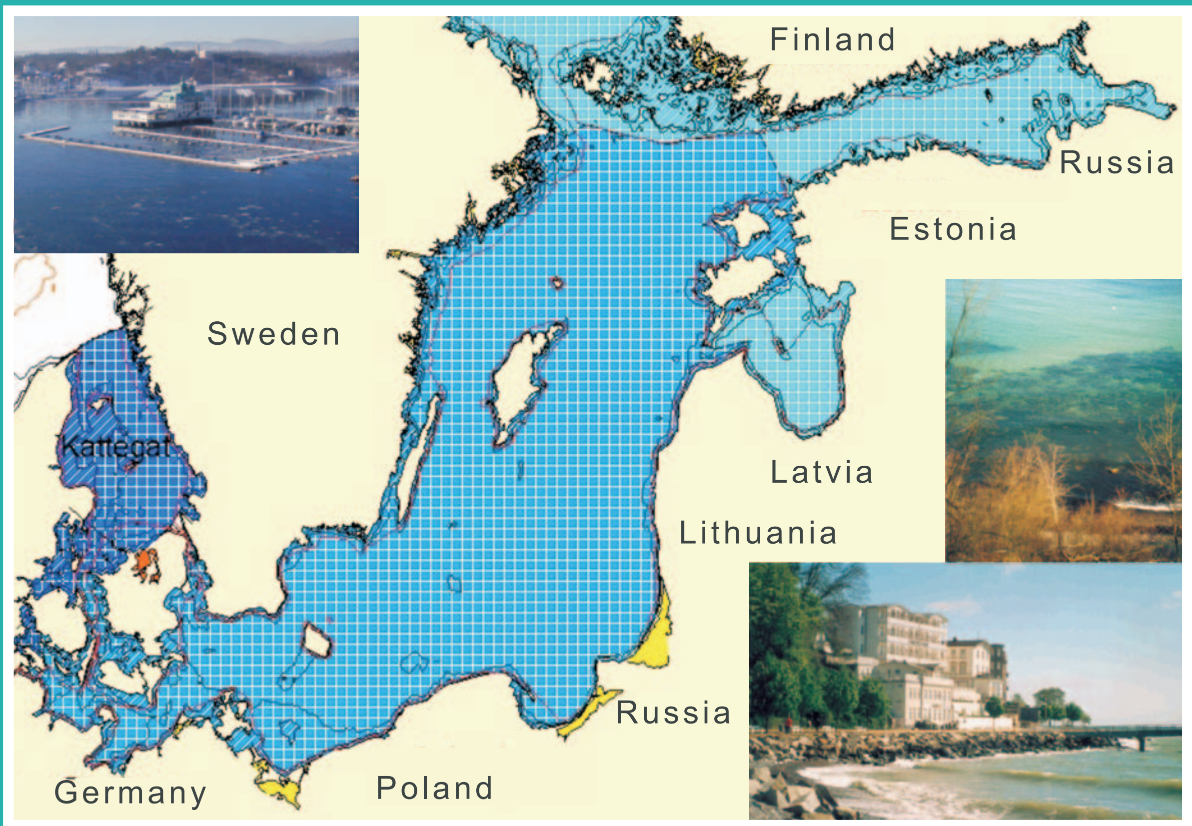
COASTLINE REPORTS

2004 - 4

Baltic Sea Typology



Editors:
G. Schernewski & M. Wielgat

EUCC

The Coastal Union

Die Küsten Union Deutschland

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Gerald Schernewski & Magdalena Wielgat

EUCC – The Coastal Union
EUCC – Die Küsten Union Deutschland e.V.
Warnemünde, 2004

ISSN 0928-2734

This volume was prepared under the EU project
CHARM - Characterization of the Baltic Sea Ecosystem
funded by the European Union within the Fifth Framework
Program. Contract no.: EVK3-CT-2001-00065.

The project "**IKZM-Oder**" funded by the Federal Ministry of Education and Research (No. 03F0403A) supported the continuation and publication of the updated work.

Impressum

Coastline Reports is published by:

EUCC – The Coastal Union
P.O. Box 11232,
2301 EE Leiden, The Netherlands

Resonsible editor of this volume:

EUCC – Die Küsten Union Deutschland e.V.
Dr. Gerald Schernewski & Dr. Magdalena Wielgat
Poststr. 6,
18119 Rostock, Germany

Coastline Reports are available online under http://www.eucc-d.de/coastline_reports.php
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P r e f a c e

The European Water Framework Directive (WFD) establishes a comprehensive framework for European Community actions in the field of water and introduces new principles of modern water management. New is especially the spatial integration of river basins, coastal and coastal waters as well as the focus on biological ecosystem quality elements (fish, macrozoobenthos, macrophytes and phytoplankton). One very important aspect in the WFD is the typology. The WFD asks all European member states to develop a national typology for their coastal and transitional waters. This typology has far reaching implications. It is, for example, the basis for the definition of reference conditions, water quality classification schemes and will cause significant adaptations with respect to monitoring.

To create a typology for the Baltic Sea means to develop a classification scheme, which unifies water bodies with a similar characteristic and separates different water bodies from each other. A typology generalizes the complex and diverse Baltic ecosystem into simplified units and makes it accessible for spacious analyses and comparisons. The underlying parameters used for a classification or typology depend on its objectives and purpose. Several schemes, which are close to a typology, already exist for the Baltic Sea. Against the background of the EC-habitats directive, for example, a mapping and classification of marine habitats was carried out. A habitat classification for the Baltic Sea is supported or independently developed by organizations like ICES, EEA and HELCOM, too. Most important in this respect are the demands arising from the WFD.

The implementation of the WFD as well as the development of a national typology is the responsibility of national authorities. The typology for every country has to be finished by the end of 2004, and monitoring programs should be operational by the end of 2006. As a result, every country develops or has already developed an independent typology. The Baltic Sea is defined as one Ecoregion in the Water Framework Directive, and the coastal waters are of international character. It is expected that some types will be intercepted at country borders and a very similar water body can belong to very different types. Independent national typologies further bear the danger of different national water quality reference states, different water quality classification schemes and finally different definitions of a good ecological state. Many national typologies would complicate large scale comparisons across the Baltic Sea. Therefore, a joint approach towards typology is required for all Baltic coastal waters.

The typology concept as defined in the WFD in general as well as the practical development of typologies always causes a simplification and bears the danger that existing complex dependencies are not reflected in an appropriate manner. Therefore, a lot of scientific discussions and criticism is linked to the typology concept. In this volume a Baltic Sea Typology according to the EC-Water Framework Directive as well as national typologies are presented and discussed. Further, these typologies are evaluated against biological spatial pattern.

In December 2001, an EU project entitled “Characterization of the Baltic Sea Ecosystem: Dynamics and Function of Coastal Types” (CHARM) was launched aiming, inter alia, at testing and validating a methodology for establishing coastal types in the Baltic Sea Ecoregion. Furthermore, by analyzing coastal ecosystems dynamics and function in relation to anthropogenic pressure, the objectives of the project were to develop recommendations on reference conditions and monitoring strategies for facilitation of the Water Framework Directive implementation for all Baltic Sea coastal waters. All Baltic states (except Russia) participated in the project. Most papers in this volume reflect the work within the CHARM project, however their content is a full responsibility of the authors.

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Warnemünde, November 2004

Gerald Schernewski & Magdalena Wielgat

- Baltic Sea Research Institute Warnemünde -

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A Baltic Sea typology according to the EC-Water Framework Directive: Integration of national typologies and the water body concept

Gerald Schernewski & Magdalena Wielgat

Baltic Sea Research Institute Warnemünde, Germany

with contributions from CHARM partners: Bjorn Sjoberg, Tobias Dolch, Andris Andrushaitis, Trine Christiansen, Fredrik Wulff & Zbigniew Witek

Abstract

This article is an update and extension of an earlier publication (SCHERNEWSKI & WIELGAT 2004). Intensive public discussions suggested slight modifications in the typology as well as an updating and completion of comparisons between our typology and the national typologies. We further show examples how the water body concept can be applied to subdivide coastal water types as a response to external pressures. The water body concept allows a kind of subdivision of the typology e.g. in river plumes or near emission sources of pollutants.
The Water Framework Directive (WFD) establishes a comprehensive framework for European Community actions in the field of water and introduces new principles of modern water management. New is especially the spatial integration of river basins, coastal and coastal waters as well as the focus on biological ecosystem quality elements. The WFD requires from all EU Member States to protect and enhance the status of water quality of all types of waters, including coastal zone of the sea. For the purpose of the WFD implementation all water bodies must be classified into types of similar characteristics based on the physical factors. This classification scheme is called typology and forms a universal basis for all other activities within the WFD implementation such as: management or monitoring. The implementation of the WFD as well as the development of a national typology are a responsibility of national authorities and are due to be operational in a few years time. As a result, every country develops or has already developed an independent typology. The WFD defines the Baltic Sea as one Ecoregion. The coastal waters have an international character but national typologies will cause interceptions at country borders and different national typologies will complicate large scale comparisons across the Baltic Sea. Further, the definition of coastal waters (1 nm off the baseline) is artificial. The division between coastal waters and open waters is not in agreement with morphological, physical, chemical or biological parameters. Therefore, a joint typology approach, not only for the Baltic coastal waters, but the entire Baltic Sea is needed. Within the EU-project CHARM (Characterization of the Baltic Sea Ecosystem) a joint Baltic Sea typology was developed. The suggestion in the EU-CIS Working Group 2.4 Guidance Document formed the basis.
Salinity was used as the main obligatory factor. For the Baltic Sea typology residence time and depth/mixing conditions were additionally used. The typology is not meant to replace national typologies. It is developed as an umbrella, which allows the integration of the national typologies and a further subdivision according to regional demands. It therefore serves as a link or an integrative element for the national typologies. The Baltic Sea typology covers the entire Baltic Sea and is not limited to the definition area of the Water Framework Directive.

1 Introduction

The Water Framework Directive (WFD) establishes a comprehensive framework for European Community actions in the field of water and introduces new principles of modern water management. New is especially the spatial integration of river basins, coastal and coastal waters as well as the focus on biological ecosystem quality elements (fish, macrozoobenthos, macrophytes and phytoplankton).

The WFD is an important element for the implementation of the new EC Marine Strategy and has indirectly influence on and is interrelated to the EC-Habitat Directive (NATURA 2000), the EC-Nitrate Directive and the EC recommendations on Integrated Coastal Zone Management. One important aspect in this very dominating WFD is the creation of typologies.

To create a typology for the Baltic Sea means to develop a classification scheme, which unifies water bodies with a similar characteristic and separates different water bodies from each other. A typology generalizes the complex and diverse Baltic ecosystem into simplified units and makes it accessible for spacious analyses and comparisons. The underlying parameters used for a classification or typology depend on its objectives and purpose. Several schemes, which are close to a typology, already exist for the Baltic Sea. Against the background of the EC-habitats directive, for example, a mapping and classification of marine habitats was carried out. A habitat classification for the Baltic Sea is supported or independently developed by organizations like ICES, EEA and HELCOM, too. Most important in this respect are the demands arising from the EC-Water Framework Directive (WFD). The WFD asks all European member states to develop a national typology for their coastal and transitional waters. This typology has far reaching implications. It is, for example, the basis for the definition of reference conditions, water quality classification schemes and will cause significant adaptations with respect to monitoring.

The implementation of the WFD as well as the development of a national typology is the responsibility of national authorities. The typology for every country has to be finished by the end of 2004, and monitoring programs should be operational by the end of 2006. As a result, every country develops or has already developed an independent typology. The Baltic Sea is defined as one Ecoregion in the Water Framework Directive, and the coastal waters are of international character. It is expected that some types will be intercepted at country borders and a very similar water body can belong to very different types. Independent national typologies further bear the danger of different national water quality reference states, different water quality classification schemes and finally different definitions of a good ecological state. Many national typologies would complicate large scale comparisons across the Baltic Sea. Therefore, a joint approach towards typology is required for all Baltic coastal waters. As recommended by the CIS Working Group reference points for monitoring purposes should be established in order to allow inter-comparison between types. A general typology should facilitate this task too.

Despite the fact that the Baltic Sea is defined as an Ecoregion, the Water Framework Directive is restricted to a coastal strip of only 1 nautical mile off the baseline. The narrow strip of coastal waters is artificially divided from open waters. This concept violates the suggested ecosystem approach for the Baltic Sea as defined in the EC-Marine Strategy. It further means that types are truncated artificially and a comprehensive Baltic system concerning reference conditions, water quality classification schemes and monitoring is hardly possible. The problems arising from the limitation of coastal waters call for a typology which covers the entire Baltic Sea.

In December 2001, an EU project entitled “Characterization of the Baltic Sea Ecosystem: Dynamics and Function of Coastal Types” (CHARM) was launched aiming, inter alia, at testing and validating a methodology for establishing coastal types in the Baltic Sea Ecoregion. Furthermore, by analyzing coastal ecosystems dynamics and function in relation to anthropogenic pressure, the objectives of the project were to develop recommendations on reference conditions and monitoring strategies for facilitation of the Water Framework Directive implementation for all Baltic Sea coastal waters. All Baltic states (except Russia) participated in the project.

Our work represents the CHARM project approach, formulating a general typology – a classification system – for the Baltic Sea Ecoregion. The aim is to cover the entire Baltic Sea in a flexible manner and to keep the system general enough, that it can serve as an umbrella, linking all national approaches to coastal waters typology for all Baltic countries under one scheme. This article is an update and extension of an earlier publication (SCHERNEWSKI & WIELGAT 2004). Intensive public discussions suggested slight modifications in the typology as well as an updating and completion of comparisons with national typologies. We further show examples how the water body concept can be applied to subdivide coastal water types according to external pressures. The water body concept allows a kind of subdivision of the typology e.g. in river plumes or near emission sources of pollutants.

2 Background: The Water Framework Directive and typology

In the year 2000, the Water Framework Directive - WFD (DIRECTIVE 2000/60/EC) entered into force. This Directive is a result of a long process of discussions in the field of water policy and replaces as well as unifies water related laws in Europe. It introduces new principles of water management and promotes sustainable water use based on long-term protection of water resources. The goal of the Directive is not only to prevent further deterioration of water bodies but also to protect and enhance the status of water resources to the level of quality defined as "good". According to the Directive requirements, all water bodies must reach at least "good water status" before year 2015. This means that the water quality must be improved close to the reference or background conditions reflecting natural, undisturbed conditions of the certain water type. The Directive provides a framework for protection of all types of waters: inland surface waters, groundwater and waters of the coastal strip for all seas around Europe.

There are two general types of waters considered in the coastal seas around Europe: coastal and transitional waters. WFD defines coastal waters as bodies of surface sea waters reaching up to one nautical mile on the seaward side from the baseline from which the breadth of territorial waters is measured (Fig. 1). According to the Directive 'transitional waters' are bodies of surface sea waters in the vicinity of river mouths … which are substantially influenced by freshwater flows". In the present work we consider only coastal waters, since most Baltic States do not intend to identify any transitional waters along their Baltic Sea coast. However, a final decision on defining some areas as transitional waters will be taken on the national level, when all Member States decide on the final classification scheme of the WFD in their coastal zone is a result of a long process of discussions in the field of water policy and replaces as well as unifies water related laws in Europe. It introduces new principles of water management and promotes sustainable water use based on long-term protection of water resources. The goal of the Directive is not only to prevent further deterioration of water bodies but also to protect and enhance the status of water resources to the level of quality defined as "good". According to the Directive requirements, all water bodies must reach at least "good water status" before year 2015. This means that the water quality must be improved close to the reference or background conditions reflecting natural, undisturbed conditions of the certain water type. The Directive provides a framework for protection of all types of waters: inland surface waters, groundwater and waters of the coastal strip for all seas around Europe.

The Directive requires that all surface waters including waters in the coastal zone of the seas - transitional and coastal waters - shall be divided into types, based on physical factors. The classification system is defined in the Directive as a typology, and factors to be used for classification are specified. Formulating a typology would mean dividing the entire coastal strip around Europe into types of water based on physical factors, such as e.g. depth, water residence time or exposure of the water type. This classification will form a background for all other Directive activities, such as: defining the present status of the water quality as compared to the natural, background status which is specific for each type, managing of waters in order to prevent further pollution and enhance the water status to the "good" level. For the purpose of the WFD implementation each type will have to be monitored and the monitoring program must reflect the need to identify the water status.

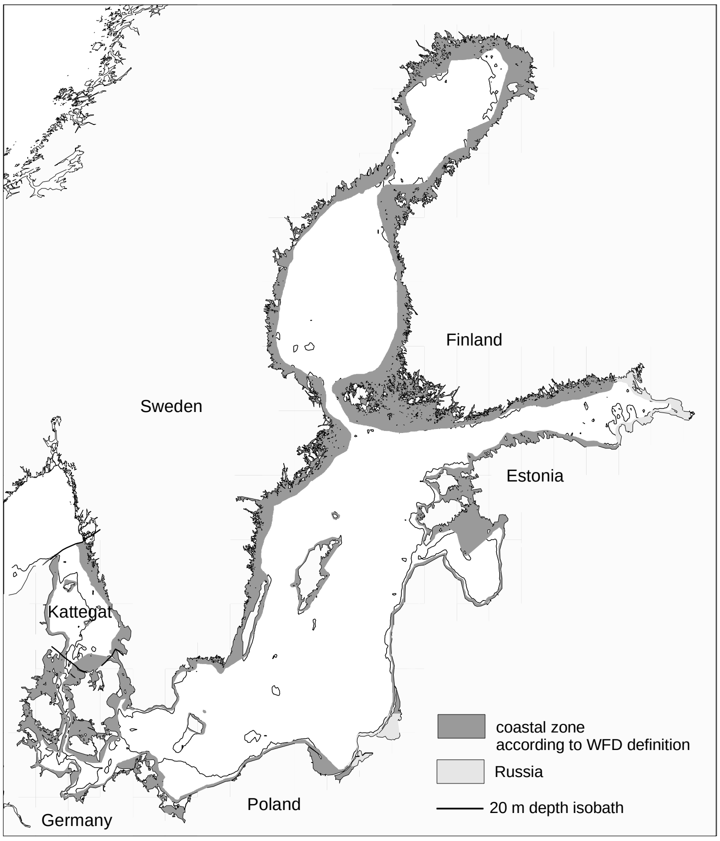


Figure 1: The coastal waters of the Baltic Sea Ecoregion as defined by the Water Framework Directive based on the baseline delimitation. Coastal waters limits as defined by national baselines correspond mostly with the 20 m isobath which is also shown.

The EU Member Countries agreed to develop a Common Implementation Strategy (CIS) for the Water Framework Directive to be worked out within the framework of the Commission. Among other working groups established to support this Common Implementation Strategy, the EU-CIS Working Group 2.4 was supposed to produce a practical guidance document on the implementation of the Directive for transitional and coastal waters. The working group included representatives from each Member State as well as experts from other countries. The Document "Guidance on typology, reference conditions and classification systems for transitional and coastal waters" (VINCENT et al. 2002) is non-legally binding. Instead, it aims at providing a practical advice for implementing WFD. The document suggests a unified, Pan-European approach. However, it is not detailed enough to answer all questions, it sets certain direction of work for WFD implementation in coastal and transitional waters and therefore can be considered as a framework for all tasks.

The Water Framework Directive (DIRECTIVE 2000/60/EC) formulated scientific basis to be used for classification of water bodies which are specified in the Annex II of the Directive document. According to the Directive requirements, the classification system – a typology – can be done based on two alternative schemes: System A or System B. System A classifies all coastal regions into Ecoregions and the Baltic Sea is one Ecoregion under System A classification. The next classification factors in system A are: salinity and depth. If the System A is not sufficient, System B can be used alternatively. The obligatory factors in System B are: Latitude/Longitude, tidal range and salinity and then optional factors can be used: current velocity, wave exposure, mean water temperature, mixing characteristic, retention time (of enclosed bays), means substratum composition and water temperature range.

Based on the two Systems the EU-CIS Working Group 2.4 formulated one classification scheme in Guidance Document (VINCENT et al. 2002). It suggested a Pan-European approach in typology to achieve a generally uniform classification system for all national typologies. A hierarchical approach is recommended and, so called; obligatory factors should be used for main classification in both systems. These are: Latitude/Longitude = Ecoregion; Tidal range; Salinity.

If obligatory factors are not sufficient, they can be followed by optional factors that are most applicable to the ecological situation. Range for each factor is pre-defined in the guidance but it is justified to aggregate or split ranges. All factors and their ranges recommended in the Guidance Document are listed in Table 1.

Table 1: Factors recommended in the EU-CIS Working Group 2.4 Guidance Document to be used for development of typology.

Factor	**Range**	**Range value**
Salinity	freshwater oligohaline mesohaline polyhaline euhaline	< 0.5 0.5 to 5 – 6 5 - 6 to 18 - 20 18 – 20 to 30 > higher than 30
Mean Spring Tidal Range	microtidal mesotidal macrotidal	< 30 m 1 m to 5 m > 5 m
Exposure (Wave)	extremely exposed very exposed, exposed moderately exposed sheltered, very sheltered	
Depth	shallow intermediate deep	< 30 m 30 m to 50 m > 50 m
Mixing	permanently fully mixed partially stratified permanently stratified	
Proportion of Intertidal Area	small large	< 50% > 50%
Residence Time	short moderate long	days weeks months to years
Substratum	hard (rock, boulders, cobble) sand-gravel mud mixed sediments	
Current Velocity	weak moderate strong	< 1 knot 1 knot to 3 knots > 3 knots
Duration of Ice Coverage	irregular short medium	< 90 days 90 to 150 days > 150 days

3 Methodology

Our work closely followed the suggestions of the WFD Guidance Document on typology. Since most countries will comply with these recommendations we wanted to ensure that our typology generally can be accepted as an umbrella. The Baltic Sea has been defined in the guidance as one Ecoregion – as equivalent to the first classification factor latitude/longitude – and this approach was the basis for our work. Thus, from first obligatory parameters, salinity remained as the main classification factor for the Baltic Sea. The Baltic Sea is a micro-tidal sea and the tidal range is not suitable as a classification factor. Other parameters related to tides, e.g. proportion of the intertidal area, cannot be used for the Baltic Sea as well.

Exposure is a very suitable parameter for open oceanic shores. In a shelf sea with sub-basins, complex coastal structures and many islands, like in the Baltic Sea, this parameter is of limited use. It would create a very small scale pattern of shelter and exposition. Besides there was also no extensive data available covering this aspect within the entire Baltic Sea. Therefore, exposure along the Baltic Sea coast was not considered. The same is true for current velocity. This parameter is very important in systems with pronounced tidal currents. In the Baltic Sea, currents are mainly wind driven, vary very much in time and space and hardly ever reach a force comparable to the Atlantic coast. Therefore this factor is not very suitable for the Baltic Sea. Instead, other parameters, as discussed below, were chosen to differentiate between the open coastal waters and more sheltered areas in the inner coast: lagoon and inner archipelagos.

Information on the duration of the ice cover for the Baltic Sea was considered as a parameter in our typology as well. Ice cover is of importance for the Baltic Sea, since the sea extends from about 54^{o}N to 66^{o}N ranging from temperate to subarctic climate. If the classification ranges given in Guidance Document on the duration of ice coverage were applied to the Baltic Sea, a zone of long ice cover above 150 days could be distinguished in the northern part of Gulf of Bothnia. The rest of the sea could be classified as one class with respect to the duration of ice cover. The ice cover data were supplied in a form of a map by the Finnish Environment Institute (SYKE) based on data about the ice conditions for the winters 1963/64 - 1979/80 - 17 winters in total (FINNISH INSTITUTE OF MARINE RESEARCH 1988). This parameter is important and allows a subdivision of types on a hierarchical level under our umbrella typology. However, it not used in the umbrella typology because of its regional importance limited to the Gulf of Bothnia.

Finally salinity, depth/mixing and water residence time of enclosed areas (residence time) were used as factors in classification of water types. It was agreed within the CHARM project that results of the typology classification should be displayed on maps and the program used was Surfer. A Baltic Sea basemap with a high resolution coastline (1 x 1 km and 100 x 100 m) for the entire Baltic Sea was obtained from the Baltic Sea Research Institute Warnemünde in Germany (IOW). In the present paper the first, coarser map is used. Most long-term data sets used in the project were for the 1990-2000 period.

3.1 Salinity

Salinity was defined as one of the obligatory factors in the WFD and also in the CIS Working Group guidance document, since it is always the first factor defining community composition in every water body and classifications of water bodies into salinity classes have been studied for decades.

The calculation of salinity was done on the basis of data provided by the Department of Systems Ecology, Stockholm University, Sweden (SUSE). It was stored in the Baltic Environmental Database (BED 2002) and the data sets were obtained from institutes from Baltic countries, which participated in the CHARM Project, as well as public data set available in the BED archives.

The calculation was carried out for the period 1990-2000, a period for which the data set is most comprehensive. Only surface data up to the 5 meter depth were considered, in order to achieve comparison between shallow coastal waters and more open, deeper sea areas. The resulting surface salinity for the whole Baltic Sea is shown in Figure 2. Salinity thresholds used to differentiate between types were chosen in line with Water Framework Directive System A and CIS Working Group Guidance ranges and according to the well accepted Venice system:

Freshwater < 0.5 PSU

Oligohaline waters 0.5 – 6 PSU

Mezohaline waters > 6 – 18 PSU

Polyhaline waters > 18 – 30 PSU

Thus, there are three salinity classes in the Baltic Sea typology; from oligohaline to polyhaline waters.

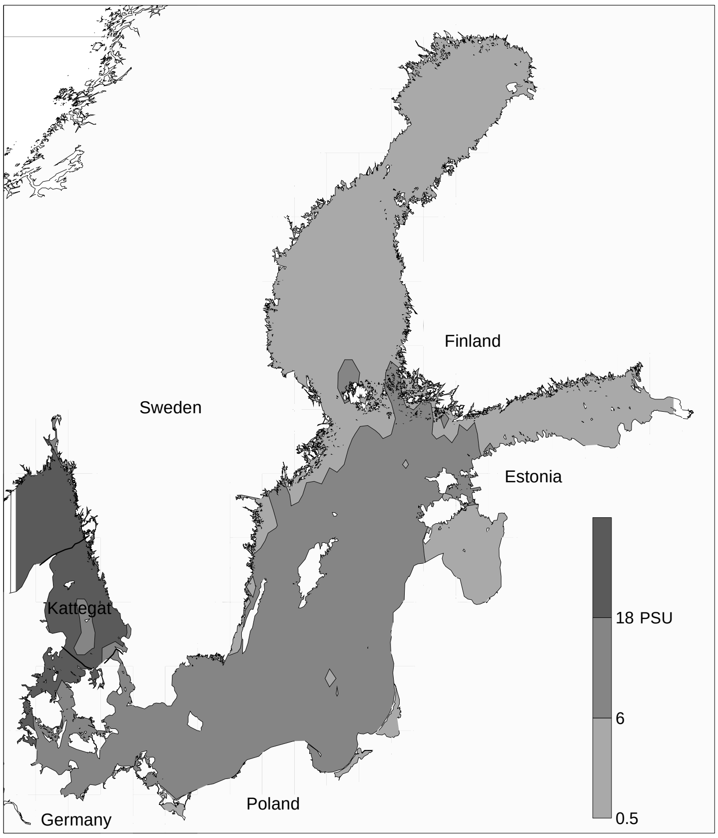


Figure 2: Distribution of salinity in surface Baltic Sea waters up to 5 meters depth. Based on data collected from all institutes participating in the CHARM Project, available via Baltic Environmental Data Base, Stockholm University (BED 2002).

3.2 Water depth

An additional factor used in the typology was depth. Depth is regarded as an important factor in the WFD, e.g according to System A, salinity and depth only can be used as classification factors in typology. Depth affects many other aspects of habitat characteristics such as mixing and stratification of the water column, light penetration and influences sediment characteristic.

A depth model (with a resolution of 2 x 1 nautical miles) for the entire Baltic Sea was provided by T. Seiffert, Baltic Sea Research Institute Warnemünde, Germany (SEIFERT T. pers. comm.). In the CHARM typology it was assumed that the coastal waters delimited by the WFD rules - 1 mn from the baseline - correspond mostly with the 20 m isobath, as shown in Figure 1. It was therefore assumed in the typology for the Baltic Sea Ecoregion that the 20 m is a depth limit for most of the WFD coastal zone. Only within a few locations coastal waters delimited by baseline are deeper than 20 meters and in such locations this typology leaves areas which, if needed, should be further classified as separate types based on the additional depth classes (e.g. under national typologies).

The 20 m isobath is fairly in agreement with the outer limits of the water framework directive, but are not a suitable boundary within a typology. One biologically important parameter is the depth of the thermocline. In a detailed analysis based on results with the Baltic Sea ecosystem model ERGOM showed that the average depth of the thermocline in summer in the Baltic Sea is in a depth of about 10 m. Therefore, the 10 m isobath was used to distinguish the shallow coastal zone, which is always fully mixed within the entire water column from open waters. Also, the 10 m depth threshold describes the euphotic zone in coastal areas, where water transparency is lower than in the open sea areas (AARUP 2002), as well. Thus, the typology has two depth classes dividing coastal waters into waters shallower and deeper than 10 m.

3.3 Residence time and stratification

Water exchange is regarded as an important factor in the coastal sea zone. The water exchange has a great impact on the concentration of substances in the water column and the sediment/water exchange in the system. It is known, that enclosed systems differ from the open coast waters since many chemical as well as biological parameters depend on the water replacement time, both in freshwater and marine systems (NIXON 1996; SCHEFFER 1998). Water exchange was also one of the major factors used in the Swedish typology (JOHANSSON 2002) for which three water classes according to the water exchange time were used: 0-10 days, 10-40 days and > 40 days. This approach in differentiating open coastal waters from enclosed areas and inner archipelagos was used in the present work. On the basis of morphological data from all CHARM partner countries, 91 prioritized semi-enclosed bays/inshore areas in Baltic Sea were delimited as separate geographical units. For these areas, water residence time and stratification calculation were carried out by the use of numerical models. For open waters residence time is not a suitable parameter, because it depends on the size of the area, which is considered.

For the reconstruction of representative forcing, which are relevant for coastal processes, a 3 dimensional baroclinic model of the Baltic Sea was set up for the 10 year period (1991-2000). It simulated the exchange with the open sea for each of the prioritized semi-enclosed bays. Input parameters were freshwater discharge and wind. The data were collected from all countries participating in CHARM for the 1991-2000 period. In order to calculate the stratification and water exchange in the inshore areas in Baltic Sea, a modified version of the WMM model (GUSTAFSSON 2000A; 2000B) was used. The model uses meteorology, freshwater supply, and offshore stratification as input. The model calculations were carried out by Björn Sjöberg from the Department of Systems Ecology at Stockholm University, Sweden (SUSE) for 31 out of 91 prioritized areas. A first very general partition of the coastal zone was made based on estimates of residence time based on the exchange between the open sea (>30 days, 10-30 days and <10 days) and stratification (fully mixed, partially mixed, stratified) was done (Fig. 4). The results were monthly averages of temperature and salinity stratification. Averages are calculated for the whole integration period, 1991-2000. The output has been compared with observations. A dispersion model was also used to estimate turnover time, transition time and age.

In the present CHARM typology only one threshold of the water residence time calculation was used. Enclosed coastal habitats, such as: lagoons and boddens in the western and southern Baltic Proper, as well as the innermost archipelagos located primarily along the Danish, Swedish and Finnish coast, with water residence time longer than 30 days were separated from the open coast with frequent water exchange based on the model calculation for these areas.

3.4 Sediments

Sediment type is a crucial parameter defining bottom habitats. In order to obtain information on the bottom substrate data on surface sediment types were requested from partner institutions, with the aim to establish a database providing information on sediment characteristics with a detailed spatial resolution. However, no raw data sets were made available, mainly due to a lack of data or limited access to existing data. Instead, maps in a digitalized form (at least 1:500000 in scale) were collected for the whole Baltic Sea area. Some regions, namely the coast of Finland, have not yet been surveyed for sediment granulometry in total, therefore, they were not covered. This is why no information is available for the Gulf of Finland, the Bothnian Sea and Gulf of Bothnia. The area covered is presented in Figure 3. This deliverable is available as a series of regional, national and large scale sediment maps, and the general map is split into regional maps - mainly country wide maps - which can be accessed from one source with metadata information. Despite many problems in detail (different size fractions, methods and spatial resolution), bottom sediment maps are useful for the southern Baltic, soft bottom regions. However, along the rocky areas, like in Scandinavia, sediments show high and small-scale variability. The first approaches to introduce soft and hard bottom as a parameter in the typology did not yield satisfying results, because of the high and small scale variability. Therefore the sediment type was not included as a parameter in the whole Baltic Sea typology.

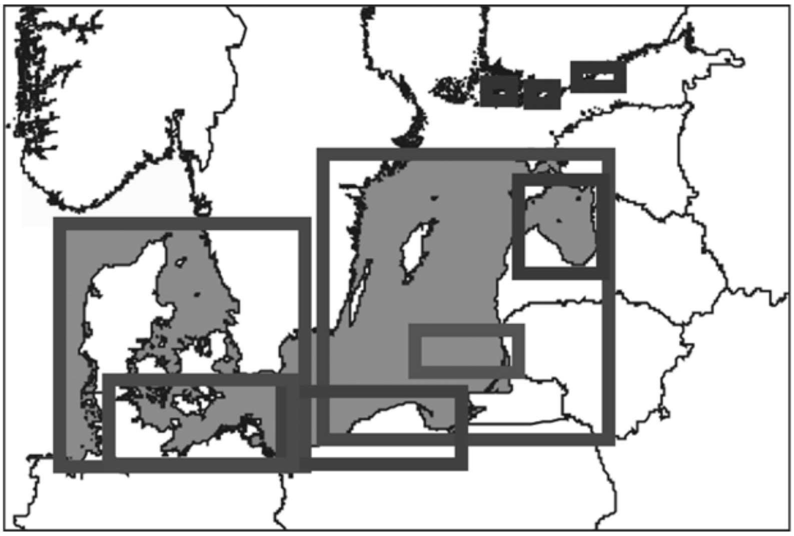


Figure 3: Coverage of the Baltic Sea sediment with sediment maps collected within the CHARM project.

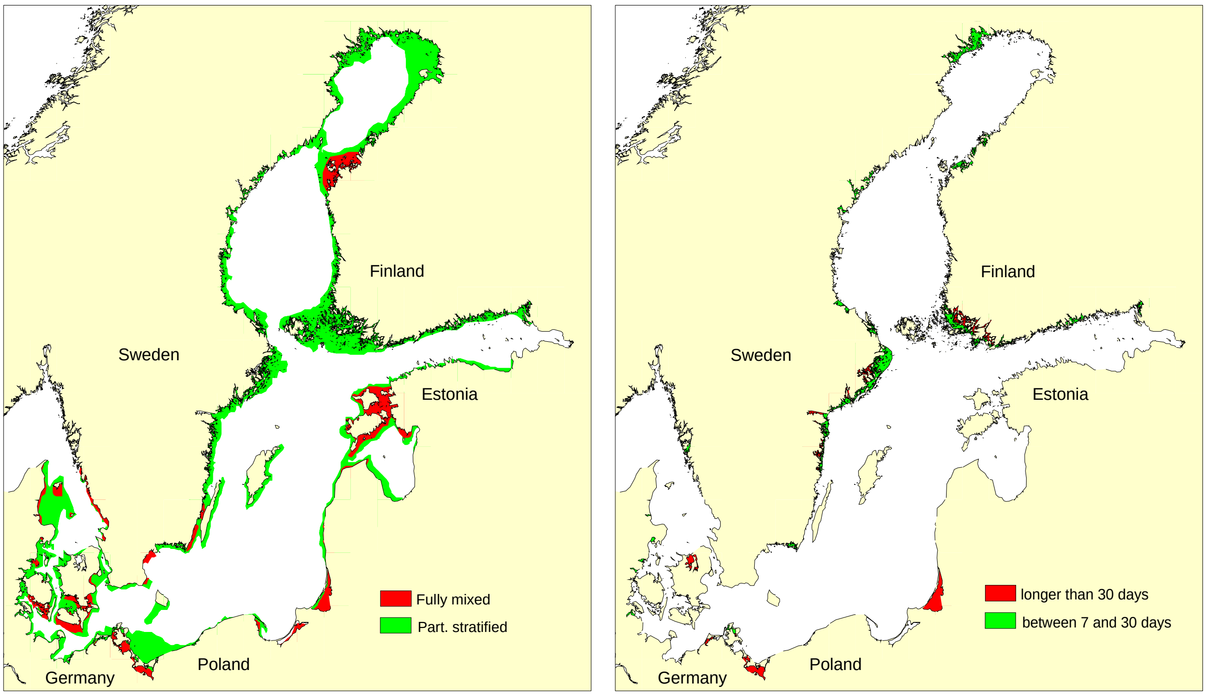
4 A typology for the entire Baltic Sea

The present classification of types within the Baltic Sea is based on three main factors (Fig. 5):

- Surface salinity;
- Water residence time which separates open coast from semi-enclosed bays/inshore areas which were delimited as separate geographical units;
- Depth, which corresponds to the mixing of the water column;
- Since the Water Framework Directive is restricted to a coastal strip of only 1 nautical mile off the baseline, the narrow strip of coastal waters is artificially divided from open waters.

As mentioned before, the Water Framework Directive defines the entire Baltic Sea as one Ecoregion. On the other hand, the WFD is restricted to a coastal strip of only 1 nautical mile off the baseline. The narrow strip of coastal waters is artificially divided from open waters. This division hardly reflects the spatial distribution of biological parameter, it limits the amount of data available for research in support of the WFD and, most importantly favours a large number of independent and hardly comparable national typology approaches. It means that types are truncated artificially and a comprehensive Baltic system concerning reference conditions, water quality classification schemes and monitoring is hardly possible. All these problems arising from the limitation of coastal waters call for a typology which covers the entire Baltic Sea.

Further, this short-coming violates the suggested ecosystem approach for the Baltic Sea as defined in the EC-Marine Strategy. Against the background of the Marine Strategy the WFD approach will have to be extended into offshore marine waters, as well. This would include the operational monitoring of biological and hydro-morphological quality elements as well as hazardous substances. The reference conditions or Ecological Quality Objectives as well as the typology have to be extended towards the open sea. The present CHARM typology is suitable for coastal waters, because the 20m depth isobath was, due to ecological reasons, used to separate coastal and open waters. This 20 m isobath is in very many cases well in agreement with the outer boundary of coastal waters as defined by the WFD. However, our approach allows the extension towards the entire Baltic Sea and a further development (further division) of the open sea waters typology as needed for the EU Marine Strategy. An extension allows a more comprehensive view concerning reference conditions, water quality classification schemes and monitoring. Figure 6 presents the type distribution along the coast of the Baltic Sea and types for the whole Baltic Sea. The 20 m depth line representing the outer limit of the WFD coastal waters is also shown.



Stratification Residence time

Figure 4: Stratification (left) and water residence time (right) in selected inshore areas of the Baltic Sea calculated for the CHARM project (Björn Sjöberg from the Department of Systems Ecology at Stockholm University, Sweden (SUSE)).

Salinity					
0.5 – 6 PSU oligohaline		> 6 – 18 PSU mesohaline		> 18 PSU polyhaline	
Water retention time & Depth	Water retention time & Depth	Water retention time & Depth	Water retention time & Depth	Water retention time & Depth	Water retention time & Depth
> 30 days < 10m	< 30 days < 10m / > 10m	> 30 days < 10m	< 30 days < 10m / > 10m	> 30 days < 10m	< 30 days < 10m / > 10m

Figure 5: Simple umbrella typology for the Baltic Sea according to the WFD.

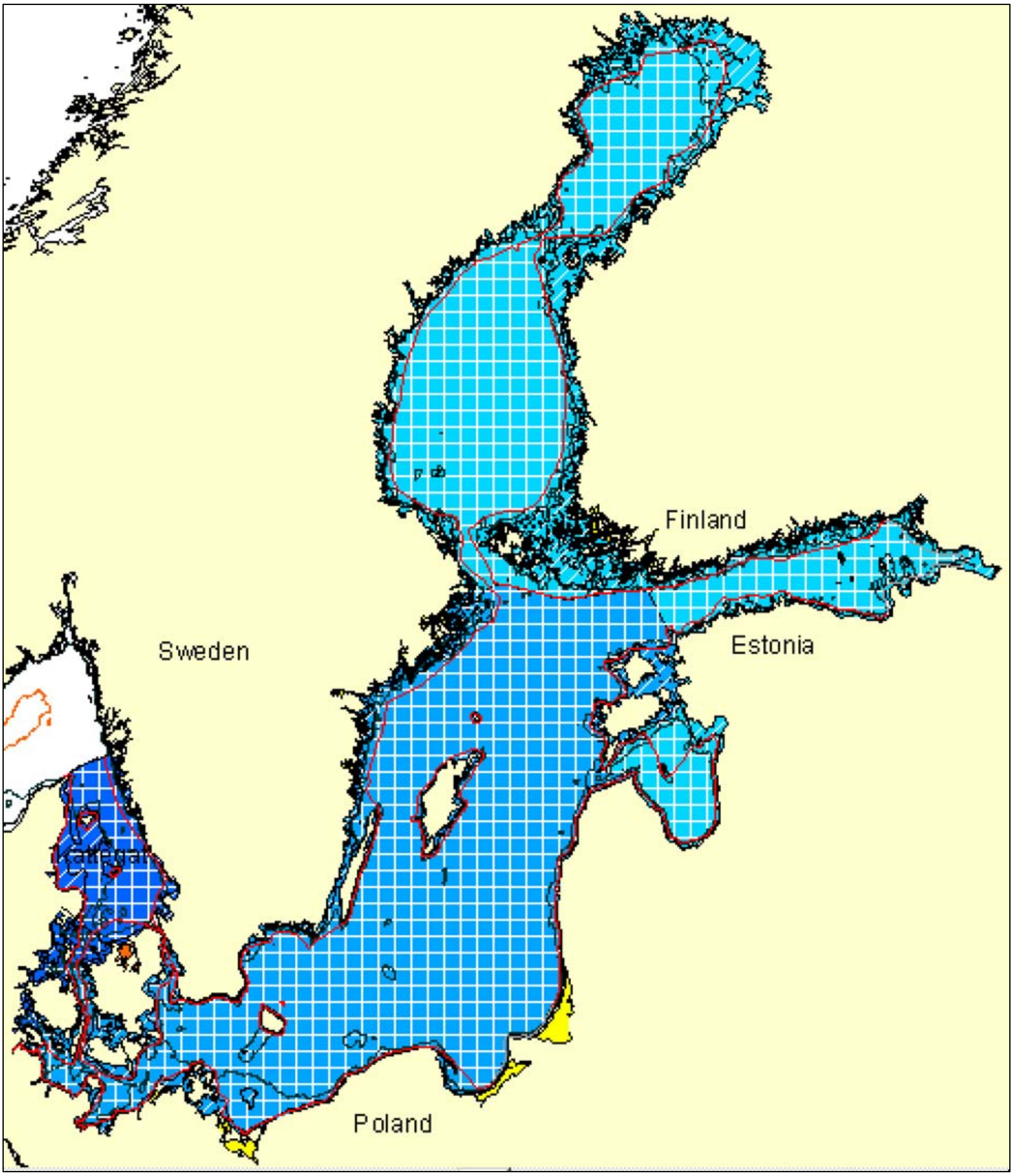


Figure 6: Distribution of types according to the CHARM umbrella Baltic Sea typology.

5 The typology as an umbrella for national typologies

In the first CHARM approach to the Baltic typology the entire Baltic Sea was subdivided into nearly 30 types. The large number of types automatically caused significant differences compared to the national typologies. The acceptance of a complex typology for the entire Baltic Sea was poor and specific regional aspects were not reflected. Against this background we changed our strategy and tried to work out the most important parameters for a typology. We tried to simplify our typology as much as possible and to develop it towards an umbrella system. Umbrella system means that the typology allows a further subdivision according to regional demands and allows the integration of the national typologies. It serves as a link between and integrative element for the national typologies.

The salinity boundaries used in our typology was used by most countries since it is based on the well established Venice system. All national typologies accept the main thresholds from 5 to 6 between oligo- and mesohaline waters and from 18 to 20 PSU between mesohaline and polyhaline waters. The strongest surface salinity gradient occurs between the Kattegat and the western Baltic Proper and salinity plays a very important role in national typologies of this region. In the draft German typology e.g. 3 PSU, 5 PSU in oligohaline class and 10 PSU in mesohaline class was used to subdivide basic four types further. Also, in countries, where all waters are oligohaline additional divisions might be suitable. In the draft Finnish national typology according to system B additional salinity threshold - 4 PSU was used and in the draft Swedish typology, there was also an additional threshold subdividing oligohaline waters – 3 PSU.

All Baltic states have chosen System B of the Water Framework Directive. Except for Germany, none of the national typology presented here is a final version and changes in approach and spatial distribution of types can be expected. However, almost all countries have now drafted prepared their own classification systems for the Baltic Sea waters. Available drafts are compared to the umbrella typology and the classification is discussed below.

5.1 Danish and German draft national typologies

Danish waters belong to the two Ecoregions: North Sea and the Baltic Sea. There are strong salinity gradients in Danish coastal waters due to the specific strong water stratification in Danish Straits region and extension of the coastal waters strip: from the North Sea to the open mesohaline waters of the central Baltic. Therefore, the first factor used for classification in Danish typology is salinity of the bottom layer with the generally acceptable thresholds. Further, the Danish classification is based on the assumption that open waters require use of different factors for classification then enclosed basins such as fiords. Thus, there are two classification systems used in the Danish typology: for open waters and for classification of fjords. Types in open waters are categorized according to:

- Bottom salinity;
- Exposure;
- Tidal regime.

Types in fjords are categorized according to:

- Bottom salinity;
- Degree of stratification;
- Degree of sensitivity to land-based input of water (CHRISTIANSEN et al. this issue); DANISH EPA 2004).

In a very general sense it can be said that the open waters are separated from enclosed waters in the Danish typology and the classification is based on the geographically defined areas. This first step is comparable to the CHARM umbrella approach; however further classification factors used for Danish waters are specific to this national typology (Fig. 7).

The German coast also faces a quite strong salinity gradient in the western part of the Baltic and salinity is the main classification factor in German typology. All open coast waters are classified as mesohaline with the exception of deeper, stratified areas, where bottom waters are of higher salinity classified as separate type – mixohaline waters. The open coast is divided into two types: open and inner mesohaline coastal waters. The inner lagoons and boddens are classified as oligohaline due to the fresh water inflow. Thus, there are four types in the German typology (INSTITUT FÜR ANGEWANDTE ÖKOLOGIE 2003; WEBER et al. 2002). The German typology can be classified within the CHARM umbrella typology (Fig. 8).

5.2 Latvian and Lithuanian draft national typologies

Latvian and Lithuanian coast represents the open sandy or mixed sandy-hard bottom sediment coast of the central Baltic. The Latvian typology considers the following factors: salinity, depth, wave exposure, mixing, residence time, bottom substratum and ice coverage. The governing factors in the Latvian typology are salinity and substratum. Water salinity in the coastal water of Latvia is in general lower then 6 PSU within the Gulf of Riga and along the open Baltic coast exceeds this value (ALBINUS et al. 2004). Thus, there are two salinity classes in Latvian typology. Division into two classes according to salinity reflects also wave exposure, since waters within the Gulf of Riga were classified as moderately exposed and the outer Baltic coast as exposed. Latvian coastal waters as defined by the WFD usually do not exceed 10 - 15 m depth along whole Latvian coast (with one exception when the coastal water stretch has mean depth of about 13 m), and the average depth is 7 m (ALBINUS et al. 2004). Within the salinity classes it is substratum that defines water types along the cost and coastal water stretches have been identified according to the dominant bottom type (ALBINUS et al. 2004). The Latvian typology can therefore be included into the CHARM umbrella classification as shown in Figure 10.

The Lithuanian typology considers similar factors (ANSBÆK & SCHWÆRTER 2004): salinity, depth, wave exposure, mixing, and bottom substratum. The open Lithuanian waters are classified as mesohaline. The other governing factor used for open coast classification is bottom substratum. The Curonian Lagoon is classified in the Lithuanian typology as transitional waters, but the open coast classification – which is not complex in the Lituanian part of the Baltic coast – can be classified under the CHARM umbrella (Fig. 9).

Both in the Latvian and Lithuanian typologies the large river plumes (the Daugava River and the outlet of the Curonian Lagoon) are classified as transitional waters. This is a different approach to the approaches taken by most other countries and also differs to the CHARM approach, and it calls for additional classification means – such as e.g. defining the river plume border.

5.3 Estonian draft national typology

The Estonian typology considers the following factors: salinity, depth, wave exposure, mixing, residence time and bottom substratum (ESTONIAN MINISTRY OF THE ENVIRONMENT 2004). Salinity is the first classification factor, based on the Venice system. The open coast and the western part of Gulf of Finland are considered to be mesohaline up to 5/6 PSU and there are two oligohaline types, along the most inner parts of cost: Parnu Bay (in the Gulf of Riga) and the Narva Bay (in the Gulf of Finland). The mesohaline waters are further divided according to the depth, into two classess: < 30 m and > 30 m. The next governing factor used is wave exposure. All types are also described with respect to mixing conditions, residence time and bottom substratum. This is a classification system similar to CHARM approach (Fig. 11).

5.4 Finnish draft national typology

Finnish coastal waters can be classified into two types based on salinity: oligohaline and mesohaline, and most of the coastal strip is shallow. For the Finnish typology the System B was chosen since classification according to System A was found to be too coarse (FINNISH COASTAL EXPERT GROUP

2001; PERUS et al. this issue). This proposal suggested 16 coastal water types (Fig. 12); based on salinity and latitude – longitude, duration of ice coverage, mean bottom substratum type and mixing conditions as well as wave exposure. Finally, some archipelago areas were differentiated after analysis of topographic complexity and zonation patterns (PERUS et al. this issue). This approach can be classified to a certain degree under umbrella typology as presented in Figure 12.

5.5 Swedish draft national typology

Sweden has the longest coast line amongst all Baltic countries stretching in the all three salinity classes from polyhaline waters in Kattegat to oligohaline waters in the Gulf of Bothnia with a complex coast structure. In the Swedish national typology non-hierarchical approach is used and types are classified on the basis of two or tree governing factors out of the following list: salinity, water exchange of bottom waters, substratum, stratification, wave exposure, ice days. Depth is also considered for the type description. Salinity is considered for most regions as a main governing factor. To differentiate between open coast areas and inner, more enclosed cost types, wave exposure and water exchange are considered as factors defining types, but in some other regions bottom substratum and stratification are taken into account. In the Gulf of Bothnia one of the main governing factors is ice cover (SWEDISH EPA 2004). This is a different strategy than hierarchical approach used in other countries, and also differs from the CHARM approach (Fig. 13 and Fig. 14).

6 Water bodies as management units of the WDF

A detailed look at the suggested typology reveals that the present ecological state of coastal waters varies significantly within a type. Types reflect coastal waters with similar framework conditions and a similar potential ecological state. Recent anthropogenic pressures, like point sources or rivers, cause very different ecological situations within one type. These anthropogenic pressures are variable in time and space and therefore not suitable to be directly included in a typology. For example, many rivers show an ongoing serious reduction of their nutrient loads. The size of river plumes, measured in form of elevated nutrient levels are decreasing and the same is true for their general impact on coastal waters. Therefore, the water body concept allows a subdivision of coastal water types according to the existing external pressures and the visible modifications of the ecological state. Different to the typology, water bodies are not fixed in time and space. Their boundaries require an adaptation from time to time, according to the changes that took place in a coastal region. Water bodies can be regarded as a flexible subdivision of types suitable for management purposes. The following cases show how water bodies can create a refined subdivision of coastal types (Fig. 15 and Fig. 16).

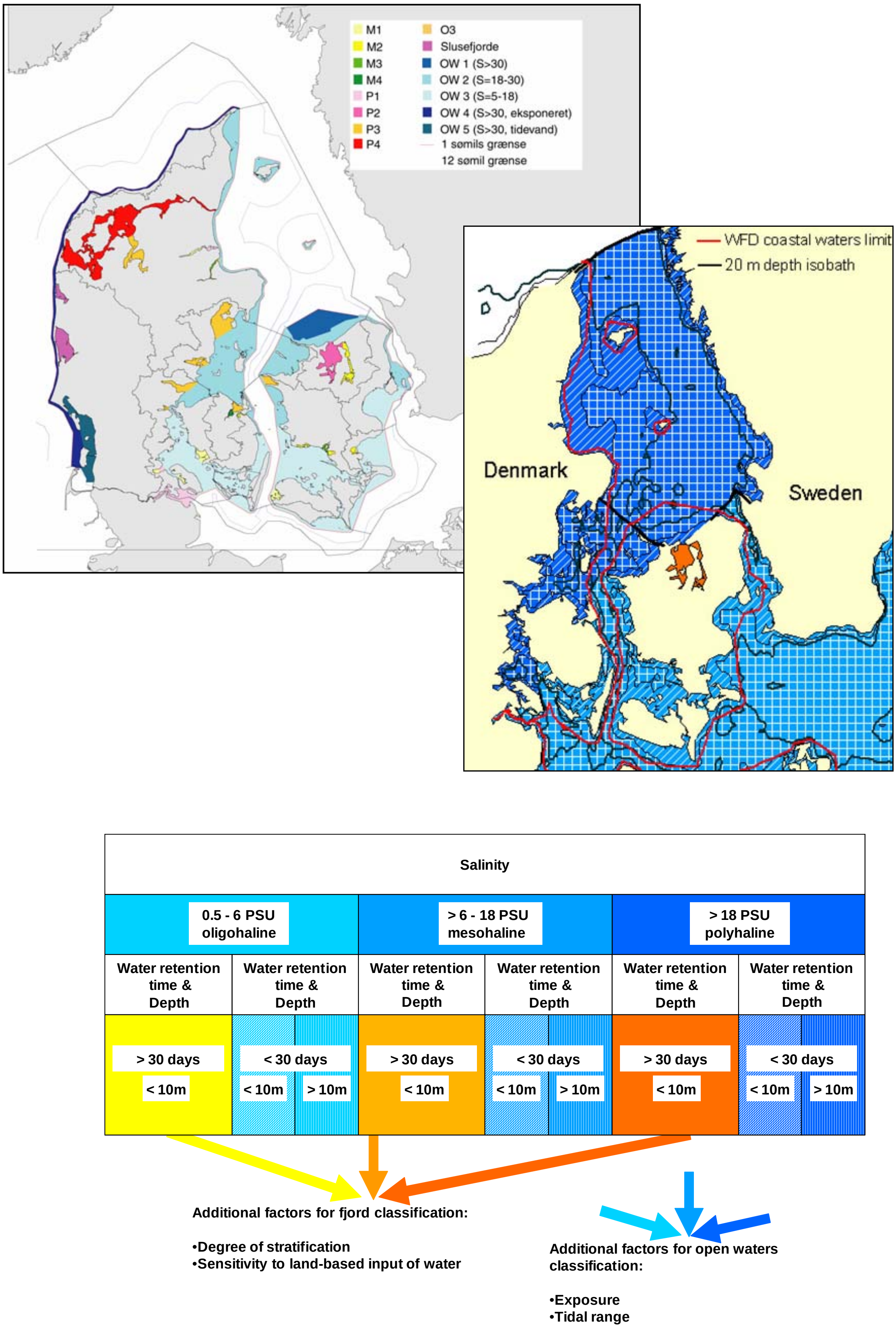


Figure 7: National Danish typology (after DANISH EPA 2004) as compared to the CHARM umbrella typology for the Baltic Sea.

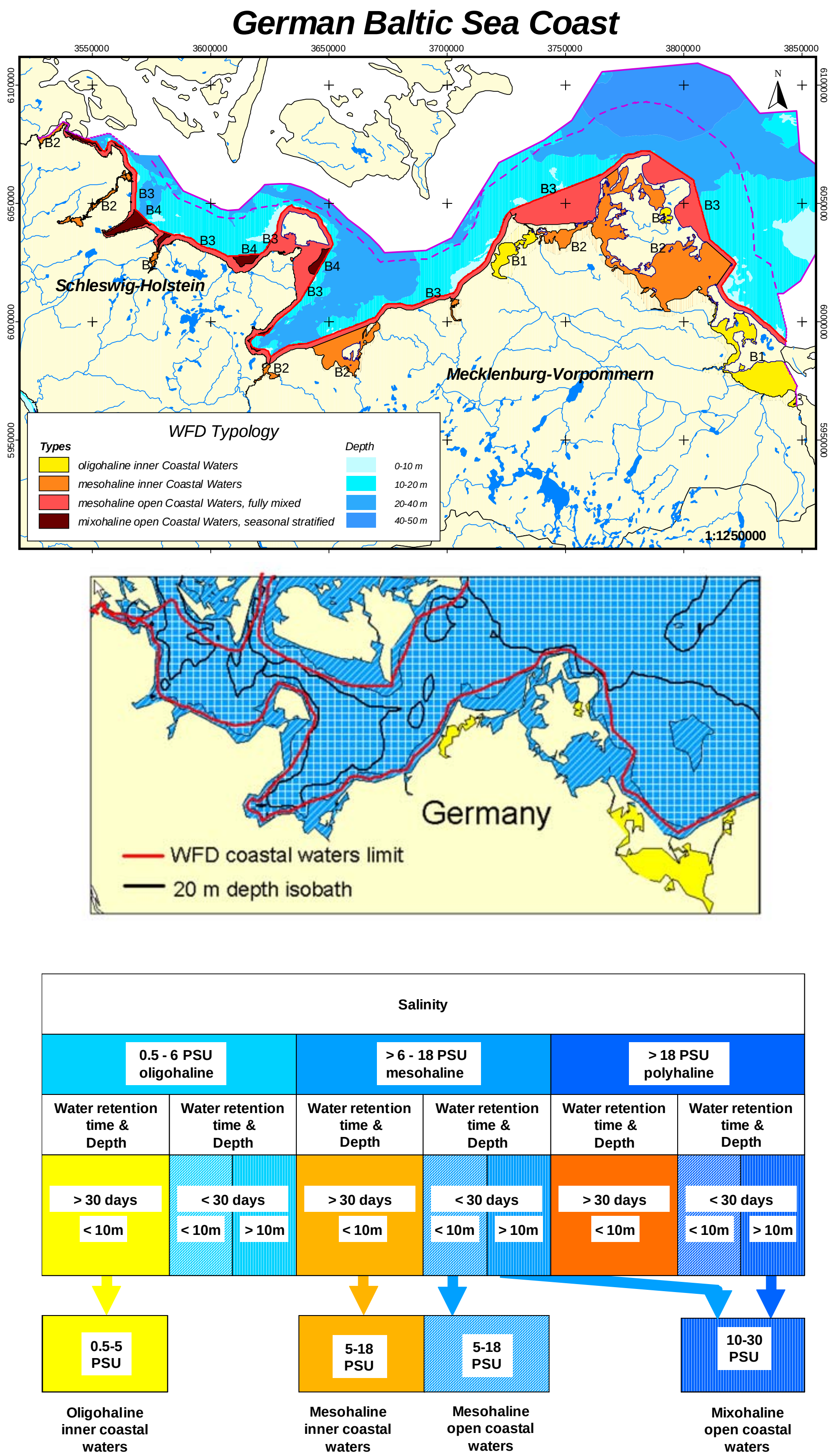


Figure 8: National German typology (after INSTITUT FÜR ANGEWANDTE ÖKOLOGIE, 2003; WEBER et al., 2002) as compared to the CHARM umbrella typology for the Baltic Sea.

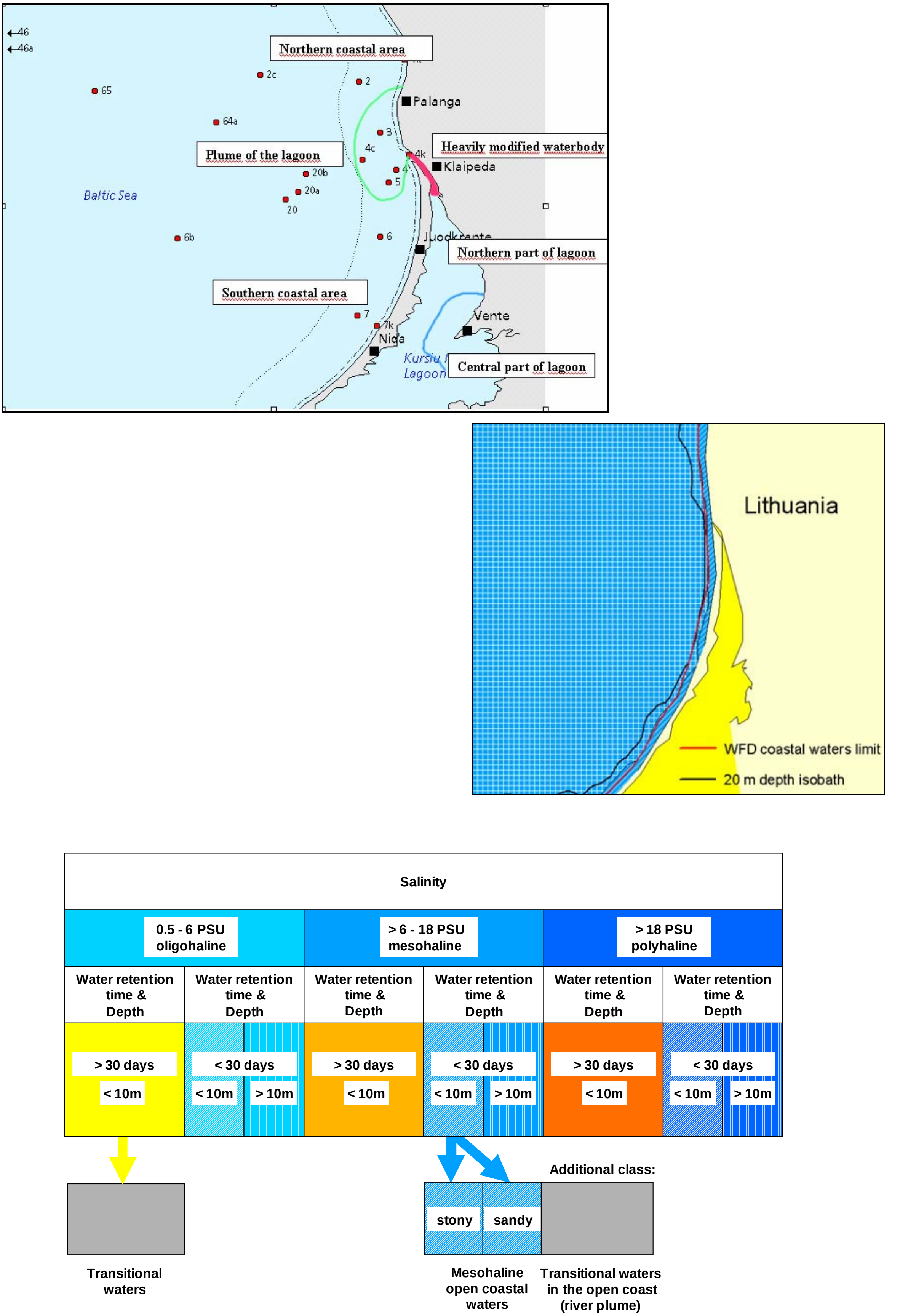


Figure 9: National Lithuanian typology (after ANSBÆK & SCHWÆRTER, 2004) as compared to the CHARM umbrella typology for the Baltic Sea.

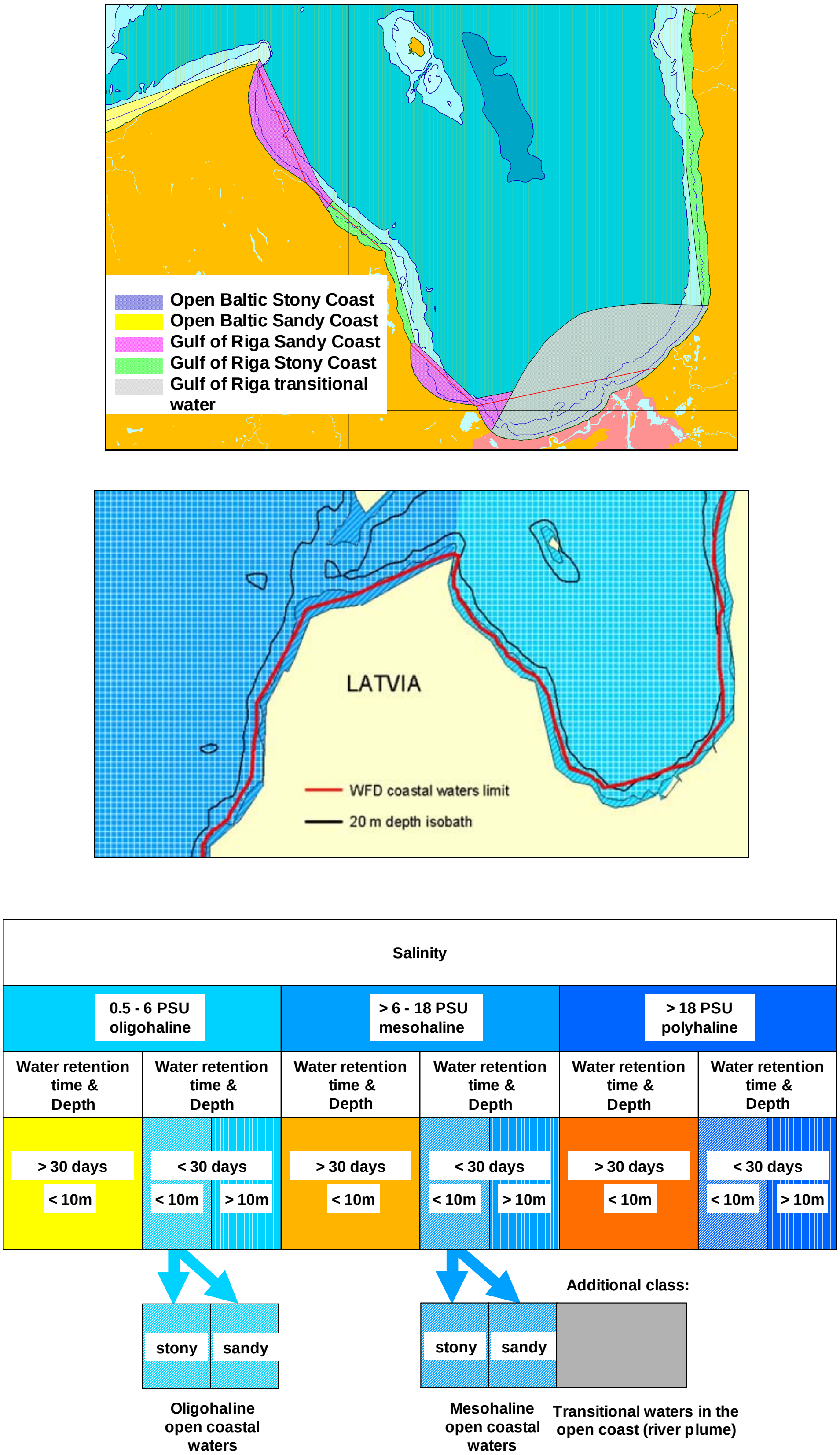


Figure 10: National Latvian typology (after ALBINUS et al. 2004) as compared to the CHARM umbrella typology for the Baltic Sea.

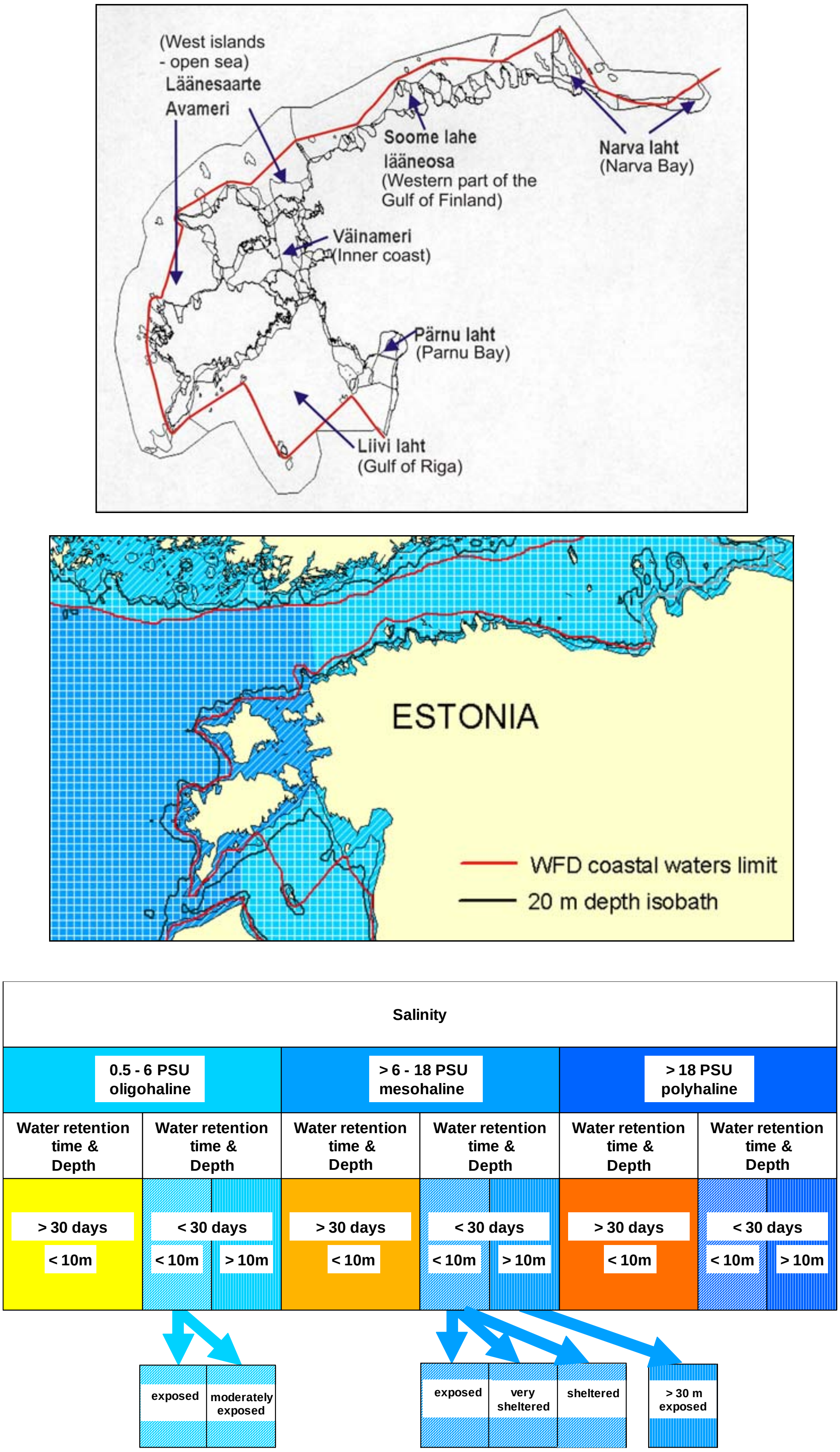


Figure 11: National Estonian typology (after ESTONIAN MINISTRY OF THE ENVIRONMENT, 2004) as compared to the CHARM umbrella typology for the Baltic Sea.

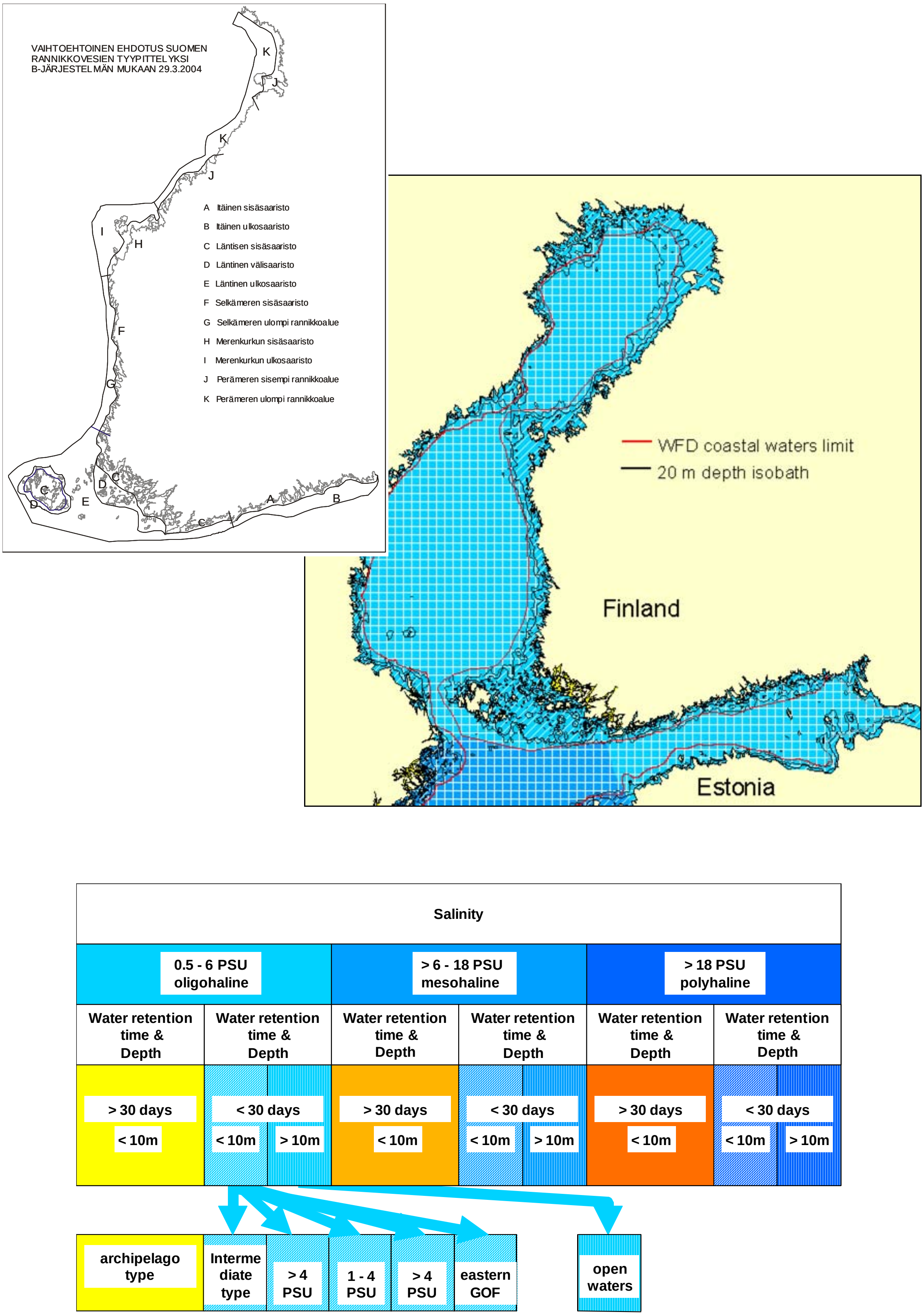
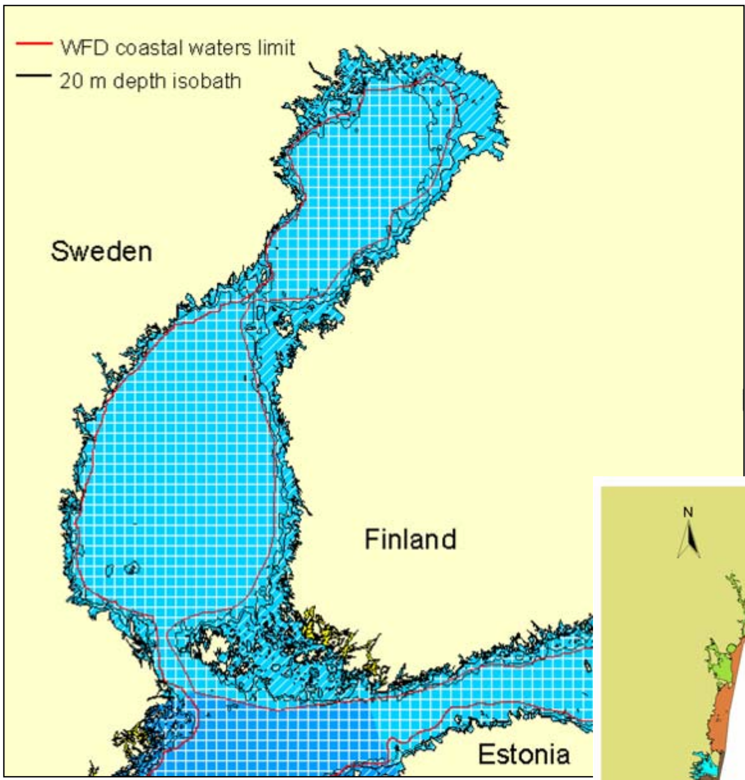
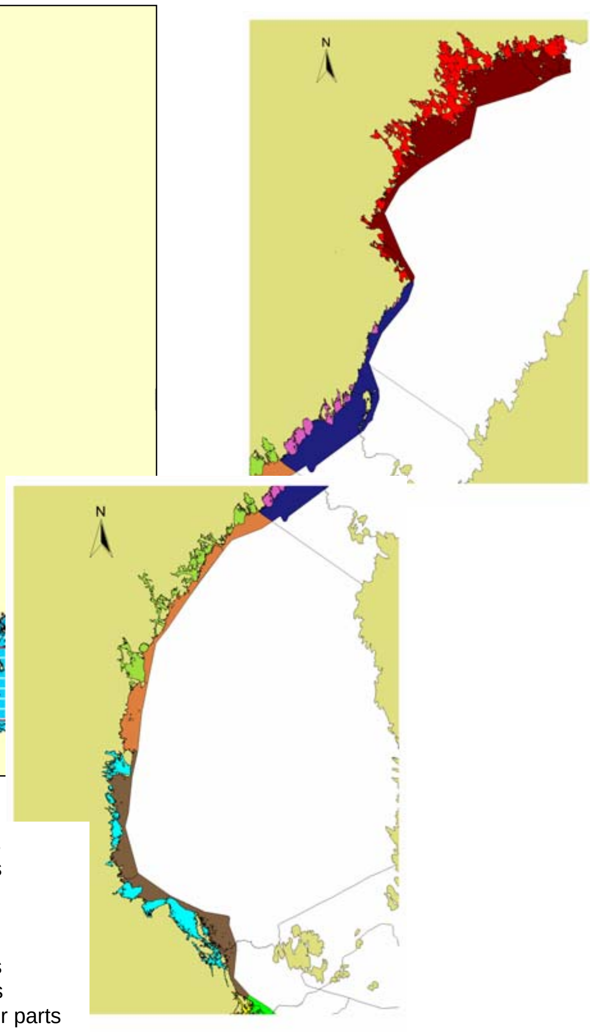


Figure 12: National Finnish typology (after FINNISH COASTAL EXPERT GROUP 2001; PERUS et al. this issue) as compared to the CHARM umbrella typology for the Baltic Sea.





- Coastal waters of south Bothnian Bay, inner parts
- Coastal waters of south Bothnian Bay, outer parts
- Coastal waters of north Bothnian Bay, inner parts
- Coastal waters of north Bothnian Bay, outer parts

- Coastal waters of south Bothnian Sea, inner parts
- Coastal waters of south Bothnian Sea, outer parts
- Coastal waters of north Bothnian Sea, Höga, inner parts
- Coastal waters of north Bothnian Sea, Höga

Salinity					
0.5 - 6 PSU oligohaline		> 6 - 18 PSU mesohaline		> 18 PSU polyhaline	
Water retention time & Depth	Water retention time & Depth	Water retention time & Depth	Water retention time & Depth	Water retention time & Depth	Water retention time & Depth
> 30 days	< 30 days	> 30 days	< 30 days	> 30 days	< 30 days
< 10m	< 10m / > 10m	< 10m	< 10m / > 10m	< 10m	< 10m / > 10m

Swedish typology uses non hierarchical approach with following factors:

Salinity	Wave exposure
Water exchange - bottom waters	Substratum
Stratification	Ice days

Figure 13: National Swedish typology (after SWEDISH EPA 2004) as compared to the CHARM umbrella typology for the Baltic Sea – oligohaline waters.

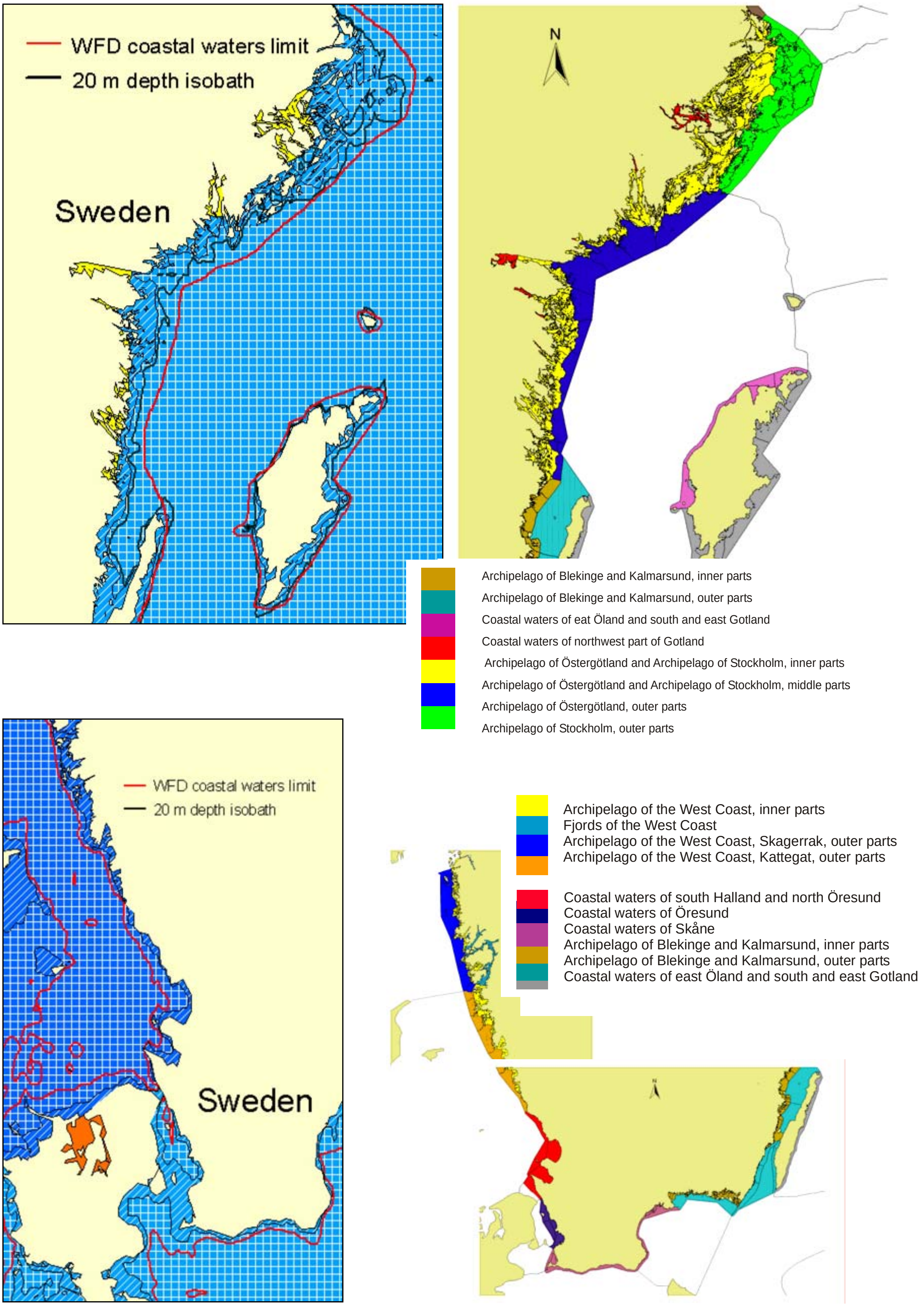


Figure 14: National Swedish typology (after SWEDISH EPA 2004) as compared to the CHARM umbrella typology for the Baltic Sea – mesohaline and polyhaline waters.

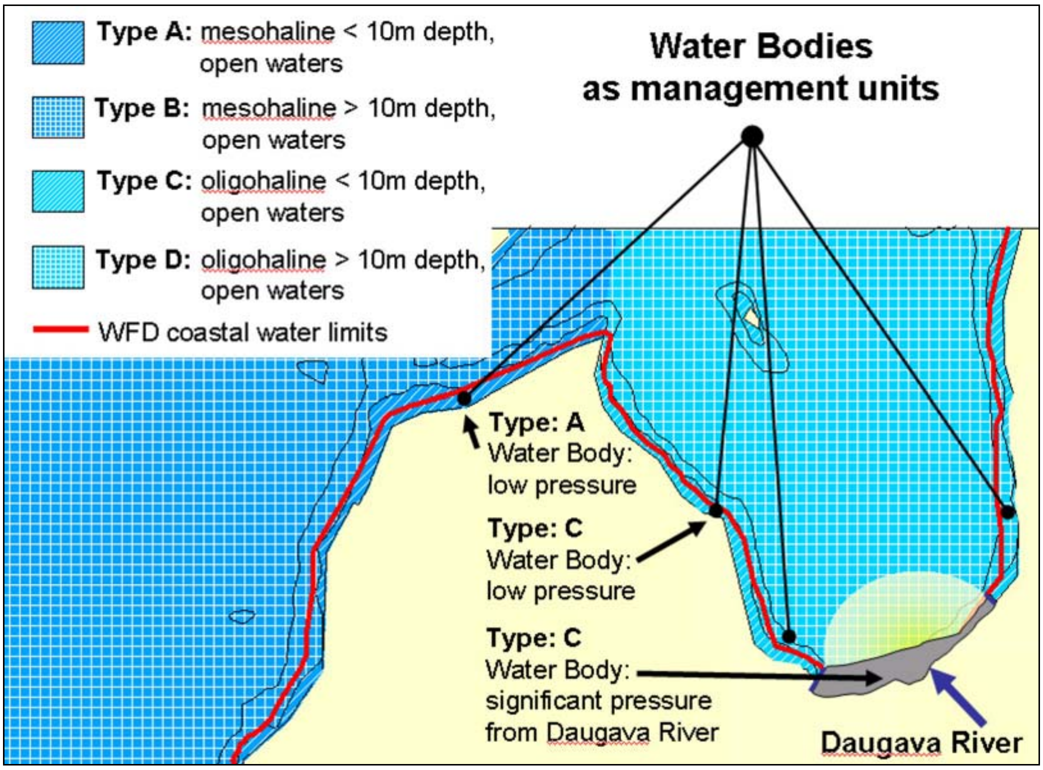


Figure 15: Designation of water bodies as management units of the WDF based on environmental preassure; example of Latvian coastal waters.

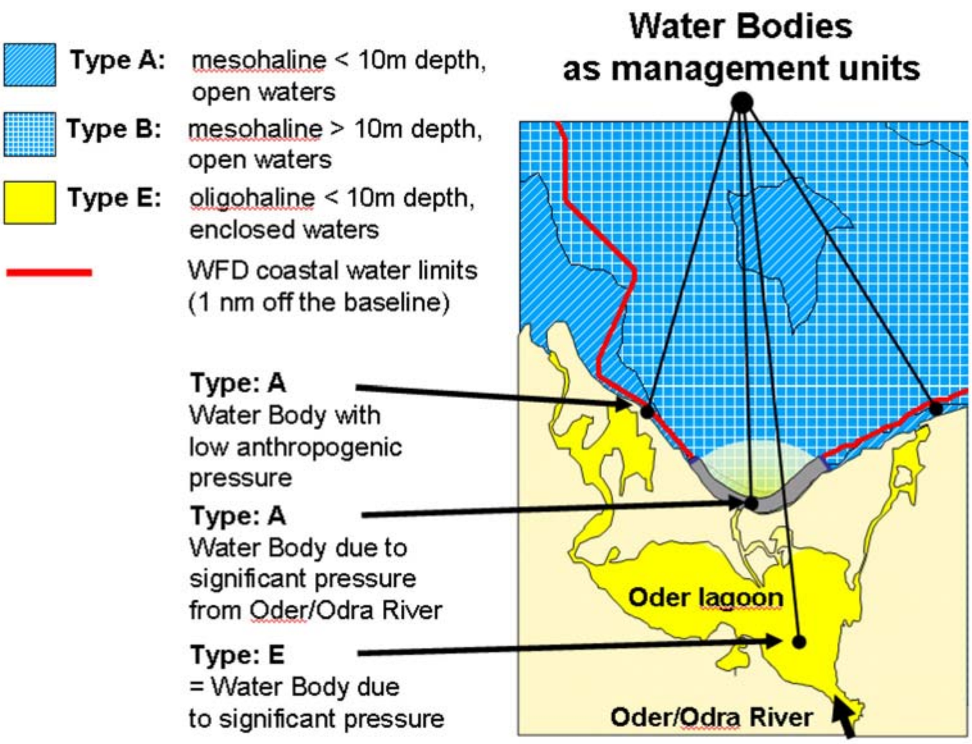


Figure 16: Designation of water bodies as management units of the WDF based on environmental preassure; example of the Oder estuary.

Acknowledgement and data sources

This work was supported by the EU-project CHARM (Contract no.: EVK3-CT-2001-00065). The CHARM work is based on contributions from the institutes participating in the CHARM project:

- National Environmental Research Institute (NERI)
- Finish Environmental Institute (FEI)
- Aabo Akademi University (AAU)
- Environmental Institute, Joint Research Centre (JRC/EI)
- Klaipeda University, Coastal Research & Planning Institute (CORPI)
- Baltic Sea Research Institute, Warnemünde (IOW)
- Estonian Marine Institute (EMI)
- University of Latvia, Institute of Aquatic Ecology (IAE)
- Stockholm University, Department of System Ecology (SUSE)
- Sea Fisheries Institute (MIR)
- University of Greifswald (EMAUG)

The data used for salinity calculation was supplied by the Department of Systems Ecology, Stockholm University, Sweden. It was stored in the Baltic Environmental Database (BED). Different research institutes contributed to BED by providing data from several monitoring programs.

The project "IKZM-Oder" funded by the Federal Ministry of Education and Research (No. 03F0403A) supported the continuation and publication of the updated work.

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Address

Priv.-Doz. Dr. habil. Gerald Schernewski
Institut für Ostseeforschung (IOW)
Seestraße 15
18119 Rostock-Warnemünde
Germany

E-mail: gerald.schernewski@io-warnemuende.de

G. Schernewski & M. Wielgat (eds.): Baltic Sea Typology
Coastline Reports 4 (2004), ISSN 0928-2734
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Coastal marine zoobenthos as an ecological quality element: a test of environmental typology and the European Water Framework Directive

Jens Perus[1], Saara Bäck[2], Hans-Göran Lax[3], Vincent Westberg[3], Pirkko Kauppila[2] & Erik Bonsdorff[1]

[1]Environmental and Marine Biology, Åbo Akademi University, Turku, Finland
[2]Finnish Environment Institute, Helsinki, Finland
[3]West Finland Regional Environment Centre, Vasa, Finland

Abstract

The European Water Framework Directive focuses on the importance of biological and ecological quality elements (phytoplankton, macroalgae, zoobenthos and fish) in classification of the ecological status (EcoQ) of surface waters within Europe. Most surface waters typologies are constructed based on hydro-morphological factors while the EcoQ is based on the status of the biological, hydro-morphological and physico-chemical quality elements, with the importance of biological elements emphasised.
A crucial question is whether a typology constructed on hydro-morphological factors reflects the characteristics of the quality elements to be used in the assessing the EcoQ, i.e. whether "ecology" follows "typology".
This contribution presents a test on the possible coupling between a proposed typology based on hydro-morphological data and the community assemblages of an ecological quality element, namely macrozoobenthos, for the Finnish Baltic Sea coastal waters under the WFD.

1 Introduction

Nutrient enrichment has been the major threat to the environmental health of coastal marine waters on a global scale for the last 30 years (NIXON 1995; CLOERN 2001; ELMGREN 2001). National and international initiatives and treaties have been agreed upon to combat this threat locally and globally. Recently new legislation was brought forward within Europe, the European Union's Water Framework Directive (2000/60/EC) (ANON 2000). The Water Framework Directive (WFD) establishes a framework for the protection of all waters (including inland surface waters, transitional waters, coastal waters and groundwater). Overall, the directive aims at achieving good ecological status for all waters by the year 2015 and all EU Member states are therefore required to protect and enhance the status of all types of water. Member states are to assess the ecological status (EcoQ) of these water bodies. The EcoQ is based on the status of the biological, hydro-morphological and physico-chemical quality elements, with the importance of biological elements emphasised. Biological elements to be used in coastal marine and transitional waters are phytoplankton, macroalgae, benthos and fish (the latter only in transitional waters).

The WFD requires surface waters to be split into water bodies, representing the classification and management unit of the Directive (BORJA et al. 2004). The Baltic Sea is defined as one Ecoregion under the WFD and its water bodies can belong to one of six surface water categories (e.g. rivers, lakes, transitional waters, coastal waters, artificial and heavily modified water bodies), which are subdivided into types into which the surface waters are later assigned. The water bodies of one type can be sub-divided into smaller units according to pressure and resulting impact (VINCENT et al. 2002). Water bodies within each surface water category are differentiated according to type using a system of typology as defined in the WFD. The use of both obligatory factors (A-system: latitude, longitude, tidal range and salinity) and optional factors (B-system: depth, wave exposure and other factors) are recommended until an ecologically relevant type of water with unique characteristics is achieved (VINCENT et al. 2002). This typology process has been tested at a Baltic Sea level within the EU-project "CHARM" (Characterization of the Baltic Sea Ecosystem: Dynamics and Function of coastal types; http://charm.dmu.dk) as well as at national level in all countries affected by the EU WFD legislation. This work requires a close link to ecology: The crucial question is whether a typology constructed on hydro-morphological factors reflects the characteristics of the ecological quality elements to be used in the assessing the EcoQ, i.e. whether "ecology" follows "typology", and whether it should, in fact, be the other way around.

The aim of this study is to test the coupling between the proposed typology built on hydro-morphological data and the community assemblages of an ecological quality element, namely macrozoobenthos, for the Finnish coastal waters under the WFD.

1.1 Characterization of Finnish coastal waters

In the Finnish national characterization process, **System A** was found to be too simplistic, providing only a crude differentiation between potential types. The system produced only three different types based on salinity and depth (SCHERNEWSKI & WIELGAT 2004). The lack of differentiation is due to the fact that most of Finnish coastal waters belong to the depth class ≤ 30 m and that salinity is within one of two categories: oligohaline (salinity < 0.5 or 0.5-5 PSU) or mesohaline (salinity 5-18 PSU). System A also characterized two remote and separate areas, namely the Bothnian Bay/Quark and the eastern Gulf of Finland as one common type, whilst the Archipelago Sea, Bothnian Sea and western Gulf of Finland formed another. Based on expert judgment (Finnish National Committee for coastal waters; SYKE), this kind of environmental typology does not form a sensible basis for reliable ecological classification.

System B created a more sensible array of types and was found better suited for the characterisation of Finnish coastal areas. This proposal (KANGAS et al. 2003) suggested 16 coastal water types (Fig. 1)**.** The coastal waters were first split into four types based on salinity and location (latitude and longitude). The resulting typology, where the Bothnian Bay and the eastern Gulf of Finland were assigned into the same type, was not considered adequate to represent the ecological communities along the coast. Therefore, each of the separate sections of the coast (Gulf of Finland, Archipelago Sea, Bothnian Sea, Quark and Bothnian Bay; Fig. 1) was divided into separate types using the duration of ice coverage and, to a lesser extent, mean substratum composition (i.e. rocky or sandy coasts, muddy or stony bottoms, etc.). Finally, each of the sections of the coast was split into an outer open zone and an inner coastal zone based on mixing conditions and wave exposure, which was derived from the density of islands, openness of water areas and mean water depth. The Archipelago Sea could be split further into inner, middle and outer zones due to its topographic complexity and zonation patterns described both for the biota (BONSDORFF et al. 1996; 2003; HÄNNINEN & VUORINEN 2001; O´BRIEN et al. 2003; PERUS & BONSDORFF 2004) and hydrography (JUMPPANEN & MATTILA 1994; BONSDORFF et al. 1997; HÄNNINEN et al. 2000).

For the entire Baltic Sea a separate **CHARM Typology** was also created as a basis for a common ecological environmental quality testing, and developing a joint monitoring strategy for all coastal waters of the Baltic Sea. This typology is intended to serve as an umbrella and be a basis for further more detailed splitting of water areas on national basis. In this classification salinity is the main factor along with depth/mixing and water residence time of enclosed areas (SCHERNEWSKI & WIELGAT 2004). This approach produced 4 water types for the Finnish coast.

In this analysis, the original national division (16 types; Fig. 1) is used and tested against soft-bottom macrozoobenthos (species composition, number of species and abundance patterns).

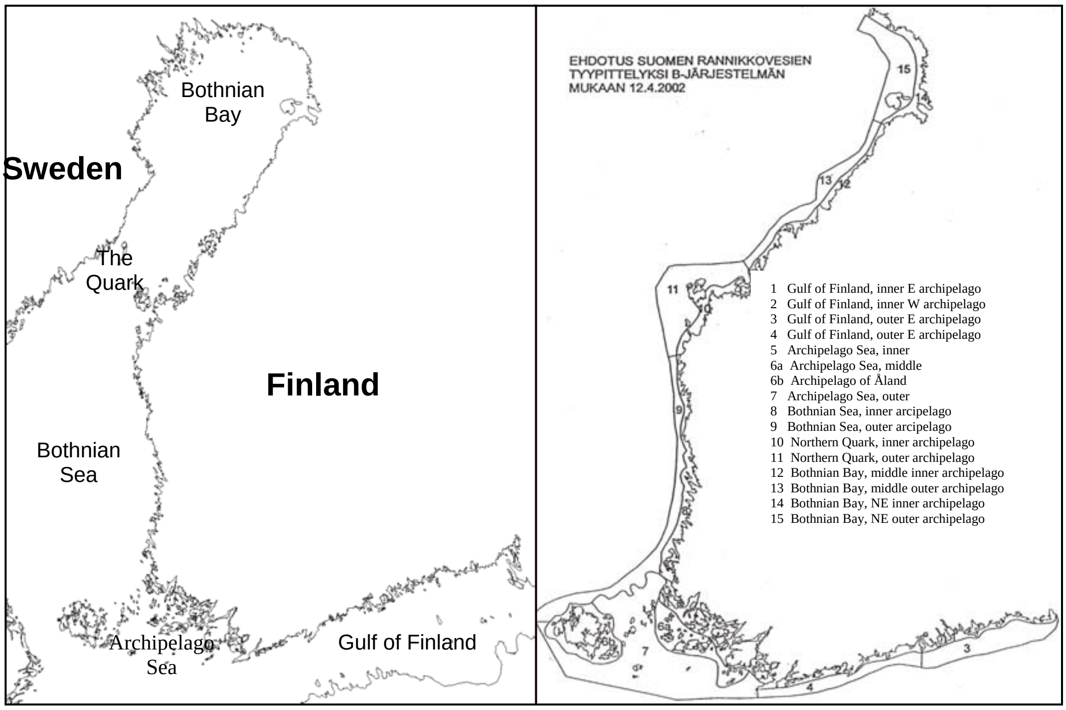

Figure 1: Finnish coastal regions and the proposed Finnish typology under the WFD (Maps from the Finnish Environment Institute, SYKE).

2 Methods

2.1 Monitoring data used

In order to be able to potentially confirm environmental typology with the use of biological data, in this case macrozoobenthos, there is a need for expert knowledge and large amounts of reliable data. Finnish coastal waters have been monitored for decades and the longest annually sampled stations were started already in 1964 for one pair of sampling-stations (KARJALA & LASSIG 1985). Monitoring can either be targeted on recipient studies of anthropogenic impact or on follow-up of the changes in relative health of coastal areas and ecosystems. Available databases of the ecological quality elements were analysed, and for macrozoobenthos data-gathering and subsequent quality-control had to be done from zero, and data requests were sent out to national, regional and local authorities, consulting firms and universities conducting monitoring- or research-studies. The database contains station-wise information about geographical position (coordinates, sea area and type), sampling date, station ID, monitoring programme, depth, number of replicates, sieve mesh-size, method of preserving samples, species, abundance, and biomass. ICES nomenclature has been applied for species, genera and higher taxa.

The benthic database today contains of some 8000 inputs from about 1000 individual stations data, spatially covering the entire Finnish coastline. The bulk of data covers the time period 1990-present.

2.2 Test of zoobenthos and typology

A test was carried out comparing the possible agreement between the proposed typology built on only hydro-morphological data and the community assemblage of the ecological quality element, macrozoobenthos.

Quality-assured abundance data was used from the database covering the time-period 1990-2000. The taxonomical resolution of some taxa was unevenly reported in the different studies and hence in the current analysis species within the family *Chironomidae* and the class *Oligochaeta* have been pooled as one each in order to standardise the data and thereby avoiding comparing the individual skills of taxonomists between geographical areas or between taxa. Only data collected with a mesh-size < 0.6 mm was used.

Abundance data was grouped into ≤10m and >10m depth-strata and divided into types assigned *a priori*. Depth plays an important role in structuring the coastal ecosystems. The choice of 10 meters as a separator was based on the knowledge that the average depth of the thermocline in the summertime in the northern Baltic Sea is at about 10m. The 10m depth threshold also reflects the euphotic zone in most coastal areas and sets the limit on the depth of the littoral zone. This depth limit, perhaps not as important for macrozoobenthos as for macroalgae and phytoplankton, will thus help compare results for similar future studies on the other two quality elements. This separation was also done in order to check for the possibility to identify type-specific community-assemblages both in the littoral zone as well as in deeper residing areas. Types were deemed significantly different if benthic community-assemblages from both depth classes showed similar interpretations, i.e. higher inter-type variation than intra-type. Types tested against each other were either neighbouring types, types within mosaic archipelago regions, types residing within common subbasin or distant types having similar hydromorphological characteristics such as salinity.

Abundance data was square root-transformed and analysed using non-parametric multidimensional scaling (MDS), analysis of similarity (ANOSIM) and similarity percentage (SIMPER) – analysis methods included in the PRIMER software (CLARK & WARWICK 1993; CLARKE & GORLEY 2001).

The ANOSIM-analysis used for testing for assemblage differences between groups of samples (types), specified *a priori*, puts no restrictions on a balanced number of replicates (CLARK & WARWICK 1994). Comparison of pairwise R values, measuring how separate groups are, on a scale of 0 (indistinguishable) to 1 (all similarities within groups are less than any similarity between groups) gives an interpretable number for the difference between groups. We interpreted R-values >0.75 as well separated; R>0.5 as overlapping, but clearly different and R<0.25 as barely separable at all, in accordance with the PRIMER-manual (CLARKE & GORLEY 2001). A SIMPER-analysis was used for identifying which species primarily account for observed differences in benthos assemblages between types. This routine also identifies species typical of a specific environmental type.

3 Results

The results showed that an environmental typology constructed solely by using factors in System B reflects the community assemblage of one of the quality elements, macrozoobenthos, reasonably well. However, there were some areas along the Finnish coastline where these two aspects did not match.

3.1 The Finnish coast

According to the definition of "coastal waters" in the WFD, Finland has a 1300 km long coastal zone (under the WFD), which comprises 34 000 km^2 of coastal waters. Below follows a brief description of the characteristics of the regions in which the different types have been defined, according to system B in the Finnish national coastal typology (KANGAS et al. 2003; Fig. 1).

3.1.1 The Gulf of Finland

The Gulf of Finland is defined as the area east of the uttermost tip of the Hankoo peninsula. In the gulf salinity ranges from 3 to 6 PSU. For typology-purposes, the gulf is split at the 5 PSU border. Extent of ice cover 60-150 d a^{-1} and level of exposure were used to divide the region into 4 categories of environmental classes (Types 1-4) within the Gulf of Finland. The eastern inshore type (Type 1) is shallow (average depth 15m) and consists of a variety of highly different environments. The shoreline is broken with many semi-enclosed bays and river mouths with large islands or groups of smaller islands outwards. The bottom-substrate is both soft and hard with deep trenches in between (30-40m).

The western inshore category (Type 2) is similar but even shallower (but more saline) than the eastern inshore type. The eastern outer category (Type 3) has an average depth of 15-30m with deeper trenches (30-60m) from the open sea area cutting into the area. Land is scarce and the islands, when present, are small. The western outshore category (Type 4) is similar to the eastern type regarding depth, land/sea ratio and bottom characteristics. However, in the westernmost part where the type borders to the mosaic Archipelago Sea a mix of different environments is created, affecting the biota, and potentially demanding an environmental category of its own.

Testing benthos on environmental typology within the Gulf of Finland showed high intra- and inter-category variation for the types defined when analysing benthic infauna. Types 1 and 2 showed high levels of similarity between categories, but species composition differed considerably, and thus these type-areas may be considered “real” in the sense that biology confirms typology.

3.1.2 The Archipelago Sea and the Åland Island

The Archipelago Sea is characterized by numerous islands and skerries covering an area of 8300 km^2. This mosaic region is shallow (average depth 23m) and the proportion of the littoral zone is pronounced, emphasising the importance of near-shore shallow areas for the functioning of the ecosystem. The water residence time varies in the area covering both inner bays and open sea. Salinity ranges between 5,5 and 6,5 PSU and is the highest along the Finnish coast. Due to the high diversity of biotopes in this region, and the relatively high salinity, benthic biodiversity is the highest found in Finnish coastal waters.

The region is split into 4 environmental classes (Types 5, 6a, 6b & 7) describing the zonation going from the inner archipelago towards the open sea. The inner zone (Type 5) is characterized by proportionally more land than sea, large islands and narrow bays stretching far inland. Water depth is shallow (< 10m) and water exchange poor. The middle part (Types 6a & 6b) of the archipelago contains numerous smaller islands separated by more exposed waters. The outer zone (Type 7) is characterized by high exposure and only small barren islands and skerries positioned in the open sea with deep furrows in between.

Benthic community data from this region showed high intra- and inter-type variability, illustrating the high complexity and multiple biotopes in the area. Inner (Type 5) and middle (Type 6a) archipelago zones showed the highest similarities but the species composition of the two types differed, separating between species of marine (e.g. common blue mussel *Mytilus edulis*, Baltic clam *Macoma balthica*) and freshwater origin (e.g. oligochaetes and chironomids).

3.1.3 The Bothnian Sea

This open coast is a rather homogenous area with a long, shallow and exposed coastline with no major shift in salinity (about 5 to 5.5 PSU). This coastal area is located in between two shallow sill areas, namely in the south by the Archipelago Sea, and in the north by the Quark.

This area is divided into an inner (Type 8) and an outer (Type 9) environmental category. The narrow and shallow inner type is characterized by shallow bays and a few large islands. The outer type is an exposed open maritime environment with increasing depth.

No ecological test on typology could be carried out for this area due to a more or less complete lack of reliable data on macrozoobenthos from the outer coastal region.

3.1.4 The Quark

The shallow (average depth ca 10m) Quark region with its extensive archipelago functions as a sill in the Gulf of Bothnia separating the Bothnian Sea and the Bothnian Bay from each other (Fig. 1). Primary production in the Bothnian Sea is normally nitrogen limited in summertime while the Bothnian Bay is phosphorus limited. The basic ecology of the system thus changes dramatically passing north of the Quark as salinity decreases from 5,5 PSU to ≤4 PSU and many species of marine origin meets their northern limit of distribution. The extent of ice cover ranges from 120-150 d a^{-1} in the outer coastal parts of the Quark to > 150 d a^{-1} in the inner nearshore regions.

The Quark is split into an inner (Type 10) and outer category (Type 11) in the Finnish typology proposal. This separation is also detectable for the benthic assemblages at depths >10m.

The environmental types in the Quark also differ from those in the Bothnian Bay (Fig. 2), reflected also in the disappearance of the benthic key-species such as *Macoma balthica* when salinity drops below 4 PSU.

3.1.5 The Bothnian Bay

The shallow Bothnian Bay is characterised by low salinities (1-4 PSU), great influence by river inflow and the long extent of ice cover (> 150 d a^{-1}). Biodiversity is low in the Bothnian Bay due to the low salinity, and the cold climate.

In the national Finnish proposal for typology under the WFD, the Bothnian Bay is split into 4 types (Types 12-15), namely inner and outer coast, and a north-south division of the Bothnian Bay, based on salinity (the 3 PSU limit).

Macrozoobenthic community data showed that the 4 types resembled each other to a high extent, and no ecological distinction could be made based on zoobenthos alone to verify or justify the division of typology.

ANOSIM-analysis showed that Types 12, 14 & 15 were barely separable at all at both depth intervals tested (Table 1). Data was too scarce from Type 13 to draw any conclusions. The typology of the Bothnian Bay can thus be pooled into 2 types separating landlocked inner bays with riverine influence from outer exposed coastal areas. SIMPER-results show low dissimilarity between community assemblages of zoobenthos in the Types 12-15 (Table 2), underlining the need to simplify or refine typology.

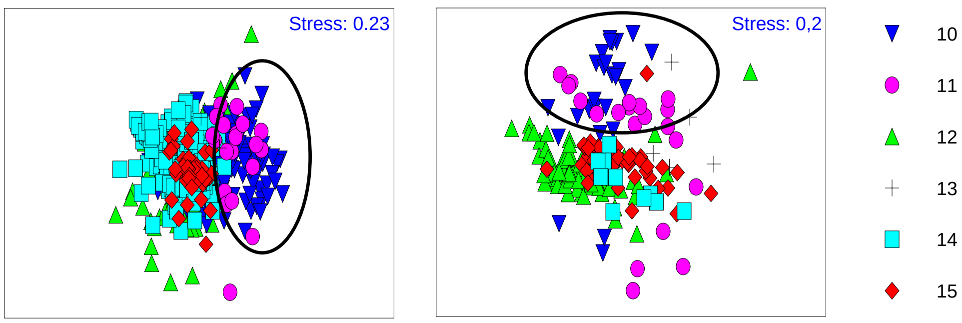

Figure 2: MDS-ordination showing a clear separation of the Quark-region (Types 10&11) from Bothnian Bay (Types 12-15). Left graph 0-10m; right graph >10m.

3.2 A uniform typology for the entire Baltic Sea coastal area?

The option of using the suggested common and general environmental typology developed within the EC-CHARM-project (SCHERNEWSKI & WIELGAT 2004) was considered, but abandoned of the following reasons. This typology divides the Finnish coastal waters into only a few types based on salinity, depth/mixing, and water residence time, but no consideration is given to the local climate, which along the Finnish coast involves ice every winter, but no tides, for example. Thus this approach only to some extent confirms the Finnish national typology proposal in using an inner and an outer basic category along the entire coastline, dividing it further along the coast bases primarily on salinity and number of days with expected ice cover. The CHARM-approach also marks out the characteristics of the inner part of the Archipelago Sea with its prolonged water residence time. The need for further splitting of the umbrella typology is needed if it is to be useful for further implementation under the WFD. The typology fails in only producing one division line for salinity (oligohaline 0.5-6 PSU). A further splitting at 4 PSU is important due to the fact that this salinity-level sets a physiological limit for many species of marine origin, and hence the entire benthic community changes when reaching salinities of 3 PSU and below.

4 Discussion

Most modern scientific research-programmes investigating marine environmental quality monitor parameters in the water column, at and in the sediment and in sentinel organisms (BORJA et al. 2000) and are centred on physico-chemical and ecotoxicological variables and to a lesser extent biological parameters. Biological parameters are important components when determining water quality since a) they are direct measures of the condition of the biota b) they may uncover problems undetected or underestimated by other methods and c) provide measurement of the progress of restoration efforts (DAUER 1993). The shift in focus towards increased importance of biotic parameters in determining ecological status of water bodies stated in the WFD is a significant challenge for most monitoring programmes operating in Europe today. The coastal waters covered by the WFD with respect to biological features are limited to surface waters one nautical mile from the coastline, or – as in the case of Finland with its extensive archipelago regions – from the outermost islands. This concept violates the suggested ecosystem approach for the Baltic Sea as defined in the EC-marine strategy. By artificially truncating environmental categories, classes or types, a comprehensive Baltic system concerning reference conditions, water quality classification schemes and monitoring is hardly possible (SCHERNEWSKI & WIELGAT 2004).

Table 1: ANOSIM R-values for assemblage-differences between coastal categories (Types 1-15) and depth strata (0-10m; 10+m). (No data available in type 9)

	1	2	3	4	5	6a	6b	7	8	9	10	11	12	13	14	15
1		0.27	0.45	0.46												
2	0,24		0,66	0,45	0,17	0,34		0,36					10+m			
3	0,08	0,27		0,83												
4	0,51	0,24	0,62		0,20	0,28		0,42								
5		0,21		0,48		0,06	0,10	0,25	0,13		0,04	0,30				
6a		0,32		0,24	0,20		0,14	0,24	0,27		0,18	0,51				
6b								0,13	0,25		0,60	0,44				
7		0,30		0,36	0,31	0,31			0,46		0,54	0,50				
8					0,05	0,14		0,09			0,33	0,37	0,69	0,72		
9																
10					0,24	0,41		0,67	0,23			0,51	0,67	0,80	0,69	0,66
11					0,14	0,15		0,82	0,01		0.018		0,75	0,43	0,47	0,66
12		0-10m							0,38		0,44	0,68		0,82	0,32	0,23
13									0,38		0,03	0,53	0,38		0,65	0,57
14											0,61	0,77	0,22	0,44		0,13
15											0,34	0,79	0,09	0,65	0,09	

>0,75 WELL SEPARATED >0,50 OVERLAPPING, BUT CLEARLY DIFFERENT
<0,25 BARELY SEPARABLE AT ALL

Table 2: SIMPER average dissimilarity values between coastal categories (Types 1-15) and depth strata (0-10m; 10+m). Lower table shows similarity-percentage of within type comparison and depth strata. (No data available in type 9).

	1	2	3	4	5	6a	6b	7	8	9	10	11	12	13	14	15
1		75,7	84,7	78,8												
2	74,8		88,0	59,7	68,9	71,7		71,6					10+m			
3	66,3	77,3		85,8												
4	81,7	77	82,2		67,4	67,6		62,9								
5		74,7		78,7		64,9	67,5	70,9	67,4		65,5	73,2				
6a		79,6		75,7	70,5		65,2	67,7	68,7		66,6	76,2				
6b								54,6	66,0		65,9	64,4				
7		78,3		65,4	73,7	72,5			73,0		71,6	71,7				
8					69,5	73,1		71,6			69,2	70,6	82,5	83,7		
9																
10					70,7	74,8		80,4	74,7			70,7	69,9	79,9	74,2	67,6
11					67,5	71,2		72,5	68,4		61,7		72,4	72,7	71,5	68,9
12		0-10m							77,4		66,2	67,4		78,6	55,2	51,0
13									80,7		61,6	64,8	55,4		68,3	62,9
14											69,9	73,4	57,9	61,9		45,7
15											66,6	70,8	53,6	58	47,2	

<60% dissimilarity 60-70% dissimilarity >70% dissimilarity

	1	2	3	4	5	6a	6b	7	8	9	10	11	12	13	14	15
0-10m	36,8	31,8	29,9	36,5	35,9	30,6	43,4	47	32,5	-	38,1	48,8	55,6	51,2	49,9	61,7
10+m	33,4	39,5	19,1	50,3	35,4	39,3	54,3	46,7	41,1	-	48,1	40,1	55,4	46,5	55,2	58,3

Macrozoobenthos is a standard element in monitoring programmes today due to its usefulness as bio-indicators sensitive to anthropogenic and natural stress (PEARSON & ROSENBERG 1978; DAUER 1993). Benthic softbottom invertebrate community structure is useful in environmental monitoring because they are relatively sedentary, long-lived and consist of different species exhibiting different tolerance to stress. They have an important role in cycling nutrients and materials between the underlying sediments and the overlying water column.

The benthic community assemblages may vary considerably between sites depending on the environmental conditions present. Factors structuring benthic communities are depth, salinity, sediment grain size, sediment organic matter content, near-bottom oxygen concentration, trophic status and water residence time of the water body.

An additional important feature in determining proper benthic communities is seafloor landscape, or benthoscape, structure. This factor is not included in the WFD. Habitat heterogeneity occurs at all scales and the relative mix of large-scale, mesoscale and small-scale heterogeneity can differ across a benthoscape depending on location in the benthoscape, the types and mixture of the elements, and prevailing hydrologic and geologic dynamics (ZAJAC et al. 2003). The existence of large-scale, as well as small-scale, patterns in infaunal community structure is well known (HALL et al. 1994). However, infaunal populations exhibit complex and spatially varying patterns of abundance in relation to benthoscape structure and suggest that mesoscale variation (km^2-m^2) may be particularly critical in this regard. Benthoscape elements add structure to the seafloor landscape, thereby increasing habitat diversity. In addition, transition zones among benthoscape features add considerably to this variation and may be ecological important areas in seafloor environments (ZAJAC et al. 2003). This would then imply the urgent need for stronger focus on sediment characteristics and biological elements in the process of typology since mesoscale will be the size-level on which most water bodies will be at. In addition to abundance, also habitat type (http://eunis.eea.eu.int) should be included when comparing calculated results of EcoQ regarding benthic quality element.

In this test no attempt of classification of the ecological status of types/water bodies within the coastal waters has been made. The classification will be based on the deviation from defined ecological reference conditions (phytoplankton, macro-vegetation and macrozoobenthos) within these water bodies. Reference conditions should have no or very minor deviations from undisturbed conditions, which in practice is defined as conditions prior to the intensification of agriculture 100-150 years ago. Post-war intensification of agriculture (nutrient enrichment in the sea) and urban pollution are believed to have had the largest impacts on coastal waters (ANON 2000). Reference conditions can be derived by a) measurements in existing undisturbed site or a site with only very minor disturbance b) using historical data and information c) models, and/or d) expert judgement (VINCENT et al. 2002). Reference conditions should be defined in a pragmatic and realistic way, taking into account existing data and expert judgement in order to avoid impossibility of accomplishing good status classification of the marine coastal environment (BORJA et al. 2004).

Paleoecological studies of sediment conditions have attracted interest in determining nutrient conditions of the recent past (CLARKE et al. 2003; ANDERSEN et al. 2004; WECKSTRÖM et al. 2004; KAUPPILA et al. in press). This is an interesting and promising approach for determining nutrient reference conditions, however the studies have only yet been made on a local scale and will probably not advance fast enough for use in the initial decision of reference conditions in the WFD.

The absence of unimpacted areas in the Baltic Sea of today means that values for the biological quality elements determining the EcoQ:s will have to be made up using either models or expert judgement since monitoring data regarding these is lacking for those time periods at question. Adding to this problem, JACKSON & SALA (2001) states that “our basic concept about the ecology of pristine marine ecosystems have hardly been questioned, even though most of our textbook wisdom was obtained long after intensive fishing began”. This also adds to the difficult task of building reliable models for reference conditions since this, to the extent it is possible, requires detailed paleoecological, archeological and historical analyses to determine what and how much was present, combined with observations and manipulations of succession due to the absolute cessation of human exploitation within very large marine areas (JACKSON 2001; JACKSON & SALA 2001). Are we then left with only expert judgement as the tool for determining ecological status within the coastal areas or are there methods that can still guide us? Various numerical indices have been available in benthic ecology already since the 1960s and are now coming into focus again. ROSENBERG et al. (2004) presents a good summary of usable indices, both subjective and objective, for detecting secondary effects of eutrophication and proposes a new benthic quality index (BQI) as well. However, most indices have been created for fully marine environments with high biodiversities and may therefore not entirely capture environmental changes in a low-diversity brackish environment such as the Baltic Sea represents. This becomes even more evident in the low-saline Bothnian Bay where only a handful of taxa are present and available for determining environmental changes and quality status. In our analyses we had pooled the records of species belonging to family *Chironomidae* and class *Oligochaeta* due to uneven taxonomic resolution in the studies, yet these are taxa where there are species indicative of specific environmental conditions. These are taxa requiring taxonomical expertise to identify and might result in comparisons of taxonomical skilfulness between areas instead of environmental status if indices involving species richness are used. The use of species richness as a parameter of environmental status should be avoided since it tells nothing about species turnover and community assemblage structure. Further, we need to consider the occurrence of non-native invasive (‘alien’) species in the coastal environment, as these undoubtedly affect the benthic assemblages (about 100 species are known invasive in the Baltic Sea; about 50% of them marine benthic), though not necessarily in a negative way. The best known example is the North American polychaete, bioturbator, *Marenzelleria viridis* (http://www.ku.lt/nemo).

Whatever methodology used in the assessment of reference conditions or ecological status they all need to be intercalibrated between ecoregions and national typologies.

Based on the results from this study together with experiences gained from co-operation with the international CIS-group, the pan-Baltic CHARM-project and comments received from the evaluation round of this proposal of the Finnish typology a new typology, containing fewer categories (11 types instead of 16), has been constructed. Borders between types have also been slightly moved in order to better reflect the ecological quality element communities. The new alternative typology proposal is currently under national scientific evaluation and, if accepted, will be presented at a later stage, and tested for suitability using not only zoobenthos, but also plankton and macroscopic vegetation.

Acknowledgements

This paper is part of and financially supported by the EU project CHARM (Characterization of the Baltic Sea Ecosystem: Dynamics and Function of coastal types; EVK3-CT-2001-00065), and Academy of Finland project IMAGINE within the Research Programme BIREME. The Finnish Ministry of the Environment has helped in financing the setup of the macrozoobenthic database. The authors thank the national expert group producing the typology proposals and West Finland Regional Environment Centre for providing work space and tools.

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Address

MSc. Jens Perus
Åbo Akademi University
Dept. Of Environmental and Marine Biology
Akademigatan 1
20500 Åbo
Finland

E-mail:jens.perus@abo.fi

G. Schernewski & M. Wielgat (eds.): Baltic Sea Typology
Coastline Reports 4 (2004), *ISSN 0928-2734*
39 - 48

Typology of Polish marine waters

Wlodzimierz Krzyminski[1], Lidia Kruk-Dowgiallo[2], Elzbieta Zawadzka-Kahlau[2], Rajmund Dubrawski[2], Magdalena Kaminska[1], Elzbieta Lysiak-Pastuszak[1]

[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 Mete-orology 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, tidesless 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 compring 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, Űcker 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)

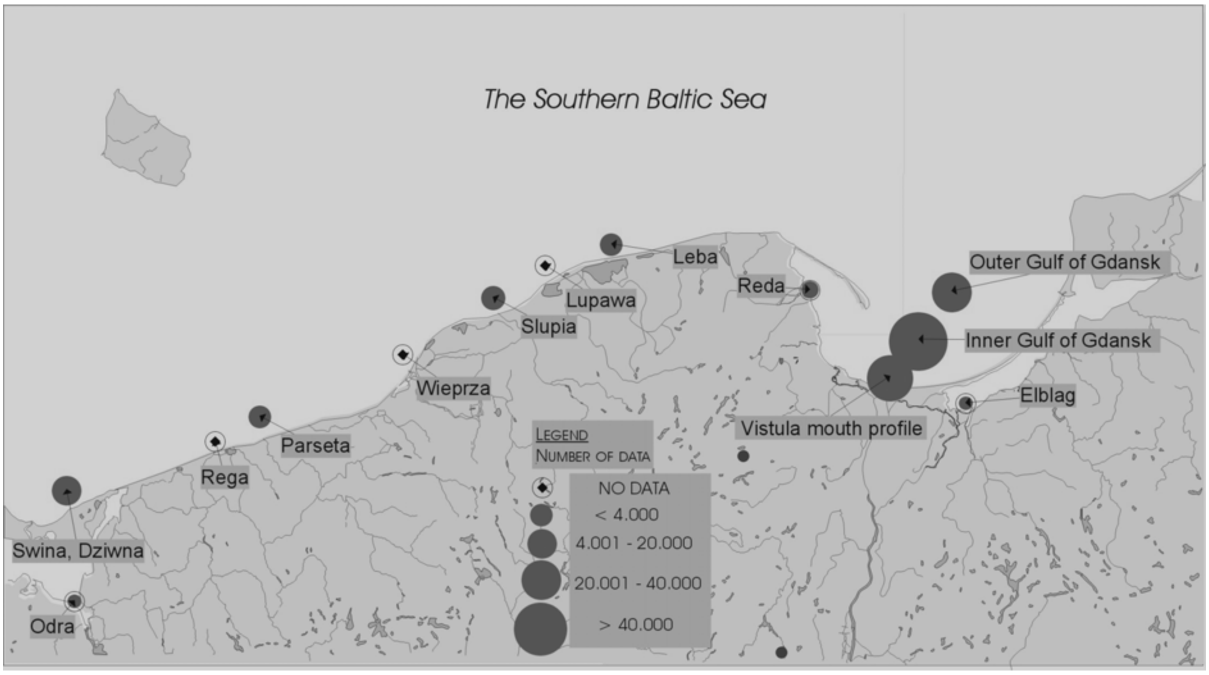

Figure 1: Total number of oceanographic data collected in different areas of the Polish coastal zone of the Baltic Sea.

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).

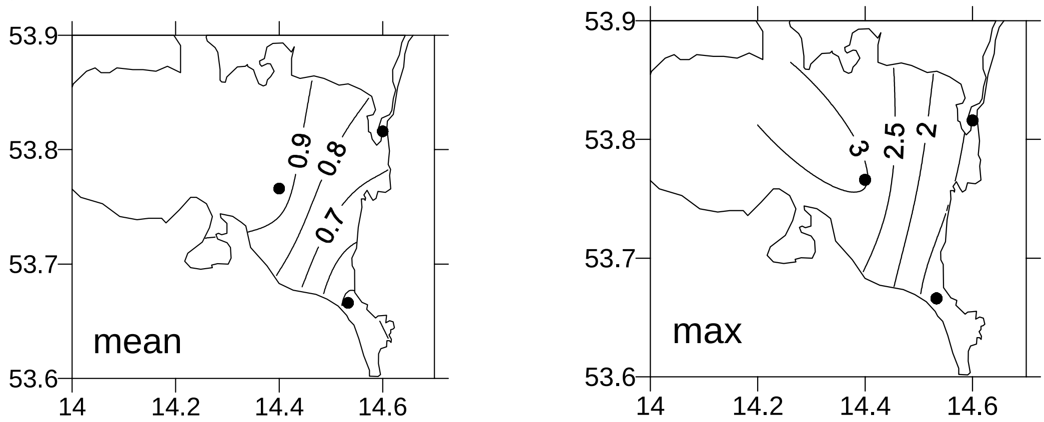

Figure 2: : An extent of the mean and maximal salinity (>0.5) in surface water layer of the Polish part of Szczecin Lagoon.

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.

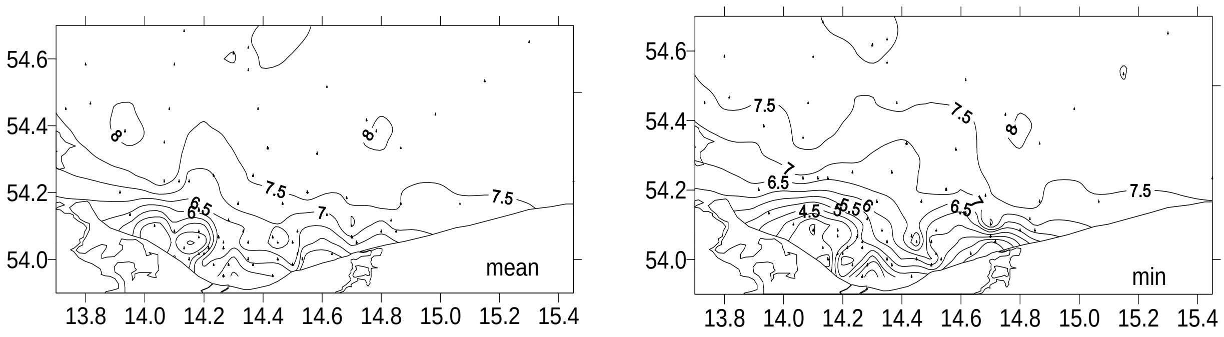

Figure 3: Extent of the mean and minimal salinity in the surface water layer of the Pomeranian Bay (both in German and Polish parts) in the foreground of the river Swina and Dziwna.

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.

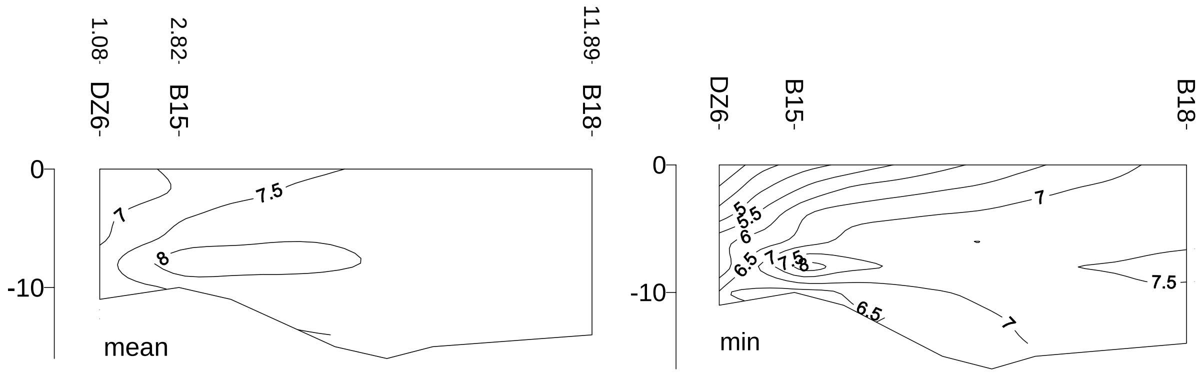

Figure 4: Distribution of salinity in vertical profile from the river Swina mouth towards the open sea. Numbers over the station names indicate distance from the shore in Nm, while vertical scale indicates depth in meters

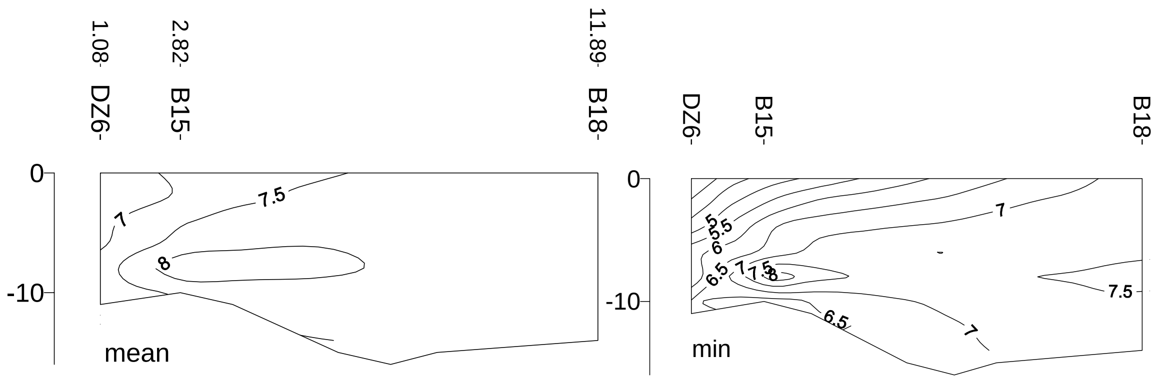

Figure 5: Distribution of salinity in vertical profile from the river Dziwna mouth towards the open sea. Numbers over the station names indicate distance from the shore in Nm, while vertical scale indicates depth in meters.

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).

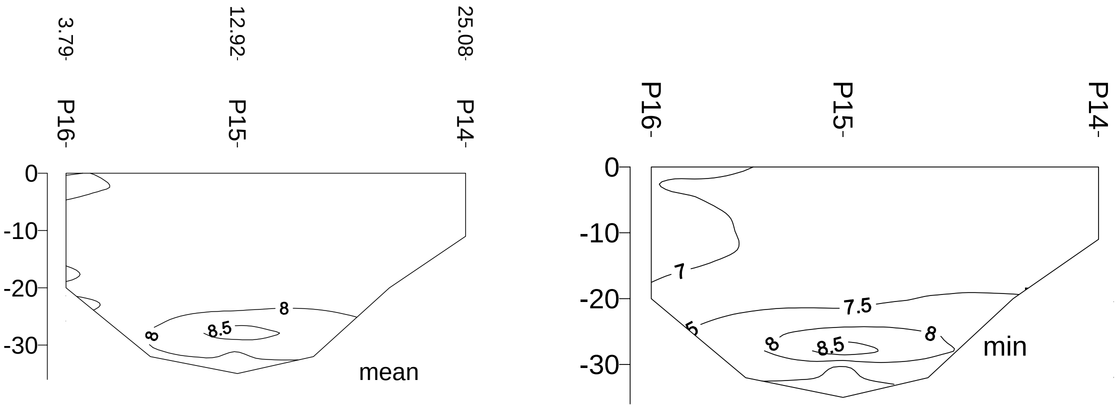

Figure 6: Distribution of the mean and minimal salinity in the vertical profile along the section from the river Slupia mouth towards the open sea. Numbers over the station names indicate distance from the shore in Nm, while vertical scale indicates depth in meters

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).

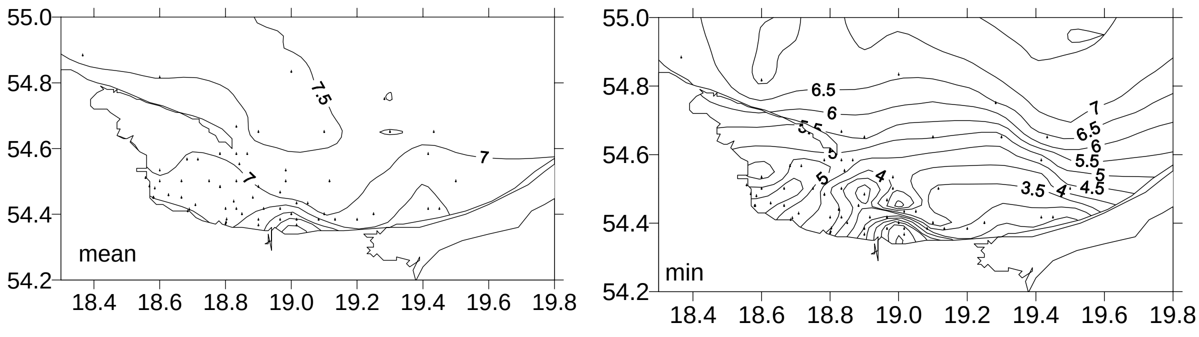

Figure 7: Surface distribution of the mean and minimal salinity in the Gulf of Gdansk.

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.

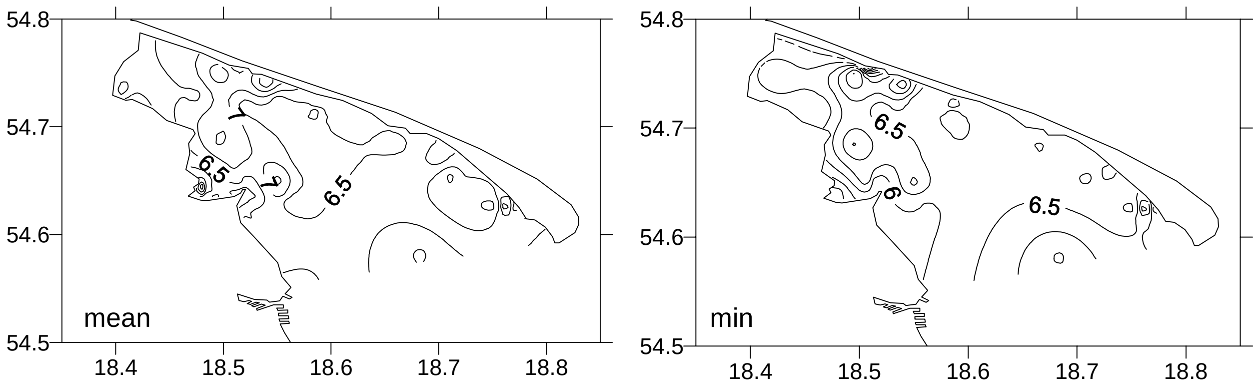

Figure 8: Surface distribution of the mean and minimal salinity in the Puck Bay.

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.

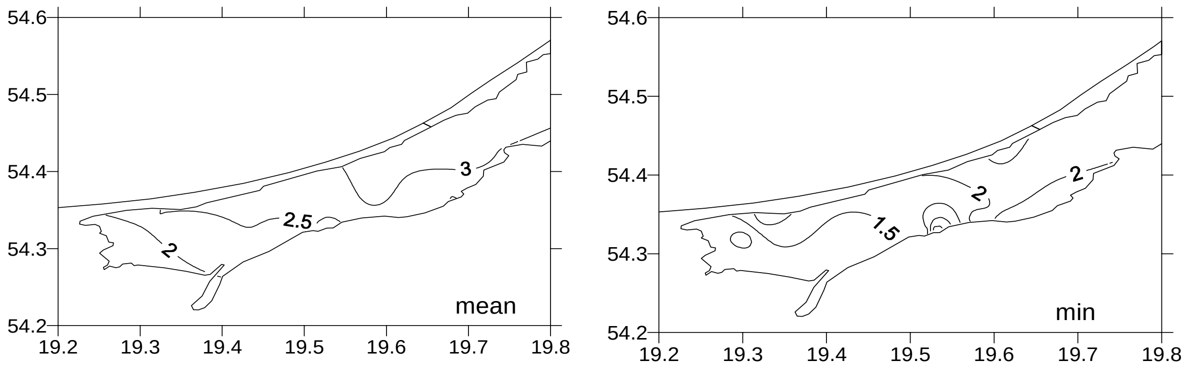

Figure 9: Surface distribution of the mean and minimal salinity in the Vistula

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.

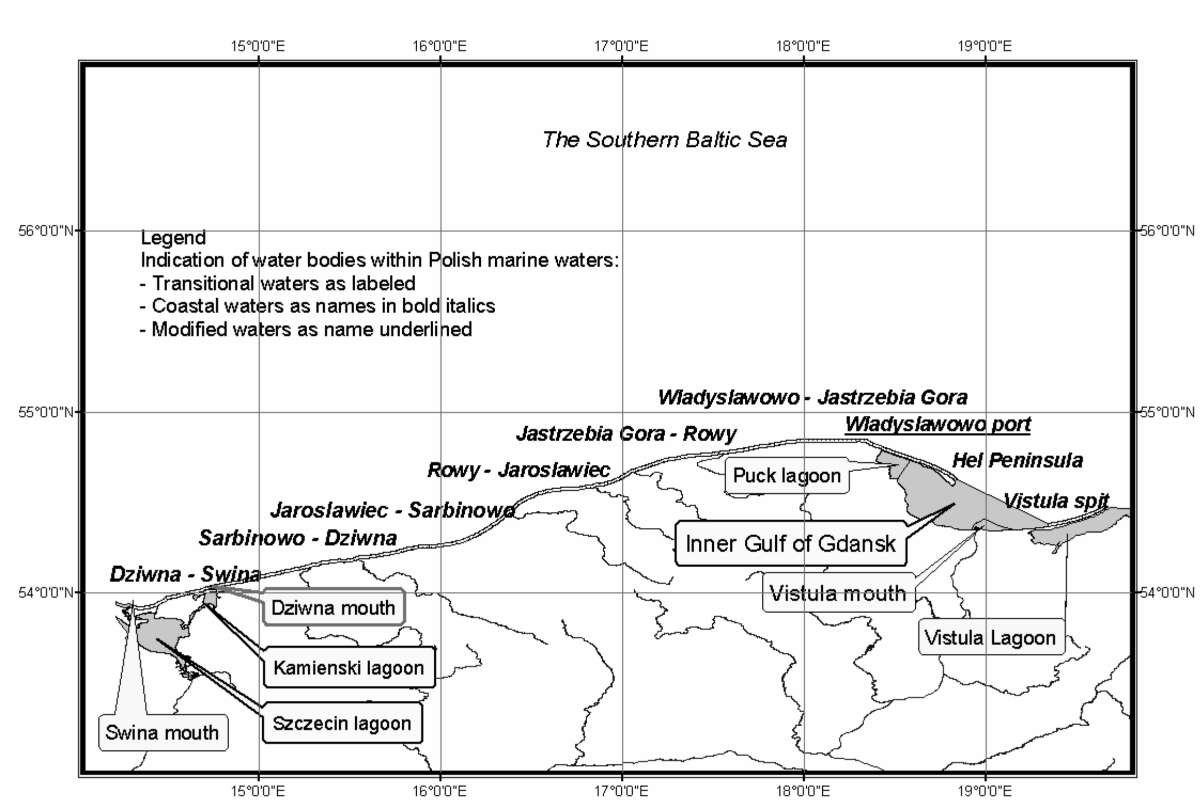

Figure 10: Water bodies determined within Polish coastal marine waters.

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 l 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

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

E-mail: wlodzimierz.krzyminski@imgw.pl

G. Schernewski & M. Wielgat (eds.): Baltic Sea Typology
***Coastline Reports 4 (2004)**, ISSN 0928-2734*
49 - 54

Defining a typology for Danish coastal waters

Trine Christiansen[1], Jesper Andersen[1] & Jens Brøgger Jensen[2]

[1] National Environmental Research Institute, Denmark
[2] Danish Environmental Protection Agency

Abstract

A typology has been developed for the Danish coastline, most of which is located in a region with a strong physical and biological gradients. It was found necessary to use different criteria for characterizing the open water coast and estuaries. The open water coast was characterized with respect to salinity, depth, wave exposure and tidal influence, whereas estuaries were characterized with respect to bottom salinity, degree of stratification, the ratio of residence time to surface runoff and sluice-control. The approach results in dividing the Danish coastal waters into 15 different types. It, however, still remains to be analyzed whether this typology is useful when considering different biological quality elements as indicators of water quality.

1 Introduction

The European Water Framework Directive (WFD, EUROPEAN UNION 2000) requires characterizing of coastal waters into types defined by distinctive hydromorphological and physical conditions. These physical conditions are specified in Annex II of the WFD and include salinity, tidal range, wave exposure and substrate type, depending on which conditions are the most defining for the biology in a given area. The idea is that physical conditions define distinct biological features in the coastal zone, with a known quality, if no other pressures are present in the area. Further, the WFD requires that reference conditions for a number of biological quality elements are developed for each type, i.e. areas of a given type has the same set of reference conditions associated with them. These reference conditions ideally describe the undisturbed state of a given type. Consequently, successful implementation of the WFD requires that the typology in fact does reflect the geographical differences among the biological quality elements.

The Danish coastline can be divided into the North Sea/Skagerrak Coast and the Kattegat and Belt Seas located in the transition area between the North Sea and the Baltic Sea. The North Sea/Skagerrak Coast is a high-energy coast, which in the southern part is also influenced by tides. The Kattegat and Belt Seas have characteristics similar to a large estuary: dynamic and large water exchange driven by meteorological conditions, and as a consequence of this exchange a large salinity gradient is present between the northern and southern parts, and the water column is almost permanently stratified. In addition to the open coastline, a number of estuaries are located along the coast. The variability of the open water is also reflected in the estuaries both in terms of salinity gradients and stratification.

The large physical gradients found in both coastal waters and estuaries means that the ecological conditions are also highly variable in both time and space. Accordingly, the coastline has been divided into a large number of types that reflect this variability. Here we discuss the criteria used for selecting physical factors used for defining these types.

2 Results

The Danish waters that are encompassed by the WFD are shown in Figure 1. The coastline is divided into two major types: open water and estuarine types. The open water coastline tends to be more exposed to waves and tides and less affected by run-off, which creates environmental conditions that are very different from those found in estuaries. The freshwater run-off to Danish estuaries means that a strong salinity gradient may exist within an estuary. Residence times are typically much longer than along the open coast, suggesting a stronger response to landbased river inputs (typically nitrogen and phosphorous load) in estuaries.

2.1 Criteria for selection of Open Water Types

The open water category comprises the Danish part of the Wadden Sea, the Danish North Sea/Skagerrak Coast, the exposed coastline of the Kattegat and Western Baltic Sea, and the coast of Bornholm. The open water category is characterized with respect to salinity, depth, exposure, and tidal regime. In most cases the biological response to these physical pressures represent a continuum of responses and consequently, only few clearly defined boundaries for biological communities exist. This lack of clearly defined boundaries often makes it difficult to argue for why one boundary should be chosen over another.

In the case of salinity, the boundaries specified in the WFD were used, resulting in three salinity categories: euhaline ($S>30$), polyhaline ($S>18$ & $S\leq30$) and mesohaline ($S>5$ & $S\leq18$). In large parts of the Danish open water coast, salinity also varies with depth. It was chosen to use bottom salinity because the WFD requires that biological response is measured in terms both benthic macro fauna and submerged aquatic vegetation, indicators that both respond more strongly to bottom salinity than to mean or surface salinity. The euhaline category is found along the North Sea/Skagerrak coast, the polyhaline category is found within the Kattegat. Apart from in the Sound, a well-defined geographical boundary between the polyhaline and mesohaline category does not exist due to the large variability in salinity in the Danish waters. In the Sound, the Drogden Sill defines the boundary between the polyhaline and mesohaline category. Here we have drawn the boundary in the Little Belt, Great Belt and the Drogden Sill in the Sound.

The tidal regime along the Danish coast ranges from micro-tidal (range < 30cm) in the Kattegat and Western Baltic Sea to mesotidal (range > 30 cm & < 1.5 meters) along the North Sea coast. The largest tidal range is found the Wadden Sea, and this area has been assigned its own type, which is expected to be the same as the German and Dutch Wadden Sea types.

Most of the open Danish coast is characterized by shallow water (depths<15m). It was none the less decided to use depth as one of the defining physical criteria because one of the most clearly defined separations of biological communities in open water exists with depth. The stratification that arises in the Kattegat due to low salinity water flowing out of the Baltic and high salinity water flowing in from the Skagerrak typically has a halocline depth of 15 meters. In areas of the Kattegat where the seafloor is at depths greater than 15 meters, salinity is typically at oceanic levels, in the euhaline range and at this depth the *Amphiura* fauna community is found. At sea floor depths shallower than 15 meters, the *Macoma* fauna community is found.

An overview of the open water types is shown in Table 1 and the distribution of open-water types is shown in Figure 1.

Table 1: Open water types in Danish coastal waters.

Salinity	Mesohaline (S>5&S≤18)	Polyhaline (S>18&S≤30)	Euhaline (S>30)		
Other physical pressures		Depth < 15 meters	Depth > 15 meters	Wave exposed	Tidal influence
Type	ow3	ow2	ow1	ow4	ow5

2.2 Criteria for selection of estuary types

The Danish coast includes a large number of shallow water estuaries. For an overview see CONLEY et al. (2000). JOSEFSON & RASMUSSEN (2000) have documented that in addition to salinity regime, estuary residence time may be important for defining the biomass of benthic macro fauna in a particular area, and unpublished observations have also shown the influence of stratification on biomass of benthic macro-fauna. Consequently the typology for Danish estuaries is based those three physical pressures. In addition, two sluice-controlled estuaries are found on the West Coast of Denmark. This man made control provides unique conditions in both estuaries and they have been characterized as their own type. The estuaries have thus been characterized in terms of salinity, stratification, a sensitivity index, defined as the ratio between run-off and residence time, as well as sluice-control at the estuary mouth.

2.3 Salinity and stratification

Salinity profile measurements made for up to 20 years in 33 estuaries were used to determine surface and bottom salinity in each set of measurements. Benthic fauna and submerged aquatic vegetation that are used as biological indicators respond to bottom salinity. Consequently, bottom salinity is used to characterize salinity of the estuary. In several estuaries, the permanent monitoring stations are located at the deepest point, which is often unrepresentative of estuary depth. Thus, we have chosen to define the depth, where 80% of the estuary has a depth more shallow than this depth, as the bottom. The limits of the salinity boundaries are the same as those used for open water. In many cases, the fresh water run-off creates a horizontal salinity gradient within an estuary, but only in 4 cases is the gradient strong enough to require division of the estuary into two or even three types.

A stratification index ΔS, has been calculated as the difference between bottom and surface salinity because the degree of stratification expresses the availability of food to bottom fauna. In a well-mixed estuary, the food supply is independent of depth, but in a stratified estuary, food availability may be very different above and below the halocline, thus providing habitat for different types of communities with depth. Further the strength of the stratification is an indicator of the estuary sensitivity to oxygen depletion events. When $\Delta S > 1$ in 50% or more of the profile measurements, the location corresponding to those measurements is considered stratified.

The run-off to most estuaries is small relative to their volume and water residence time is typically controlled by exchange at the estuary mouth rather than by the magnitude of catchment surface water discharge. Most estuaries border the inner Danish waters that are micro tidal and consequently the water exchange between the estuary and adjacent sea is driven more by morphology of the estuary mouth and by meteorological conditions than by tidal elevation.

A sensitivity index (F) has been calculated as the ratio between run-off and residence time to identify the sensitivity to freshwater inputs and thus nutrient inputs. An estuary with a long residence time will be more sensitive to nutrient inputs, but if the run-off to that estuary at the same time is small, the effect will be less. When calculating the sensitivity index, run-off in m^3s^{-1} and residence time in days was used. This provided values ranging from 10^{-4}to14 $m^3 s^{-1}$ day^{-1}, and the median value rounded off to the nearest decade was used as boundary between two categories.

The residence times used to calculate the sensitivity index are estimated from the following two relations:

$$T = \frac{V}{Q+R} \qquad \text{and} \qquad Q = \frac{\frac{S}{Sm}}{\left(1-\frac{S}{Sm}\right)} R$$

where *V* is estuary volume, *Q* is salt water supply, *R* is run-off, *S* is surface salinity in the estuary and *Sm* is salinity at the estuary mouth (RASMUSSEN OG JOSEFSON, 2002). This relation provides an estimate of residence time that is within the right order of magnitude, but also one that may deviate from other estimates for example calculated using hydraulic models. It will also only provide the correct result in those situations where the salinity is lower inside than outside the estuary and uncertainty increases when run-off is very small.

An overview of the estuary types is shown in Table 2.

The criteria defined in the previous section have been used to characterize both open water and the 33 largest estuaries in Danish coastal waters. Types O1, O2, and O3 are not present in any of the selected estuaries. The geographical distribution of types is shown in Figure 1.

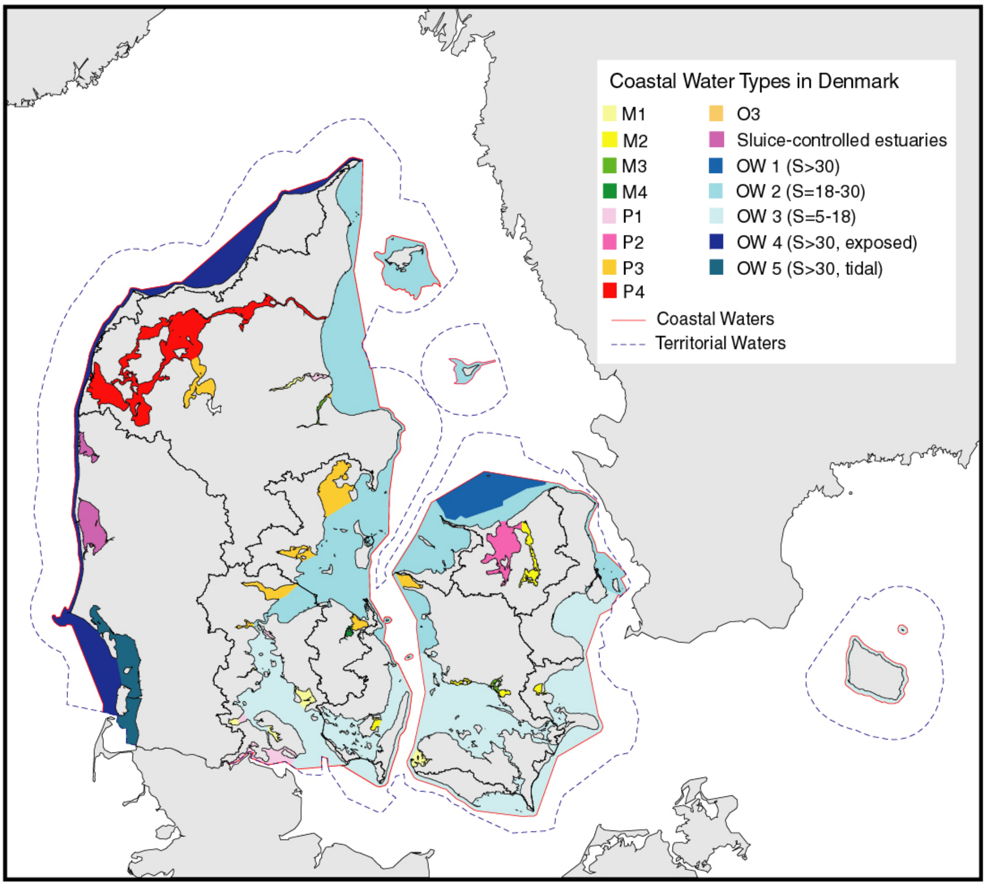

Figure 1. Open water and estuary types in Danish coastal waters.

Table 2: Estuary types in Danish coastal waters.

Oligohaline (S≤5)				Mesohaline (S>5&S≤18)				Polyhaline (S>18&S≤30)			
Stratified ΔS>1		Mixed ΔS≤1		Stratified ΔS>1		Mixed ΔS≤1		Stratified ΔS>1		Mixed ΔS≤1	
F≤0.1	F>0.1	F≤0.1	F>0.1	F≤0.1	F>0.1	F≤0.1	F>0.1	F≤0.1	F>0.1	F≤0.1	F>0.1
O1	O3	O2	O4	M1	M3	M2	M4	P1	P3	P2	P4

3 Discussion

Here we have presented a simple method for developing a typology for coastal waters in an area with large geographical differences, which results in 15 different open water and estuary types. While these 15 different types represent a wide range of physical conditions, it is still unclear to which extent they also represent the variability within biological communities.

The biological quality elements specified in the WFD are abundance and sensitive species of benthic macro fauna, species composition, abundance and biomass of phytoplankton, and abundance, distribution and biomass of bottom vegetation. All of these quality elements have been systematically monitored at a large number of stations in Danish waters since 1989, and thus, a large base of information is available for linking biological quality to types in this area. There are, however, a number of difficulties related to establishing agreement between type and ecological quality, and while ongoing work aims at relating biological quality elements to the typology, this work has not yet been completed.

The lack of clear boundaries between biological communities makes it difficult to establish a “reasonable” number of types. For example, preliminary work shows that this typology describes differences in species diversity of benthic macro fauna, but the analysis also suggests that using different values to describe the boundary between two types may describe this measure of environmental quality equally well. Types have also been defined where no or only few measurements of biological elements have been made, making it difficult to determine whether the type is relevant.

The physical environments relevant for the different biological elements are very different. The definition of types used here is based on bottom salinity because benthic macro fauna and aquatic vegetation are expected to respond to local bottom conditions. Bottom salinity is, however, not the relevant salinity for phytoplankton in stratified environments. Phytoplankton are only associated with the photic zone, which is very shallow in this area (8-10 meters deep). In addition, phytoplankton and other pelagic organisms are transported over large distances in this region, and thus, phytoplankton communities may not necessarily be different in areas of different type.

Eelgrass (*Zostera marina*) is the most widespread angiosperm in the Danish coastal waters, and it is regarded as a useful indicator of water quality because water clarity regulates its extension towards deeper waters. In a study where the depth limit of eelgrass was used as an indicator of ecological quality, KRAUSE-JENSEN et al. (2004) found that it was not possible to establish sufficiently accurate reference conditions for depth limit within a distribution of types that was based on salinity and depth. The eelgrass depth limit also responds to other pressures such as exposure levels and sediment composition that are also not included in the typology presented here. Including those factors in the typology would mean developing types that would have very small geographical extent, which is not the intent of the WFD.

This study represents a method for developing a typology in a region with a highly variable physical and biological environment. The approach results in dividing the Danish coastal waters into 15 different types. It, however, still remains to be defined how useful this typology is when considering different biological quality elements as indicators of water quality.

Acknowledgements

This work has been funded in part by contract EKV3-CT-2001-0065 with the European Commission and in part by the Danish Environmental Protection Agency.

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Address

Dr. Trine Christiansen
National Environmental Research Institute
Frederiksborgvej 399
DK-4000 Roskilde
Denmark

E-mail: trc@dmu.dk

G. Schernewski & M. Wielgat (eds.): Baltic Sea Typology
Coastline Reports 4 (2004), ISSN 0928-2734
55 - 64

Typology as a structuring mechanism for phytoplankton composition in the Baltic Sea

Jacob Carstensen[1,2], Ulla Helminen[1] & Anna-Stiina Heiskanen[1]

[1] Inland and Marine Waters Unit, Institute for Environment and Sustainability, Joint Research Centre, Italy
[2] Dept. of Marine Ecology, National Environmental Research Institute, Denmark

Abstract

Phytoplankton composition is a biological quality element to be used for ecological classification within the Water Framework Directive. Seasonal proportions of diatoms, dinoflagellates, cyanobacteria and chlorophytes calculated from species-specific phytoplankton biovolumes sampled in 38 water bodies within the Baltic Sea were investigated to determine if the typology, defined by salinity, depth and retention time regimes, provided a useful separation of water bodies into groups for intercomparison of phytoplankton compositions. Variations in the phytoplankton composition could be significantly related to a combination of salinity and depth regimes. The significance of retention time as structuring mechanisms could not be properly assessed due to relatively few water bodies with long retention times. Cyanobacteria and chlorophytes were almost completely absent in the more saline and turbulent waters of the Kattegat and Belt Sea, whereas the proportion of diatoms and dinoflagellates generally increased with salinity. The significance of the depth regime relied entirely on few water bodies in the German part of the Baltic Proper that had a phytoplankton composition deviating substantially from other water bodies with similar salinity. Consequently, salinity ranges may provide a useful typology definition for segregating water bodies into distinct groups, however, other characteristics, not exploited in this study, need to be included as well to be able to distinguish different water body types based on their phytoplankton composition.

1 Introduction

The overall aim of the Water Framework Directive (WFD, Directive 2000/60/EC) is to establish good ecological status in all European waters by 2015. For the implementation of WFD all water bodies must be classified into types of similar characteristics based on the geographical, geological, morphological, physical factors governing the functioning and structure of the biological communities. The main purpose of typology is to enable type specific reference conditions to be defined, which in turn are used as the anchor of the classification system (ANONYMOUS 2003). Two main approaches can be taken in the determination of the surface water body types (HEISKANEN et al. 2004): 1) types are defined from knowledge of how physical drivers determine biological communities (‘*a priori*’ approach), and 2) types are distinguished by analysing survey data from reference sites (‘*a posteriori*’ approach).

Although the implementation of WFD is a national obligation, a common typology framework for the Baltic Sea has been established through the EU-project CHARM (SCHERNEWSKI & WIELGAT 2004). The ‘*a priori*’ typology established in the CHARM project is based three main factors: 1) salinity, 2) residence time and 3) depth/mixing conditions. For the Baltic Sea three distinct salinity regimes were considered in agreement with the guidance from the WFD Common Implementation Strategy (CIS) working group (ANONYMOUS 2003): oligohaline waters from 0.5 to 6, mesohaline waters from above 6 to 18 and polyhaline waters from above 18 to 30. Estuaries, lagoon and archipelagos with residence time above 30 days were separated from water bodies with more frequent water exchange. Finally, water bodies were separated into shallow (<10 m) and deep (>10 m) in contrast to three CIS recommendation of three distinct classes with 30 m and 50 m as boundaries. In the Baltic Sea water bodies with depths below 10 m are frequently fully mixed and stratification often occurs at depths just below 10 m. Therefore the threshold of 10 m was also used as a surrogate measure for stratification. The aim of the CHARM project, as the next step, was to test the 'ecological relevance' of the '*a priori*' typology using biological data from national monitoring programs.

Phytoplankton is one of four biological quality elements of the WFD and taxonomic composition, abundance, biomass and plankton blooms should be considered for the ecological classification of transitional and coastal waters (Directive 2000/60/EC). Salinity is known to be a structuring mechanism for the phytoplankton composition, since estuaries and coastal areas provide a transition zone between freshwater and marine species. However, between ecosystems there can be large differences in the phytoplankton composition versus salinity. For instance RIJSTENBIL (1987) found that this transition in a Dutch delta was most pronounced for diatom species shifting from freshwater to marine species, whereas LORENZO et al. (2004) documented a shift from large diatoms and dinoflagellates in the estuaries to cyanobacteria in the offshore waters in Western Spain. Although salinity can explain some of the changes in the phytoplankton community of estuaries, it cannot account for all the spatial variation (MUYLAERT et al. 2000). Moreover, turbulent waters are known to favour large phytoplankton (MARGALEF 1979; KIØRBOE 1993), which may also effect the phytoplankton composition in relation to typology, particularly if the tidal influence is large.

Seasonal succession of phytoplankton is another highly important mechanism to consider for phytoplankton composition. Generally the spring bloom in temperate and boreal coastal and offshore waters is dominated by diatoms, shifting towards dinoflagellates and cyanobacteria during summer with diatoms reappearing as the dominating taxonomic group during the autumn blooms (SMAYDA 1980; BIANCHI et al. 2002). However, deviations from this pattern have been reported (e.g. OLLI & HEISKANEN 1999; TAMELANDER & HEISKANEN 2004). Thus, phytoplankton composition as a biological quality element has to take the seasonal shifts into account if such indicator should be useful for ecological classification.

The objective of this study was to investigate if the phytoplankton community structure indicators at different seasons over a wide range of water bodies within the Baltic Sea would verify the typology defined in the CHARM project. This objective was achieved by calculating the mean proportions of different taxonomical groups for the different water bodies and investigating differences in these indicators between the three considered typology definitions.

2 Material and methods

A comprehensive phytoplankton database has been compiled within the framework of the CHARM project covering almost the entire Baltic Sea. The database contains bio-volumes at species level with additional taxonomical, morphological, functional and size group distribution for the different species recorded. In addition, hydrophysical and – chemical measurements from the same samples have been collected from the contributors and combined with the phytoplankton data. The CHARM phytoplankton database included data from 1970 to 2001, however, with the largest amount of data sampled within the last two decades.

In the present study, data from 38 distinct water bodies, including estuaries, coastal and open waters, were selected (Fig. 1) covering the period from 1990 to 2001 when the data coverage was reasonable high and the quality of data presumably better. Due to differences in the national monitoring programs, water bodies were represented by 1 up to 13 stations (Table 1). Stations within water bodies were included only if there were at least 10 samples taken at that particular station. The samples were partitioned according to seasons that varied between the different basins of the Baltic Sea. The definition of seasons was partly extracted from HELCOM (2002) as given in Table 2.

For each phytoplankton sample the proportions of diatoms, dinoflagellates, cyanobacteria, chlorophytes and other species out of the total sample bio-volume were calculated. If a specific taxonomical group was not present in the sample, the zero value was replaced by a sufficiently small bio-volume for the purpose of data transformations below before calculating the proportion. Based on these five taxonomical groups six indicators were examined: 1) proportion of diatoms in spring, 2) proportion of diatoms in autumn, 3) proportion of dinoflagellates in spring, 4) proportion of dinoflagellates in summer, 5) proportion of cyanobacteria in summer and 6) proportion of c*hlorophytes* in summer. Proportions of the taxonomical groups (denoted *P*) were transformed by means of the logistic function in order to obtain data that was approximately normal distributed and unboundedthe logistic function in order to obtain data that was approximately normal distributed and unbounded.

Figure 1: The investigated 38 water bodies within the Baltic Sea comprised a combination of estuaries, coastal and open waters. The numbers refer to the specific water bodies listed in Table 1.

Since the monitoring data was unevenly distributed in time and between stations, mean values for the different indicators were calculated employing a general linear model (e.g. MCCULLAGH & NELDER 1989) taking spatial and temporal variations into account:

Logit(P)=water body + station(water body) + year + month

where *water body* described the mean proportion for the 38 water bodies, *station(water body)* described the variation between monitoring stations within the water body, *year* described the interannual variation common to all water bodies (1990-2001) and *month* described differences between months of sampling. Mean levels of the transformed observations for the 38 water bodies were calculated as marginal means from this model, i.e. producing mean values that were not biased by skewed sampling in time or space. This implied that the mean values for water bodies were represented by the mean level of all monitoring stations within the water body.

The mean proportions for the six indicators were (transformed values) analyzed with respect to typology (salinity, depth and retention regimes) by means of a three-way analysis-of-variance. The significance of the different factors was investigated by means of F-test (type III test) using a 5% significance level. Mean levels for the 3 salinity regimes, the 2 depth regimes and 2 retention regimes were similarly calculated as marginal means from the analysis-of-variance.

Table 1: Typologies for the water bodies investigated and the number of phytoplankton samples taken and stations sampled within each water body (1990-2001). Salinity and depth regimes for the different water bodies were derived from the monitoring data, whereas retention regimes were determined by investigating the location of stations on the typology maps in SCHERNEWSKI & WIELGAT (2004).

No.	**Water body**	**Typology**			**#stations**	**#samples**		
		Sali	Depth	Retent.		Spring	Sum.	Aut.
1	Bothnian Bay Finnish coast	oligo	deep	<30 d	1	8	52	4
2	Bothnian Sea Finnish coast	oligo	deep	<30 d	1	8	19	3
3	Inner archipelago	oligo	deep	<30 d	5	31	56	7
4	Tvärminne coast	meso	deep	<30 d	1	43	58	19
5	Coast east of Helsinki	oligo	shallow	<30 d	2	40	108	31
6	Huovari	oligo	deep	<30 d	13	98	165	33
7	Narva Bay	oligo	deep	<30 d	3	38	46	13
8	Gulf of Finland	oligo	deep	<30 d	11	173	392	116
9	Tallinn Bay	oligo	shallow	<30 d	7	133	350	89
10	Pärnu Bay	oligo	shallow	<30 d	3	68	141	41
11	Gulf of Riga coastal	oligo	shallow	<30 d	6	61	104	37
12	Gulf of Riga open-part	oligo	deep	<30 d	4	86	93	53
13	Curonian Lagoon	oligo	shallow	>30 d	8	130	176	100
14	Lithuanian coast	meso	deep	<30 d	8	53	71	56
15	Bight of Gdansk coastal	meso	shallow	<30 d	4	48	59	10
16	Bight of Gdansk open-part	meso	deep	<30 d	2	29	39	9
17	Coast off Swinoujscie	meso	deep	<30 d	4	63	103	67
18	Oderhaff	oligo	shallow	>30 d	2	64	99	58
19	Greifswalder Bodden	meso	shallow	<30 d	1	47	68	51
20	Prohner Wiek/Bodden	meso	shallow	<30 d	3	74	100	68
21	East of Rügen	meso	deep	<30 d	3	85	146	76
22	West of Rügen	meso	shallow	<30 d	11	164	278	174
23	Der Grabow	oligo	shallow	<30 d	2	23	44	19
24	Warnow estuary	meso	shallow	<30 d	5	40	85	50
25	Warnemünde coast	meso	deep	<30 d	1	54	76	51
26	Mecklenburg Bight	meso	deep	<30 d	3	95	149	86
27	Western Baltic open-part	meso	deep	<30 d	3	47	64	42
28	South Little Belt	meso	deep	<30 d	1	52	65	51
29	Great Belt	meso	deep	<30 d	2	44	72	54
30	The Sound	meso	deep	<30 d	1	34	63	42
31	Kolding Fjord	poly	shallow	<30 d	1	33	74	42
32	Vejle Fjord	poly	shallow	<30 d	1	56	114	65
33	North Little Belt	meso	deep	<30 d	2	74	112	71
34	Horsens Fjord	poly	shallow	<30 d	1	60	91	67
35	Århus Bight	poly	deep	<30 d	1	79	108	76
36	Mariager Fjord	meso	deep	>30 d	1	86	183	95
37	Coastal Kattegat	poly	shallow	<30 d	2	95	147	111
38	Skive Fjord	poly	shallow	<30 d	1	93	147	73

Residuals from the analysis-of-variance were examined for normality (Kolmogorov-Smirnov test), independence and variance homogeneity. Standardized residuals were calculated from the analysis-of-variance and water bodies exceeding the 95% confidence limits of the normal distribution (±1.96) were identified. Mean levels and their confidence limits of the transformed observations were back-transformed to proportions using the inverse logistic function. Consequently, the back-transformed values corresponded to median levels on the proportion scale.

Table 2: Definition of seasons employed in the present study. Water body numbers refer to the list in Table 1.

Baltic Sea regions	Water body no.	Spring	Summer	Autumn
Gulf of Bothnia	1-2	Apr-Jun	Jul-Sep	Oct-Nov
Baltic Proper, Gulf of Riga, Gulf of Finland	3-23	Mar-May	Jun-Sep	Oct-Dec
Belt Sea, Sound, Kattegat	24-38	Feb-Apr	May-Aug	Sep-Nov

3 Results

The variation in the considered indicators with respect to typology could be attributed to differences in salinity and depth regimes, whereas the retention time did not have any significant effect on the proportions investigated (Table 3). Discarding retention as explanatory factor did not induce any changes in the significance of the two other factors. Salinity regimes was the most significant source of variation between the water body indicators, except for the proportion of dinoflagellates in spring that varied significantly with depth regimes only. The depth regime also had a significant effect on the proportion of diatoms in autumn, dinoflagellates in summer and cyanobacteria in summer. However, the explanatory power was low for all indicators but the summer proportion of cyanobacteria and chlorophytes, where a substantial part (65%) of the variation could be attributed to differences in salinity regimes (Table 3).

Only the proportion of dinoflagellates in spring did not pass the Kolmogorov-Smirnov test for normality. For this specific indicator data from Der Grabow, East and West of Rügen cropped out with a much smaller proportion than predicted by the typology. The two water bodies, Der Grabow and East of Rügen, were also exceeding the 95% confidence limits for the residuals for some of the other indicators, most pronounced for spring diatoms from Der Grabow having a standardized residual of -3.67, corresponding to a probability of 0.0001 that this observation belongs to the same distribution.

Diatoms were generally favoured by high salinities in both spring and autumn, as was dinoflagellates in summer (Fig. 3). The median proportion of cyanobacteria and *chlorophytes* in summer was approximately 4% for oligohaline water bodies decreasing to less than 1% for mesohaline waters and almost non-observable for polyhaline waters. Dinoflagellates in spring and summer as well as diatoms in autumn had relatively higher proportions for deeper water bodies, whereas the proportion of cyanobacteria in summer was higher in the shallow water bodies

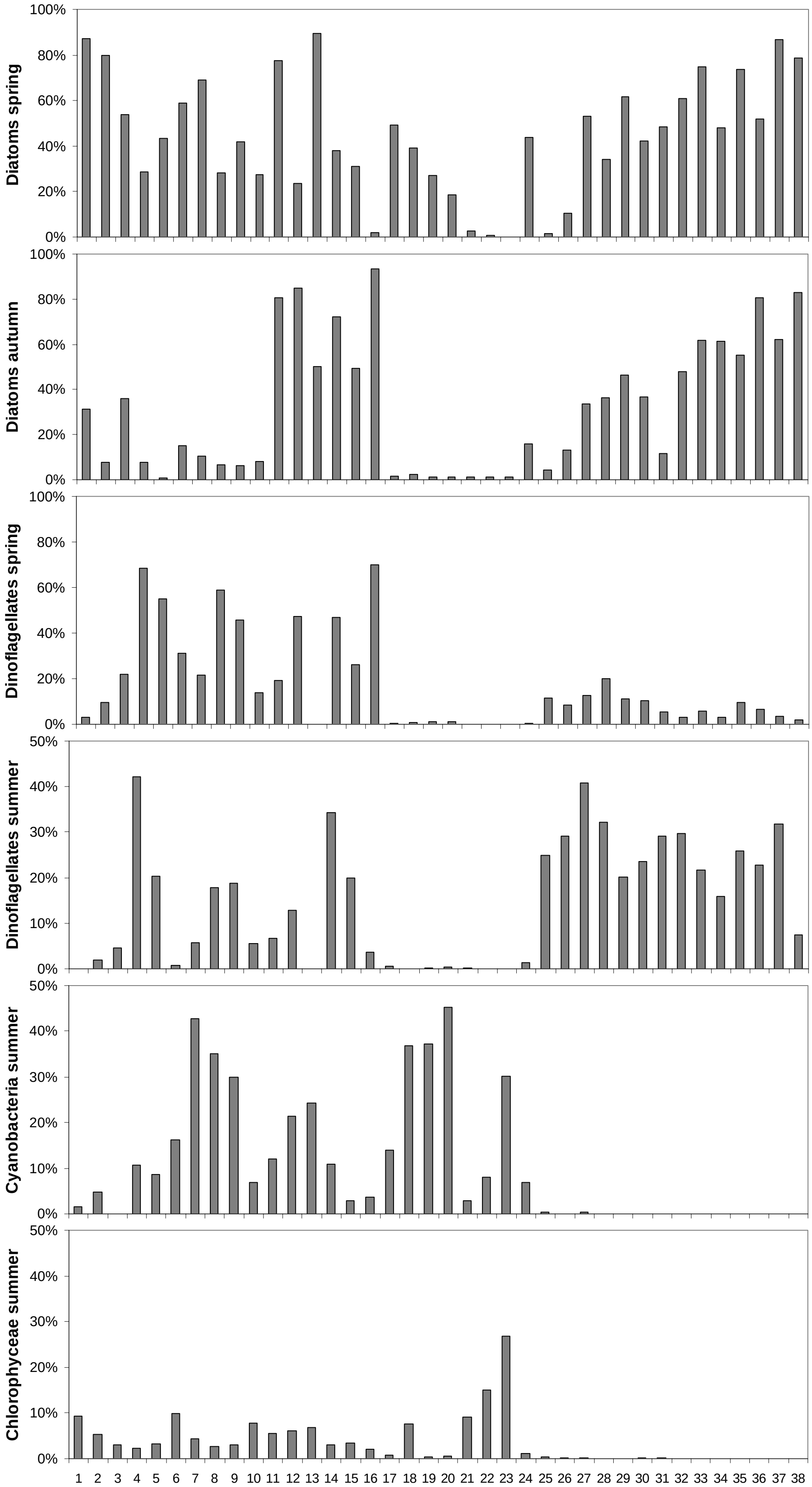

Figure 2: Estimated median proportions of indicators after back-transformation for the 38 water bodies identified by numbers given in Table 1. Note the difference in scaling on the lower three graphs.

Table 3: Analysis-of-variance for mean proportions (transformed values) of the different indicators (n=38 water bodies) analyzed for variation attributable to the typological features of the different water bodies (df=degrees of freedom, F=F test statistic, P=probability of no variation with respect to factor).

Indicator	**Factor**	**df**	**F**	**P**
Diatoms spring	Salinity regime	2	4.12	0.0253
(R^2=0.23)	Depth regime	1	2.03	0.1636
	Retention	1	1.93	0.1742
Diatoms autumn	Salinity regime	2	4.00	0.0278
(R^2=0.24)	Depth regime	1	5.14	0.0301
	Retention	1	1.60	0.2152
Dinoflagellates spring	Salinity regime	2	0.76	0.4748
(R^2=0.23)	Depth regime	1	6.26	0.0175
	Retention	1	1.91	0.1761
Dinoflagellates summer	Salinity regime	2	4.23	0.0231
(R^2=0.35)	Depth regime	1	5.06	0.0313
	Retention	1	2.32	0.1372
Cyanobacteria summer	Salinity regime	2	30.23	<0.0001
(R^2=0.65)	Depth regime	1	6.25	0.0176
	Retention	1	2.28	0.1405
Chlorophytes summer	Salinity regime	2	30.87	<0.0001
(R^2=0.65)	Depth regime	1	2.33	0.1364
	Retention	1	1.69	0.2026

4 Discussion

In this study we have shown that the phytoplankton composition could be related to differences in salinity and depths/mixing conditions. The significance of retention time could not be adequately investigated as there were only three water bodies with a high retention time giving little power to the statistical test. Although salinity is a well-known structuring factor for the phytoplankton community, this study confirms this across a wide range of different ecosystem as opposed to the majority of reported studies from the literature analysing data from a specific localised area, typically estuaries.

The most pronounced salinity effect was observed for cyanobacteria and chlorophytes. A considerable portion of the chlorophytes encountered was comprised of freshwater species and the highest proportions of chlorophytes were typically seen in water bodies affected by large freshwater inputs from Oder, Vistula, Nemunas, Daugava, Neva and Kemijoki. The presence of chlorophytes in the Baltic coastal waters is not solely related to riverine discharge points, since the proportion of chlorophytes in the Inner archipelago, Gulf of Finland open-part, Gulf of Riga open-part, Lithuanian coast, Bight of Gdansk open-part and in particular, West of Rügen and Der Grabow, had relatively high proportions of chlorophytes. Thus, the presence of chlorophytes in the Baltic Sea is not only due to dilution of freshwater species in the river plumes.

In the more saline and turbulent waters of Kattegat and Belt Sea chlorophytes and cyanobacteria almost completely disappear, and this may be related to the stabilisation of the water column. The Kattegat and Belt Sea are separated from the Baltic Proper by two shallow sills. While the Kattegat and Belt Sea are dominated by strong advective transports and a high degree of mixing across the pycnocline, the rest of the Baltic Sea has a much more stable water column. Thus, the sharp decline in the proportion of chlorophytes and cyanobacteria in Figure 3A could be due to a combination of changing salinity and turbulence conditions. In fact, salinity may be a pseudo explanatory factor since turbulence and salinity conditions are correlated.

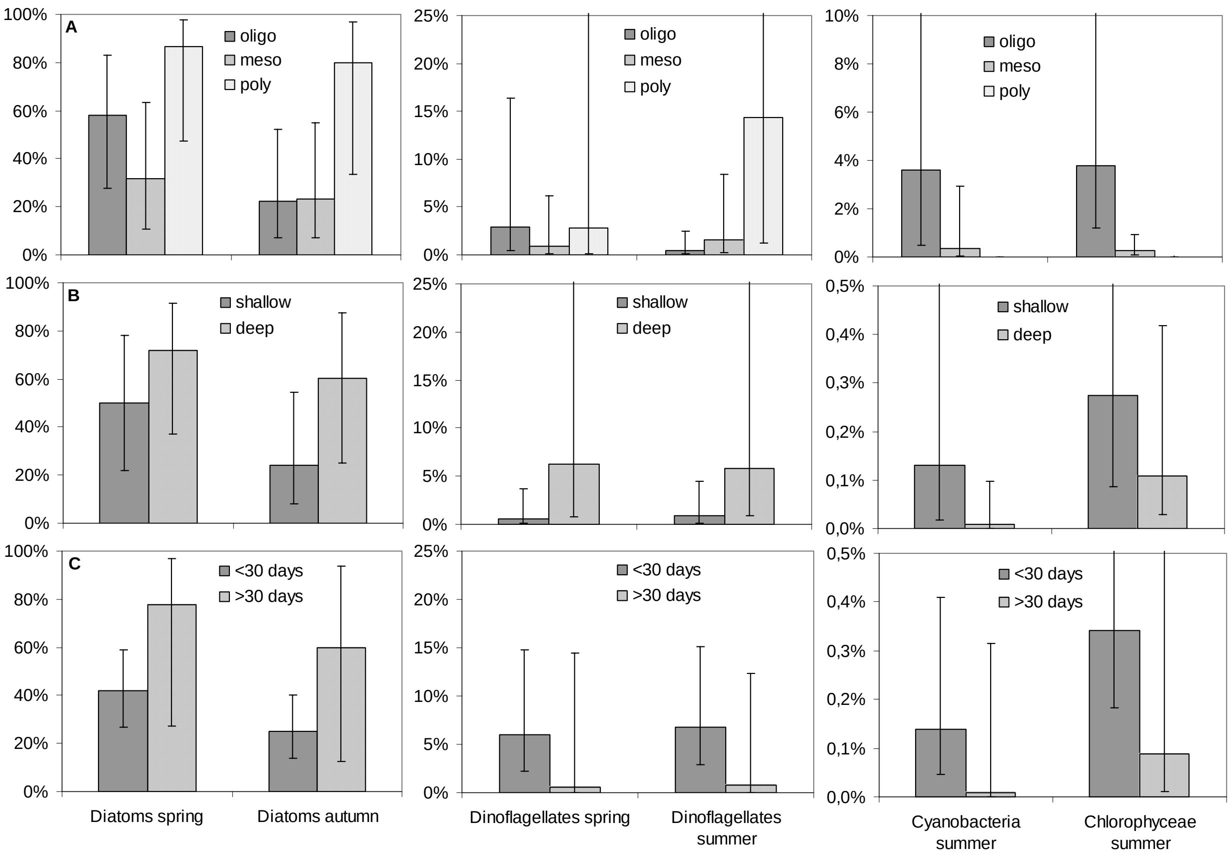

Figure 3: Estimated median proportions of indicators after back-transformation for the three typologies A) salinity, B) depth and C) retention time. Error bars show the 95% confidence limits for the mean level. Note that the scaling differs between the indicators.

The proportion of diatoms in spring and autumn as well as the summer proportion of dinoflagellates were related to the salinity level, although only diatoms in autumn and dinoflagellates in summer reflected a monotone gradient with respect to salinity. The proportion of diatoms in spring in oligohaline waters was relatively higher than in mesohaline waters but lower than in polyhaline waters. Several of the oligohaline water bodies were dominated by freshwater species in spring as documented in WASMUND et al. (1999) and this may have given rise to this non-monotone relationship with salinity, i.e. a decreasing trend for freshwater diatoms and increasing trend for marine diatoms with salinity resulting in a minimum proportion of spring diatoms in mesohaline waters.

Cyanobacteria had a relatively higher proportion in shallow waters during summer, but not sufficient to account for the observed change in the dinoflagellates proportion from shallow to deep waters. The depth-related changes in diatoms proportions are opposite to those in CARSTENSEN et al. (2004). In fact, the significance of depth regime for all six indicators was associated with German water bodies from the Baltic Proper region that reflected a very different composition in general. These water bodies were dominated by cyanobacteria, chlorophytes and other species, whereas diatoms and dinoflagellates were almost absent. However, this strongly deviating composition corresponded partly to the results in FEUERPFEIL et al. (2004) where diatoms disappeared after the spring bloom.

The three considered typology regimes could only account for a minor part of the total variation in the six indicators only, and the unexplained remaining variation within typologies suggests that the phytoplankton composition is indeed governed by other factors as well. Turbulence is an obvious typology classification parameter, and bioassay experiments have shown that pulses of nitrogen may favour diatom growth (ÖRNÓLFSDÓTTIR et al. 2004) and it is therefore likely that nutrient conditions and N/P/Si ratios may also have a structuring mechanism for the phytoplankton community.

Validation of different types by evaluating the within-type variability of biological communities would require good quality biological data from unimpacted sites (HEISKANEN et al. 2004). As most of the coastal water bodies, where the data for this study was compiled from, are impacted by human pressures (HELCOM 2002), it is difficult to distinguish between the impact of pressures (such as anthropogenic nutrient loading) and the type-specific physical and morphological factors that shape the structure of phytoplankton communities.

In conclusion, for classification of ecological status by means of phytoplankton taxonomic composition it is necessary to consider different salinity regimes. We did not analyse if other boundary values for the salinity regimes would provide a clearer grouping of the investigated water bodies. Still considerable variation remains within the employed salinity regimes, some of which appear to be systematic, suggesting that additional characteristics for sub-grouping may be required for comparing phytoplankton composition across the wide range of ecosystems in the Baltic Sea.

Data sources/Acknowledgements

The present work is a contribution from the CHARM project (contract no. EVK3-CT-2001-00065) funded by the European Commission. We acknowledge Renata Pilkaityte, Zita Gasiunaite, Ibrahim Juha and Arturas Razinkovas from the Coastal Research & Planning Institute, Klaipeda University, Lithuania, for compiling the CHARM phytoplankton database used in the present study, and the following colleagues for carrying out the taxonomic harmonisation and quality control of the phytoplankton data, and providing data for the database:

- Norbert Wasmund, Baltic Sea Research Institute, Germany
- Andres Jaanus, Estonian Marine Institute
- Pirkko Kauppila and Arjen Raateland, Finnish Environment Institute
- Renata Pilkaityte, Zita Gasiunaite, and Arturas Razinkovas Klaipeda University, Coastal Research & Planning Institute, Lithuania
- Irina Olenina, Center of Marine Research, Lithuania
- Peter Henriksen and Ole Manscher, National Environmental Research Institute, Denmark
- Slawomira Gromisz and Zbigniew Witek, Sea Fisheries Institute, Poland (MIR)
- Ingrida Purina, University of Latvia, Institute of Aquatic Ecology
- Sigrid Sagert and Hendrik Schubert, University of Rostock, Institute for Aquatic Ecology, Germany

The Alg@line ship-of-opportunity data from the Gulf of Finland was collected and provided by the Estonian Marine Institute and the Finnish Institute of Marine Research as parties of the Alg@line consortium.

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Address

Dr. Jacob Carstensen
Dept. of Marine Ecology
National Environmental Research Institute
Frederiksborgvej 399
DK-4000 Roskilde
Denmark

E-mail: jac@dmu.dk

G. Schernewski & M. Wielgat (eds.): Baltic Sea Typology
Coastline Reports 4 (2004), ISSN 0928-2734
65 - 83

Coastal typology based on benthic biotope and community data: The Lithuanian case study

Sergej Olenin & Darius Daunys

Coastal Research and Planning Institute, Klaipėda University, Klaipėda, Lithuania

Abstract

The proposed typology is based on the analysis of the abiotic conditions, benthic biotope and community data obtained in the Lithuanian part of the south-eastern Baltic coastal zone and in the Curonian Lagoon. The classification approach is hierarchical, comprising three main levels: coastal type, benthic biotope and benthic macrofauna community. The core of the classification system is a benthic biotope, which is defined as a distinctive sea bottom area with conventionally uniform physical-chemical environment (salinity, substrate, hydrodynamics, light climate, temperature regime, etc.) and matching biological features. A coastal type is characterized as a biotope complex, i.e. a part of the coastal zone comprising several neighbouring interrelated biotopes. Various coastal types may include identical biotopes, however the combination and spatial distribution of the biotopes in each coastal type is different. Qualitative and quantitative data on benthic communities are used for characterization of relevant benthic biotopes. Possibility to use the existing biotope classification systems (e.g. HELCOM 1998; EUNIS 2004) for coastal typology is discussed.

1 Introduction

Coastal typology is a necessary basement of the coastal zone management and a prerequisite for the evaluation and risk assessment of losses or changes of coastal resources. The scientifically sound coastal typology should be based on detailed information on the distribution, quality and quantity of various physical-geographical and biological features, however, in many cases such information may only be derived from heterogeneous data sets with different quality and longevity of observations.

In our study we suggest to use a notion of biotope in order to integrate variable environmental data (such as salinity, depth, wave exposure, substrate, etc) into an operational constituent to be used for the coastal classification. The term “biotope” was introduced by a German scientist, F. DAHL (1908) as an addition to the concept of ‘biocenosis” twenty years earlier formulated by K. MÖBIUS (2000). Initially it determined the physical-chemical conditions of existence of a biocenosis (“the biotope of a biocenosis”). Further, both biotope and biocenosis were considered as abiotic and biotic parts of an ecosystem, accordingly. This notion (“ecosystem = biotope + biocenosis”) became the classics in German, French, Russian and other “continental” ecological literature (OLENIN & DUCROTOY submitted). The new interpretation of the same term (“biotope = habitat + community”) appeared in the United Kingdom in the early 1990s while elaborating the classification of the natural conservation objects of the coastal zone (HISCOCK 1995; CONNOR et al. 1997) This meaning was used also in the international European environmental normative acts (EUNIS 2004).

For the purpose of this study we define a benthic biotope as a distinctive sea bottom area with conventionally uniform physical-chemical environment (salinity, substrate, hydrodynamics, light climate, temperature regime, etc.) and matching biological features. For illustration of methodology we use data collected in the Lithuanian coastal zone, Baltic Sea.

2 Study area

Open coast

The Lithuanian coastal waters are situated in the south-eastern part of the Baltic Sea and comprise the mesohaline (7-8 ppt) waters of the Baltic Proper and oligohaline-to-freshwater (0-3 ppt) of the Curonian Lagoon (Kuršių marios). Comparative characteristics of the environmental conditions of both aquatic systems are generalized in Table 1.

In the Baltic coastal zone major hydrological features are determined by the interaction between the south-eastern Baltic offshore waters and the runoff of the mostly freshwater Curonian Lagoon. The average temperature of the coastal waters has an annual range of 22 °C, showing a typical boreal seasonal pattern (OLENIN & KLOVAITE 1997 and references therein). In July-August the summer thermocline is formed at the depth of approximately 20-30 m, so almost all the coastal zone is influenced by the warm water above the thermocline. In winter, ice is a normal phenomenon along the shoreline; its width varies from 20-30 m to several hundred meters, with a thickness from 10-15 to 40-50 cm, depending on the severity of the winter.

Table 1. Environmental changes along the salinity and depth gradients from the Curonian Lagoon to the coastal areas of the Baltic Sea, Lithuanian waters.

Area*	Depth range, m	Salinity range, PSU	Temperature range, °C	Main bottom substrate	Wave exposure	Major anthropogenic pressures
			Curonian Lagoon			
Central	1-3	<0.5	0-24	Sand, silt, shell deposits	Moderate	Eutrophication
Northern	1-3	0.0-3.0	0-24	Sand, silt, shell deposits	Weak- moderate	Eutrophication
Klaipeda Strait	5-14	0.5-7.5	0-22	Sand, moraine clay, artificial hard substrates	Weak	Eutrophication, dredging, industrial and municipal wastes
			South-eastern Baltic			
South off Klaipeda	5-30	6.0-8.0	0-20	Sand	Strong-moderate	
North of Klaipeda	5-30	6.0-8.0	0-20	Stones, gravel, sand	Strong-moderate	Outflow of the eutrophied Lagoon's water, Būtingė Oil terminal
Offshore	30-55	7.0-8.8	0-11	Silt	Weak-none	Dredge spoil dumping

The permanent influence of winds, waves and water currents produces a hydrodynamically very active environment resulting in no oxygen deficiency and no oxygen based gradients in the distribution of bottom biota in the coastal area in contrast to the deeper offshore areas. Wave exposure is a very important factor shaping benthic biotopes and bottom communities in the upper part of the underwater slope down to the depth of approx. 20 m (OLENIN et al. 1996; OLENIN 1997A).

According to geomorphological and geological studies (e.g. GUDELIS, JANUKONIS 1977; PUSTELNIKOV 1990; ŽAROMSKIS 1992; GULBINSKAS & TRIMONIS 1999) the Curonian Lagoon alluvium (deposits) and abrasive-erosive processes determine the distribution of bottom sediments in the coastal zone. Accumulation sites alternate with intensively and moderately (Palanga - Būtingė) erosive areas. The mainland sub-marine coastal slope (north off Klaipėda), extending from the shore down to about 30 m is characterised by very diverse bottom types, including glacial deposits (morainic clay), large boulders, gravel and pebbles, course, medium and fine sands (GULBINSKAS & TRIMONIS 1999). The uppermost part of the coastal slope, from 0 to approximately 6 m, is covered by quartz sand, movable during storms. A morainic bench lies beneath the sand stripe, extending down to 25-30 m. The upper boundary of the morainic bench may be found approximately at the depth of 15 m in the vicinity of Būtingė and at the depth of about 4-5 m in front of Palanga. Sandy and stony bottoms alternate each other on a small scale from few to hundred meters, creating the sea bottom patchiness, exceptional for the whole coastal zone of Lithuania.

Along the Curonian Spit the bottom sediments are much more homogenous, with sand prevailing throughout the entire area. In the areas south off Klaipėda, the stony bottoms are found only on the southern border of the Lithuanian Exclusive Economic zone at the depths approx. 40-50 m (BUBINAS & REPECKA 2003).

Curonian Lagoon

The Curonian Lagoon is a large (1584 km^2) (ŽAROMSKIS 1996) coastal water body connected to the south-eastern Baltic Sea by a narrow (0.4-1.1 km) strait (Klaipėda port area). Traditionally the Lagoon is divided into the strait area (Klaipėda Strait), northern, central and southern parts according to the major physiographic features (ŽAROMSKIS 1996). The later part belongs to the Kaliningrad District of Russian Federation, and therefore it is not considered in this study. As a transitory system, the Lagoon has many estuarine attributes; from this point of view its strait area, northern and central parts may be regarded as lower, middle and upper reaches, respectively.

The mean depth of the Curonian Lagoon is approx. 3.8 m (ŽAROMSKIS 1996). The strait is ca. 11 km long, with artificially deepened water ways down to 14 m depth. In the rest of the study area the eastern side (mainland shore) represents a shallow plain gently sloping westward down to 1-2 m depth, whereas its western side (the Curonian Spit shore) is deeper, on sites reaching the 4 m depth.

Approximately 23 km^3 of freshwater gained in the form of riverine runoff pass the study area annually. More than 40% of this amount is discharged into the sea during spring months, whereas 5 km^3 of incoming seawater are mixed in the Lagoon mostly in autumn months (PUSTELNIKOVAS 1998). Duration and extent of seawater intrusions are coupled with a wind caused rise of water table in the sea. Episodic inflows of the sea water cause irregular rapid (hours-days) salinity fluctuations in the range of 0 - 7 psu in the Strait and to a less extent, in the northern part of the Lagoon (DAUNYS 2001). One-to-two days seawater inflows are most frequent (ŽAROMSKIS 1996) with a residence time of mixed waters within Lagoon not longer than 5 days. The seawater intrusions are mostly restricted to the northern part of the Lagoon, only rarely propagating into its central part for ca. 40 km.

Water temperature dynamics is typical for shallow temperate Lagoons with annual amplitude up to 25-29°C (ŽAROMSKIS 1996). In the Strait it is affected by seawater intrusions and may differ by 1-2 °C from the rest of the Lagoon (GASIŪNAITĖ 2000). The Strait is always ice free, while in the rest of the Lagoon the ice cover is present for 110 days on average (ŽAROMSKIS 1996).

Oxygen concentrations are subject to spatial and temporal (both diurnal and seasonal) variations (JUREVIČIUS 1959). Low concentrations down to 1.8 ml/l were found during the ice cover period in the lower part; local anoxia may take place in summer.

The main bottom sediments in the Lagoon are sand and silt, on sites with shell deposits (mainly of invasive bivalve *Dreissena polymorpha* and native gastropods of the genus *Valvata*). In the Klaipėda strait, the bottom sediments are greatly influenced by constant dredging for the waterway maintenance. The northern part of the Lagoon is acting as a transitory area of sediment transportation, while the central part is most heterogeneous in respect to bottom geomorphology and sediment type. Here, prevailing type is fine sand, on sites mixed with gravel and pebbles, peat and moraine. Muddy bottoms occur in local depressions in the deeper western part of the Lagoon along the Curonian Spit.

Benthic studies in the area and availability of historical data

Studies of benthic macrofauna in the Lithuanian coastal zone of the Baltic Sea were initiated by the Lithuanian government in 1928, when an invited Danish hydrobiologist (Blegvad) took first quantitative samples (presumably with a Petersen type grab) in the northern part of the coastal zone (GASIŪNAS 1963). Unfortunately, neither location of the sampling stations nor the source where the data were published are known.

The macrofauna studies were renewed after the World War II with a research on large-scale distribution patterns of trophic types and zoogeographic complexes in the southern part of the Baltic Sea (LUKSENAS 1967; 1969). However, the Lithuanian coastal zone in these studies was represented by few stations only.

Since 1980's several descriptive studies focused on distribution of selected species and structure of benthic communities were carried out with particular reference to human impacts such as an oil spill (ANDRIUSCTCHENKO et al. 1985; OLENIN 1990) and dredge spoil dumping (OLENIN 1992). Also in 1981 monitoring of the bottom macrofauna in the south-eastern Baltic, including the coastal waters of Lithuania was started using the standard sampling methodology (OLENIN 1987B). Since early 1990's several studies were initiated to classify and map benthic biotopes in the Lithuanian coastal zone (OLENIN et al. 1996; OLENIN 1997C), however this research is still restricted to the areas of highest conservation value in the north off the Curonian Lagoon outlet. The first exhaustive study on the distribution of bottom macrofauna species and communities along the southern Lithuanian coastal zone was only recently carried out (BUBINAS & REPECKA 2003). However, comparative value of published data is relatively low since only few quantitative results are given either on selected species or community level.

Studies on bottom macrofauna in the Curonian Lagoon started in early 1920's with a general focus on diversity and biology of benthic species (SZIDAT 1926; WILLER 1931; LUNDBECK 1935). Later an exhaustive study was carried out in 1950's with a particular reference to diversity and structural characteristics of the main complexes of the bottom macrofauna in the Lagoon (GASIŪNAS 1959). This study is still considered as the most comprehensive inventory of the Curonian Lagoon bottom macrofauna.

Several studies were focused on estimation of acclimated species production (RAZINKOV 1990), evaluation of food sources for commercial fishes (BUBINAS 1983; LAZAUSKIENĖ et al. 1996), accumulation of heavy metals and cytogenetic damage in bottom dwelling animals (JAGMINIENĖ 1995; BARŠIENĖ & BARŠYTĖ 2000). Main structural characteristics of benthic communities and trophic groups were also investigated (ARISTOVA 1965; 1971; BUBINAS 1983; OLENIN 1987A).

Regional biological monitoring program, which started in the Curonian Lagoon in 1980 was aimed to track changes at various levels of biological life. These long-term observations resulted in description of quantitative macrofauna characteristics at 7 monitoring sites (OLENIN 1987A). In 1990's an attempt was made to use the modern functional group approach to understand possible role of macrofauna in the Lagoon's ecosystem (OLENIN 1997B). Later the ecological effect of invasive alien species was summarized by OLENIN & LEPPÄKOSKI (1999).

However, in spite of quite long history of benthic research in the Curonian Lagoon, the role of environmental factors and driving forces in the Lagoon's benthic system is still poorly understood. Even if series of quantitative data exist, they are hardly comparable due to different techniques used in various studies. In most of studies no numeric methods were applied to test relationships between environmental characteristics and structure of the bottom macrofauna, however salinity was frequently suggested to be an important factor for reproduction success and distribution of some benthic species

(GASIŪNAS 1959; BUBINAS 1983; OLENIN 1987A; DAUNYS et al. 2000; DAUNYS 2001). Effect of sediment characteristics (organic carbon, granulometric parameters, depth) was tested in one of the recent works on Lagoon's macrofauna (DAUNYS 2001).

Summarizing published historical material (Table 2) on bottom macrofauna in the Lithuanian waters it can be concluded, that species diversity is rather well described. For the Curonian Lagoon the most comprehensive inventory on species diversity is still based on data collected in 1954-57 (GASIŪNAS 1959), while for the coastal zone of the Baltic Sea the material is spread between different scientific publications, reports and unpublished material. Only few publications contain lists of species and quantitative information on the community level. Use of historical data is also difficult due to different (or not specified) sampling methods and different (or unknown) procedures of sample sorting (onboard immediately after sampling or as fixed material under microscope in a on land laboratory; weight determination method).

On another hand, various indices describing diversity and/or evenness patterns were not popular in earlier studies. Therefore, generally quantitative information of high comparative value is not available for tracing historical changes in macrofauna neither in the Curonian Lagoon nor in the coastal zone of the Baltic Sea. The only material which could be used for quantitative analysis of the long-term changes is the monitoring data from few fixed stations in the Lagoon (observations made since 1980) and in the coastal zone (since 1981). Other sources may only support comparative analysis by providing long-term data on selected species/areas and allow verification of comparison results for longer time periods. Data from GASIŪNAS (1959) were used to complete species inventory of the Curonian Lagoon as well as to distinguish between categories of species (rare, common, very common and dominant). Also data on distribution of selected species in the same paper was used for detection of long-term changes in benthic macrofauna in the Lagoon, however no quantitative comparisons were carried out due to reasons mentioned above.

Table 2. Summary of information on previous studies in the Curonian Lagoon and the Lithuanian coastal zone of the Baltic Sea.

Reference	Period of studies	Methods used	Applicability for coastal typology
Gasiūnas 1959	1954-1957	Ekman-Berdge (0.0225 m^2) and Petersen (0.025 m^2) grabs, sediment core (0.01 m^2)	Inventory of species diversity, biomass/abundance of selected species, description of macrofauna complexes. Sampling methodology as well as details of sample proceeding are not given, therefore study is limited for comparative analysis based abundance and biomass values.
Luksenas 1967	1964-1966	Okean type grab (0.1 m^2), drag, mysid trawl	Distribution of bottom macrofauna that belong to different zoogeographic regions in the southern and south-eastern parts of the Baltic Sea
Luksenas 1969	1964-1966	Okean type grab (0.1 m^2), drag, mysid trawl	Distribution of bottom macrofauna that belong to different trophic types in the southern and south-eastern parts of the Baltic Sea
Aristova 1965	not indicated	Reference to unavailable sources	Description and distribution of bottom communities in the Curonian Lagoon
Aristova 1971	not indicated	Reference to unavailable sources	Description and distribution of *Dreissena polymorpha* community
Bubinas 1983	1978-80	Grab type not given	Description of bottom macrofauna in selected stations of the northern part of Curonian Lagoon
Olenin 1987a	1980-1984	Petersen type grab (0.025 m^2)	Description of benthic communities at 11 monitoring stations; species lists, mean values of abundance and biomass
Olenin, 1990	1981-83	Van-Veen, Okean, dredge	Results from "Globe Assimi" oil spill environmental impact assessment.
Olenin,	1994	Van-Veen grab (0.1 m^2);	Classification and description of benthic com-

Reference	Period of studies	Methods used	Applicability for coastal typology
Chubarova, 1994		SCUBA diving	munities in the northern part of Lithuanian coastal zone
Olenin et al. 1997	1993-1996	Van-Veen grab (0.1 m^2); SCUBA diving	Classification, description and mapping of benthic biotopes in the northern part of Lithuanian coastal zone
Bubinas et al. 1998		Van-Veen grab (0.1 m^2)	Distribution of bottom macrofauna, quantitative characteristics of selected species
Daunys 2001	1980-2001	Petersen type grab (0.025 m^2); Van-Veen grab (0.1 m^2); sediment core	Description of benthic communities including littoral part, statistical analysis of relationships between bottom macrofauna and environmental variables
Bubinas, Repecka 2003	1998-1999	Van-Veen grab (0.1 m^2)	Description of bottom macrofauna with notes on benthic communities in the southern part of Lithuanian coastal zone; descriptive analysis of relationships between sediment granulometry and macrofauna
Olenin et al. 2004	2002-2003	Veen grab (0.1 m^2); SCUBA diving	Description of biodiversity; classification, description and mapping of benthic biotopes in the northern part of the Lithuanian coastal zone.

3 Materials and methods

Collection of benthic data

Data on benthic macrofauna was collected in period from 1980 to 2003. Investigations were performed in the framework of biological monitoring programs, various environmental impact assessments and benthic biotope mapping surveys. In total 420 and 188 samples were taken in the Curonian Lagoon and in the coastal zone of the Baltic Sea respectively. The material was collected using Petersen and Van-Veen grabs, hand operated corers and SCUBA diving methods. All samples washed through a 0.5 mm mesh sieve, preserved with 4 % formalin and treated in a land laboratory according to HELCOM recommendations (1988).

Bottom macrofauna was identified to species level where practicable; such groups as oligochaets, chironomides were identified to appropriate higher taxonomic layer (class, family). Biomass was determined as formalin wet weight (g/m^2). Species which formed more than 40% of total macrozoobenthos biomass were considered dominants. Occurrence in 40% of samples was selected as a conventional threshold to distinguish constant species in a community. Detailed description of the methods used is given in the previous publications (OLENIN 1987A; 1987B; 1992; 1997A; 1997B; 1997C; DAUNYS & OLENIN 1999; DAUNYS 2001).

SCUBA diving observations and remote underwater video survey

SCUBA divers estimated visible geomorphological and biological features of benthic biotopes such as: sediment type and its heterogeneity, bottom vegetation, blue mussel and barnacle colonies, biogenic tubes, holes and animal crawling tracks on the soft sediment, using a semi-quantitative 5-grade scale for the assessment. For standardized descriptions, the divers used a weighed, 10 m long transect line. The SCUBA diver observations were performed at the depths from 3 to 18 m during 1993, 1996, 1997, 1999, 2002 and 2003 field seasons in the northern part of the open Lithuanian coast and in the area of the Klaipėda port breakwaters.

A remote video survey of the sea bottom was performed using various types of underwater video cameras during the same field seasons as SCUBA diving in the northern and southern parts of the open coast. A camera was hauled down from the ship (or a boat) to the bottom. The ship was drifting approximately 100 to 150 m. The analysis of video material included registration of same geomorphological and biological features as in case of SCUBA diving. Detailed description of the methods used is given in the previous publications (OLENIN et al. 1996; OLENIN 1997C). SCUBA diving observations and video surveys were not performed in the Curonian Lagoon because of a very low visibility (usually < 0.5 m).

Identification of benthic biotopes

Identification of the biotopes was based on both physical and biological features. The physical features included: type and uniformity of substrate (sand, gravel, stones or mixture of stones and sand, etc.), depth (as proxy for light availability for plants and comparative strength of wave action), presence of sandy ripples, etc. The biological features used for biotope discrimination comprised: character of coverage of the red algae *Furcellaria lumbricalis*, blue mussel *Mytilus edulis*, barnacle *Balanus improvisus*; presence of mobile nectobenthic species, such as mysids and burrowing amphipods *Bathyporeia*, infaunal bivalves *Mya arenaria* and *Macoma baltica*, as well as visible biogenic signals (empty shells, traces of crawling bottom animals, siphon and burrow openings, etc.).

The procedure of biotope identification included several steps. The first step was the analysis of all information available and preliminary identification of the biotope type for each sampling station. In large extent, that preliminary identification was based on the previous knowledge of the area (OLENIN et al. 1996; OLENIN 1997A; 1997B; DAUNYS & OLENIN 1999; DAUNYS 2001). Then the similar stations were grouped according to the biotope type defined. Specific abiotic and biotic features, which distinguish one group of stations from another, were defined and the level of heterogeneity was evaluated. In case of high heterogeneity, the quantitative biological data were examined using the cluster analysis and/or ordination procedures in order to determine "exceptions" (or "internal groups") within a given group of stations. Those "internal groups" were additionally analyzed in order to find more specific abiotic or biotic features, distinguishing them from each other. This procedure was aimed to identify the benthic biotopes as objectively as possible.

After preliminary identification and subsequent valuation of the biotope type, the sampling stations were plotted on the geological maps available for the Curonian Lagoon (GULBINSKAS et al. 2003) and for the coastal zone (GULBINSKAS et al. unpublished). The biotope type at each station was compared with the geological map readings and specified by available video and SCUBA diver observation materials (specification using video and SCUBA diving materials was possible only for the northern part of the open coast). The final step was the expert evaluation and extrapolation of the biotope type on the adjacent areas (less covered by the sampling stations).

Definition of a coastal type

The proposed typology is based on the analysis of the abiotic conditions and studies on benthic biotope and communities performed both in the Baltic Sea coastal zone and in the Curonian Lagoon (OLENIN et al. 1996; OLENIN 1997A; 1997B; DAUNYS & OLENIN 1999; DAUNYS 2001). The classification approach is hierarchical, comprising three main levels: 1) coastal type, 2) benthic biotope and 3) benthic community.

Definition of a benthic biotope was used in earlier studies (OLENIN et al. 1996; OLENIN 1997C); it corresponds to the notion used for the benthic biotope classification in Great Britain and Ireland: "the physical habitat with its biological community, i.e. the combination of physical environment (habitat) and its distinctive assemblage of conspicuous species" (CONNOR et al. 1997A; 1997B; MARLIN 2004). Benthic macrofauna communities were identified by the names of the biomass dominant species (e.g., *Macoma baltica, Dreissena polymorpha*) in accordance to the benthic ecology tradition (PETERSEN 1911-1918 cit. by NESIS 1977). Due to high heterogeneity of substrate and presence of microhabitats more than one benthic macrofauna communities may be found in most of the biotopes; in such cases we identified the main, most characteristic communities and additional ones.

A coastal type is defined as a biotope complex, i.e. a part of the coastal zone comprising several neighbouring interrelated biotopes. Identical biotopes (e.g. biotope of mobile sands, stony bottoms with macrophytes, soft sandy bottoms with infauna, etc.) may be integrated in various combinations into different coastal types. Therefore, the coastal typology should be based on the analysis of composition and spatial distribution of the biotopes, comprising the biotope complexes within a certain geographical location.

4 Results

4.1 Classification of the coastal types

A general scheme of the classification procedure is shown in Figure 1. At the first step two principally different types of aquatic environment were distinguished: 1) marine, the open Baltic Sea coast, and 2) estuarine (transitional), the Curonian Lagoon.

At the second step two coastal types were identified for the open coast of the Baltic Sea: 1) the area to the north of the Curonian Lagoon outlet, and 2) the southern coastal area. Due to prevailing northern direction of currents, the first area is much more influenced by the freshwater outflow than the second one. Both areas also differ in terms of their geomorphology and origin: the southern area stretches along the Curonian Spit, which evolved as a large alluvial deposit form, with sand being the prevailing type of the bottom sediments. In opposite, the great variety in bottom substrate in the northern area is formed due to an underwater extension of the morainic mainland coast (GUDELIS 1998).

At the third step, the assemblage of benthic biotopes was defined for each coastal type, taking into account the nature of substrate (soft or hard bottoms), depth range and light climate (within or below the euphotic zone). In fact, the classification of biotopes included several intermediate steps which are not shown in Figure 1 for the purpose of simplicity. For instance within the biotope “Stony bottoms in aphotic zone” one may distinguish few lower level biotopes such as “Boulders with dense colonies of blue mussel *Mytilus edulis* and barnacle *Balanus improvisus*”; “Gravel and pebble patches with polychaetes *Nereis diversicolor* and *Marenzelleria viridis*” and, “Sand patches with bivalve *Macoma baltica* and *Marenzelleria viridis* between stones”.

In total, seven main benthic biotopes were distinguished for the open coast: five for the northern and two for the southern area (Table 2). According to the geological data, the later area is much more monotonous in terms of the bottom substrates. However, further research may reveal other biotopes in this part of the coastal zone, since yet it was not studied in such details as the northern one.

Finally, the forth step included identification of the main and co-occurring benthic communities which are represented for a given biotope (Table 2).

Table 3. Coastal types, biotopes and characteristic benthic communities of the south-eastern Baltic coastal zone.

Coastal type	Biotope	Abbreviation	Communities*				
			Mac. balt.	*Mya aren.*	*Mar. vir.*	*Bal. imp.*	*Myt. edul.*
Northern coastal area	Mobile sand	NOC.MSD	+				
	Soft bottom	NOC.SFT	++	+	+		
	Mixed bottom	NOC.MIX	+		+	+	+
	Stony bottom in the euphotic zone	NOC.STE				+	++
	Stony bottom in the aphotic zone	NOC.STA				+	++
Southern coastal area	Mobile sand	SOC.MSD	+?				
	Soft bottom	SOC.SFT	++	+			

Mac. balt. – Macoma baltica, Mya aren. – Mya arenaria, Mar. vir. – Marenzelleria viridis, Bal. imp. – Balanus improvisus, Myt. edul. – Mytilus edulis;
++ - main community of the given biotope, + - additional community, ? – status unknown

The same procedure was applied for classification of the Curonian Lagoon. Here, three coastal types were distinguished based on the peculiarities of the salinity regime: 1) Klaipėda Strait, most influenced by the sea water inflows and showing the highest range of salinity fluctuations; 2) the northern part of the Lagoon less exposed to the salinity changes; and 3) the freshwater area in front of the River Nemunas delta in the central part of the Lagoon. At the third step, the assemblage of characteristic benthic biotopes was defined for each coastal type. In total, six main benthic biotopes were distinguished; and at the forth step the characteristic benthic communities were identified (Table 3).

Table 4. Coastal types, biotopes and characteristic benthic communities of the Curonian Lagoon.

Coastal type	Biotope	Abbreviation	Communities*					
			N. div.	*M. vir.*	*V. pisc.*	*U. tum.*	*D. pol.*	*Ol.+Ch.*
Central part of the Lagoon (Delta area)	Muddy bottoms in the central part of the Lagoon	DEL.MUD					++	+
	Sandy bottoms in the central part of the Lagoon	DEL.SND					+	++
Northern part of the Lagoon	Muddy bottoms in the northern part of the Lagoon	LAG.MUD			+		+	++
	Sandy bottoms in the northern part of the Lagoon	LAG.SND		+		++	+	+
Klaipėda Strait	Muddy bottoms in Klaipėda Strait	STR.MUD	+	+				++
	Mixed bottoms in Klaipėda Strait	STR.MIX	++	+				+

**N. div. – Nereis diversicolor, M. vir. – Marenzelleria viridis, V. pisc. – Valvata piscinalis, U. tum. – Unio tumidus, D. pol. – Dreissena polymorpha, Ol.+Ch. – Oligochaeta + Chironomidae*; ++ - main community of the given biotope, + - additional community.

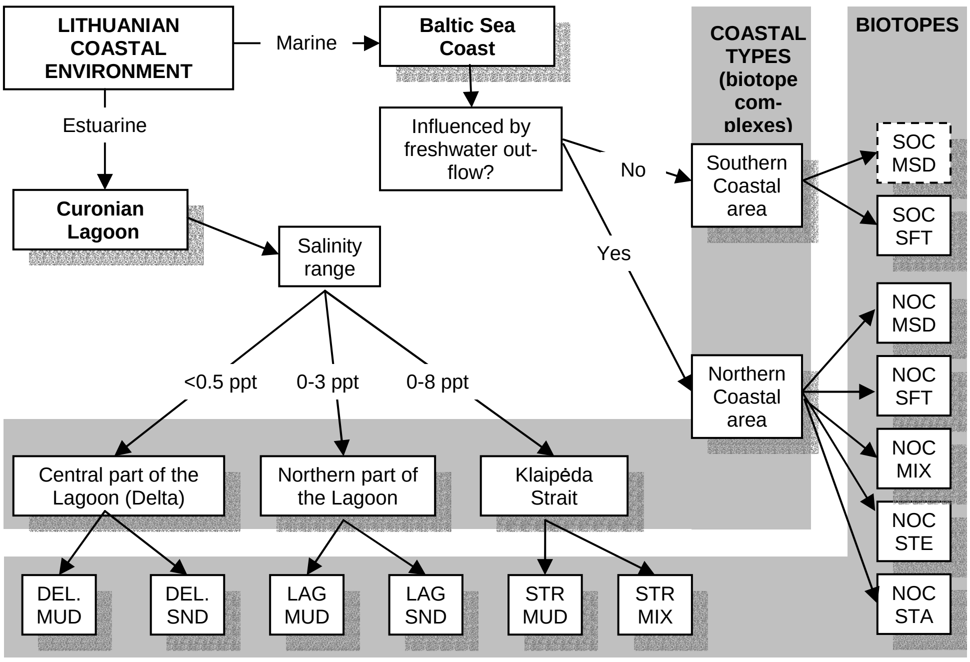

Figure 1. Typology of the Lithuanian coastal benthic environment based on benthic biotopes and biotope complexes. Abbreviations: DEL – delta, LAG – Lagoon, STR – strait, SOC – southern coast, NOC – northern coast; MUD – mud, SND – sand, STE – stones in euphotic zone, STA – stones in aphotic zone, MSD – mobile sands, SFT – soft bottoms, MIX – mixed (stones, gravel and sand) bottoms. See text for explanation.

4.2 Characterization of coastal types and benthic biotopes

Biotopes of the northern open coast type

The general scheme showing distribution of the coastal types and main benthic biotopes in the Lithuanian part of the Baltic Sea and in the Curonian Lagoon is shown in Figure 2. The northern coastal type stretches from the Curonian Lagoon outlet to the Latvian border (approx. coordinates: N 56°03', N 55°43', E 21°03', N 20°03'). This area is characterized by the most diverse bottom substrates and the highest patchiness of the bottom in the entire Lithuanian coastal zone. Brief description of the main benthic biotopes is given below.

The mobile sand biotope (NOC.MSD in Fig. 1) occupies the uppermost sublittoral from the shore line to approximately 6 m depth, where sands are permanently transferred due to wave and current action. This biotope forms a narrow band along the entire shore line. Instability of the substrate prevents formation of established benthic communities. Species diversity is low: only 8 species were found (3 species per sample). These species are either burrowing infaunal (*Marenzelleria viridis, Pygospio elegans, Macoma baltica*) or actively swimming nectobenthic (*Bathyporeia pilosa, Crangon crangon*) forms adapted to the active hydrodynamic conditions of the exposed sandy coast. No macrophytes occur on such bottoms. The total community biomass ranges from 3 to 93 (mean 33±9) g/m^2. Abundance is much lower than in other sandy bottom biotopes laying beneath the wave exposure zone: 70-3900 (2200±530) ind./m^2. No macrophyte species were found in this biotope during SCUBA diving and remote underwater video surveys in 1993-2003.

Soft bottom biotopes (NOC.SFT in Fig. 1) include “Sand banks in the middle sublittoral with bivalves *Macoma baltica* and *Mya arenaria*” and “Fine sand in the lower sublittoral (20-30 m) with bivalve *Macoma baltica* and isopod *Saduria entomon*”. Both biotopes are rather similar in their physical and biological features with no clear boundaries due to variety of transitional forms.

The first biotope typically occupies a wide (up to 6 km) band within the depth range from 5 to ca. 15 m along the shore in Butinge area (close to Latvian border); it shrinks to few fragments within large stony fields near Palanga. The benthic community comprises about 20 species (6 species per sample) with the biomass dominant bivalve *M. baltica* and total biomass ranging from 0,5 to 123 (37±7) g/m^2 and abundance - 850 - 48530 (22684 ± 2900) ind./m^2. The most characteristic species (occurrence > 60%) are typical coastal infaunal dwellers: polychaetes *M. viridis, Nereis diversicolor* and *P. elegans,* bivalves *M. baltica* and *M. arenaria,* crustacean *C. volutator*. Due to numerous juvenile forms, the abundance of benthic macrofauna is 4-10 times higher than in other sandy bottom biotopes. Due heterogeneity of environment the structure of benthic communities is also rather variable: on sites, the dominant bivalve *M. baltica* is shifted by the polychaetes *M. viridis* and *N. diversicolor.* Although the light penetration is sufficient in the upper part of the biotope, no macrophytes occur there.

Another soft bottom biotope is mostly characteristic for the Klaipėda – Palanga area. It may be found also in a form of rather wide (hundred meters) sandy bottom inclinations among the stony fields in lower sublittoral (ca. 20 m depth) in Palanga area. The environment in this biotope is less heterogeneous and more stable comparing to the sandy bottoms in middle and upper sublittoral. The distinctive biological feature is presence of the isopod *S. entomon*, which does not occur on sands in the upper sections of sublittoral and on stony bottoms. In opposite, some shallow sandy coast dwellers, such as *M. arenaria* are absent in this biotope. The most characteristic species (occurrence > 60%) are: the bivalve *M. baltica,* polychaetes *N. diversicolor, Marenzelleria viridis, P. elegans* and the isopod *Saduria entomon*. The total number of species found is 12 (7±1 per sample in average). The biomass and abundance are less variable than in other sandy bottom biotopes: 17 – 48 (28 ± 10) g/m^2 and 1340 ± 11280 (5390 ± 3010) ind./m^2.

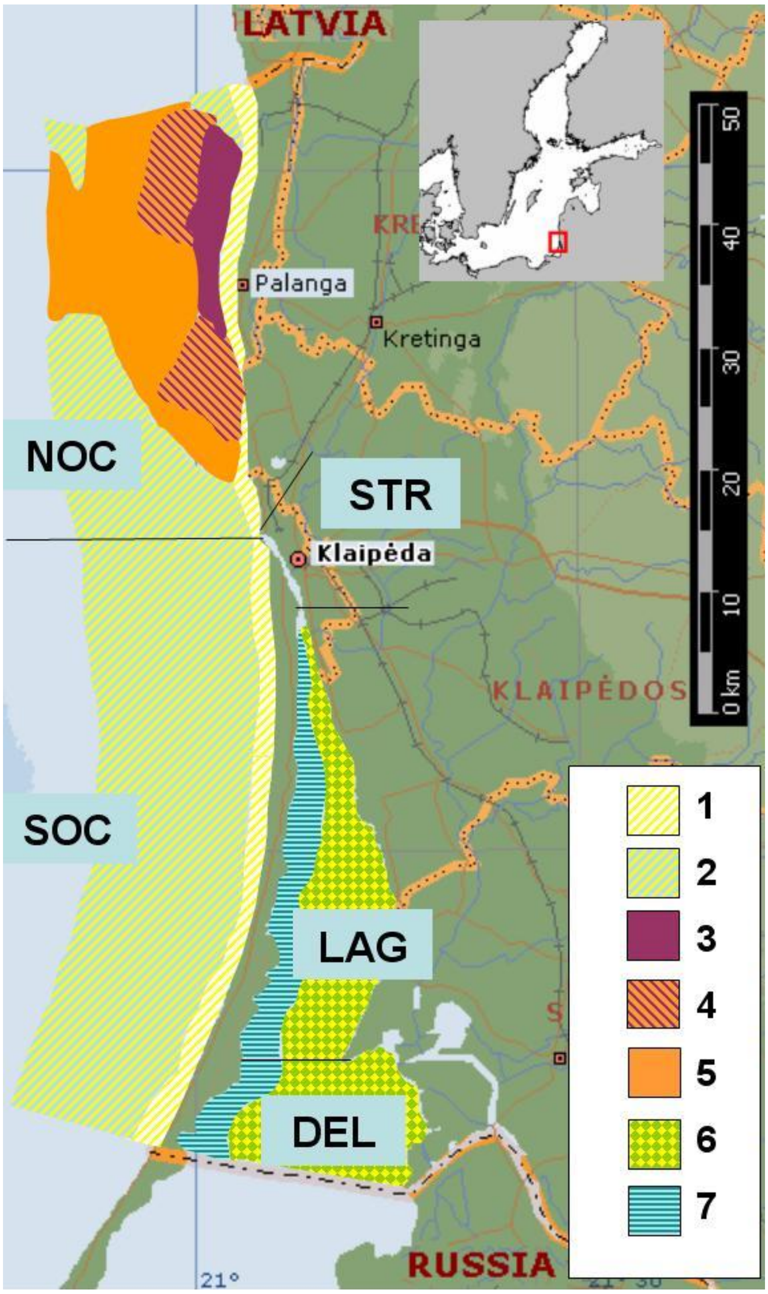

Figure 2. Scheme showing location of the coastal types and main benthic biotopes in the Lithuanian waters of the Baltic Sea and the Curonian Lagoon. Open coast biotopes: 1 - mobile sand, 2 - soft bottoms, 3 - stony bottoms in the euphotic zone, 4 - stony bottoms in the aphotic zone, 5 - mixed bottoms. Curonian Lagoon biotopes: 6 - sandy bottoms, 2 – muddy bottoms.

Stony bottom biotopes within the euphotic zone (NOC.STE in Fig. 1) include "Boulder reefs with red algae *Furcellaria lumbricalis*" and "Stony and gravel bottoms with red algae *Furcellaria lumbricalis*". The first biotope is characterised by fields of densely packed stones and large boulders with very little or no sand and gravel parches. This biotope is found in front of Palanga, where it occupies a small area (ca. 1 km^2) within the depth range 5 to 10 m. This is the only place in the entire Lithuanian coastal zone where the red algae *F. lumbricalis* may form dense colonies and successfully compete for space with the blue mussels and barnacles due to favorable lithodynamic and geomorphological conditions within the euphotic zone (BUCAS et al. in prep.). The biomass of *Furcellaria* may be as high as 4 kg/m^2. In opposite, the blue mussel biomass is 5-6 times less in this biotope than in the similar habitats beneath the euphotic zone. *F. lumbricalis* is the only habitat forming perennial algae at the Lithuanian coast; the dense colonies of this red algae create microhabitats for diverse macrofauna, especially for phytophagous *Idothea baltica* and nectobenthic species such as gammarids and mysids. The species richness is comparatively high: 14±1 species per sample (31 species in total). The most characteristic species are: *Mytilus edulis*, *Balanus improvisus*, *Fabricia sabella*, *Nereis diversicolor*, *Hydrobia sp.*, *Gammarus salinus* and *Jaera albifrons*. The total benthic community biomass varies from 187 to 1429 (663 ± 135) g/m^2 and abundance - 1100 – 81275 (16860 ± 6420) ind./m^2.

In another biotope, stony and gravel bottoms are still suitable for *F. lumbricalis* due to favourable light conditions. However, high hydrodynamic activity facilitates the abrasive effect of sand and gravel, and therefore there are many spots on boulders with no attached plants or animals. In general, the stones which are elevated to less than ca. 20 cm above the bottom are not covered by any attached fauna or flora. The most characteristic forms are: *M. edulis, B. improvisus, Bathyporeia pilosa, Fabricia sabella, Gammarus salinus, C. volutator* and oligochaetes. The total benthic community biomass varies from 47 to 5735 (2 488 ± 286) g/m^2 and abundance - 1900 – 37750 (17473 ± 1561) ind./m^2. Areas occupied by this biotope are found within the depth range 5-16 m near Karkle (10-15 km north off Klaipėda) and in Palanga area.

<u>Stony bottom biotope in the aphotic zone</u> (NOC. STA in Fig. 1) includes fields of densely packed stones and large boulders nearly entirely covered by colonies of blue mussels *M. edulis* and barnacles *B. improvisus* represent features which are usually typical for reefs. This biotope occupies the area off Palanga in the depth range of ca. 15-20 m, where the abrasive effect of sand and gravel is low. This biotope displays the most favourable environment for epifaunal species: their total biomass, ranging from 3515 to 5530 (4500±208) g/m^2, is the highest at the Lithuanian coast. Abundance varies within 15375 – 33 850 (25747 ± 2261) ind./m^2. The blue mussel constitutes about 90 and *B. improvisus* 5% of total biomass, the role of other species is insignificant. Besides these two species other characteristic invertebrates are: *Jaera albifrons*, *N. diversicolor*, *Gammarus zaddachi* and *G. salinus*. Variability of the biomass of blue mussels between samples is considerably lower than in other stony bottom biotopes. On the upper edge of the biotope (ca. 15 m) single specimens of macroalgal species, such as *Coccotylus truncatus* tolerant to low light conditions may be found.

<u>Biotopes of mixed bottoms</u> (NOC.MIX in Fig. 1) comprise stony and gravel fields with blue mussel *M. edulis* and barnacle *B. improvisus* as the most conspicuous biological features. These heterogeneous biotopes are the most typical for the entire northern coastal area within approximately 5 to 25 m depth range. Here stony areas and large boulders alternate with patches and stripes of sand, gravel, pebbles and moraine on a scale of meters - tens of meters. Species composition and dominant species of macrofauna also varies depending on the character of the bottom sediments. The blue mussels and barnacles form dense colonies on boulders and stones, attracting associated fauna. The species diversity here is higher than at the adjoining sandy or gravel locations. Besides *M. edulis* and *B. improvisus*, other characteristic species are: *N. diversicolor*, *Gammarus salinus*, *Jaera albifrons* and *Corophium volutator.* The total benthic community biomass varies from 22 to 6060 (1950 ±280) g/m^2 and abundance - 390 – 97210 (16250 ± 2490) ind./m^2. Bottom macroflora is represented by very rare single specimens of some tolerant species.

The patches of <u>gravel</u> and pebbles are mostly inhabited by polychaetes *N. diversicolor* and *M. viridis.* The larger pebbles are still suitable for *B. improvisus* and *M. edulis*, however both species do not form dense colonies and the total species richness is lower than on boulders (6±1 per sample). Gravel and pebbles are not suitable for typical infaunal sandy bottom dwellers such as *M. arenaria*, *C. volutator* and *P. elegans.* The variation in quantitative parameters is very high, from no macrofauna in some pebble patches to rather high values: 0 –310 (64± 34) g/m^2 and 0 – 4350 (1290± 450) ind./m^2.

Sandy patches between stones are occupied by the benthic community dominated by *M. baltica* and *M. viridis* with other characteristic forms such as oligochaetes, *N. diversicolor* and *Hydrobia sp*. In contrast to the typical sandy bottom biotopes the biomass is 3-5 times less here, but the species richness is similar (7±2 species per sample). On sites, the gastropod *Theodoxus fluviatilis* may be found, which is rare in the other parts of the coastal zone within the stony bottoms. The total benthic community biomass varies from 3 to 15 (7,8 ± 3,6) g/m^2 and abundance - 650 – 8160 ind./m^2.

Biotopes of the southern open coast type

The southern coastal type is situated along the Curonian Spit (approx. coordinates: N 55°43', N 55°16', E 21°04', N 20°40').

<u>The mobile sand biotope</u> (SOC.SFT in Fig. 1) was defined by the analogy with the same biotope in the northern coastal area. Its existence may be confirmed by geological maps and geomorphological studies (GUDELIS & JANUKONIS 1977; PUSTELNIKOV 1990; ŽAROMSKIS 1992; GULBINSKAS & TRIMONIS 1999). Although only preliminary observations of benthic environment have been performed in that biotope, it may be assumed that species composition, abundance and biomass should be similar to those found in the northern area.

<u>The soft bottom biotope</u> (SOC.SFT in Fig. 1) in the southern coastal area occupies the largest area in the Lithuanian coastal zone, stretching along the entire Curonian Spit within the depth range from ca. 10 to 30 m. The bottom substrate is much more monotonous than in the same biotope in the northern area. The main community is that of bivalve *Macoma baltica;* other characteristic benthic macrofauna forms are: *Pygospio elegans, Nereis diversicolor, Marenzelleria viridis, Mya arenaria, Cerastoderma lamarcki* and oligochaetes. The total biomass varies within 5 – 314 g/m^2, the total abundance within 800-30000 ind./m^2. *M. baltica* is the biomass dominant species constituting 40- 90% of total community biomass; while *M. arenaria* is might be dominant in front of Nida at the depths of about 15 m.

Biotopes of the central part of the Curonian Lagoon

The central part of the Lagoon (approx. coordinates: N 56°20', N 55°15', E 21°17', N 20°58') situated in front of the Nemunas delta area is strongly influenced by the river outflow. Two main biotopes were identified preliminary for this part of the Lagoon: one with mud as prevailing bottom substrate and another with fine sand. Both biotopes alternate each other on the scale of hundred meters. <u>The muddy bottom biotope</u> (DEL.MUD in Fig. 1) is, in great extent, "created" by the zebra mussel *Dreissena polymorpha,* which invaded the Curonian Lagoon approximately two hundred years ago (OLENIN et al. 1999). Shell deposits and clusters of living mussels cover the largest part of the delta area, their distribution well coincide with that of mud. The later is formed in spite of the active hydrodynamic regime caused by the outflow current of Nemunas and comparatively high wave exposure. *D. polymorpha,* as a very effective seston feeder, deposits suspended material from the water column in form of faeces and pseudofaeces. Besides, the shell deposits and clusters of living mussels trap suspended particles contributing to formation of biogenic mud within and around the shell deposits. Due to habitat engineering activity of *D. polymorpha*, community of co-occurring species is rich in species number (up to 29 per sample, and about 50 in total). The total biomass (up to 11 kg/m^2) and abundance (up to 100000 ind./m^2) are the highest in the entire Curonian Lagoon.

<u>The biotope of sandy bottoms</u> (mainly fine sand and aleurite) in the central part of the Lagoon (DEL.SND in Fig. 1) is occupied by the community of "Oligochaeta + Chironomidae", which is the most widespread in the Curonian Lagoon (OLENIN 1987A; 1988) and the most variable in structure (DAUNYS 2001). Approximately half of the species recorded in the Lagoon were present in that community, however none of them was constant. The species number varied from 2 to 16 per sample, and total biomass – from 10 to 40 g/m^2. Fine sand was mixed with mud on sites situated close to local organic pollution sources (Nida, Juodkrantė, etc.). In such places only oligochaetes and chironomids were found in benthic samples.

Biotopes of the northern part of the Curonian Lagoon

The northern part of the Lagoon (approx. coordinates N 55°38', N 56°20', E 21°15', N 21°04') is under the influence of both the Nemunas outflow and episodic inflows of sea water. Preliminary two groups of biotopes are distinguished in that area: one in the large eastern shallow (depth < 1,5 m) flat area with fine sand as prevailing bottom substrate and another one in the deeper (1,5 <depth< 4 m) western area along the Curonian Spit.

<u>The sandy bottom biotope on the eastern side</u> LAG.SND in Fig. 1) of the Lagoon may be sub-divided into variety of lower level biotopes: fine sands with macrophytes; sand with large native unionids (*Unio tumidus* as the most characteristic species); fine sand and silt with oligochaets and chironomids as well as biotopes with alien invasive species *Dreissena polymorpha, Marenzelleria viridis* and Ponto-Caspian amphipods of genus *Chaetogammarus* and *Pontogammarus*. The later one is present in a very narrow (<20 m) uppermost part of the underwater slope (depth <0,5 m) and may be distinguished only during the warm period of the year when the dense communities of Ponto-Caspian gammarids are developed (DAUNYS & OLENIN 1999). All other biotopes alternate each other on the scale of tens – hundreds meters. Invasive benthic macrofauna constitutes an important part of the biotope forming species, on sites contributing up to 95% of total community biomass. Even in locations where the unionids are predominant species approximately 65 % of them are fouled by the zebra mussels. In general, benthic environment in that part of the Lagoon is essentially changed by the invasive species (OLENIN & LEPPÄKOSKI 1999).

The main community <u>in the muddy bottom biotope</u> (LAG.MUD in Fig. 1) is "Oligochaeta + Chironomidae", which, in general, is the same as in the central part of the Lagoon. Comparatively large part of the muddy bottoms is covered by shell deposits formed mainly by *Valvata* species with admixture of *Bithynia spp., Radix spp., D. polymorpha, Potamopyrgus antipodarum* and *Theodoxus fluviatilis.* Presence of *Valvata* shell deposits with large number of other species is characteristic feature of the muddy bottoms in this area, in opposite to the central part of the Lagoon where *D. polymorpha* is predominant species. On sites, clusters of living zebra mussels also may be found in that part of the area which is less exposed to the saline water inflows (close to the central part of the Lagoon).

Biotopes of the Klaipėda Strait

Benthic environment in the Klaipėda Strait (approx. coordinates N 55°43', N 55°38', E 21°08', N 21°05') is characterized by the most changeable conditions due to natural factors: rapid salinity fluctuations, changes in water hydrochemistry and shifts in temperature regime caused by alternate movements of limnic and marine water masses. On another hand, the area is exposed to the highest anthropogenic pressure for the entire coastal region caused by dredging operations, organic and chemical pollution from industrial and municipal waste waters and ships, hydrotechnical construction, etc. There is a clear difference between muddy biotopes situated in the eastern (harbour) part of the Strait and those on the western side, more flashed by running waters.

<u>Mixed bottoms in Klaipėda Strait</u> (STR.MIX in Fig. 1). The western side of the Strait is characterised by the great variety of bottom substrates: fine and coarse sands, gravel and pebble bottoms, moraine - clay and stones, patches of mud as well as artificial substrates, such as concrete embankments, submerged wood, etc. The array of relevant benthic communities is also very broad, on sites such dominants may be found as: *Nereis diversicolor, Marenzelleria viridis,* oligochaets and chironomids, *Balanus improvisus, Cordylophora caspia, Mya arenaria, Macoma baltica, Mytilus edulis.* The most widespread are the *Nereis diversicolor* and Oligochaeta + Chironomidae communities. The number of species, abundance and biomass vary within large limits and are subject to rapid changes. Due to active hydrodynamic and absence of large inlets the area is not exposed to oxygen deficiency and due to that is inhabited by rather diverse benthic fauna which is able to withstand rapid environmental fluctuations and essential anthropogenic pressure.

<u>Muddy bottoms in Klaipėda Strait</u> (STR.MUD in Fig.1) comprise inlets on the eastern side of the Strait belonging to the port area. The main bottom sediment is black mud on sites with admixture of sand and gravel, containing also human litter. The sediments are polluted with organic material, heavy metals and oil products. Only most tolerant species may survive in this heavily disturbed biotope: oligochaetes and chironomids as the main forms, while *Nereis diversicolor* and *Marenzelleria viridis*

may be found in comparatively less polluted locations. In the most polluted sites benthic macrofauna is absent.

5 Discussion

The notion of biotope is being more and more widely used in aquatic and terrestrial environmental research (OLENIN & DUCROTOY submitted). For instance, the Internet search system for scientific literature SCIRUS (www.scirus.com) recently (October 2004) indicated 246 links to research papers in which the terms “biotope” and “benthic” were used, 51 journal articles for the combination “biotope” and “landscape planning”, 52 for “biotope” and “indicator species”, 213 for “biotope” and “biodiversity”.

Our study shows that the biotope is a convenient unit which may be used for the coastal typology. We identified five coastal types, one of them being heavily impacted by human activity (Klaipeda Strait), and four comparatively less disturbed: two areas belonging to the transitional waters (the Central and Northern parts of the Curonian Lagoon) and two belonging to the coastal waters (the Southern and Northern parts of the Lithuanian coast). All these types clearly differ in terms of composition and distribution of benthic biotopes. Thus, by our opinion, the coastal type, defined as a biotope complex, may be efficiently used for the purposes of the coastal typology within the Water Framework Directive. There are several arguments to support such point of view.

First of all, the biotope integrates several, if not all, obligatory and optional factors listed in the relevant WFD recommendations (GUIDANCE DOCUMENT 2003). The biotope classification procedure takes into account the tidal range, salinity, depth, current velocity, wave exposure, turbidity, etc. (Fig. 3).

Furthermore, it includes such a necessary step as the analysis of matching between physical and biological features used to characterize the biotopes. The next step, following the creation of the biotope classification system and its use for coastal mapping, includes identification of coastal types as the complexes of interrelated neighboring biotopes. This step gives the coastal typology a solid natural background and provides it with essential ecological relevance.

Yet another argument to use biotopes for the coastal typology is that there are already several national and international biotope classification systems developed for the coastal zones of Europe. For instance, in the United Kingdom, the marine biotope classification was published by the Joint Nature Conservation Committee (CONNOR et al. 1997A; 1997B). This classification was developed as a contribution to BioMar, a project part-funded by the EU’s Life programme. In France, the Zones Nationales d'Intérêt Scientifique, Faunistique et Floristique (ZNIEFF) have been created for the Atlantic and Mediterranean coasts (DAUVIN et al. 1996). A regional international classification of coastal biotopes and their complexes was developed for the Baltic Sea (HELCOM 1998). Later, the above mentioned and several other classifications were unified in the European Nature Information System (EUNIS 2004). The later is the product of the European Topic Centre for Nature Protection and Biodiversity (ETC/NPB in Paris), which was created for the European Environment Agency (EEA) and the European Environmental Information Observation Network (EIONET). We believe that use of the EUNIS approach may give productive results for the coastal typology, not only on a local (Lithuanian) and regional (Baltic) but also on the EU scale.

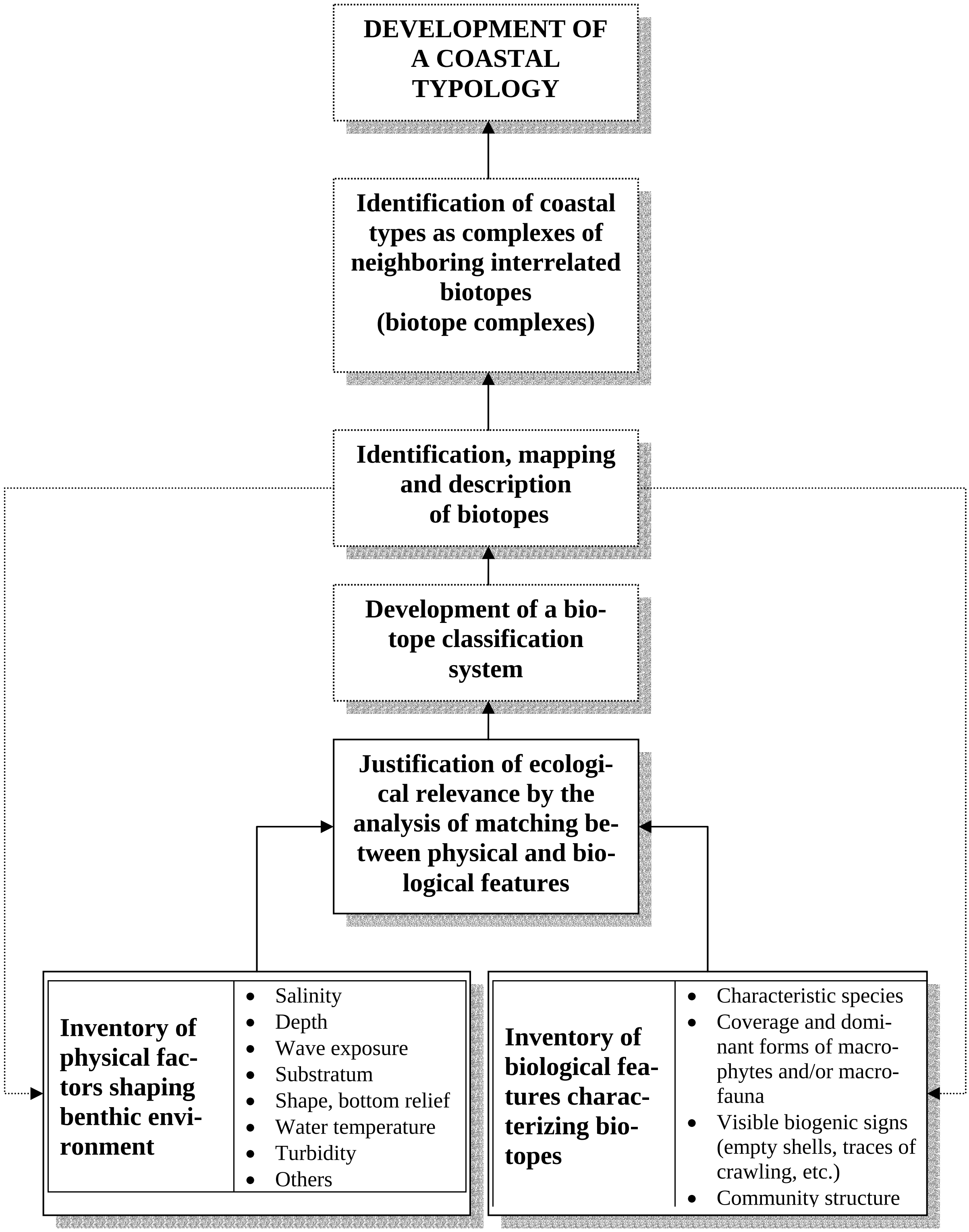

Figure 3. Generalized scheme showing the benthic biotope classification procedure and its relevance to the coastal typology

Acknowledgements

This study was supported by the EU FW6 project EVK3-CT-2001-00065 CHARM "Characterization of the Baltic Sea Ecosystem: Dynamics and Function of Coastal Types".

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Address

Sergej Olenin
Coastal Research and Planning Institute, Klaipėda University
H. Manto 84, 5808 Klaipėda,
Lithuania

E-mail: serg@gmf.ku.lt

G. Schernewski & M. Wielgat (eds.): Baltic Sea Typology
Coastline Reports 4 (2004), ISSN 0928-2734
85 - 109

Spatial phytoplankton pattern in the Baltic Sea

Ramona Thamm[1], Gerald Schernewski[2,3], Norbert Wasmund[2] & Thomas Neumann[2]

[1] UmweltPlan GmbH Stralsund, Germany
[2] Baltic Sea Research Institute Warnemünde, Germany
[3] EUCC – The Coastal Union Germany

Abstract

We try to give a comprehensive overview about the spatial distribution of phytoplankton biomass, groups, selected indicators and species for three selected years and different seasons in the entire Baltic Sea, based on the comprehensive CHARM phytoplankton data base. We analyse the interpolations with respect to the requirements of the European Water Framework Directive and compare the spatial phytoplankton pattern to the Baltic Sea Typology. The phytoplankton distributions are further compared with spatial interpolations of abiotic parameter and model results, to see if the model is potentially suitable to overcome short-comings in spatial phytoplankton data availability.

1 Introduction

In 2000, the European Water Framework Directive (WFD) (Directive 2000/60/EC) entered into force. The WFD establishes a comprehensive framework for European Community actions in the field of water and introduces new principles of modern water management. New is especially the spatial integration of river basins and coastal waters as well as the focus on biological ecosystem quality elements namely fish, macrozoobenthos, macrophytes and phytoplankton. The implementation of the WDF requires e.g. the development of a typology for coastal waters, reference conditions describing the very good ecological state of coastal ecosystems, a quality evaluation system for coastal ecosystems and finally a new monitoring strategy. An important aspect in the WFD is that it asks for spatial analyses and interpolations of all kind. The typology has a spatial focus and e.g. spatial distributions of biological elements are required for a comparison with the spatial distribution of types as well. With respect to abiotic data, spatial interpolations covering the entire Baltic Sea are well available e.g. in the Baltic Environmental Database (BED). Concerning biological elements, spatial analyses are partly available as well (WASMUND et al. 1999) but are less common. The first trial to compile coastal data from the different countries of the south-eastern Baltic Sea was made by WASMUND et al. (2000) for the years 1993-1997. However, a comprehensive attempt to present e.g. spatial phytoplankton distributions over large areas is lacking. The motivation for this study was to overcome this deficit.

The WFD has caused many activities and requires a lot of research. The EU project "Characterization of the Baltic Sea Ecosystem: Dynamics and Function of Coastal Types" (CHARM) was launched in 2001. Aim was to support the implementation of the WFD e.g. by developing a Baltic Sea typology (SCHERNEWSKI & WIELGAT 2004), by analyzing and evaluating biological data, or by suggesting reference conditions (SCHERNEWSKI & NEUMANN in press). All Baltic states (except Russia) participated in the project and contributed to a joint database on phytoplankton. The work described here is part of the CHARM project and utilizes this outstanding database.

Aims of this study are:

- To develop and validate a methodology, which allows the presentation and analysis of spatial phytoplankton pattern.

- To analyse the short-comings of the available phytoplankton data, to derive suggestions towards a reliable monitoring and to evaluate the value of the spatial phytoplankton data for the purposes of the WFD.
- To give a comprehensive overview about the spatial distribution of phytoplankton biomass, groups, selected indicators and species for three selected years and different seasons in the entire Baltic Sea and based on the best available data.
- To link phytoplankton pattern to spatial distributions of abiotic parameter and to compare it with model results (NEUMANN et al. 2002). The question is if models are suitable to overcome possible short-comings in phytoplankton data?
- To compare phytoplankton pattern with the typology. The present typology is based on three main factors surface salinity, water residence time and water depth, which corresponds to the mixing of the water column. The WFD assumes that the spatial pattern of these parameters reflect the biological parameters as well. The question is, if the spatial distribution of types can be validated with respect to phytoplankton.

Methods and a critical evaluation of the present spatial data for the purpose of the WFD are the focus of this study. This study shall not analyse phytoplankton pattern, their spatio-temporal behaviour or interdependencies in detail. Therefore this work is a first basis and leaves a lot of room for future detailed phytoplankton studies.

2 Methods

2.1 Data basis

The Baltic Phytoplankton Database of the CHARM-Project is based on monitoring data of the countries Denmark, Germany, Poland, Lithuania, Latvia, Estonia and Finland. Swedish data is lacking. The data was compiled and evaluated by phytoplankton experts and linked to abiotic data. The CHARM database mainly contained coastal data. To get a full coverage of the central Baltic Sea, the HELCOM data (Baltic Monitoring Program) were used additionally. The focus area of this study is given in Figure 1.

2.2 Data selection and aggregation

A full spatial documentation of phytoplankton pattern for many years is laborious and not necessary with respect to the aims of this study. We focussed our efforts on three years 1987, 1990 and 1997. These years show very different atmospheric conditions and one can expect that they caused very different phytoplankton developments and reflect the possible variability in the Baltic Sea fairly well.

1987 started with one of the twelve coldest winters of the century. The Baltic Sea showed a long-lasting and extensive ice cover. Spring and summer were too cold as well, followed by average conditions in autumn. The summer 1987 belonged to the four coldest of the century. Surface water temperatures were below the average all the year until November and reached only 12-14°C in July in the central Baltic Sea. The thermocline was relatively close to the surface and less pronounced compared to average years.

1990 was characterised by a very warm winter. The temperatures in the western Baltic Sea never dropped below 4°C. It followed a warm spring and a fairly normal summer with water temperatures close to the average. Altogether the year was outstanding sunny and dry.

1997 had an average winter. The spring was cool and the surface water temperatures increased only slowly. A thermal stratification was observed not before middle of Mai. In June a lasting heat period started and made the summer the warmest since 1890. In the central and western Baltic Sea surface water temperatures reached outstanding 23°C. The autumn was slightly colder than the average.

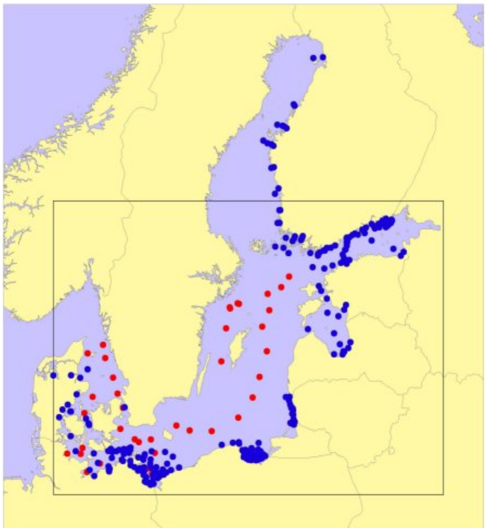

Figure 1: Study area as well as CHARM- and HELCOM sampling locations.

• CHARM station • HELCOM station

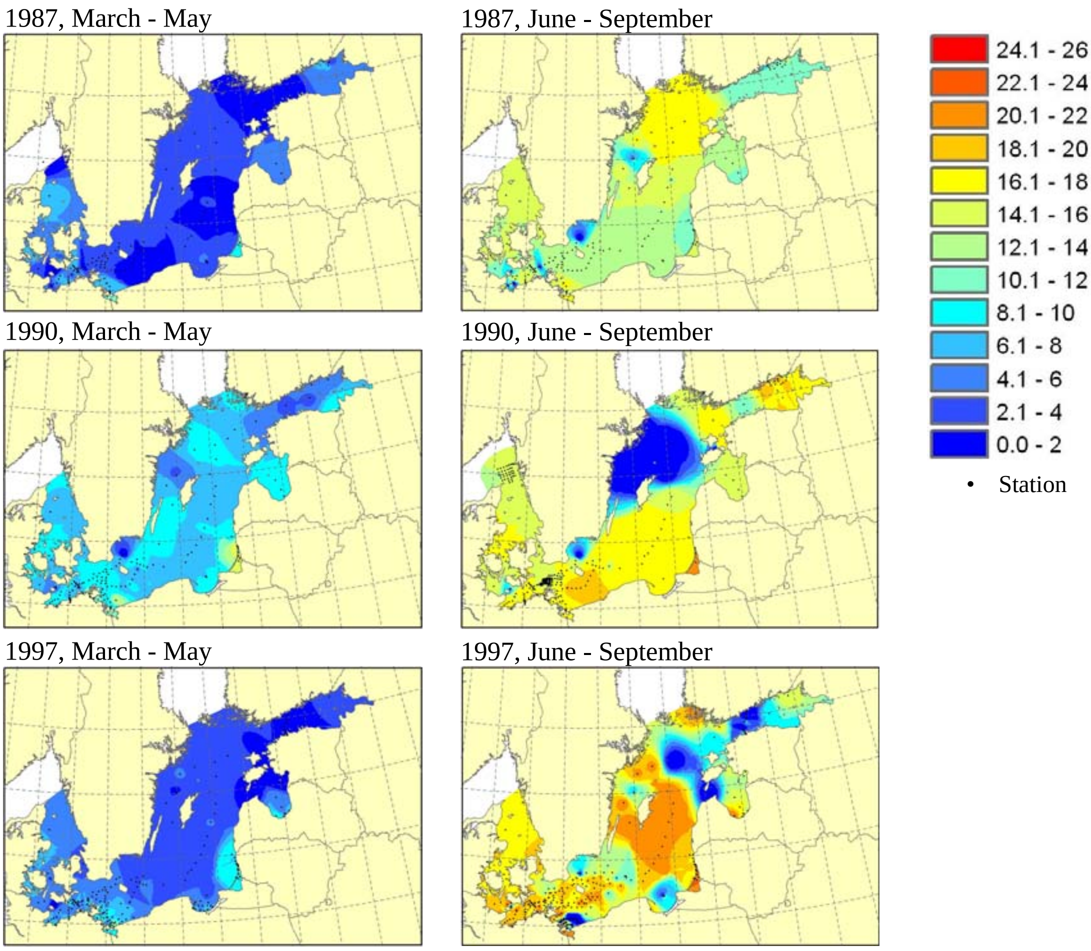

Figure 2: Seasonal average of temperature (°C) in the surface water (0-10 m) in 1987, 1990 and 1997 (Data: CHARM, HELCOM).

Usually, intensive phytoplankton developments (blooms) in the Baltic Sea are observed in spring, summer and autumn. Therefore, all biomass data was subdivided into seasons and averaged within these seasons. These seasons are defined according to the occurrence of phytoplankton blooms and differ between different regions in the Baltic Sea. In this study spring covers the month March until May and summer is represented by the period between June and September. This is in agreement with the definitions after HELCOM (1996) for the Baltic Proper. The coarse temporal resolution of the monitoring causes the situation that sampling hardly ever meets the peaks of the blooms (WASMUND et al. 1998).

2.3 Data processing and interpolation

According to the selected years and seasonal aggregations all relevant data was selected and compiled into a new data base. Data processing and statistics were carried out with the geographic information system (GIS) ArcView 3.3.

Table 1: Number of available data sets (DS) in the original data bases and the compiled data for his study.

		Nutrients	Phytoplankton	Stations
CHARM (BPDB)	DS altogether	14 365	309 881	
	DS 1987, 1990, 1997	2 032	45 077	
HELCOM (BMP)	DS altogether	25 269	74 128	
	DS 1987, 1990, 1997	2 327	13 445	
Compiled data	DS 1987, 1990, 1997 (without duplicates and averaged over 0-10 m)	4 004	45 964	304

Several interpolation programs and methods were applied and the results compared according to six pre-defined criteria (THAMM 2004). The relatively simple IDW-method (Inverse Distance Weighted) provided by the Spatial Analyst of ArcGIS 8.3 turned out to be most suitable. In all interpolations four neighbouring points, a weighting power of three and a search radius of 400 km was applied. Islands and the coastline were considered as boundaries. A disadvantage of the IDW method is the so-called ‘Bull’s-eye’ effect in the direct vicinity of single measured data.

3 The annual phytoplankton dynamics

To understand spatial phytoplankton distributions, their seasonality and interannual variability requires a sound knowledge of the underlying processes and interactions. Therefore, the temporal phytoplankton dynamics in the Baltic Sea has to be briefly mentioned.

In winter (January, February), the essential nutrients have accumulated in the water, but light intensity is limiting excessive phytoplankton growth. In spring, light conditions improve continuously. The phytoplankton of the upper mixed layer receives suddenly a much higher integral light intensity if the mixing depth becomes lower than the euphotic zone, i.e. it is trapped in the illuminated upper water layers. This is the condition the phytoplankton needs for the outburst of its growth (WASMUND et al. 1998). Best adapted to these conditions are the diatoms (e.g. *Skeletonema costatum*), which form a spring bloom in most of the areas of the southern Baltic Proper in March. As soon as the nutrients (primarily nitrogen) are exhausted, the bloom disappears. After the diatom bloom, motile phytoplankton (e.g. *Mesodinium rubrum*, *Dictyocha speculum* and diverse dinoflagellates) develops, which is capable of vertical migration and therefore able to use nutrients from deeper water layers. In the central regions of the Baltic Sea, the spring bloom develops later (April, May) and is mainly composed of dinoflagellates (e.g. *Peridiniella catenata*). As nitrogen is the limiting nutrient in the Baltic Proper, nitrogen fixation by diazotrophic cyanobacteria may overcome the nutrient limitation. These nitrogen fixing cyanobacteria (primarily *Nodularia spumigena* and *Aphanizomenon* sp.) may form extensive blooms in July and August and supply the fixed nitrogen also to other components of the ecosystem. Now, phosphorus becomes the limiting nutrient. Its exhaustion or a deeper mixing of the water column causes the end of the summer bloom. In the western Baltic, dinoflagellates (e.g. *Ceratium* spp.) develop slowly. As they are not heavily grazed due to their big size, they grow up to bloom concentrations until autumn. In October or November, thermal convection causes a deep circulation and brings new nutrients to the upper water layers, where a diatom bloom (e.g. *Coscinodiscus granii*) can develop again. The phytoplankton biomass decreases in November to the low winter level. The winter phytoplankton is frequently dominated by small flagellates (cryptophyceae), which obviously may grow under low-light conditions.

A detailed spatial analysis of phytoplankton pattern usually requires information on transport processes and flow pattern. With respect to the Baltic Sea the spatial resolution of the phytoplankton data is too coarse and spatial differences can hardly be explained by flow pattern.

4 Spatial phytoplankton pattern

4.1 Biomass

The increase in nutrient input, which is the main reason for eutrophication, leads directly to an increase in phytoplankton biomass. Therefore, phytoplankton biomass may serve as an indicator of the trophic state. A trophic classification scheme based on winter nutrient concentrations and annual means of phytoplankton primary production and biomass was developed by WASMUND et al. (2001) for the Baltic Sea including the outer coastal waters. According to this classification scheme, the river plumes of Oder, Vistula and the outflow of the Curonian Lagoon are eutrophic, whereas the open Baltic waters are mesotrophic. The inner coastal waters, exemplified by the Darss-Zingst bodden chain, an estuarine lagoon system of the German coast, may reach from the mesotrophic to the hypertrophic state (WASMUND 1990). We confirm that lagoons and river plumes contain a much higher phytoplankton biomass than open waters, as shown in Figure 3 for Szczecin Lagoon, Curonian Lagoon and the plumes of Newa, Oder, Daugava, Vistula rivers and of the outflow of Curonian Lagoon. This pattern is also found in the separate seasons (Fig. 4). As the river runoff is lower in summer than in spring, phytoplankton biomass in the plumes is also decreasing from spring to summer in some areas (eastern Gulf of Finland, Gulf of Riga, Gulf of Gdansk). The increase from spring to summer 1997 in the Pomeranian Bight and Gulf of Gdansk is caused by additional inputs owing to the exceptional floods (HUMBORG et al. 1998). Patches of very low phytoplankton biomass may also be caused by upwelling of deeper water, e.g. off the Lithuanian coast in summer 1990.

In general, the patterns of phytoplankton biomass are also found in the distribution of chlorophyll-a (Fig. 5). This pigment is a component of all phytoplankton cells. As it occurs in a more or less known percentage of the cell (e.g. HUNTER & LAWS 1981) it may serve as a proxy for total phytoplankton biomass. It may not used, if the species or phytoplankton groups are of interest.

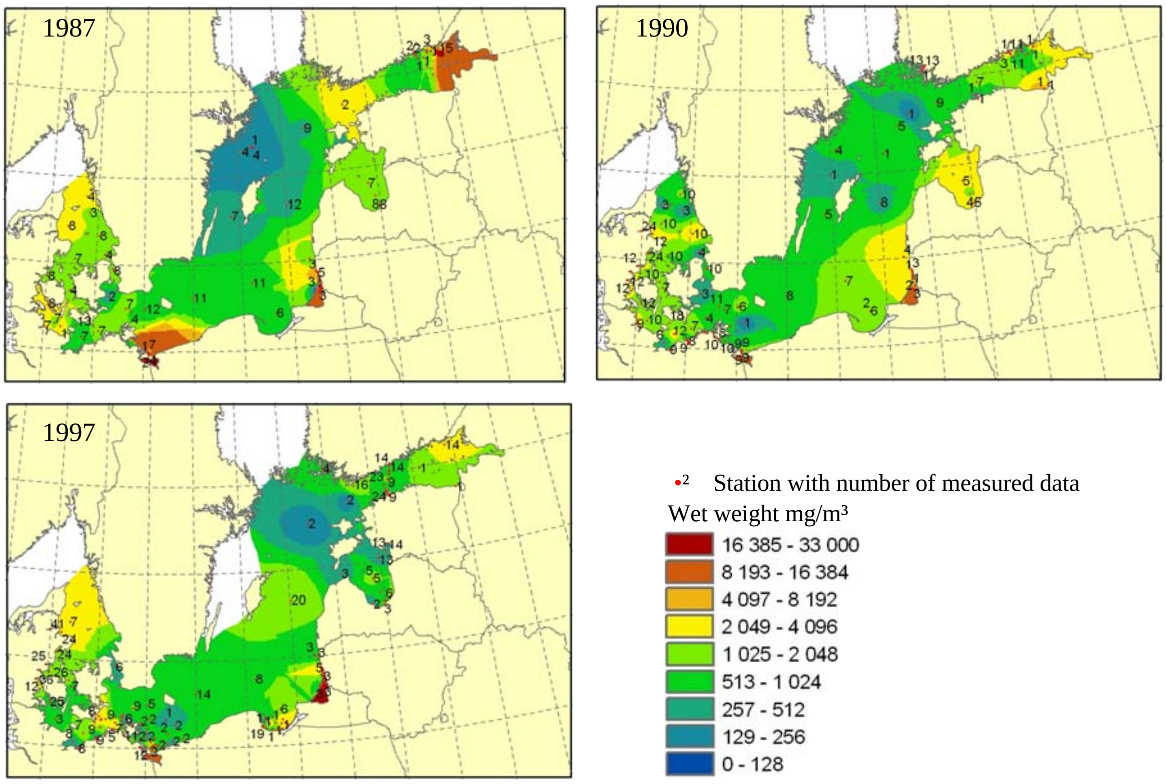

Figure 3: Annual average of phytoplankton biomass in the surface water (0-10 m) in 1987, 1990 and 1997 (Data: CHARM, HELCOM).

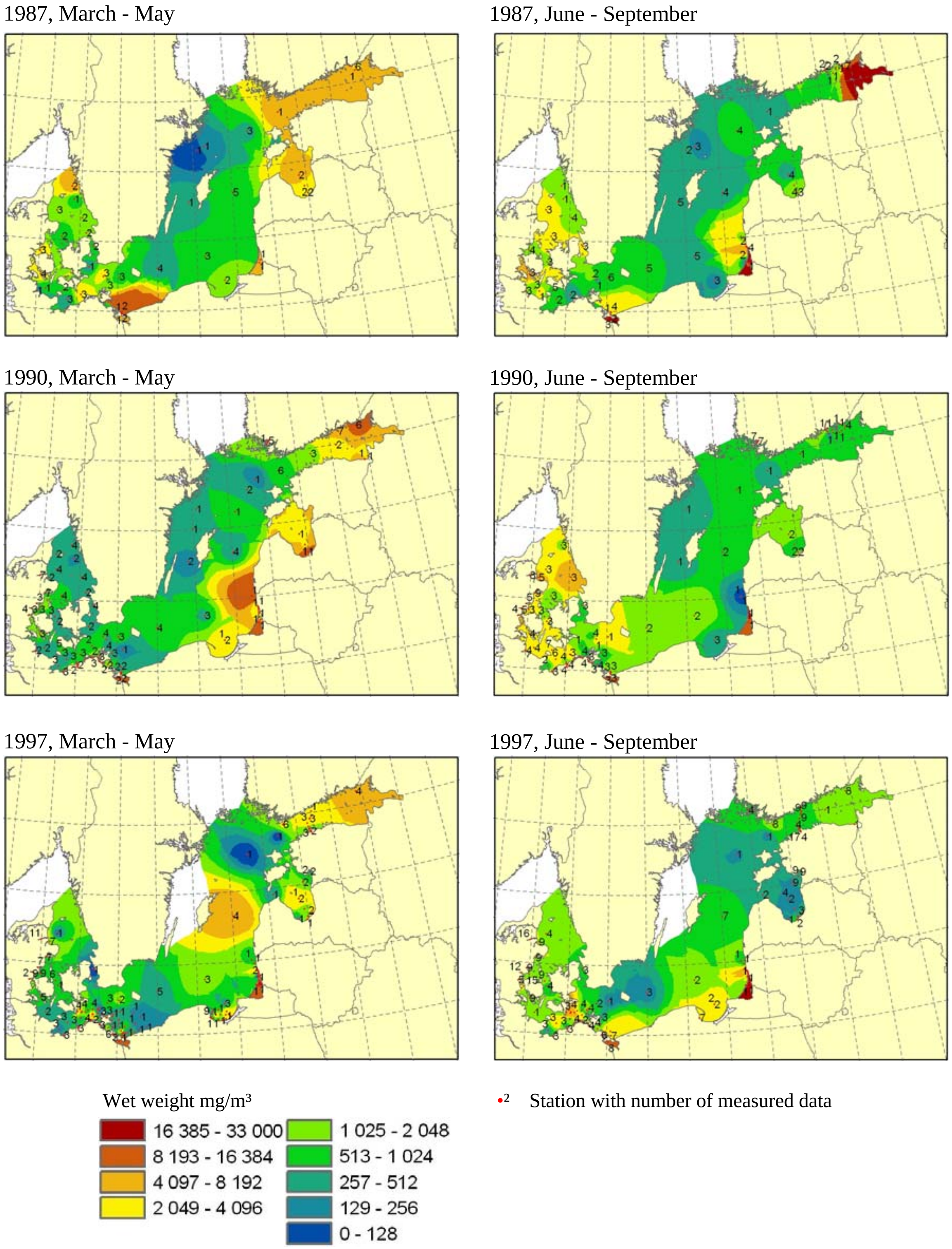

Figure 4: Seasonal average of phytoplankton biomass in the surface water (0-10 m) in 1987, 1990 and 1997 (Data: CHARM, HELCOM).

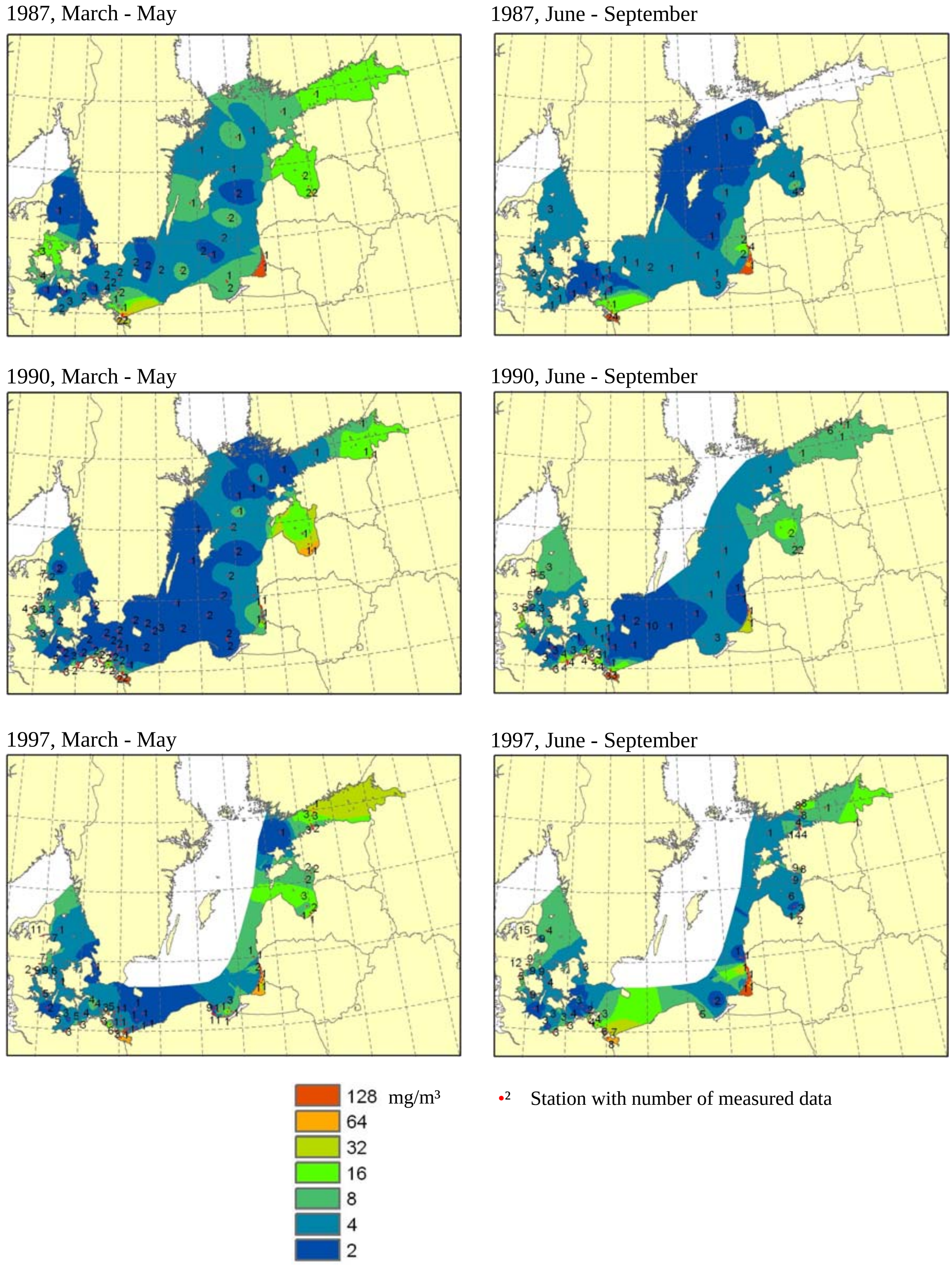

Figure 5: Seasonal average of chlorophyll-a in the surface water (0-10 m) in 1987, 1990 and 1997 (Data: CHARM, HELCOM).

4.2 Phytoplankton groups

As already shown in chapter 3, non-motile algae (mainly diatoms) and motile algae (flagellates) have different preferences of environmental conditions owing to their different abilities. Diatoms prefer turbulent waters in order to keep suspended whereas flagellates need stratified waters if they want to benefit from their ability to choose their optimum water depth. Some cyanobacteria may also accumulate at specific water depths by buoyancy regulation and therefore dislike mixing of the water.

Dinoflagellates are the largest group of flagellates in the Baltic Sea. Therefore, their distribution is similar to that of the total flagellates, whereas the other flagellates are different from the total flagellate group (Fig. 6). Dinoflagellates are especially dominant in spring. Thus, their spring patterns are similar to the annual patterns. Moreover, the spring distribution of dinoflagellates (Fig. 6) resembles that of the total phytoplankton biomass in spring (Fig. 4) because they account for the biggest part of the spring biomass.

Diatoms are the second important part of the spring phytoplankton. Originally, they were the main component of the spring bloom, as shown in chapter 3. The year 1987 (Fig. 7) is typical for this situation. In the 1990s, they are strongly reduced, as exemplified by the years 1990 and 1997. Possible explanations for this trend are given by WASMUND et al. (1998). They think that the mild winters in the 1990s and the related non-appearance of deep mixing in the water column are responsible for the replacement of diatoms by dinoflagellates in the spring bloom. Concerning the composition of the spring bloom, the situation of the year 1987 can be assumed as a reference condition for the ecosystem.

Cyanobacteria occur mainly in summer and may form big blooms. Therefore, the annual data shown in Figure 7 reflect mainly the distribution in summer (Fig. 10). The cyanobacteria blooms (e.g. *Microcystis* spp.) in the lagoons are related to high nutrient input and are promoted by high temperature. The big blooms in the open waters of the Baltic Sea (KAHRU et al. 1994) occur even at low nutrient concentrations (WASMUND 1997) because they meet their nitrogen demand from dissolved atmospheric nitrogen. This nitrogen fixation occurs in specialised cells, so-called heterocysts. These heterocystous cyanobacteria have to be strictly kept apart from cyanobacteria that are not able to fix nitrogen. They establish a well-defined functional group (Figure 8: "cyanobacteria with heterocysts"). Because of their impressive, sometimes toxic blooms they are of common interest and activate the question whether these blooms are increasing due to anthropogenic impact. As long as nitrogen is the limiting nutrient in the Baltic Proper, they cannot be related to eutrophication because they supply themselves with the nitrogen needed for growth. They are, however, limited by phosphorus. Consequently, increased phosphorus input into the ecosystem would promote the growth of nitrogen fixing cyanobacteria. FINNI et al. (2001) discussed that cyanobacterial blooms are known already from the mid of the 19th century but might have increased at least until the 1960s. During the last decades, they have established on a high level. Warm summer may support these blooms. Trends are however hard to be proved because of the high patchiness and therefore low representativeness of samplings in time and space. Satellite images (KAHRU et al. 1994) may supply additional information on distribution especially of the buoyant cyanobacterial blooms.

Other functional groups (Fig. 8) are less precisely defined than the cyanobacteria with heterocysts. The freshwater and brackish/marine spring blooms are not spatially separated as expected. Even those species considered as freshwater species are not only restricted to lagoons and river plumes but are also found in the open sea. They show a similar distribution as the mixotrophic and heterotrophic species. The spring and autumn bloom species are more evenly distributed in the sea, indicating that the blooms develop autochthonously in the whole sea areas. A few patches of low biomass, e.g. the autumn bloom in the Eastern Gotland Sea, are owing to low sampling frequency and therefore missing of the bloom.

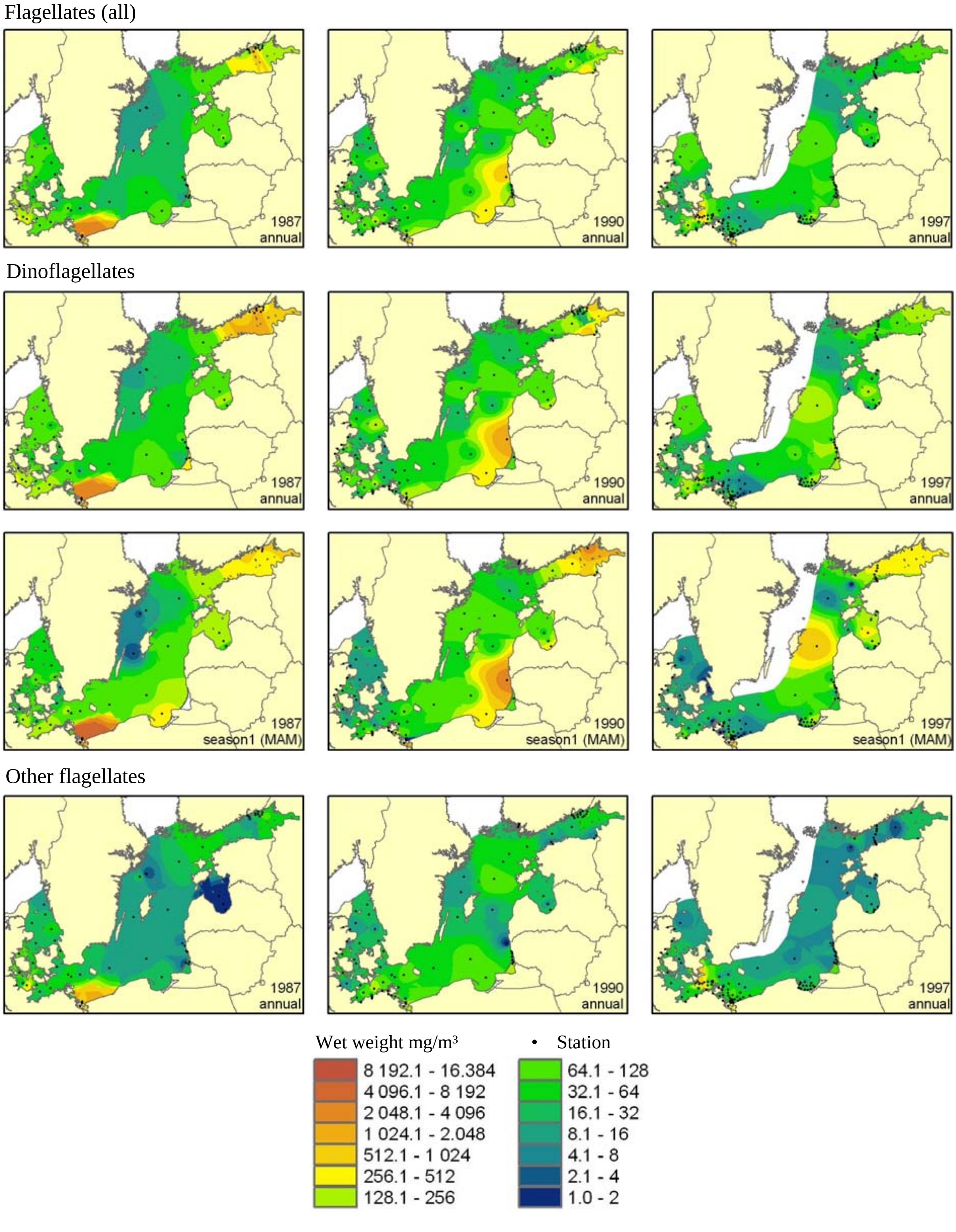

Figure 6: Flagellates - seasonal average of biomass in the surface water (0-10 m) in 1987, 1990 and 1997 (Data: CHARM, HELCOM).

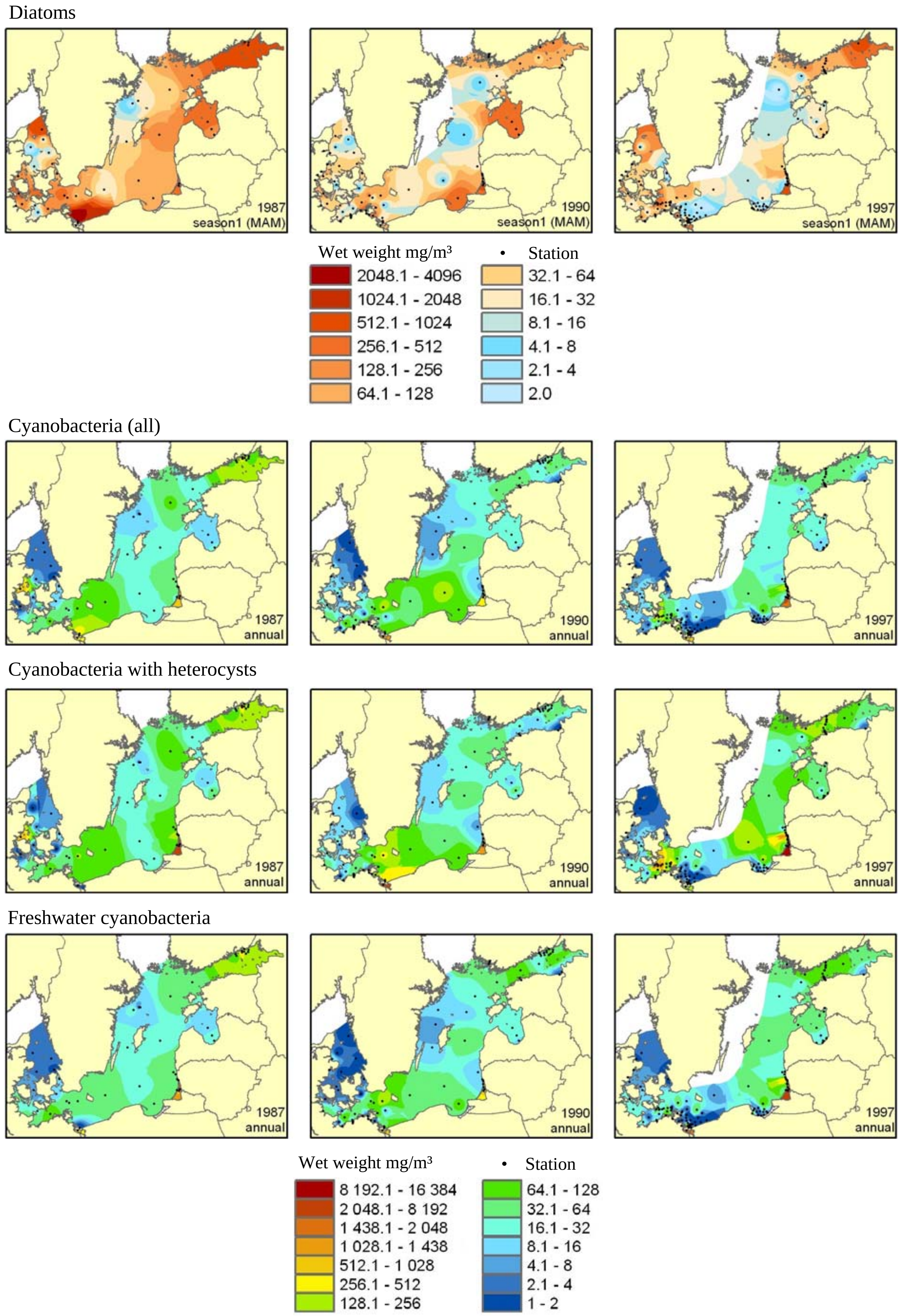

Figure 7: Diatoms and cyanobacteria - seasonal average of biomass in the surface water (0-10 m) in 1987, 1990 and 1997 (Data: CHARM, HELCOM).

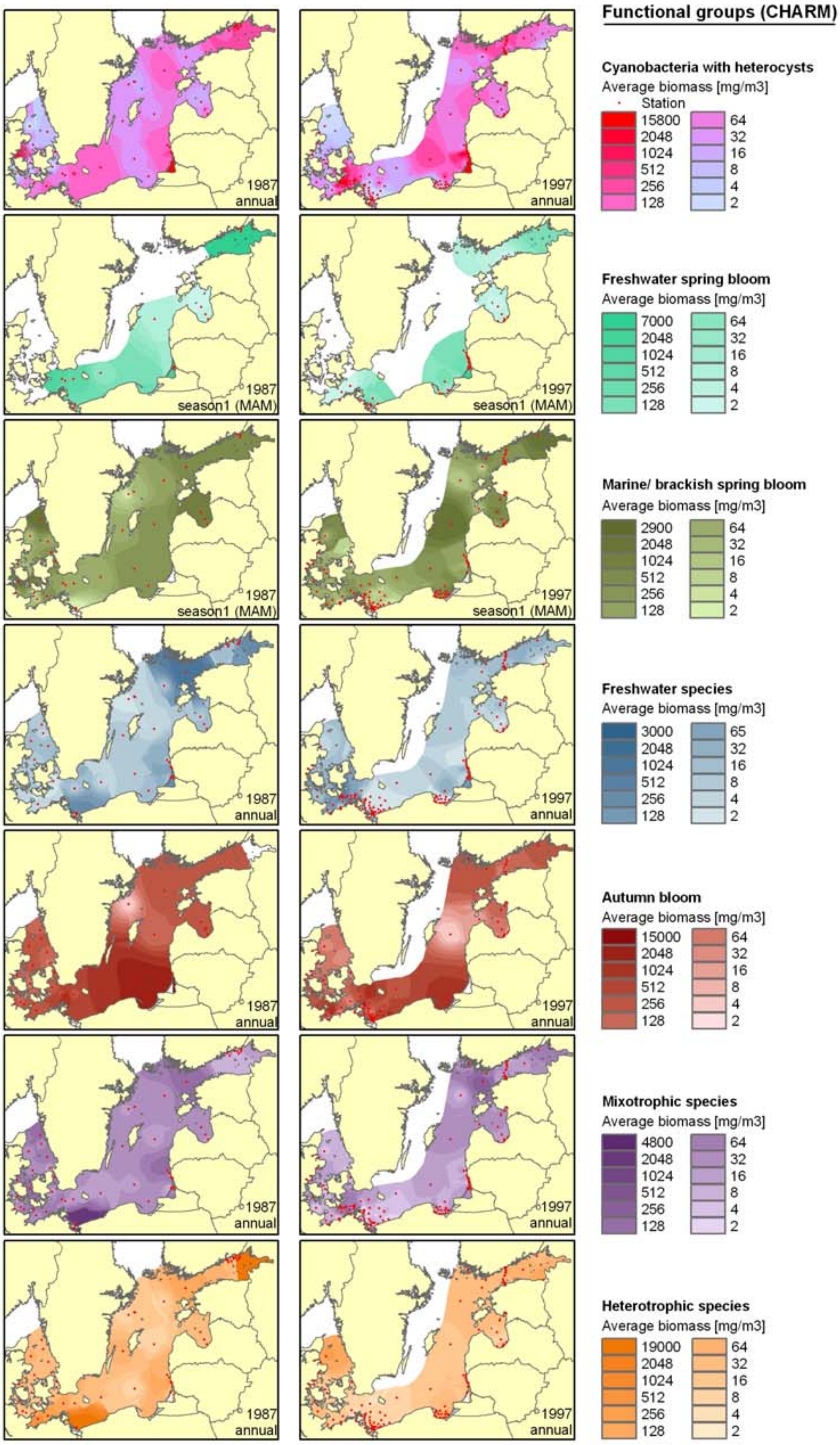

Figure 8: Functional groups - average of biomass in the surface water (0-10 m) in 1987, 1990 and 1997 (Data: CHARM, HELCOM).

4.3 Phytoplankton species

Only for the most abundant species, natural patchiness and methodological inaccuracy are low enough to design reliable distribution patterns. *Skeletonema costatum* is the dominant species in most of the spring diatom blooms. As it is mostly restricted to the spring period, annual and spring values show the same distribution patterns (Fig. 9). This species disappears by the end of spring due to nutrient limitation. Only in some coastal areas, where continuous nutrient input occurs, the species can survive until summer. This was especially noticed in the Kattegat/Belt Sea area and may be interpreted as an eutrophication indicator (HENRIKSEN pers. comm.). The high patchiness in this area reflects discrepancies between bloom growth and sampling scheme. Mixing of different water bodies causes different timing of the bloom in these areas and therefore patchiness is likely to occur even with synoptic sampling.

The patchiness is lower with the photoautotrophic ciliate *Mesodinium rubrum* (Fig. 9) because it is not as short-living as *Skeletonema costatum* but may dominate the phytoplankton for many months. There seems to be a shift of the peak occurrence from spring (in 1987) over spring/summer (in 1990) to summer (in 1997). Therefore, both spring and summer distribution patches appear in the annual means (cf. 1987 in Fig. 9).

4.4 Phytoplankton indicators

As shown above, phytoplankton composition and biomass changes in time and space. It is, however, hard to prove trends statistically because of high variability due to natural patchiness and insufficiencies in sampling. Nevertheless, WASMUND & UHLIG (2003) found a decrease in diatoms but an increase in dinoflagellates in spring and summer at most stations of the open sea. For summer cyanobacteria biomass, only a decrease could be found in the Bornholm Sea and in the Kattegat. This is supported also by our Figure 10. These trends may not be related to eutrophication because the trophic state did not change significantly in the investigation period. However, these trends show that something changed in the ecosystem. Therefore, at least the spring diatom biomass may be a useful indicator for environmental changes like global warming. It is supposed that warming reduces spring diatoms (WASMUND et al. 1998) but increases cyanobacteria (WASMUND 1997). Therefore, the biomass ratio of summer heterocystous cyanobacteria and spring diatoms should be a good indicator for the reaction of the phytoplankton to global warming. Figure 10 shows that it increases from 1987 to 1997. The high value of this ratio in front of Stockholm in 1987 is caused by the exceptionally low diatom biomass because the spring bloom was completely missed at this one station. This ratio cannot be applied in the Kattegat and river plumes (e.g. outflow of the Curonian Lagoon) because the heterocystous cyanobacteria do not occur there due to the unpleasant N/P ratios (Fig. 14) and salinities (Fig. 12).

Other indices proposed by the CHARM Phytoplankton WP, like the cyanobacteria/chlorophyta ratio, are less promising. Chlorophyta are mostly related to eutrophic freshwater. As also most of the cyanobacteria species prefer eutrophic freshwater, the ratio of these two components levels this specific feature off.

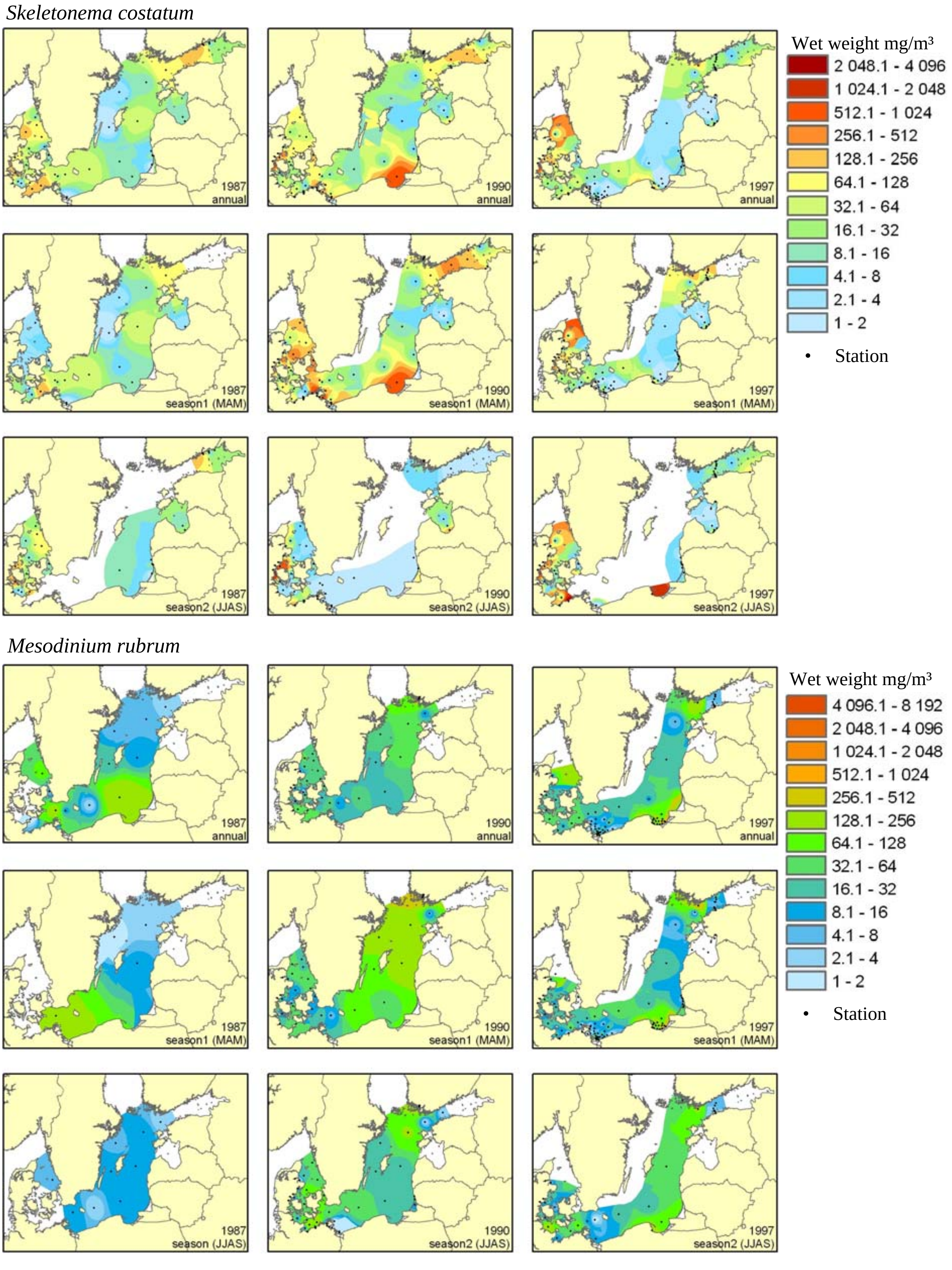

Figure 9: *Skeletonema costatum* and *Mesodinium rubrum* - average of biomass in the surface water (0-10 m) in 1987, 1990 and 1997 (Data: CHARM, HELCOM).

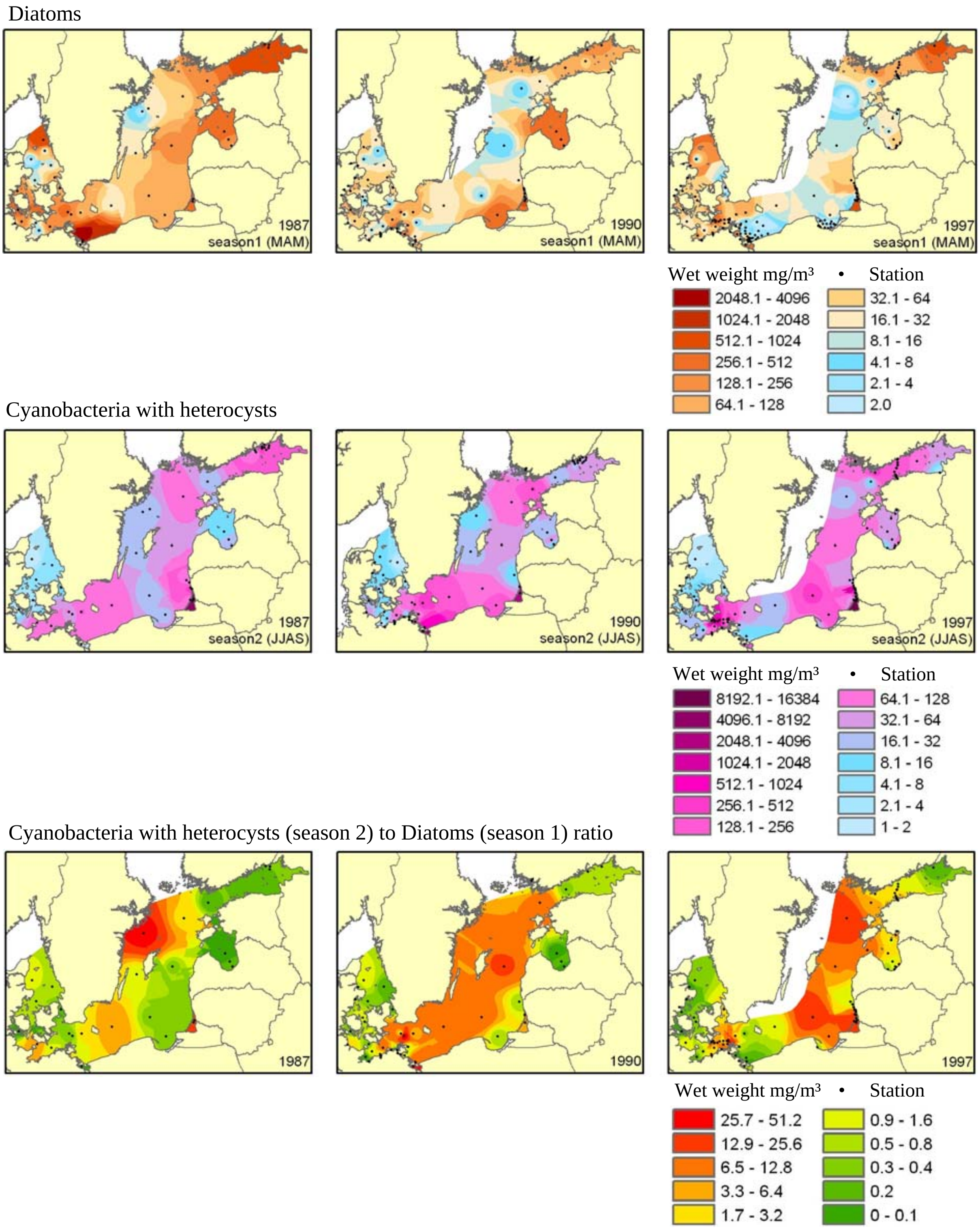

Figure 10: Cyanobacteria with heterocysts to diatoms ratio - average of biomass in the surface water (0-10 m) in 1987, 1990 and 1997 (Data: CHARM, HELCOM).

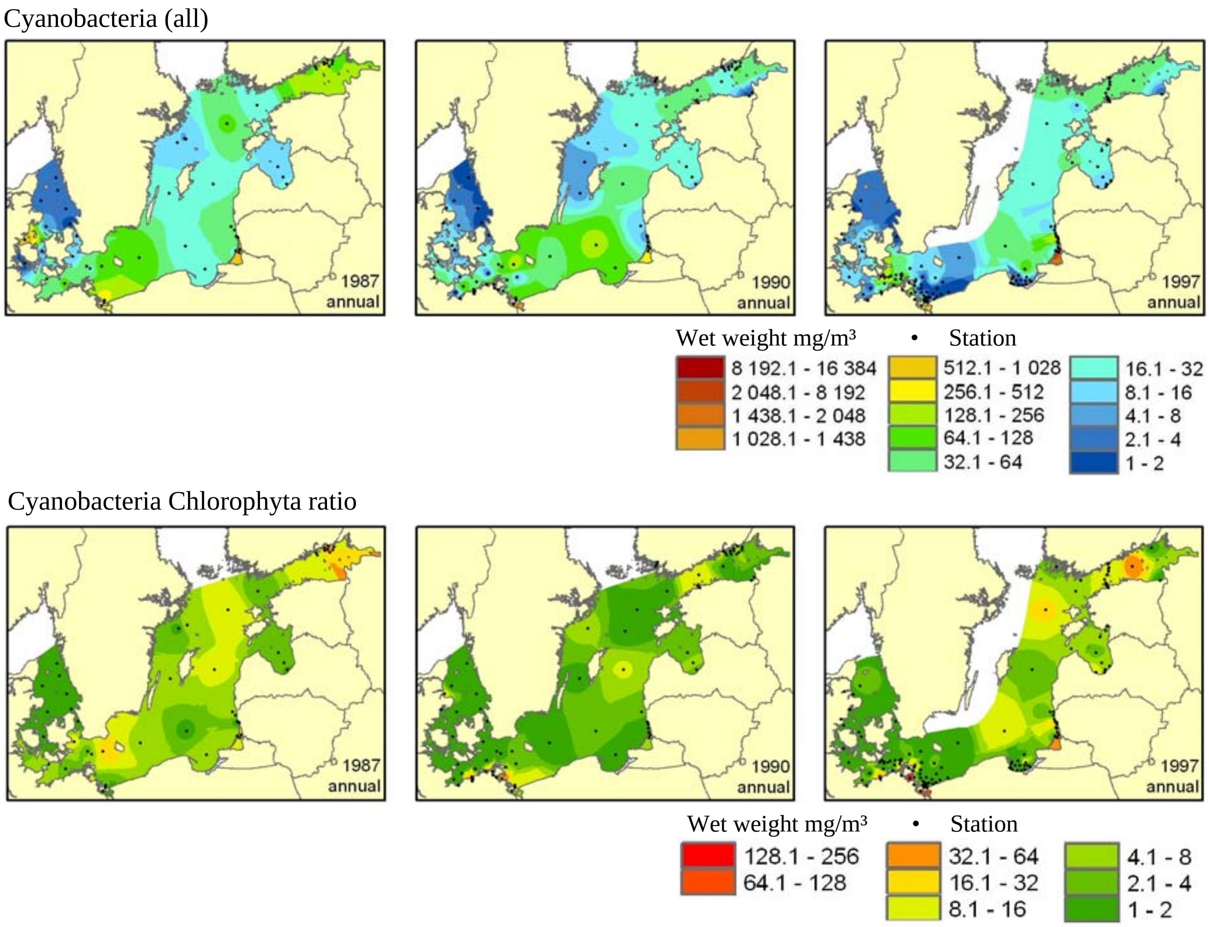

Figure 11: Cyanobacteria to chlorophyta ratio - average of biomass in the surface water (0-10 m) in 1987, 1990 and 1997 (Data: CHARM, HELCOM).

5 Spatial comparison with abiotic parameter

Several well known dependencies of the phytoplankton growth on abiotic parameters are reflected in the spatial distributions. Shallow mixed coastal waters show a larger relationship between euphotic and aphotic zone. It means that in average phytoplankton is potentially exposed to light for a longer time and can maintain a higher biomass compared to unstratified open waters with a comparable transparency. During summer open waters are stratified and phytoplankton is kept within a narrow mixed layer there as well. River plumes with their higher turbidity and small scale stratifications often show a very different behaviour with respect to light availability compared to other coastal waters. Especially in spring shallow areas warm up faster and allow an earlier development of phytoplankton in spring. This is true for the south-western part of the open Baltic Sea as well. These areas show the first diatom blooms in early spring and with increasing temperatures the blooms are propagating towards north-eastern parts of the open Baltic Sea. The positive influence of summer temperatures of at least 16°C on cyanobacteria growth is known, too, but their development depends on nutrients as well. River plumes are not only shallow (and warm up fast) but provide additional nutrients for an enhanced phytoplankton growth. All river plumes are well reflected in the spatial phytoplankton distributions.

If one tries to go further into detail, the strong spatial variability of the phytoplankton data and its insufficient spatial coverage restricts comparisons. Often, several abiotic parameters influence phytoplankton growth at the same time and prohibit simple evaluations on the basis of spatial interpolations. To be able to interpret spatial pattern, the temporal development usually has to be considered, too.

Generally, salinity is one of the major factor that determines the spatial distribution of species. In the Baltic Sea with its strong and large scale salinity gradients, this is clearly visible, as already shown by REMANE (1934) in his pioneering work. Blooms of nitrogen-fixing cyanobacteria, for example, develop at a salinity between 3.5 and 11.5 PSU (WASMUND 1997). Because of the high importance of salinity it is taken as the basis for the development of a typology according to the Water Framework Directive. The spatial salinity pattern in the Baltic Sea is fairly stable over the years (Fig. 12). High biomass is found in the high-saline Kattegat and the low-saline river plumes as well. If the biomass of large groups is considered rather than species, the influence of nutrients concentrations is much more relevant than the salinity because the nutrients are the factor that limits the phytoplankton growth.

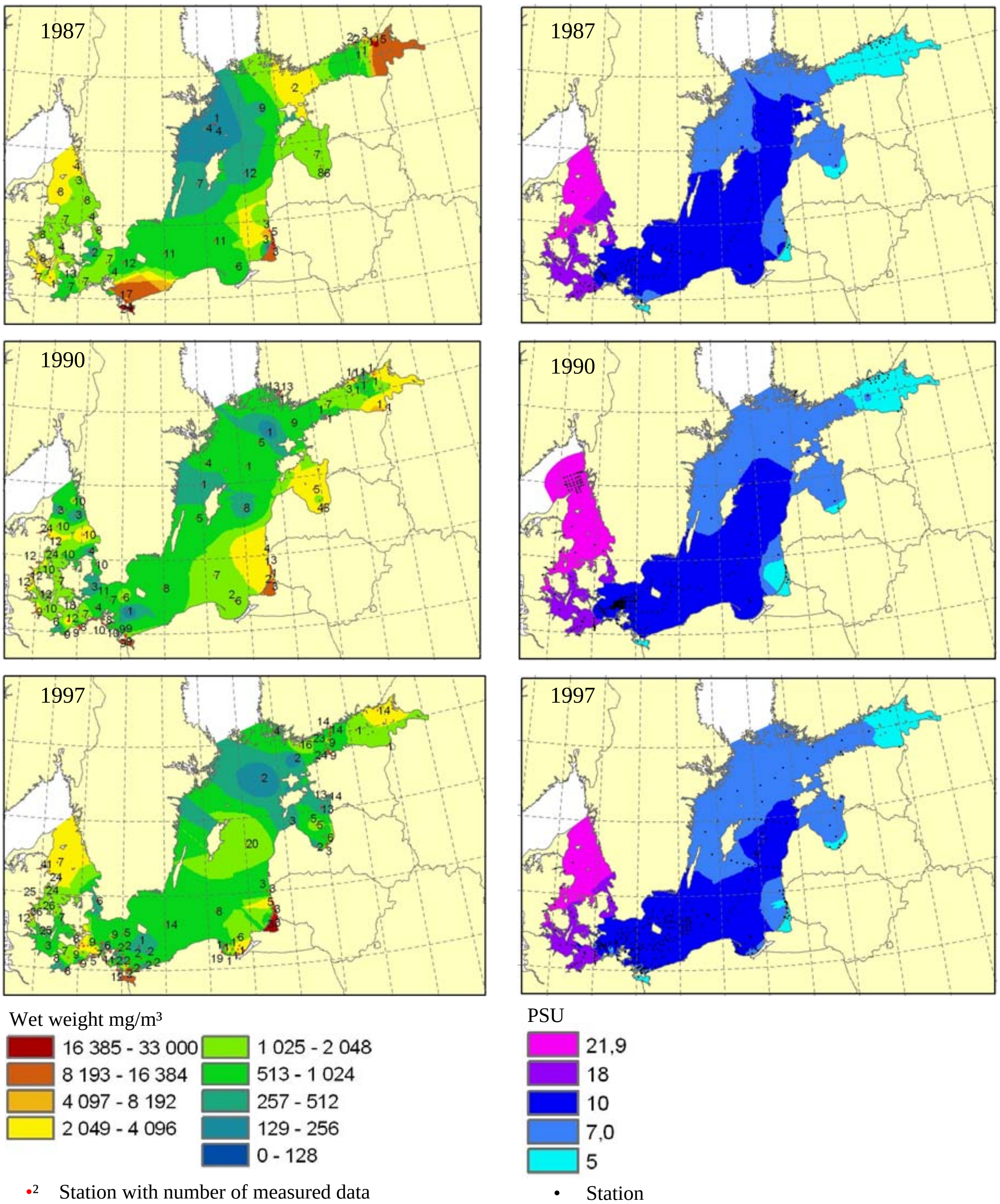

Figure 12: Annual average of phytoplankton biomass (left) and salinity (right) in the surface water (0-10 m) in 1987, 1990 and 1997 (Data: CHARM, HELCOM).

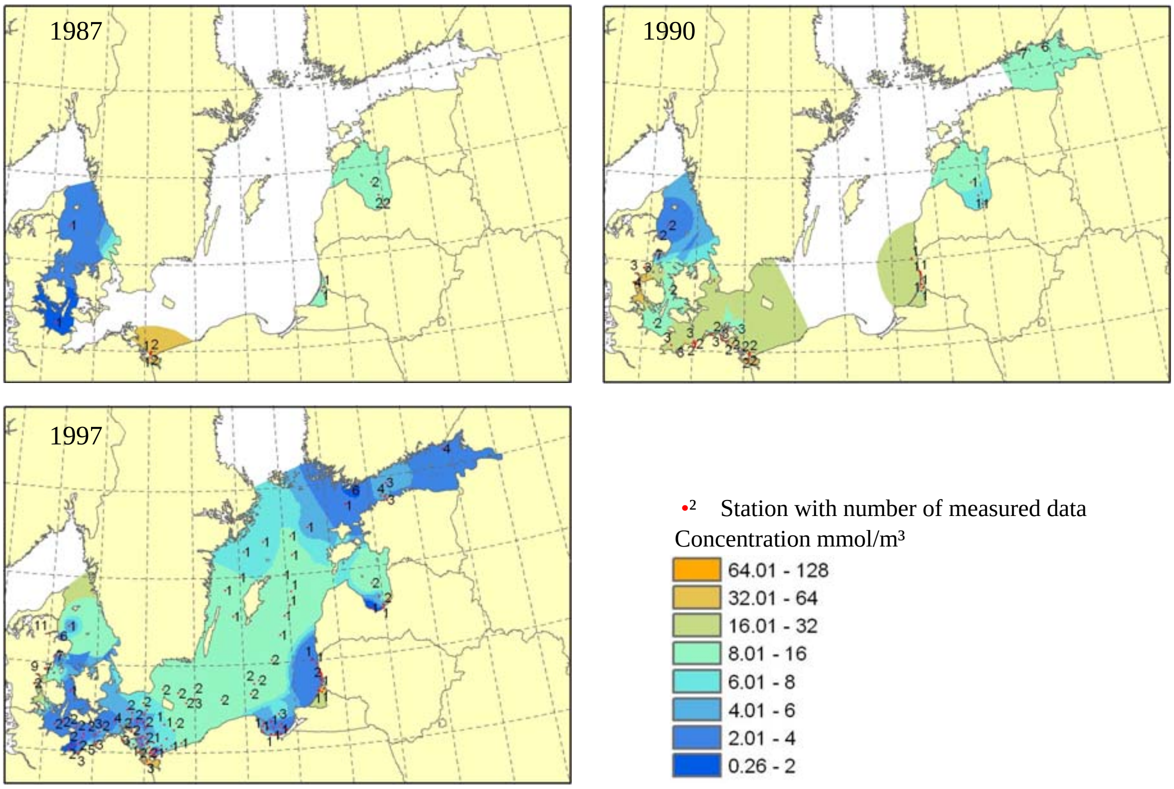

Figure 13: Average of silicate concentration in spring (March, April, May) in the surface water (0-10 m) in 1987, 1990 and 1997 (Data: CHARM, HELCOM).

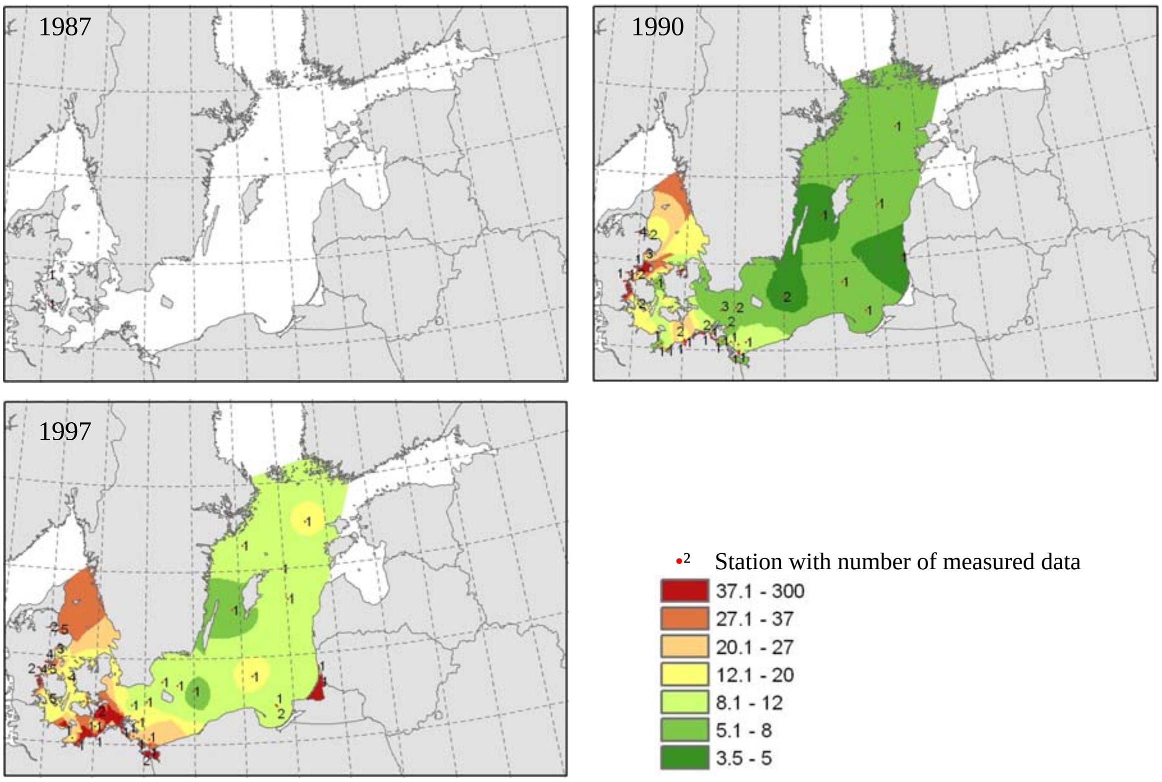

Figure 14: DIN to PO_4 molar ratio in winter (January, February) in the surface water (0-10 m) in 1987, 1990 and 1997 (Data: CHARM, HELCOM).

Silicate is needed for the growth of diatoms. As shown in Figure 13, there are rarely samplings of silicate in 1987 and 1990. Therefore, only spatial pattern of the year 1997 can be compared with distributions of the diatoms biomass. In river plumes and the western coastal Baltic Sea, average silicate concentrations in spring 1997 (Fig. 13) are very low, but significantly higher in the Baltic Proper. Several regions, like the western Baltic Sea, the Gulf of Finland and some river plumes show low silicate concentrations in spring 1997, which are linked to high diatom concentrations. Silicate in spring is already exhausted after the earliest diatom spring bloom and the concentrations remain low during the following time. High silicate concentrations in the Baltic Proper indicate that the diatom bloom has not taken place when the samples were taken. The figures indicate an inverse relationship between nutrient and diatoms concentrations. However, due to the limited data this relationship is not always reflected in large-scale spatial pattern. The results further show, that the sampling time and onset of diatom play an important role for the observed spatial distributions. Strong inter-annual variability in these processes cause very different spatial pattern from year to year.

During winter the nutrients nitrogen and phosphorus are mineralised and accumulate in the water body. The nitrogen/phosphorus ratio (N/P) indicates the general relative availability of these nutrients. It is assumed that nitrogen and phosphorus are taken up by phytoplankton according to the molar Redfield ratio of 16:1. The open Baltic Sea shows a ratio around 8, indicating that nitrogen is the scarce and potentially limiting nutrient. In the western Baltic Sea and in coastal waters the ratio is much larger and indicates a potential shortage of phosphorus (Fig. 14). A nitrogen limitation is common in open marine systems. The average biomass distribution fairly reflects the nutrient availability in the Baltic Sea. High nutrient concentrations in river plumes and near shore are usually linked to a higher phytoplankton biomass (Fig. 3). The N/P ratio resp. the limiting effect of nitrogen for phytoplankton growth is partly reflected in the concentration of cyanobacteria, which are able to overcome the nitrogen limitation.

6 Spatial comparison with results of the Baltic Sea Model (ERGOM)

Are models a suitable possibility to overcome the short-comings in phytoplankton data?

The Baltic Sea Model (ERGOM) is an integrated biogeochemical model linked to a 3-D circulation model and covers the entire Baltic Sea. The circulation model is an application of the Modular Ocean Model (MOM 3) code and includes an explicit free surface, an open boundary condition to the North Sea as well as riverine freshwater input. A thermodynamic ice model is used to simulate ice cover. A horizontally and vertically extending model grid was used. High horizontal resolution (3 nm) was applied in the south-western Baltic Sea. Towards north and east the grid size gradually increased. Altogether 30 vertical layers were assumed. The first 12 layers possessed a constant thickness of 2 m. Deep layers increased in thickness. The deepest layer (in the Gotland Deep) finally has a thickness of 36 m.

The biogeochemical model consists of nine state variables. The nutrient state variables are dissolved ammonium, nitrate, and phosphate. Primary production is provided by three functional phytoplankton groups: diatoms, flagellates, and cyanobacteria with heterocysts. Diatoms represent larger cells which grow fast in nutrient-rich conditions. Flagellates represent smaller cells with an advantage at lower nutrients concentrations especially during summer conditions. The cyanobacteria are able to fix and utilise atmospheric nitrogen and therefore, the model assumes phosphate to be the only limiting nutrient for cyanobacteria. Due to the ability of nitrogen fixation, the cyanobacteria are a nitrogen source for the system.

A dynamically developing bulk zooplankton variable provides grazing pressure on phytoplankton. Dead particles are accumulated in a detritus state variable. The detritus is mineralized into dissolved ammonium and phosphate during the sedimentation process. A certain amount of the detritus reaches the bottom, where it is accumulated in the sedimentary detritus. Detritus in the sediment is either buried in the sediment or resuspended into the water column, depending on the velocity of near-bottom currents. For a more detailed model description see NEUMANN (2000) and NEUMANN et al. (2002).

The most comprehensive data sets of river loads, atmospheric deposition, and meteorological data were available for the period between 1980 and 2000. This period was simulated and the results compared to measured data to evaluate the model performance. Validation results concerning chlorophyll, salinity and temperature are documented in NEUMANN et al. (2002). Altogether the model performance was satisfying and allowed the simulation of several nutrient load reduction scenarios on the trophic state of the Baltic Sea (NEUMANN et al. 2002; NEUMANN & SCHERNEWSKI in press; SCHERNEWSKI & NEUMANN 2002).The model was further applied to simulate reference conditions in the Baltic Sea according to the demands of the water framework directive. A spatial comparison of measured phytoplankton distributions with model results has not taken place so far.

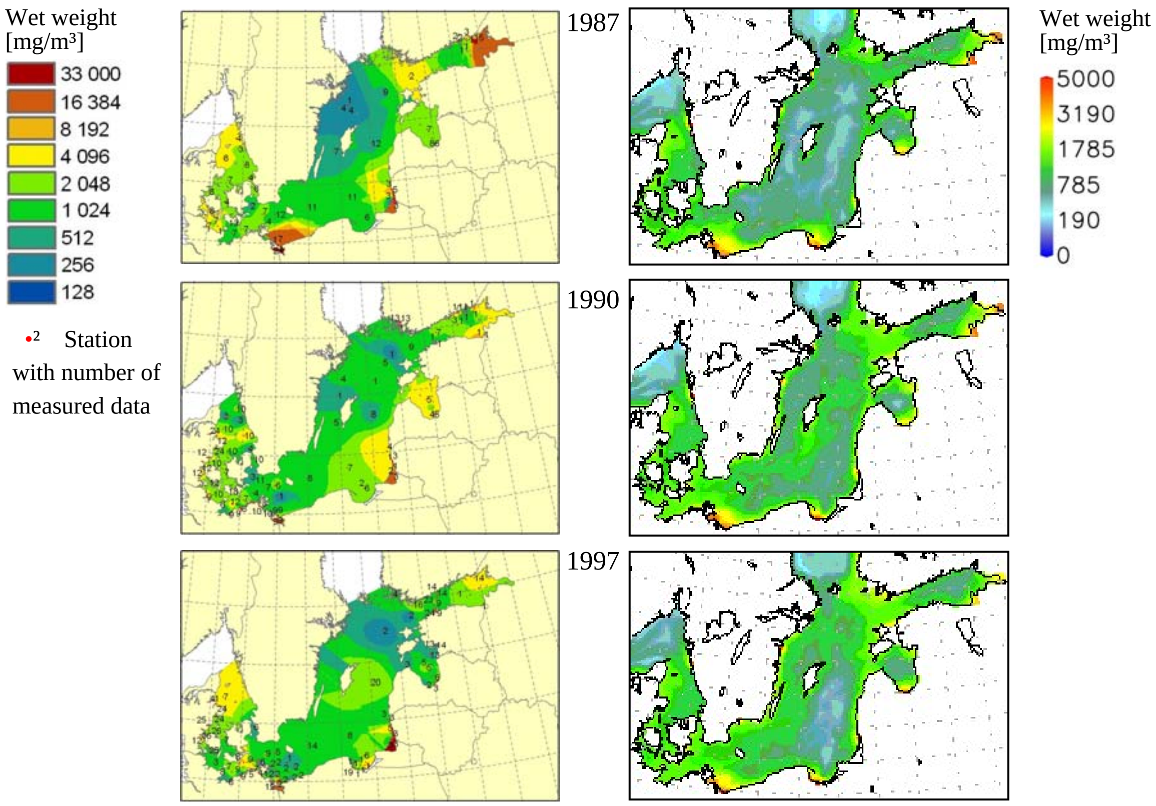

Figure 15: Annual average of phytoplankton biomass in the surface water (0-10 m) interpolated with monitoring data (left) and simulated with the Baltic Sea model ERGOM (right) in 1987, 1990 and 1997 (Data: CHARM, HELCOM, ERGOM).

The model phytoplankton biomass was calculated by using the C:N ratio of 106:16 (Redfield ratio), the assumption that half of the dry weight is due to carbon and converted to wet weight assuming a water content of 80 %.

The annual average of phytoplankton biomass shows the expected spatial distribution (Fig. 15). The highest concentrations in the river plumes are indicated in the interpolated as well as in the simulated maps. Differences in the distribution patterns between interpolation and simulation can be seen in the Baltic Proper. It is caused by the fact that the interpolation is a momentary view based on few data. Differences between station due to methodological errors or local phytoplankton patches create large scale pattern. The model calculates large amounts of data and is not affected by methodological problems or small scale patchiness. Therefore, the model gives a much smoother general picture, but basic elements in both pictures are well in agreement. A problem is the difference in the range of concentrations between the model and the observations. In reality, much higher values are observed in some regions than predicted by the model.

The spatial patterns of the nitrogen-fixing cyanobacteria between interpolation and model differ partly significantly (Fig. 16). This is especially true for the eastern coastal Baltic Sea and the Gulf of Gdansk. 1997 is known as the year with the most extensive surface accumulation of cyanobacteria (KAHRU et al. 2000; SIEGEL & GERTH 2000). This fact is well reflected in the model but not well visible in the interpolation. This clearly indicates the limited reliability of the data for spatial analysis.

Data together with spatial model applications might complete the spatio-temporal phytoplankton distribution in the Baltic Sea. The model ERGOM is potentially a suitable model for this purpose, but will require a further development.

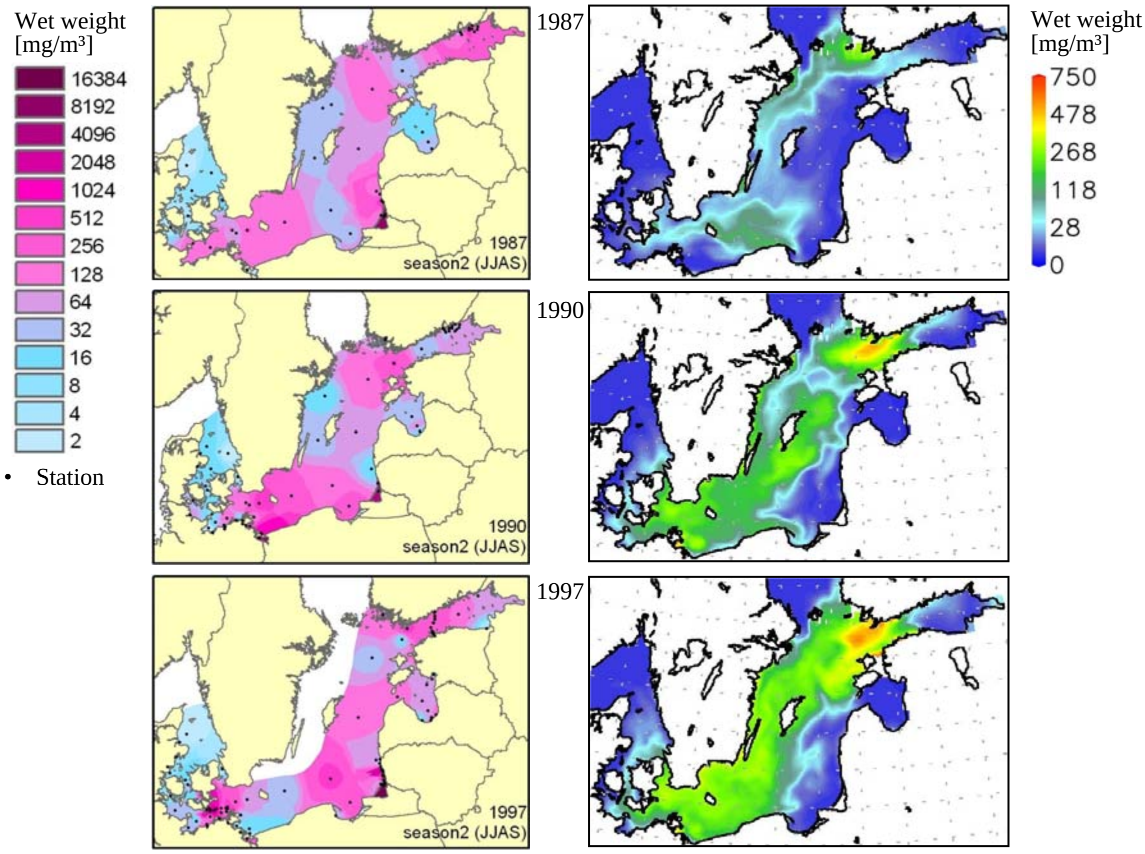

Figure 16: Average of cyanobacteria with heterocysts biomass in summer (June, July, August, September) in the surface water (0-10 m) interpolated with monitoring data (left) and simulated with the Baltic Sea model ERGOM (right) in 1987, 1990 and 1997 (Data: CHARM, HELCOM, ERGOM).

7 Spatial comparison with the Baltic Sea Typology

The first step in the implementation of the Water Framework Directive in marine systems is the development of a coastal water typology. A typology is a classification system, which divides all transitional and coastal waters into types, based on physical factors. A typology always is accompanied by a map showing the spatial distribution of the types. It is of outstanding importance and forms the basis for all other Directive activities. The implementation of the WFD and the development of national typologies are the responsibility of national authorities. As a result, every country has already developed an independent typology. The WFD defines the Baltic Sea as one Ecoregion. The coastal waters have an international character but national typologies will cause interceptions at country borders and different national typologies will complicate large scale comparisons across the Baltic Sea. Further, the definition of coastal waters in the WFD of 1 nm off the baseline is artificial. The division between coastal waters and open waters is not in agreement with morphological, physical, chemical or biological parameters. Therefore, a joint typology, not only for the Baltic coastal waters, but the entire Baltic Sea was suggested within the CHARM project (SCHERNEWSKI & WIELGAT 2004). It serves as an umbrella, which allows the integration of the national typologies and a further subdivision according to regional demands.

Salinity was used as the main obligatory factor in this Baltic Sea typology. Residence time and depth/mixing conditions were additionally used. It is expected that these abiotic parameter control the biology of coastal waters. Therefore, the spatial distribution of these abiotic types should be reflected in biological spatial pattern as well. The question is: Are the phytoplankton distribution and the spatial distribution of types in agreement? Are the abiotic types a mirror of spatial phytoplankton distributions?

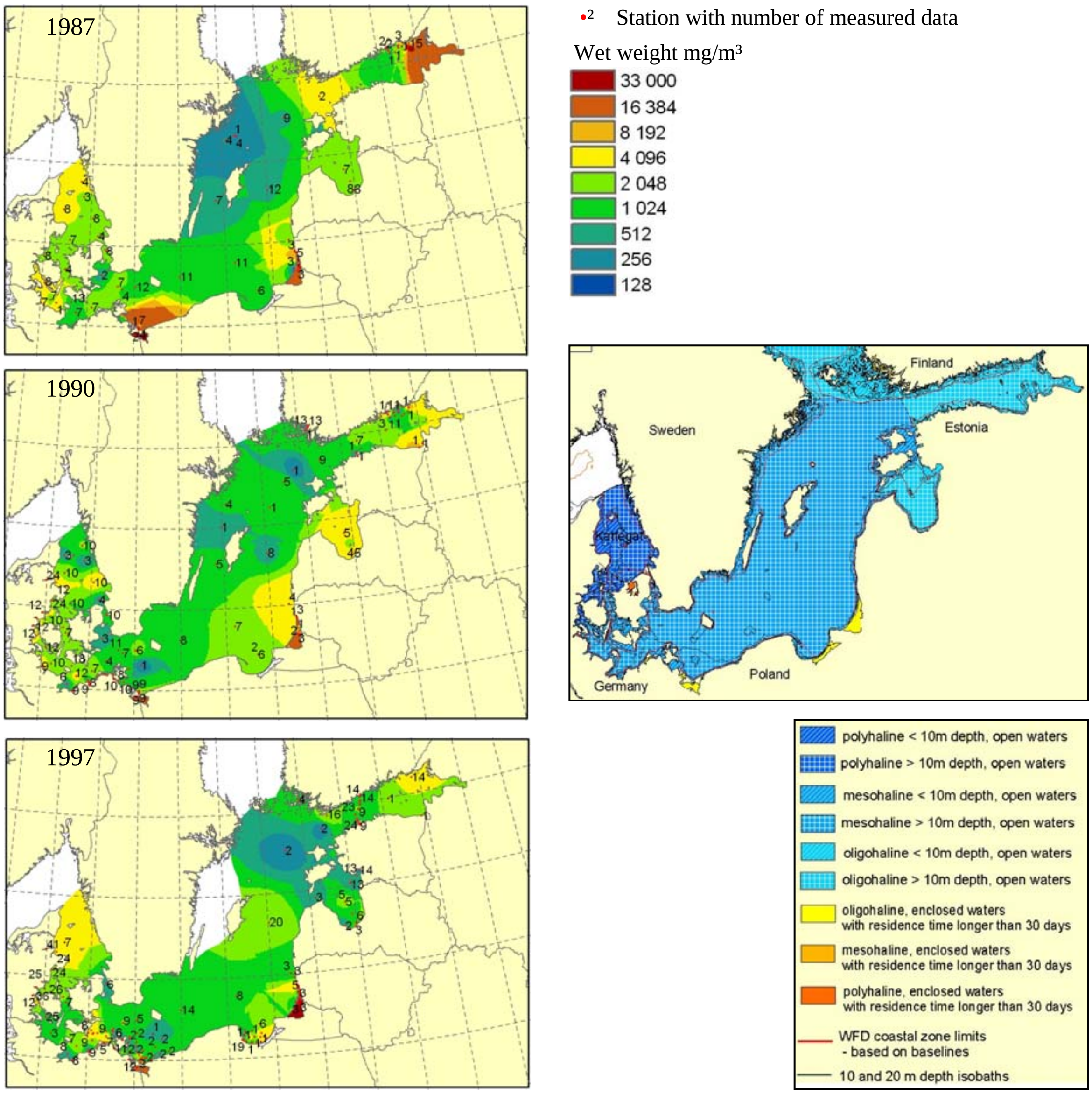

Figure 17: Comparison of annual average of phytoplankton biomass in 1987, 1990 and 1997 and Typology of the Baltic Sea (Data: CHARM, HELCOM, SCHERNEWSKI & WIELGAT 2004).

A general comparison between the average annual phytoplankton biomass and the spatial distribution of types shows a good agreement in all oligohaline bays and lagoons as well in oligohaline regions of the open sea (Fig. 17). The Gulf of Finland and the large Riga Bay are separate types and they are in reality characterised by higher phytoplankton biomass. However, this can be an effect of higher nutrient loads as well.

The biomass in the open Baltic Sea shows a strong spatial and interannual variability. This certainly is a result of the coarse spatial resolution of the data and methodological problems linked to the sampling. The shown spatial distributions do not allow a subdivision of the open Baltic Sea and it is therefore reasonable to define it as one large type, as done in the typology. The tendency to higher biomass in the polyhaline Kattegat is well reflected in a separate type as well.

Apparent disagreements between the typology and phytoplankton biomass distributions occur near large rivers and their plumes. River plumes with their elevated nutrient concentrations are a result of anthropogenic pressures. According to the WFD these pressures shall not be reflected in a typology, because they are not permanent. The river plumes and their special features are covered by another concept, which allows a subdivision of types, the water body concept. The typology, subdivided according to external pressures into water bodies, is well able to cover river plumes (SCHERNEWSKI & WIELGAT 2004).

The comparison between the phytoplankton groups, diatoms (Fig. 7), flagellates (Fig. 6) and cyanobacteria (Fig. 7), and the typology show a very reasonable agreement. The regular occurrence of different groups in the western Arkona Sea as well as in the central Arkona Sea and the Bornholm Sea suggests treating these parts of the Baltic Sea as a separate type. This is in agreement with HELCOM, who calls this region the southern Baltic Proper. River plumes and the western Arkona Sea reflect the anthropogenic influence and suggest separate water bodies.

The two analysed species *Skeletonema costatum* and *Mesodinium rubrum* are very patchy and can hardly be compared with the typology. Altogether, the basic average phytoplankton biomass distribution is well reflected by the Baltic Sea typology.

8 Discussion and conclusion

In this study we apply and validate interpolation methods, which allow the presentation and analysis of spatial phytoplankton pattern. The relatively simple IDW-method (Inverse Distance Weighted) turned out to be most suitable. However, the interpolation methods were not the major problem in this study. Nearly all phytoplankton interpolations clearly show the short-comings of the available phytoplankton database. The sampling frequency and spatial coverage is often not suitable to allow a reliable spatial phytoplankton distribution. Methodological problems, especially when considering single phytoplankton groups decrease the reliability of the data further. Temporal data aggregation into seasons is necessary. However, the used database is outstanding and by far the most comprehensive in the Baltic Region. This database allows a certain overview about the spatial distribution of phytoplankton biomass, groups, selected indicators and species for three selected years and different seasons in the entire Baltic Sea. Linking phytoplankton pattern to spatial distributions of abiotic parameter clearly shows that detailed interpretations always require time series for different regions. The knowledge of the temporal development of processes in different regions is imperative for an interpretation. We limit ourselves to the spatial aspect. Our work therefore remains in a preliminary stage and can to be regarded as basis for further analysis and interpretations.

One aim was to compare phytoplankton pattern with the typology according to the Water Framework Directive. The typology is based on three main factors surface salinity, water residence time and water depth, which corresponds to the mixing of the water column. The WFD assumes that the spatial pattern of these parameters reflect the biological parameters as well. In general, this typology reflects basic properties of the spatial phytoplankton distribution. In detail, several modifications of the typology might be useful, but due to the uncertainty of the phytoplankton data a very detailed spatial comparison is hardly possible. Altogether the existing amount and quality of phytoplankton data is not sufficient to meet all requirements in the Water Framework Directive.

How could a phytoplankton monitoring for the Baltic Sea look like? To increase the number of sampling stations and the temporal frequency of sampling significantly is necessary but hardly realistic due to financial restrictions. Measurements based on frequently travelling ferries are certainly one solution to increase the temporal data resolution and the spatial density of data along this ferry route. Several additional automatic recording moored stations in several locations are another possibility to increase the temporal data density. Together with satellite data, covering large areas and contributing the spatial aspect, an improved spatio-temporal picture of phytoplankton distributions in the Baltic Sea might result. Finally, models are another possible solution. Data together with spatial model applications might complete the spatio-temporal phytoplankton distribution in the Baltic Sea. The model ERGOM is potentially a suitable model for this purpose, but will require a further development.

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Address

Ramona Thamm
Feldstraße 41
18057 Rostock
Germany

Email: ramona.thamm@gmx.de

Priv.-Doz. Dr. habil. Gerald Schernewski
Institut für Ostseeforschung (IOW)
Seestraße 15
18119 Rostock-Warnemünde
Germany

E-mail: gerald.schernewski@io-warnemuende.de

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