isoline 6 [PSU] and the remaining area of the Gulf of Gdansk as another water body.

Table 1: Water bodies within Polish marine waters.

Type	Water body	Salinity (range)	Temp. (mean)	Mixing	Retention time	Wave exposure	Substrate (IG 1988-1992)
Coastal waters							
I	Vistula Spit	5.0-18.0	8.25	partly stratified	<7 days	partly open	marine fine and medium grained sand
I	Hel Peninsula	5.0-18.0	6.79	partly stratified	<7 days	partly open	marine fine I and medium grained sand
II	Wladyslawowo-Jastrzebia Gora	5.0-18.0	8.12	partly stratified	<7 days	partly open	marine medium grained sand, coarse grained gravel, coubles, boulders
II	Jastrzebia Gora-Klif Rowy	5.0-18.0	8.57	partly stratified	<7 days	partly open	fine and medium grained sand
II	Klif Rowy-Jaroslawiec	5.0-18.0	8.31	partly stratified	<7 days	partly open	marine vari grained sand, marine gravely-sand, sandy gravel
III	Jaroslawiec-Sarbinowo	5.0-18.0	8.43	partly stratified	<7 days	partly open	marine vari grained-sand , gravely sand
II	Sarbinowo-Dziwna	5.0-18.0	8.55	partly stratified	<7 days	partly open	marine vari grained sand, gravel, coubles
III	Dziwna-Swina	5.0-18.0	11.4	partly stratified	<7 days	partly open	marine fine and coarse grained sand, gravely sand
Transitional waters							
I	Vistula Lagoon	0.5-5	14.07	not stratified	45 days	protected	lagoonal clayey silt, lagoonal sandy silt, lagoonal silty sand
II	Puck Lagoon	0.5-5	12.19	not stratified	138 days	protected	lagoonal fine and medium grained sand, silty sand
III	Internal Gulf of Gdansk	5.0-18.0	8.54	partly stratified	<7 days	partly protected	medium grained sand, marine silty sand, sandy silt, marine clayey silt
IV	Vistula mouth Przekop	0.5-5	9.55	partly stratified	<7 days	partly protected	medium and coarse grained sand, marine silty sand, marine sandy silt, s
IV	Dziwna mouth	0.5-5	10.28	partly stratified	<7 days	partly protected	medium grained sand, silty sand,
IV	Swina mouth	0.5-5	13.11	partly stratified	<7 days	partly protected	fine and medium grained , sand and deltaic silt in the retrograde delta
I	Szczecin Lagoon	0.5-5	14.1	not stratified	52 days		silt, sandy silt, silty sand
I	Kamienski Lagoon	0.5-5	10.4	not stratified	>30 days	protected	silt, sandy silt, silty sand
Modified waters							
1	Wladyslawowo port			not stratified	>30 days	partly protected	medium and coarse grained sand

The analysis of salinity distribution in the mouths of rivers along the central Polish coast have pointed out that it is not reasonable to delineate separate water bodies within the category of transitional waters for each river. Therefore estuaries of these rivers have been included in the category of coastal waters as individual water bodies basing mainly on the morphological conditions differentiation and the features of substratum.

According to the definition of the WFD it is proposed to define the seaward border of the coastal waters along the Polish coastal zone at the distance of 1 Mm from the base line. The band of coastal waters will be disrupted by the appearance of transitional water in the river mouth areas of Swina, Dziwna and Vistula.

Subsequently to the proposition of the absence of transitional waters along the central Polish coast, it is suggested to determine modified water category and the relevant water bodies in this category in the mouth areas of the rivers along the shoreline and simultaneously to determine heavily modified water category and the water bodies within the radius of ca. 1 Mm for the marine ports not constructed in the river mouths (Wladyslawowo, Hel, Gdynia) and the outlets of wastewater collectors that discharge into the sea (Koszalin, Gdansk).

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Address

Włodzimierz Krzyminski
Institute of Meteorology and Water Management, Maritime Branch (IMWM MB)
Waszyngtona 42
81-342 Gdynia
Poland

E-mail: wlodzimierz.krzyminski@imgw.pl